Eisenhower Johnson Memorial Tunnel (EJMT)

Fixed Fire Suppression System Preliminary Design:

Task 3 – Preliminary Design of Retrofitting a Water Mist System at EJMT

Prepared for the
Colorado Department of Transportation

August 2012
Revised October 9, 2012

Hatch Mott MacDonald

PARSONS

Some of the information in this report has been provided to HMM, Parsons and CDOT in confidence and should not be disseminated.

Prepared by

Hatch Mott MacDonald

475 Park Avenue South, 10th Floor

New York, New York 10016-6901

And

Parsons

1700 Broadway, Suite 900

Denver, CO 80290

This page is left intentionally blank.

TABLE OF CONTENTS

1.0 Introduction

Hatch Mott MacDonald (HMM) and Parsons have been engaged by the Colorado Department of Transportation (CDOT) to undertake a water mist fixed firefighting system (WM-FFFS) preliminary design for EJMT. The scope of this project includes the following:

- Task 1 – Further evaluation of the WM-FFFS based on the full scale tunnel fire tests
- Task 2 - CFD model studies to examine system performance and gain more insight of the effects of the water mist system on tunnel fires
- Task 3 – Preliminary design for retrofitting a WM-FFFS at EJMT
- Task 4 – Verification of CFD ventilation model via field tests in EJMT

This report documents the preliminary design for retrofitting a water mist fixed firefighting system at EJMT. An additional work item, which is the result of part of the rearrangement of the scope of Task 3, a white paper showing the logic behind the decision on the use of water sprinkler system in the tunnels of Alaskan Way Viaduct Project and some of the recent data on WM-FFFS in world's road tunnels, is also given in Appendices D and E.

2.0 Preliminary Design of Retrofitting a Water Mist FFFS at EJMT

2.1 Design Objectives, Standards & Design Criteria

The design objectives of the proposed water mist FFFS system is the following:

- Improve the self-rescue conditions,
- Improve access and operating conditions of fire and rescue,
- Prevention of fire spread from one vehicle to another,
- Limit structural damage to the tunnels.

The water mist system will be designed in accordance with UPTUN WP2 D251–"Engineering guidance for water based fire fighting systems" [3], NFPA 750 [5], and NFPA 502 [2].

Practical design criteria for the water mist system are the following:

- The fire load with a potential HRR up to approximately 200 MW (for both pool fires and solid fuel fires),
- Fire should not spread from the incident vehicle to other vehicles at a distance of 5 m (16 ft) downstream,
- The Fire Fighters should be able to get within at least 5 m (16 ft) of the fire from the upstream direction and access the area in the tunnel 20 m (66 ft) downstream,
- At 40 m (131 ft) downstream there should be at least 15% oxygen and a maximum of 5% CO_2.

2.2 Design Concept, Calculation Criteria and System Design Calculations

2.2.1 Design concept of a water mist system

The design concept of the proposed water mist system for EJMT is based on the test results from several research projects, and many other accepted full scale fire tests using water mist system technology (see Task 1 report of this project). This preliminary design has been in accordance with UPTUN WP2 D251, NFPA 502 and NFPA 750.

The main components of water mist systems in tunnels are illustrated in Figure 2-1. The wet main pipe (blue color) comes from the pump station and is pre-pressurized with low-pressure (~10 bar or 145 psi) water to ensure that the WFS is operating in the relevant zones not later than 60 sec. after activation. The section valve is the border between the wet main pipes and the dry section pipes. The section pipes connect all nozzles in every section together. In the case of opening the section valve, water will be supplied to every nozzle in this section. Normally an external linear heat detection system is installed to the tunnels to trigger the fire fighting system and also indicate the location of fire to the control system that opens the section valves. Alternatively, a triggering message can come through a video based incident detection or fire detection system or by the operator.

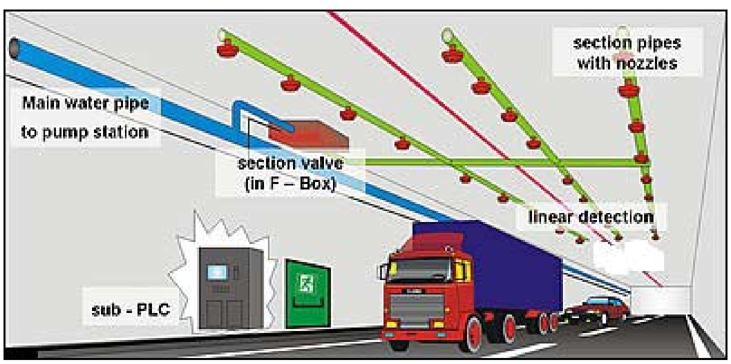


Figure 2-1: Layout of a water mist system

The water mist system is designed to cover the roadway area of the tunnels using nozzles installed at a regular spacing. There will be 3 ~ 4 longitudinal nozzle rows depending on the tunnel geometry. The tunnel is divided into zones of length 25 m (82 ft) to 30 m (98 ft), with every zone having identical length and nozzle lay-out. Three zones will be activated in case of fire by opening the section valves of fire zone sections (fire incident zone and two adjacent zones). The pump system will start simultaneously.

2.2.2 Calculation criteria and system design calculations for EJMT

The calculation criteria for the system design for EJMT are based on manufactures' operational parameters obtained from the full scale fire tests.

Task 1 of this project concluded that there are significant differences in the operational parameters for different supplier's systems (AQUASYS, FOGTEC, HI-FOG) such as operating pressure, water droplet sizes and water flow rate density. Since the conclusions of Task 1 are not absolute in terms of a particular system and its ability to protect for certain types of fire, three system designs by AQUASYS, FOGTEC, HI-FOG are provided respectively in the following sections. Note that among these three system designs,

- AQUASYS system has been designed and tested for 200MW solid fuel and pool fire scenarios,
- FOGTEC system has been designed based on HGV risk scenario (180 MW large solid fuel fires) and its system design may need to be modified to combat large pool fire scenarios,
- HI-FOG system has been designed and tested for 100 MW solid fuel fires (large vehicle fire scenarios) and the design was claimed (by the supplier) to be adequate for large pool fire scenarios based on simulation results.

Table 2-1 shows the design calculation criteria of AQUASYS system, FOGTEC system and HI-FOG system established by full scale tunnel fire tests.

Table 2-1: Design Calculation Criteria for Three Water Mist Systems (AQUAYS, FOGTEC, HI-FOG)

SUPPLIERS	AQUASYS	FOGTEC	HI-FOG
Nozzle, K factor	DKIT 38/0-6.9-xL, proprietary information	Not specified by the supplier, proprietary information	4S 1MD 6MD 1000; K=5.5 lpm/bar$^{0.5}$
Spacing between nozzles in a row (longitudinal)	2 m (6.56 ft)	4.17 m (13.68 ft)	3.42 m (13.12 ft)
Distance between rows	4 m (13.12 ft)	3.56 m (11.68 ft)	3.35 m (11.0 ft)
Nozzle distance above floor	4 m (13.12 ft)	~4.7 m (15.4 ft) at tunnel ceiling	~4.7 m (15.4 ft) at tunnel ceiling
Operating (minimum) pressure at nozzles	35 bar (507.6 psi)	50 bar (725 psi)	80 bar (1160 psi)
Zone length	30 m (98.4 ft)	25 m (82 ft)	27.44 m (90 ft)
Nominal water flux density, L/(min. m^3)	0.9	0.5	0.8
Nominal water flow rate, L/(min. m^2)	4.7	2.25	4
Operation time of water mist system (min)	60	60	60

The pipe work shall be dimensioned to ensure that at least the minimum pressure tested in the relevant full size fire tests is achieved at all nozzles of the activated sections in any part of the tunnel. The maximum allowable pressure loss shall be within the limits given by the maximum and minimum tested pressure. Note that some suppliers are withholding nozzle characteristics information for proprietary reasons, therefore detailed hydraulic calculation were done by the suppliers and not presented in this report. Nevertheless the following presents a brief summary of some hydraulic calculation procedures for a water mist system:

1. Flow rate through a single nozzle q_i

$$q_i = K\sqrt{10\,P_i}$$

   Where P_i, K are the nozzle working pressure and nozzle K factor respectively

2. Total flow rate of the system

$$Q = \sum_{i=1}^{n} q_i$$

   Where n is the number of the activated nozzles, q_i is the actual flow rate for each nozzle based on actual working pressure at the nozzle P_i (MPa).

3. Total water usage

$$W = t * Q * (105\% \sim 120\%)$$

   Where Q is the total flow rate of the system, t is the water mist system activation time

4. Water mist system pipe design

   The estimated pipe size can be calculated by

$$d = 0.0188 * \sqrt{q_v/V}$$

   Where q_v is the volume flow rate (m^3/h), V is the flow velocity through the pipe (m/s)

5. Pressure loss due to friction

   The pipe friction losses can be determined via Darcy-Weisbach calculation method

$$\Delta p_i = 2.252\,\frac{fL\rho Q^2}{d^5}$$

$$where\ \Delta p_i = \ friciton\ loss\ (bar\ gauge)$$

$$L = \ length\ of\ pipe\ (m)$$

$$f = \ friciton\ factor\ (\frac{bar}{m})$$

$$\rho = fluid\ density\ (kg/m3)$$

$$Q = flow\ rate\ (\frac{L}{min})$$

$$d = \ internal\ pipe\ diameter\ (mm)$$

Table 2-2 shows the hydraulic calculation results for the water mist systems for EJMT. Other design calculation results such as number of nozzles for each section, total water discharge rate for the three-zone operation, water storage requirement for 60 min. of operation time are also given in the Table.

Table 2-2: Design Calculation Results of Three Water Mist Systems (AQUAYS, FOGTEC, HI-FOG) for EJMT

SUPPLIERS	**AQUASYS**	**FOGTEC**	**HI-FOG**
Main Pipes Diameter	168.3mm (O/D) (6.6")	88.9mmx3.05mm (3.45''x0.12''); duplex stainless steel (EN/DIN:1.4462, AISI:UNS31803)	114.3mm (O/D) (4.49'') 316 stainless steel
Section Pipes (Longitudinal Branch Pipe) Diameter	22 mm – 35 mm (O/D) (0.87" – 1.38")	21.3mmx2mm (0.83"x0.078'') High grade stainless steel AIS1316TI (1.4571)	25mm (O/D) (1'') 316 stainless steel
Distribution Pipes (From Section Valves to Branch Pipes) Diameter	42 mm (O/D) (1.65")	48.2mmx2.8mm (1.9"x0.11") High grade stainless steel AIS1316TI (1.4571)	60.3mm (O/D) (2.37'') 316 stainless steel
Number of Fire Zones (Sections) for Each Tunnel of EJMT (Eisenhower bore-2724 m and Johnson bore -2731 m long)	91	110	100
Number of Nozzles for Each Zone (Section)	45	21	24
Total Water Discharge Rate For Operation of Three Zones (Liter/min)	3000 lpm (792.5 gpm)	1800 lpm (475.5 gpm)	3542 lpm (935.7 gpm)
Water Storage Requirement (for 60 min operation time)	180 m^3 (47551 gallon)	126 m^3 (33285 gallon)	234 m^3 (61816 gallon)

2.3 Main Components and Layout of a Water Mist System for EJMT

The following subsections explain the main components and layout of the water mist system proposed for EJMT.

2.3.1 Nozzles and nozzle layout

The water mist system is designed to cover the entire area of the tunnels by nozzles installed at regular spacing. The nozzles are of open type and will be grouped into longitudinal zones of 25 m (82 ft) to 30 m (98 ft) length along the tunnels. Three longitudinal nozzle rows are proposed in every section. The nozzles will operate at a pressure range 35~ 50 bar (507 ~ 725psi) for AQUASYS system, 50 ~ 100 bar (725~1450 psi) for FOGTEC system, and 80-140 bar (1160~2030 psi) for HI-FOG system as tested in full scale tunnel fire tests.

The nozzle types and characterics of the AQUASYS, FOGTEC and HI-FOG systems are listed in Table 2-1 and Appendices A, B, C. The layout of these nozzles for EJMT can also be found in the same Table and Appendices. The nozzle type and layout parameters are all based on full scale tunnel fire tests.

There are many supply and exhaust vents openings on the tunnel ceilings of EJMT, therefore nozzles have to be carefully installed (e.g., in the middle of vents) to minimize the negative impact of ventilation (see Figure 2-2 for an illustration of a portion of the water mist nozzles layout proposed for EJMT).

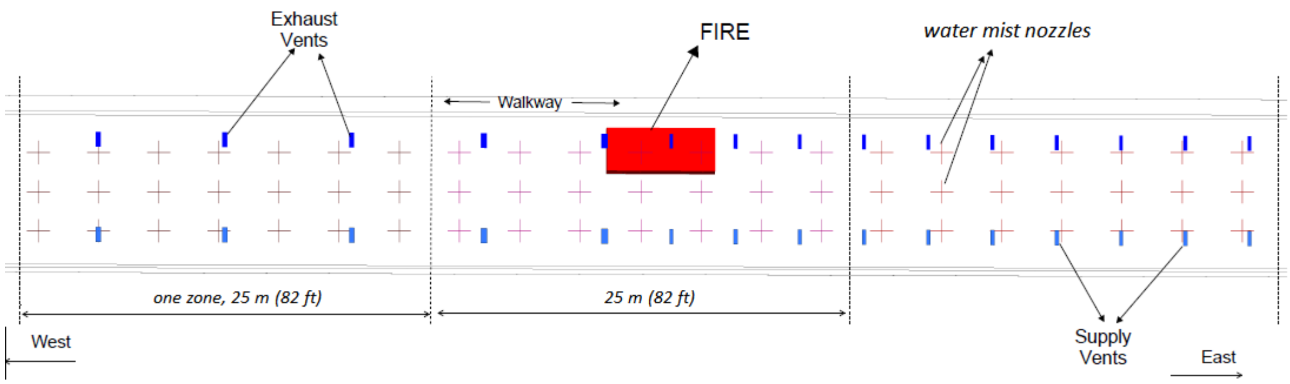


Figure 2-2: Layout of water mist nozzles proposed for EJMT

2.3.2 Main pipe and section pipes with nozzles

The pump system is connected to the section valves via a high pressure stainless main pipe. The main pipe is water filled in the stand-by condition to reduce the time delay between water mist system activation and discharge from the nozzles. The main pipe is pressurized to around 10 bar (145 psi) or so (depending on detailed engineering design) in the stand-by condition by means of a jockey pump[1].

[1] A jockey pump is a small pump which is used to pressurize the main pipe to a suitable stand-by pressure. The jockey pump compensates for small leaks. Any major leakages can be detected by monitoring the stand by pressure. Jockey pumps work relatively often and therefore it is good practice to arrange a self cleaning filter to ensure faultless operation.

The main pipe is connected to the sections pipes through distribution pipes. The nozzles are installed at regular intervals to the section pipes (longitudinal branch pipe). Every section (with a length of 25m to 30m, or 80 ft to 100ft) is closed towards the main pipe with a remotely controlled section valve which is normally closed, which means sections (section pipes) are normally dry. See Appendix B (4. section pipes) for a typical section pipes and distribution pipes layout of the water mist system.

The main pipes, section pipes and distribution (or manifold) pipes are dimensioned via hydraulic calculations by the suppliers and listed in Table 2-2.

The pipe materials for some of the water mist systems are also listed in the Table 2-2. To fulfill UPTUN WP2 D251 [3], pipe material shall be tolerant against corrosion. The minimum requirement is 1.4571/AISI316Ti. The material requirement is the same for all pipe connectors (basically, the fittings and flanges). All parts of the connectors shall be made of stainless steel in order to maximize the corrosion resistance and life time in tunnel environment. To avoid the risk of galvanic corrosion the use of stainless steel and carbon steel materials in the same piping connector is not permitted even if carbon steel is plated.

Installation of the pipe-work at the lower parts of the walls of the tunnels should be avoided to eliminate damage of the pipes (which would in turn cause failure of the water mist system) in the case of accidents. Having safe locations for critical components of a water mist system is essential to have high reliability FFFS system. For EJMT, it is proposed to install the main pipe, the section valves and control boxes in the supply air duct (see Figures 2-2, 2-3). Only the nozzle lines (section pipes with nozzles) will be installed on the tunnel ceilings. This installation setup has been used for the Felbertauern Tunnel (with AQUASYS system), which has a rather thin ceiling that cannot carry high loads. EJMT has the similar issue with the tunnel ceilings as advised by CDOT (see Figure 2-4). Another benefit of installing some of the water mist system components in the fresh air duct is that the WFS components can be accessed at all time for maintanance with no need to close down the traffic in the tunnels.

The exact locations of the main pipe and section pipes will be further assessed during the final structural engineering design.

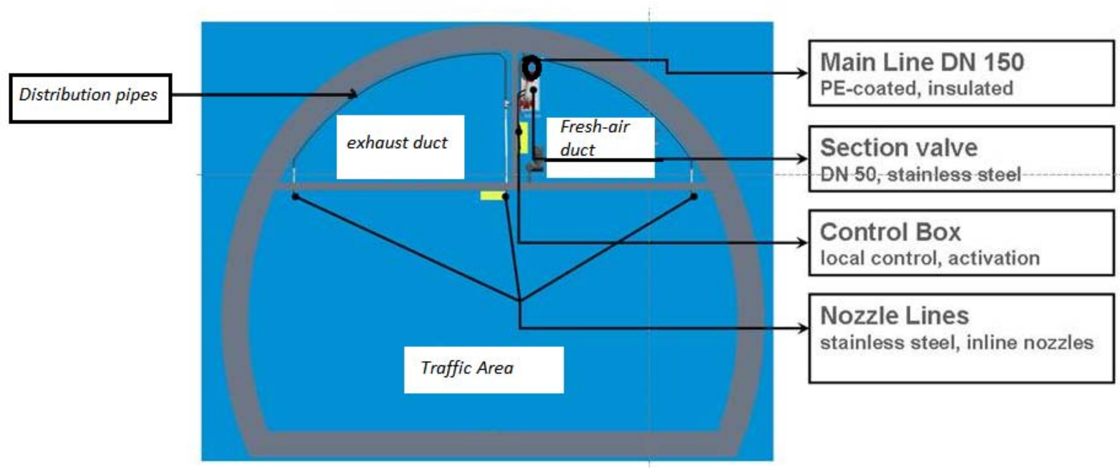


Figure 2-2: Installation of a water mist system proposed for EJMT (the Felbertauern Tunnel set-up: AQUASYS system)

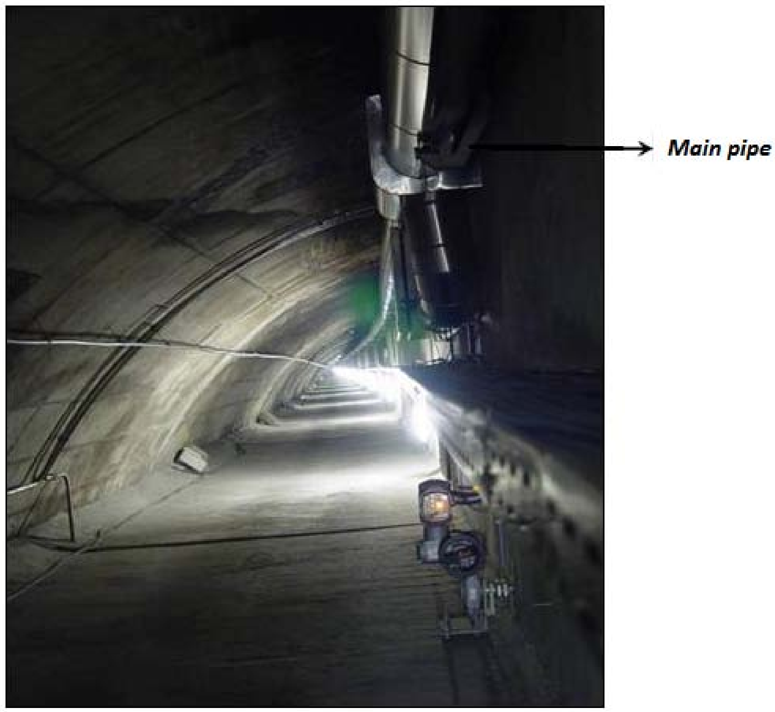


Figure 2-3: Installation of the main pipe (the Felbertauern Tunnel with AQUASYS system)

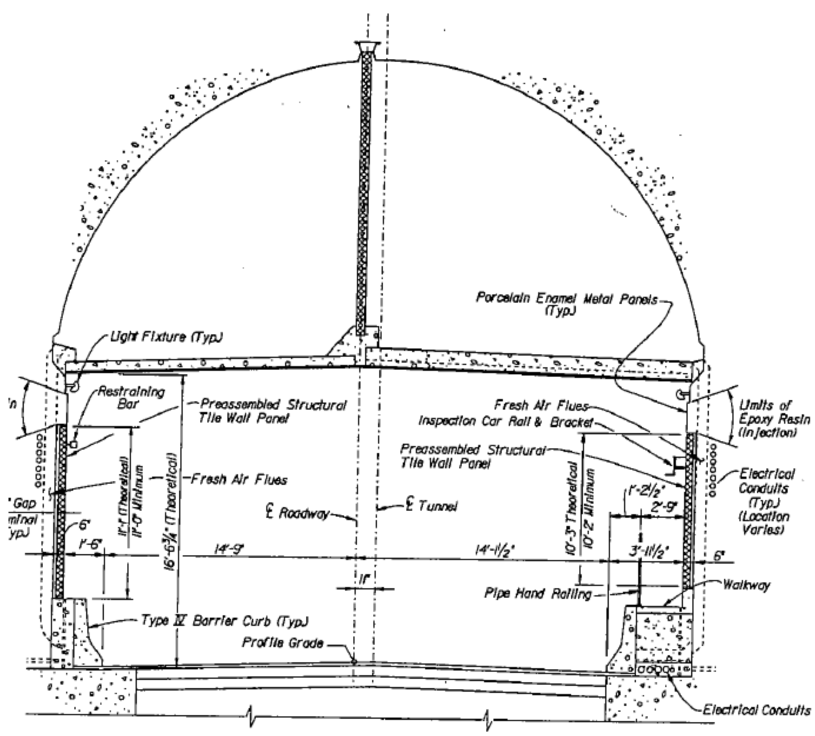


Figure 2-4: Typical north tunnel cross section (EJMT)

2.3.3 Section valves

UPTUN WP2 D251 indicated that that section valves shall be robust, remotely controlled and fully leakage free. Only ball valves shall be used. Valves should be equipped with an adequate drive. This can be either pneumatic, water hydraulic or electric. Valves shall not be activated by thermal elements. Sections valves shall be provided such that a monthly test operation can be carried out without allowing water to flow from the main pipe to the relevant section. If sections valves are installed inside the tunnel they shall be protected by enclosures with a suitable fire rating. Section valves should be equipped with suitable shut off means, which allow the replacement of a section valve without draining water from the main pipe.

For EJMT, section valves will be located on the walls under the tunnel ceilings or inside the supply air duct (see previous section 2.3.2) to ensure the reliability even in the case of an accident in the tunnel.

For AQUASYS system, a total of 91 section valves (one per section) will be installed along one tunnel (there are 182 sections in total for EJMT).

For FOGTEC system, a total of 110 section valves (one per section) will be installed along one tunnel (there are 220 sections in total for EJMT).

For HI-FOG system, a total of 100 section valves (one per section) will be installed along one tunnel (there are 200 sections in total for EJMT).

2.3.4 Pump stations

Recommended by UPTUN WP2 D251 [3], the total capacity of the pump unit shall be 110% of the amount of water required to supply the protection area at the minimum pressure specific to the nozzles. The recommended pump type for most tunnel applications is the triplex plunger pump, because the available flow rates cover normal tunnel requirements. In addition, the constant high pressure level, tolerant suction conditions and low filtration requirements are benefits when compared to other pump types. It is recommended to limit the number of pumps used in fire protection systems mainly because of the complexity of systems and the lifetime costs. A large number of pumps will lead to complex pump unit arrangements and interactions between pumps, and, a greater number of parts that will be subject to wear. The more moving parts a pump unit consists of the greater potential risk of failure. The greater the number of moving parts and components in general, for a pump system will increase the maintenance and lifetime costs. The optimum design would be only one pump per system (plus a stand-by pump), however, due to the high flow requirements in a tunnel application this is normally impossible to realize. The necessary redundancy level is another factor which dictates the use of more than one pump.

From AQUASYS system, the required flow rate for the protection area is 3000 lpm@35 bar (793 gpm @508 psi). Three electrically or diesel powered main pumps, two for normal operation, one for back-up are proposed for EJMT. Each AQUASYS main pump unit has a capacity of 1800 lpm@64 bar (476 gpm@928psi). The power consumption for this design is 550 KW (738 HP) for two main pumps operation. If two pump rooms are proposed, each of the pump room would require a space 8.94m by 4.75~6 m (29 ft by 16~19 ft, see Appendix A) and one more back-up pump is needed. For EJMT, only one pump room is proposed and installed right next to the water reservoir at the west portal; the pump room of AQUASYS system would require a space approximately 14 m by 4.75~6 m (46 ft by 16~20ft).

For FOGTEC system, the required water flow rate for the protection area is 1800 lpm@50 bar (476 gpm@725 psi). Three main pumps, two for normal operation and one for redundancy, are proposed for EJMT. Each pump unit has a capacity of 1051 lpm @115 bar (278gpm @1668psi). The maximum power consumption for this design is 510 KW (684 HP). The pumps can be equipped with electric or diesel driven motor. The pump room layout for the FOGTEC system is shown in Appendix B. The pump room of FOGTEC system would require a space 11m by 6 m (36ft by 20ft) and is proposed to be installed next to the water reservoir at the west portal of EJMT.

For HI-FOG system, the required water flow rate for the protection area is 3542 lpm@80 bar (936gpm@1160psi). Six SPU8 pump units, five for normal operation, one for redundancy, are proposed for EJMT. Each SPU8 pump unit has electrical motors connected to 16 high pressure pumps, and has a capacity of 779 lpm@140bar (206gpm@2030psi). The power consumption for this design is 1080KW (1448HP). At the moment, HI-FOG does not have proper diesel units to offer; they are investigating the issue and will get back with us when they have information available about their possibilities to offer such big diesel units. The pump room of HI-FOG system would require a space approximately 11.4 m by 8.07 m (37 ft by 26.5 ft) and be installed next to the water reservoir at the west portal of EJMT (see also Appendix C –3, 4).

High pressure pumps are equipped with a booster pump that keeps the most ideal working conditions for the main pumps and maximizes the life time. A separate jockey pump unit will pre-pressurize the wet main pipes in stand-by condition. Note that the pump rooms should always be kept at a temperature above 4°C (39°F) in order to prevent freezing. The pump rooms should be equipped with a suitable drainage and ventilation.

2.3.5 Water reservoirs

The high pressure pumps are supplied by fresh water from water tanks. The required minimum operation time of the water mist system shall normally be 60 min for tunnels longer than 500 m (1640 ft) or 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) [3]. The minimum operational time may increase if required by the authorities having jurisdiction.

The water volume requirement for 60 minutes operation is 126 m^3 (33286 gallon) for FOGTEC system, 180 m^3 (44551 gallon) for AQUASYS system, 234 m^3 (61817 gallon) for HI-FOG system (see Table 2-2). The existing fresh water storage tank of EJMT is located at the west end of the tunnels and has a volume of 454 m^3 (120,000 gallon) [4], therefore the volume of this water storage tank in EJMT is adequate for the operation time of 60 min. of a water mist system.

Noted that the water reservoir shall be of stainless steel, coated carbon steel, plastic or coated concrete to avoid contamination of the water with rust or particles originally from the tank structure itself [3]. Water reservoir shall be provided with a drain valve and an overflow outlet. A manual ball valve shall be placed in the outlet of the reservoir for maintenance purposes. Reservoirs shall be provided with venting to atmosphere to avoid over/under pressure. This venting shall be protected by a breather filter to prevent the infiltration of particles into the reservoir.

2.3.6 Drainage requirement

UPTUN WP2 D251 [3] recommended that a drainage system is sized and designed such that it will be sufficient to handle any liquids originating from accidents and water run-off, generated by the water mist systems and the emergency services. NFPA 502 [2] also indicates the following:

- The drainage collection system shall be designed so that spills of hazardous or flammable liquids cannot spread or cause flame propagation. The system shall intercept tunnel roadway drainage from an arrangement of side gutter catch basins or other drain inlets, such that the length of surface drain path from any potential spill point to the drain inlet is minimized.
- The minimum design flow rate shall include, the design spill rate for fuel or other hazardous liquids, the proposed water mist system discharge rate, discharge rate by the emergency fire service, environmental sources (rain, snow, etc.), and any other catchments sharing the tunnel drainage system piping. Where the tunnel roadway drainage system discharges by gravity or by pumped discharge, it shall be provided with a separator sufficient for the design spill rate for the hazardous liquids and with adequate storage capacity.

The maximum demand on the drainage capacity for a water mist system proposed for EJMT is in the range of 126 m^3 (33286 gallon) to 234 m^3 (61817 gallon), depending on type of water mist systems used, for 60 minutes operation time. (Also note that a single large flammable/combustible liquid tanker is approximately 8000 U.S. gallons from a single tank, or 16,000 gallons from a combination truck and trailer tanker.)

Further evaluation and design modification of the EJMT drainage system to sufficiently handle effluent from a water mist system and any liquids from accidental spills is recommended in the final design stage.

It should be noted that in some water mist system tunnel applications, AFFF was used to prevent fires which are beyond the initial accident such as fires under the stopped vehicles. Particularly, if burnable liquids are washed into the tunnel drainage system, the AFFF can prevent those burnable liquids getting re-ignited by the hot surfaces. Although corrosion by AFFF is not a big issue as all parts of the water mist system are made from stainless steel, the use of additives introduces concern about possible negative effects on human health. (If AFFF is included in the system, the total cost of the water mist system will increase by less than 3 %.)

2.3.7 Activation (fire detection) and system control

Once the fire is detected, the relevant section is either automatically or manually activated. Three sections will be activated simultaneously. Water mist system will then encapsulate the three section areas [75 m (246 ft) to 90 m (295f t) long]. The fire detection system is not included in the budgetary quotation discussed in section 2.4.

2.3.8 Filtration, water quality and frost protection

Filtration is of great importance to the WMS functioning reliably. Water shall be pre-filtered when filling up the water reservoir. For this purpose filters with a filtration grade of not higher than 150 micron shall be installed at the tank inlet. Suitable filter means shall be provided between the reservoir and the pump unit, of a filtration grade according to the table shown in chapter 11.2.5.2 of UPTUN WP2 D251, to prevent particles which may have built up in the reservoir over time entering into the supply system. Such filters shall:

- be 100% redundant or self cleaning
- provide a by-pass for the case of blocking
- be monitored
- have a sufficiently large filter surface.

Each nozzle or nozzle head shall be equipped with a strainer.

The water supply must be protected from frost. The pump system must be installed in a frost free area. The main pipe must be protected from freezing where such risk exists (e.g., by trace heating; the freeze protection is not included in the budgetary estimate).

AQUASYS proposed to use cycling of water rather than trace heating to protect the main (wet) pipe from freezing. If the water temperature in the main pipe drops below 5°C (41F), the jockey pump starts to keep the water in the main pipe flowing from the water tank through one tunnel and returning to the tank through the other tunnel. Electric heaters at the jockey pump and water tank may be necessay to keep the water temperature of above 5 to 8°C (41 to 46F)at all times. And the main pipe must be equipped with thermal insulation. This approach has been used in the Felbertauern Tunnel in the Austria, which is at an elevation of 1750 m (5740 ft) and can be exposed to temperatures of -30°C (-22F) in winter. The cost increase with regarding to the frost protection, according to AQUASYS, is marginal using this water cycling approach for the Felbertauern Tunnel.

2.4 Cost Estimate

2.4.1 AQUASYS system

Table 2-3 presents the detailed price estimate of AQUASYS water mist system for EJMT. The budgetary quotation includes pump room installations (main pumps, jockey pumps, pump room piping), main (pipe) lines through both tunnels, deluge valve units, section (nozzle) lines and water mist nozzles in tunnels, water mist control system with interface to tunnel control system, design and engineering, installation and commissioning of water mist system (WMS). The budgetary quotation does not including the following: pump room building at the west portal, fire detection system (preferable linear heat detection system), and acceptance by local authorities. Items that can be sourced locally are also listed in the Table.

Table 2-3: Budgetary Quotation of AQUASYS WMS for EJMT

No.		Qty	Unit	Unit Price	Total Price in €	Total Price in US $
1	**Design, Test, Commissioning, Project Management**	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
2	**Main Pumps**	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
3	**Pump Room Installations**	[redacted]		[redacted]	[redacted]	[redacted]
4	**Main Pipe Line (includes pipes, hangers, brackets, fittings)**	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
5	**Section/Nozzle Lines (include pipes, hangers, brackets, fittings)**	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
6	**Water Mist Nozzles**	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
7	**Diverter Valve Units**	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
8	**Control System**	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
9	**Installation**	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Total System Price				[redacted]	[redacted]
item 4	Main line pipes, hangers, brackets, fittings could be sourced locally					
item 5	Nozzle line pipes, hangers, brackets, fittings could be sourced locally					
Item 9	Installation could be sourced locally					

2.4.2 FOGTEC system

Table 2-4 presents the detailed price estimate of FOGTEC water mist system for EJMT.

The budgetary quotation covers designs, materials, prefabrication and installation, testing and commissioning, project management and commissioning of FOGTEC system. Electrical/controlling limited to pumping rooms and section valve cabling/controlling is excluded (which are to be connected to tunnel management/control system). Additional civil works, water and power supply to pump rooms are excluded. Fire detection system (preferable linear heat detection system), and acceptance by local authorities are also excluded. The costs are based on European cost level and typical site conditions and installation programs. This cost estimate excludes VAT and other possible taxes, import duties.

Table2- 4: Budgetary Quotation of FOGTEC WMS for EJMT

No.		Total Price in €	Total Price in US $
1	**Design, Test, Commissioning, Project Management, Transportation, Insurances**	[redacted]	[redacted]
2	**Pump Stations (two) and Pump Room Installations**	[redacted]	[redacted]
3	**Main Pipe Line (includes all straight pipes, all pipe accessories such as reducers, elbows, tees, fittings, flanges, all supports and anchors for piping, shutoff valves, drain valves and venting valves); Main Pipe Network Prefabrication and Installation**	[redacted]	[redacted]
4	**Section/Nozzle Lines (include all straight pipes, all pipe accessories such as reducers, elbows, tees, fittings, flanges, all supports and anchors for piping); Section Valve DN40 (with manual shut-off maintenance valve); FOGTEC Water Mist Nozzles; Section Lines Prefabrication and Installation**	[redacted]	[redacted]
	Total System Price	[redacted]	[redacted]

2.4.3 HI-FOG system

Table 2-5 presents the detailed price estimate of HI-FOG water mist system for EJMT.

The budgetary quotation includes mechanical and electrical installations, local project management, all piping materials, pipe clamps, pipe fittings, spray (nozzle) heads, zone valves placed in fire proof cabinets, main pipes, water filter packs, local I/O control cabinets, design, engineering, installation work, project management and commissioning of HI-FOG system.

The budgetary quotation does not include the following: system control at the pump station, a control system and its equipment for the zone valve operation (main control system = SCADA or similar), fire rated cables between the local control cabinets and zone valves for the valve operation, pipes trace heating and insulation if required, water reservoir, feed water pump, water supply, power supply, civil works, pump room building and its equipment, fire detection for fire indication, main control system (SCADA or similar) which is to be connected to local I/O units and pump room control interfaces to operate the whole system (valves and pumps).

The calculated installation price does not include the following: dismantling and reinstalling of tunnel lining or other equipment disturbing water mist piping or nozzles or installation, extra bracketing which may be required, night time working rates, cost for storage area at site, cost for logistics at site and required security services. (The local installation cost varies from country to another depending on local conditions, requirements and workman cost. This price estimation is based on the tunnel installation projects HI-FOG experienced in other countries. It should be also noted that during a wide refurbishment work in a tunnel the installation time could be longer due to difficulties with logistics and schedules in conjunction with other works. Therefore this installation costs are budgetary only and will need to be finalized based on US contractor requirements and any special project considerations not identified in this estimation).

Table 2-5: Budgetary Quotation of HI-FOG WMS for EJMT

No.		Qty	Unit	Total Price in US $
1	**Design, Test, Commissioning, Project Management**	[redacted]	[redacted]	[redacted]
2	**Pump Room Components**	[redacted]	[redacted]	[redacted]
3	**Pump Room Installations**	[redacted]	[redacted]	[redacted]
4	**Main Pipe Line (includes pipes, hangers, brackets, fittings)**	[redacted]	[redacted]	[redacted]
5	**Nozzle Lines (include pipes, hangers, brackets, fittings)**	[redacted]	[redacted]	[redacted]
6	**Water Mist Nozzles**	[redacted]	[redacted]	[redacted]
7	**Diverter Valve Units**	[redacted]	[redacted]	[redacted]
8	**Control System**	[redacted]	[redacted]	[redacted]
9	**Installation**	[redacted]	[redacted]	[redacted]
	Total System Price			[redacted]

2.5 Maintenance

A strict and regular maintenance program shall be followed to ensure the reliable operation of the water mist system. The property owner and the operator of the system shall be responsible for this program. Maintenance shall be carried out in accordance with the design, installation, and maintenance manual of the manufacturer. UPTUN WP2 D251 [3] indicates that the regular maintenance shall at least cover the following:

- Monthly pump test runs for a minimum of 10 min. without pressurizing the pipe work in the tunnel; where applicable, all pumps of one pump unit shall be tested simultaneously
- Monthly test of all section valves (test by operation)
  Note: Section valves do not normally have any redundancy.
- Monthly collecting of information on running times of jockey pumps and automatic filters in order to detect leaks and water quality problems.
- Quarterly visual inspections of piping and nozzle heads.
- Twice a year (minimum) the system shall be maintained in accordance with the manufacturer's instructions by a company authorized by the manufacturer.
- Every five years pressure testing of the pipe work with 150% of the working pressure for one hour.

The operator's inspection program is intended to detect faults at an early stage to allow rectification before the system may have to operate. The manufacturer shall provide the tunnel operator with a monitoring software collecting 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.

NFPA 750 [5] also indicates that the frequency of inspections of components of water mist systems shall be in conformance with the manufacturer’s listing requirement and NFPA 25 [6]. NFPA 25 suggests that the frequency of inspection and tests shall be in accordance with Table 12.1.2 (also listed in Table 2.6 of this report) or as specified in the manufacturer’s listing, whichever is more frequent. Scheduled maintenance shall be performed as outlined in Table 12.2.4 of NFPA 25 (also listed in Table 2.7 of this report).

Table 2-6: Maintenance of Water Mist Systems

Item	Task	Weekly	Monthly	Quarterly	Semi-annually	Annually	Other
Water supply (general)	Check source pressure.			x			
	Check source quality (*first year).				x*	x	
	Test source pressure, flow, quantity, duration.					x	
Water storage tanks	Check water level (unsupervised).	x					
	Check water level (supervised).			x			
	Check sight glass valves are open.		x				
	Check tank gauges, pressure.			x			
	Check all valves, appurtenances.				x		
	Drain tank, inspect interior, and refill					x	
	Inspect tank condition (corrosion).					x	
	Check water quality.					x	
	Check water temperature						Extreme weather
Additive storage cylinders	Inspect general condition, corrosion.			x			
	Check quantity of additive agent.				x		
	Test quality of additive agent.					x	
	Test additive injection, full discharge test.					x	
Water recirculation tank	Check water level (unsupervised).		x				
	Check water level (supervised).			x			
	Inspect supports, attachments.					x	
	Test low water level alarm.					x	
	Check water quality, drain, flush and refill					x	
	Test operation of float operated valve.					x	
	Test pressure at outlet during discharge					x	
	Test backflow prevention device (if present).					x	
	Inspect and clean filters, strainers, cyclone separator.					x	

Table 2-6: Maintenance of Water Mist Systems (continued)

Item	Task	Weekly	Monthly	Quarterly	Semi-annually	Annually	Other
Pumps and drivers	Inspection, testing, and maintenance shall be in accordance with the requirements of NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection*, and NFPA 25.	x	x	x	x	x	
Standby pump	Check outlet water (standby) pressure.		x				
	Test start/stop pressure settings for standby pressure.			x			
System control valves	Inspection, testing, and maintenance shall be in accordance with the requirements of NFPA 25.	x	x	x	x	x	
Control equipment	Inspection, testing, and maintenance shall be in accordance with the requirements of *NFPA 72, National Fire Alarm and Signaling Code*						
Water mist system piping and nozzles	Inspection, testing, and maintenance shall be in accordance with NFPA 25.	x	x	x	x	x	After discharge
	Inspect sample of nozzle screens and strainers (see 10.5.1.4 of NFPA 750)						
Enclosure features, interlocks	Inspect enclosure integrity.				x		
Ventilation	Test interlocked systems (e.g., ventilation shutdown).					x	
	Test shutdown of fuel/lubrication systems.					x	

Table 2.7 Maintenance Frequencies

Item	Activity	Frequency
Water tank	Drain and refill	Annually
System	Flushing	Annually
Strainers and filters	Clean or replace as required	After system operation

References

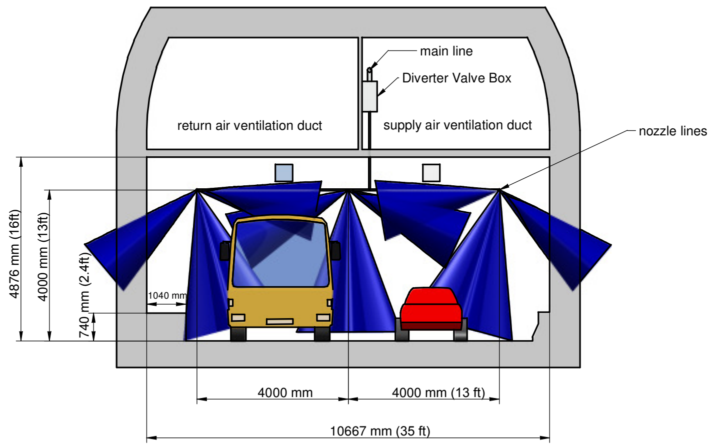
1. PIARC 2008: Road Tunnels: An Assessment of Fixed Fire Fighting Systems.
2. NFPA 502, Standard for Road Tunnels, Bridges, and Other Limited Access Highways, 2011 Edition, National Fire Protection Association.
3. UPTUN, *Engineering Guidance for Water Based Fire Fighting Systems for the Protection of Tunnels and Sub Surface Facilities.* Work Package 2 of Fire development and mitigation measures, Research Project UPTUN of the European Commission, Document D251, by Toby McCory, Dirk Sprakel, Erik Christensen, 2008.
4. Risk Analysis Study of Hazardous Materials Trucks through Eisenhower/Johnson Memorial Tunnels, June 2006, PB.
5. NFPA 750, Standard on Water Mist Fire Protection Systems, 2010 Edition, National Fire Protection Association.
6. NFPA 25, Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection System, 2011 Edition, National Fire Protection Association.
7. NFPA 13, Standard for the Installation of Sprinkler Systems, 2010 Edition, National Fire Protection Association.
8. NFPA 15, Standard for Water Spray Fixed System for Fire Protection, 2007 Edition, National Fire Protection Association.
9. Water Mist Fire Suppression Systems for Road Tunnels, Final Report, the SOLIT Research Project, 2007.
10. The HIFOG Truck Fire Tests Reports 2004 - 2007.
11. AQUASYS Preliminary Design Submission 2012.
12. HI-FOG Preliminary Design Submission 2012.
13. FOGTEC Preliminary Design Submission 2012.

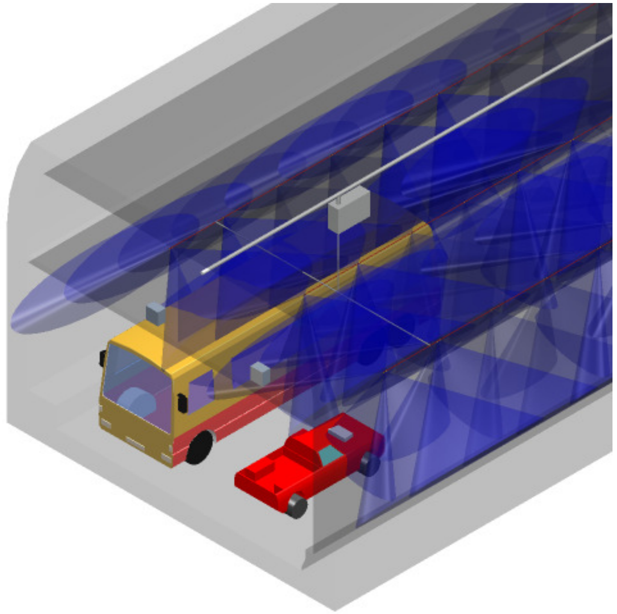
Appendix A: Preliminary Design Drawings of a Water Mist System for EJMT: AQUASYS System

Drawings include

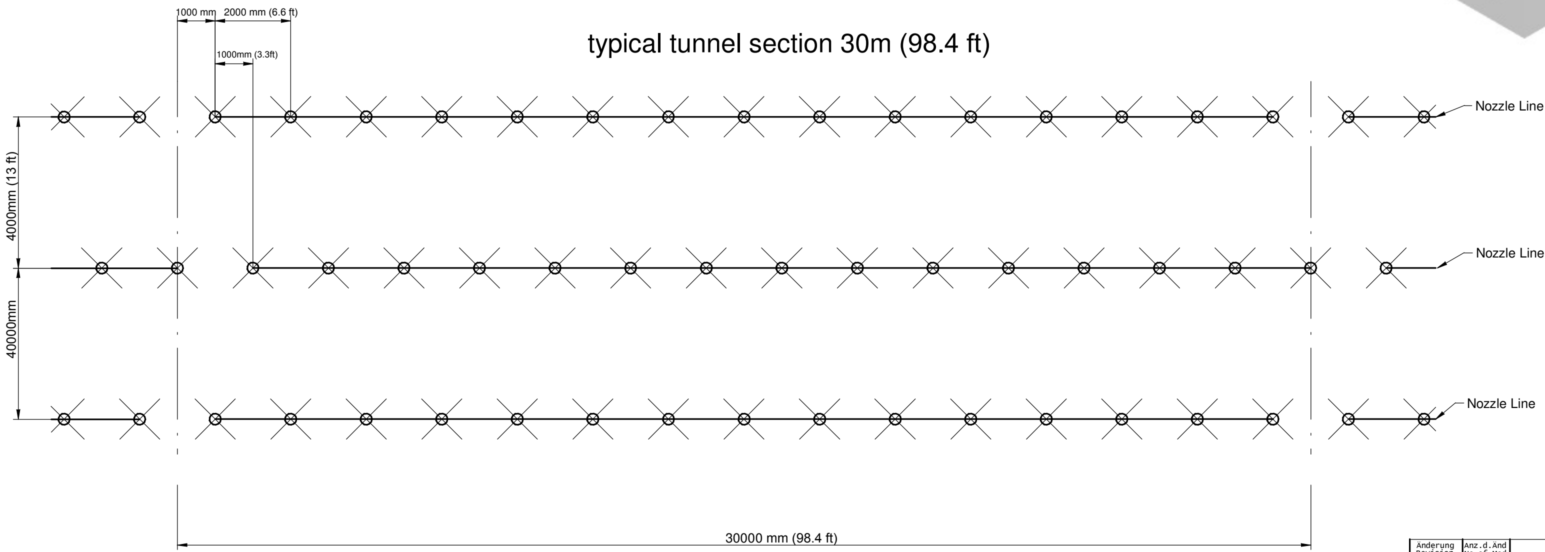
1. Nozzle Layout
2. Nozzle Head Characterics
3. Diesel Powered Motor Pump
4. Electrical Powered Motor Pump
5. Pump Room Layout

Nozzle Layout





typical tunnel section 30m (98.4 ft)



Änderung Revision	Anz.d.Änd No.of Mod	Änderungsinhalt Modification	Datum Date	Erstellt Prepared	Geprüft Checked

Urheberschutz gemäss Copyright according to ISO 16016	AQUASYS firefighting is responsibility	Gez. Prep. ps 111123	Maßstab / Scale 1 : 1
Allgemeintoleranzen (Freimaßtol.): Untoleranced dimensions: DIN ISO 2768 -m -K DIN EN ISO 13920 - A - F	POSTFACH 100, INDUSTRIEZEILE 56, A - 4021 LINZ TEL ++43 732 7892 449 FAX ++43 732 7892 373 info[at]aquasys.at	Gepr. Check. ps 111108	Masse / Weight 0,0 kg
Project Projekt	Kunde: Customer:	Blatt Sheet 1 von of 1	
Benennung/Designation tunnel		Material Material Edelstahl 316L 1.4404	Wärmebehandlung / heat treatment . .
		Zng.Nr. Drawing No. A300101-06489	Format Format 2 / Änderung Revision B
		Material Nr. Material No.	

A2

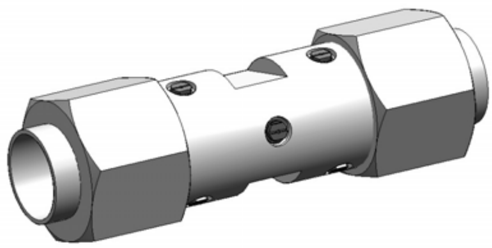
C:\Programme\Solid Edge V12\Program\Template\ASNormal_Gewicht_Material.dft

AQUASYS firefighting is responsibility

DKIT

In Line - Nozzle Head

In Line - Düsenkopf



- Tunnel configuration:
  - AISI 316 L, Stainless Steel
  - pressure stage: PN 64

- Tunnelausführung:
  - V4A, Edelstahl
  - Druckstufe: PN 64

Standard

Type	k - factor	Maße / Dimensions
DKIT	38	118 x 42
		(4.6 in x 1.6 in)

other configurations on request

andere Konfigurationen auf Anfrage

DKIT 38 / 0 – 6.90 – x L

flow rate l/min @ 100 bar,
e.g.: 38 = 38 l/min @ 100 bar

0 - 6.90 : AQUASYS internal code

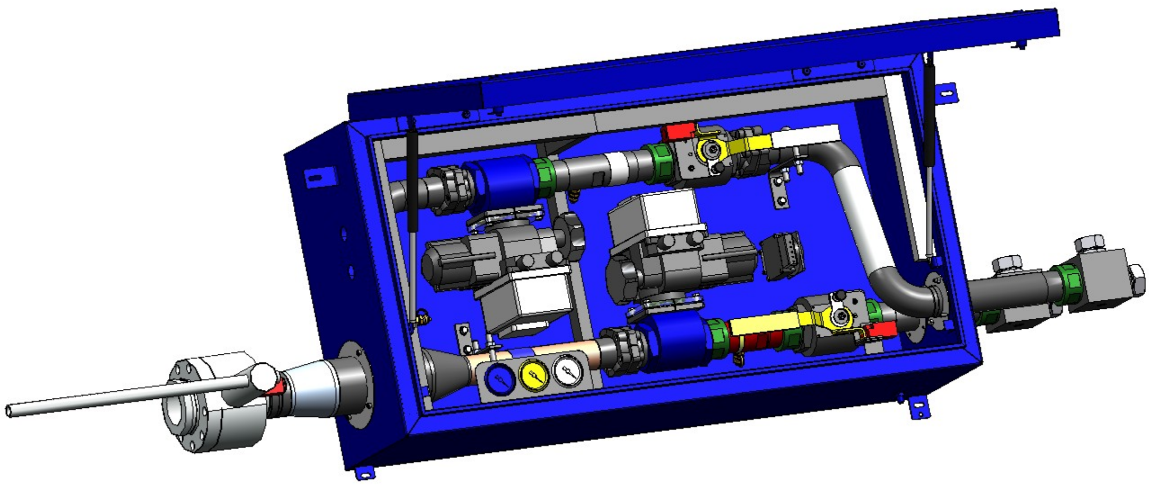
pipe dimension **x L : e.g. 22L**

AQUASYS firefighting is responsibility

DVS

Diverter Valve System

Bereichsventileinheit



- Configuration for 2 sections:
  - Stainless steel AISI 316 L
  - pressure stage: PN 64
  - additional test port
  - scavenge port (air)
  - service ball valve with position monitored
  - power supply 230 VAC
  - pressure switch
  - pressure gauges
- Options:
  - 24 VDC

- Standardausführung für 2 Sektionen:
  - V4A Edelstahl
  - Druckstufe: PN 64
  - zusätzlicher Messanschluss
  - Anschluss für Spülluft
  - Servicekugelhahn mit überwachter Endlage
  - Stromversorgung 230 VAC
  - Druckschalter
  - Druckmanometer
- Optionen:
  - 24 VDC

Type	L x B x H (mm)
DVS 42L-230VAC ST	ca. 1300 x 400 x 700

4.3 x 1.13 x 2.3 (ft)

other configurations on request / andere Ausführung auf Anfrage

DVS T2 - 230VAC ST

Type: **DVS T2 = for 2 Sections**
DVS T4 = for 4 Sections

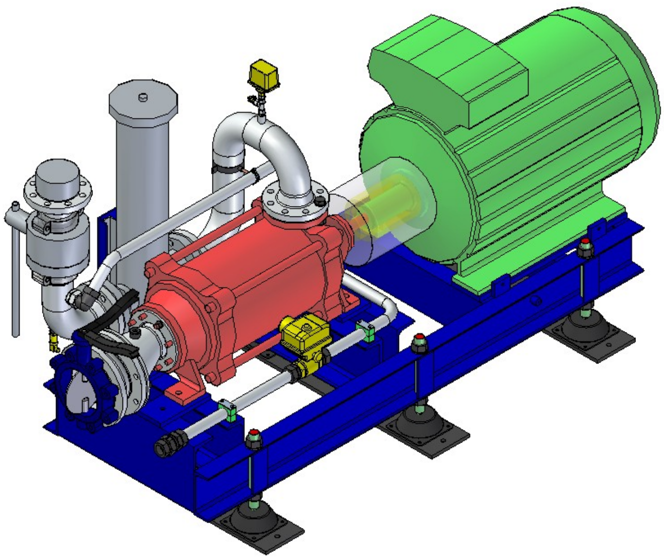
Voltage: **230 VAC**
24 VDC

ST - AQUASYS internal code

AQUASYS
firefighting is responsibility

PP 1500 E
PP 1800 E

Electric Power Pack Tunnel



- **Standard configuration:**
  Electrically powered motor-pump unit
  pump for pure potable water
  pressure relief valve, pressure switch
  built in performance test unit,
  protection class: IP 54
  maximum pressure: 64 bar
  required pressure stage: PN 64
- **Options:**
  - soft start control
  - frequency converter for flow rate control

other configurations on request

- **Standardausführung:**
  Elektrisch angetriebene Motor-Pumpeneinheit
  Pumpe für Trinkwasser
  Druckbegrenzungsventil, Druckschalter
  eingebaute Leistungsmessung,
  Schutzart: IP 54
  maximaler Druck: 64 bar
  erforderliche Druckstufe: PN 64
- **Optionen:**
  - Soft Start Anlauf
  - Frequenzumrichter zur Regelung der Förderleistung

andere Ausführungen auf Anfrage

Type	**Maße/dimensions** LxBxH	**Gesamtgewicht / total weight**	**Power / Voltage** main pumps
PP 1500 E	2800 x 1200 x 1500 mm	ca. 1.750 kg	230 kW / 400 VAC
PP 1800 E	2800 x 1200 x 1500 mm	ca. 1.800 kg	275 kW / 400 VAC
	9.2 x 4 x 4.9 (ft)		308 HP/400 VAC 369 HP/400VAC

PP 1500 / 64 - E - 0001

Flow rate : **1500 l/min @ 64 bar**
1800 l/min @ 64 bar

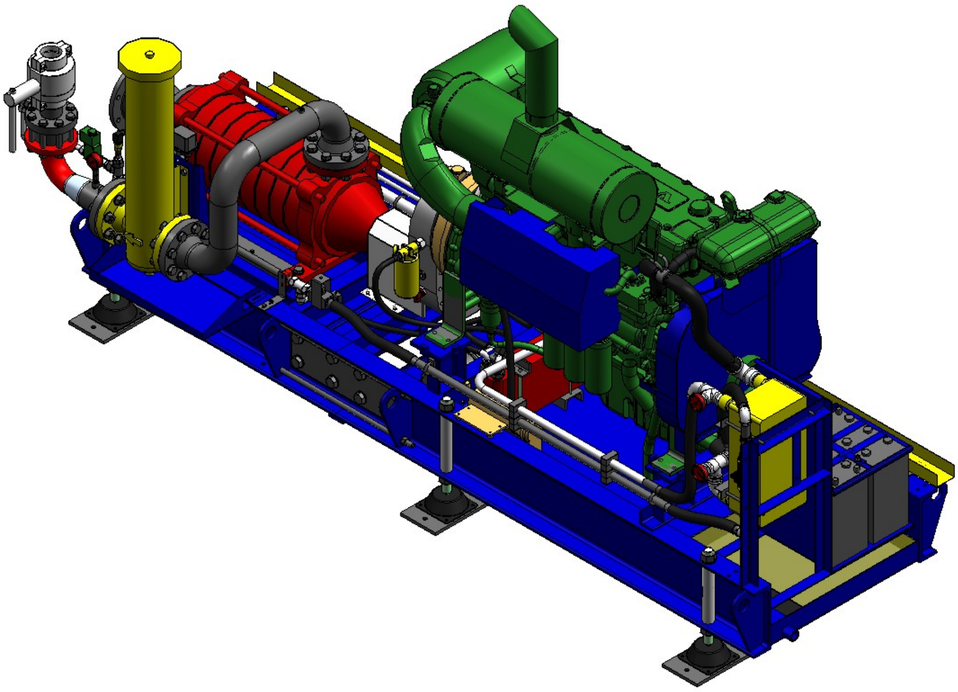
Type of drive: **E = Electric motor**

0001 - AQUASYS internal code

AQUASYS
firefighting is responsibility

PP 1500 D
PP 1800 D

Diesel Power Pack Tunnel



- **Standard configuration:**
  Diesel powered motor-pump unit
  pump for pure potable water
  pressure relief valve, pressure switch
  built in performance test unit,
  Diesel tank
  redundant starting batteries packs
  protection class: IP 54
  maximum pressure: 64 bar
  required pressure stage: PN 64
- **Options:**
  - pump start control
  - redundant battery charging unit

other configurations on request

- **Standardausführung:**
  Diesel Motor-Pumpeneinheit
  Pumpe für Trinkwasser
  Druckbegrenzungsventil, Druckschalter
  eingebaute Leistungsmessung,
  Kraftstofftank
  redundante Starterbatterien- Sätze
  Schutzart: IP 54
  maximaler Druck: 64 bar
  erforderliche Druckstufe: PN 64
- **Optionen:**
  - Steuerung für Pumpenstart
  - redundantes Batterieladegerät

andere Ausführungen auf Anfrage

Type	**Maße/dimensions** LxBxH	**Gesamtgewicht / total weight**	**Power / Voltage** main pumps
PP 1500 D	4100 x 1300 x 2000 mm	ca. 3.600 kg	230 kW (308 HP)
PP 1800 D	4100 x 1300 x 2000 mm	ca. 3.700 kg	275 kW (369 HP)
	13.4 x 4.3 x 6.6 (ft)		

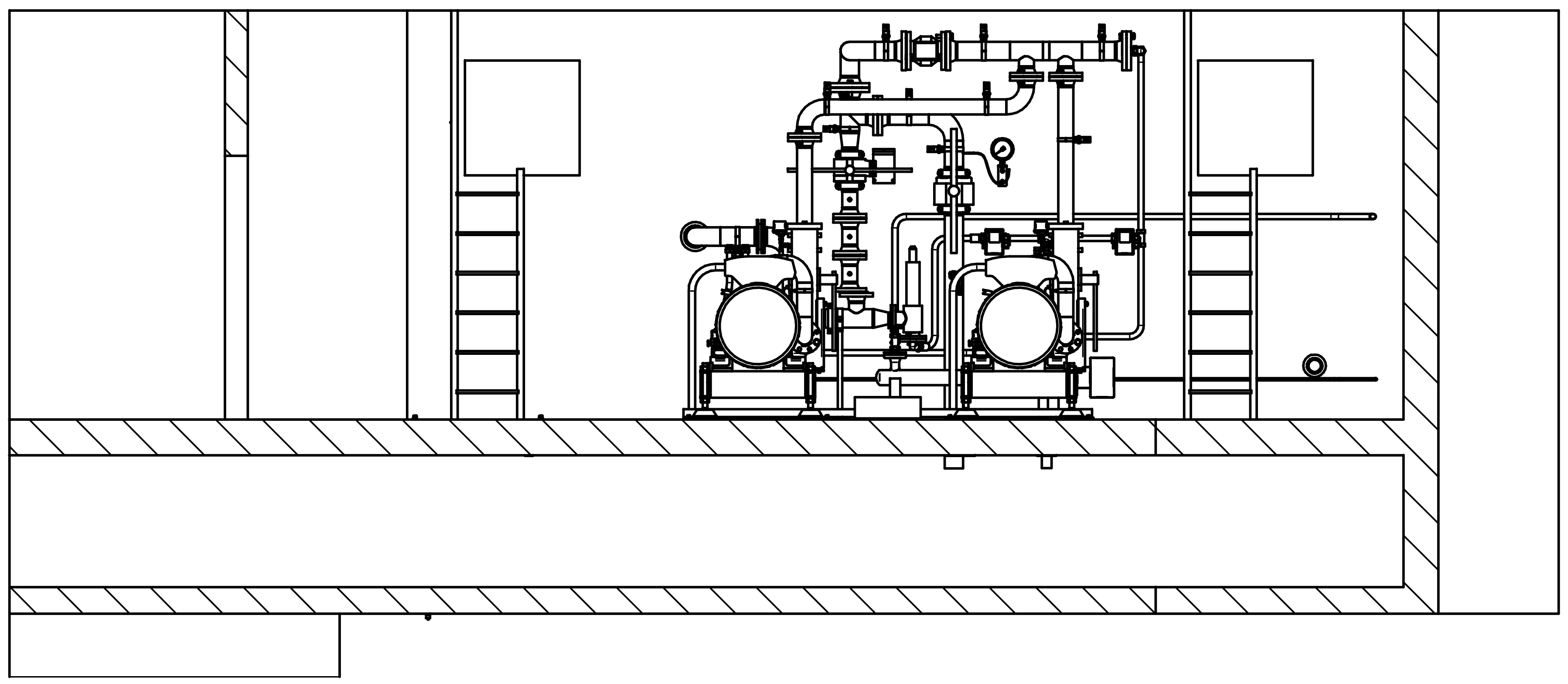
PP 1500 / 64 - D - 0001

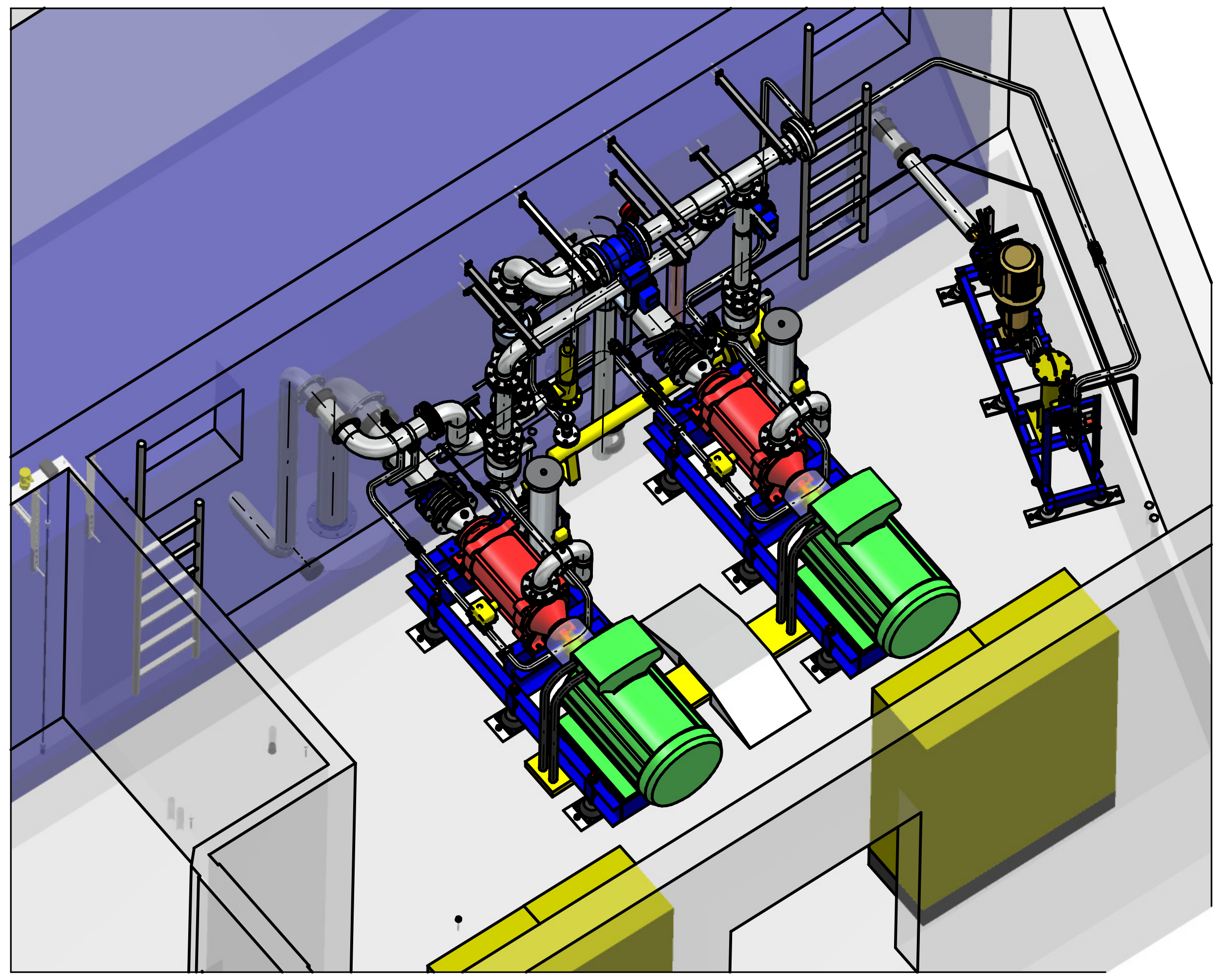
Flow rate : **1500 l/min @ 64 bar**
1800 l/min @ 64 bar

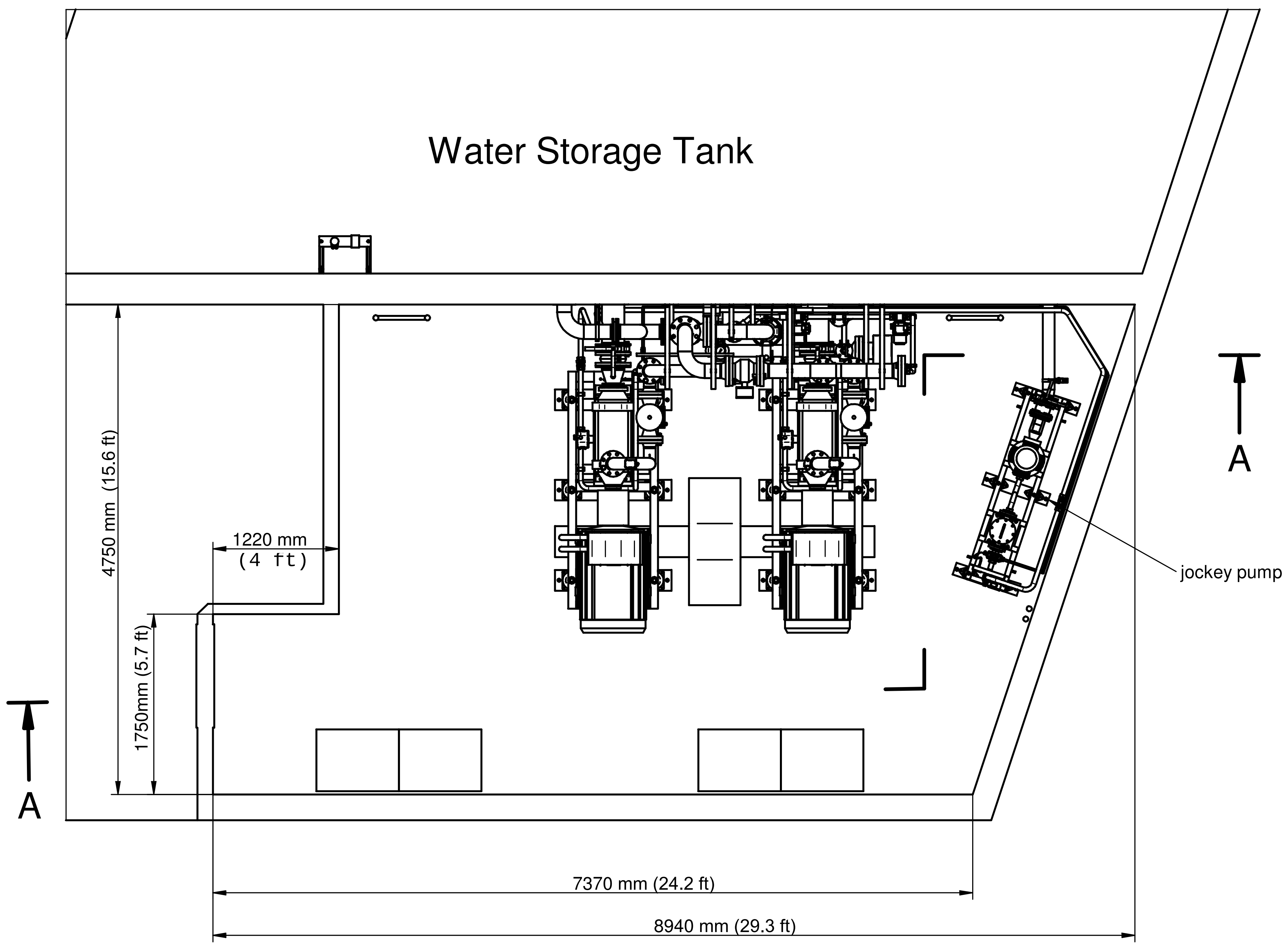
Type of drive: **D = Diesel engine**

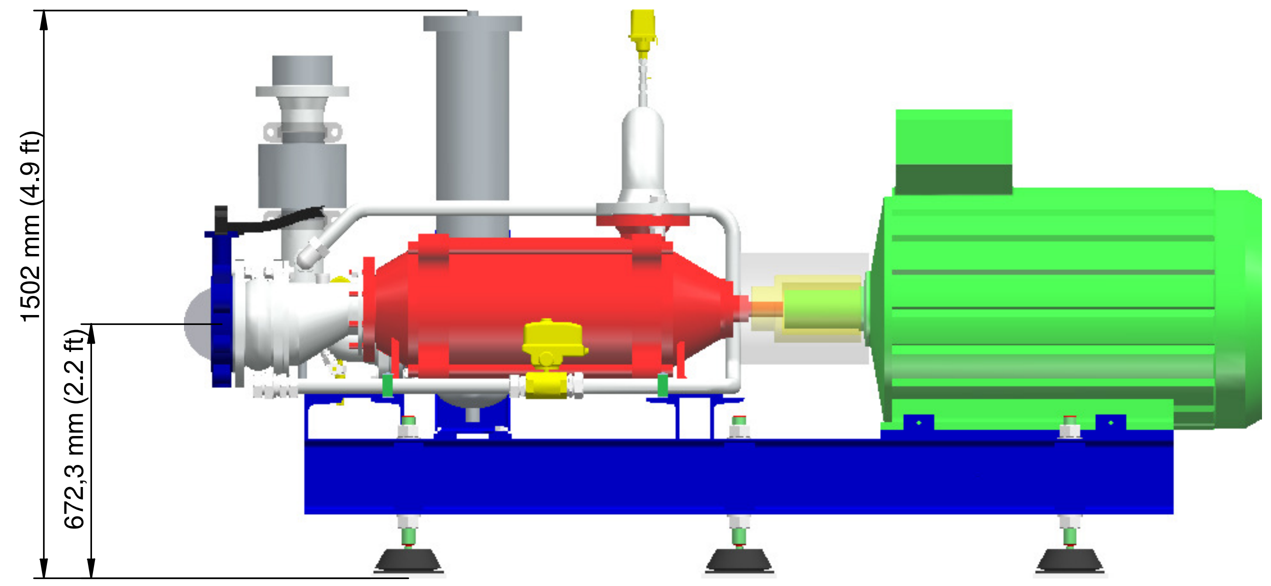
0001 - AQUASYS internal code

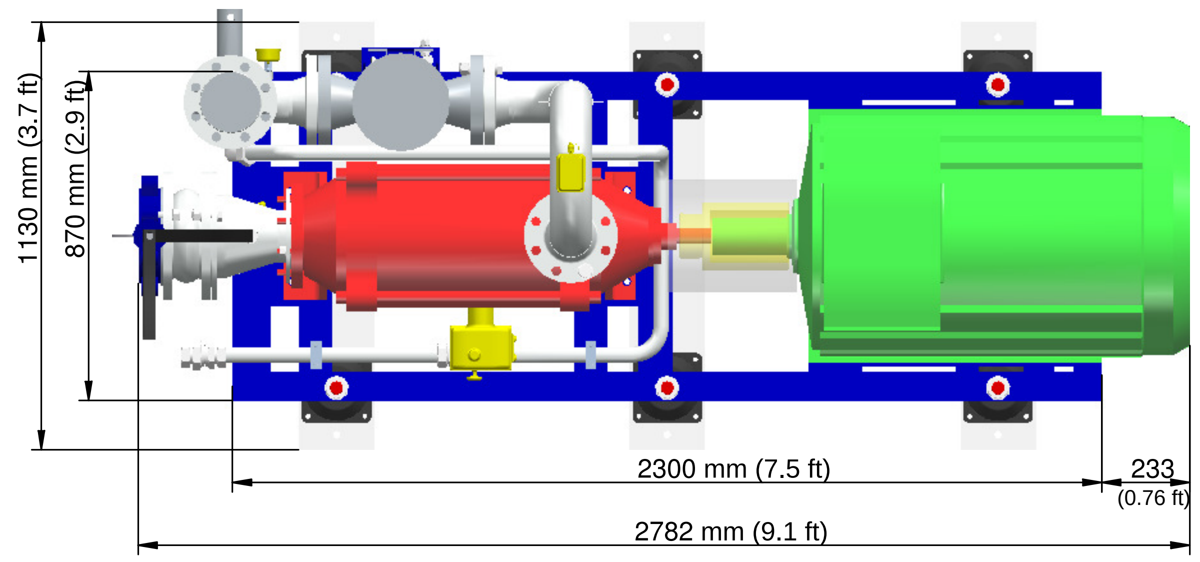
section A-A











Änderung Revision	Anz.d.Änd No.of Mod	Änderungsinhalt Modification	Datum Date	Erstellt Prepared	Geprüft Checked

Allgemeintoleranzen (Freimaßtol.): Untoleranced dimensions:
DIN ISO 2768 -m -K
DIN EN ISO 13920 - A - F

AQUASYS
firefighting is responsibility
POSTFACH 100, INDUSTRIEZEILE 56, A - 4021 LINZ
TEL ++43 732 7892 449 FAX ++43 732 7892 373
info[at]aquasys.at

Gez. Prep.	ps	110407
Gepr. Check.	ps	110407

Maßstab / Scale: 1 : 20
Masse / Weight: 0,0 kg
Blatt Sheet 1 von of 1

Project Projekt: –
Kunde: Customer: -
Material Material: - -
Wärmebehandlung / heat treatment: . .

Benennung/Designation

Pumproom typical example

Zng.Nr. Drawing No.: A300600-06052
Format Format: 2
Änderung Revision: A
Material Nr. Material No.: –

C:\Programme\Solid Edge V12\Program\Template\ASNormal_Gewicht_Material.dft

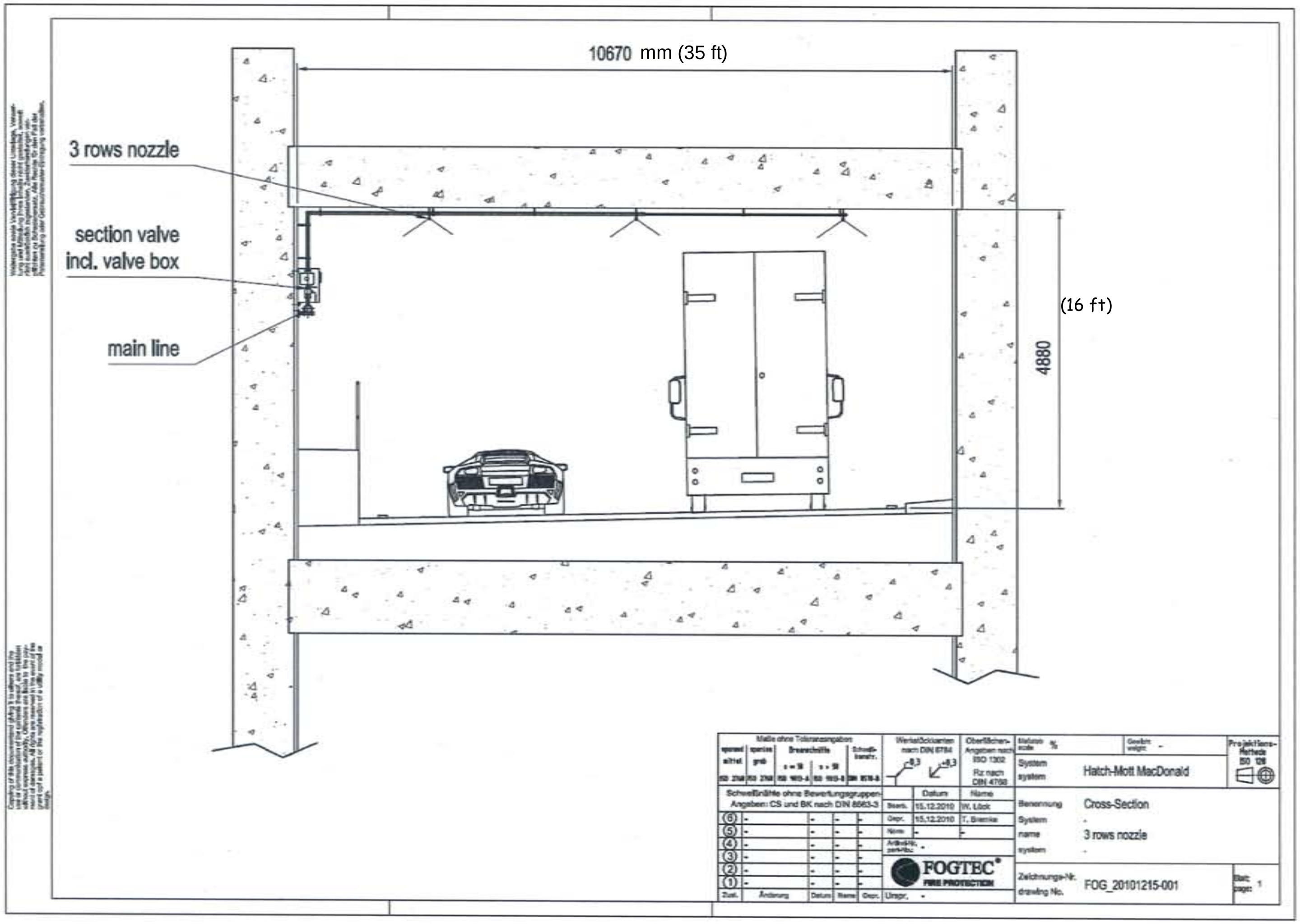
Appendix B: Preliminary Design Drawings of a Water Mist System for EJMT: FOGTEC System

Drawings include

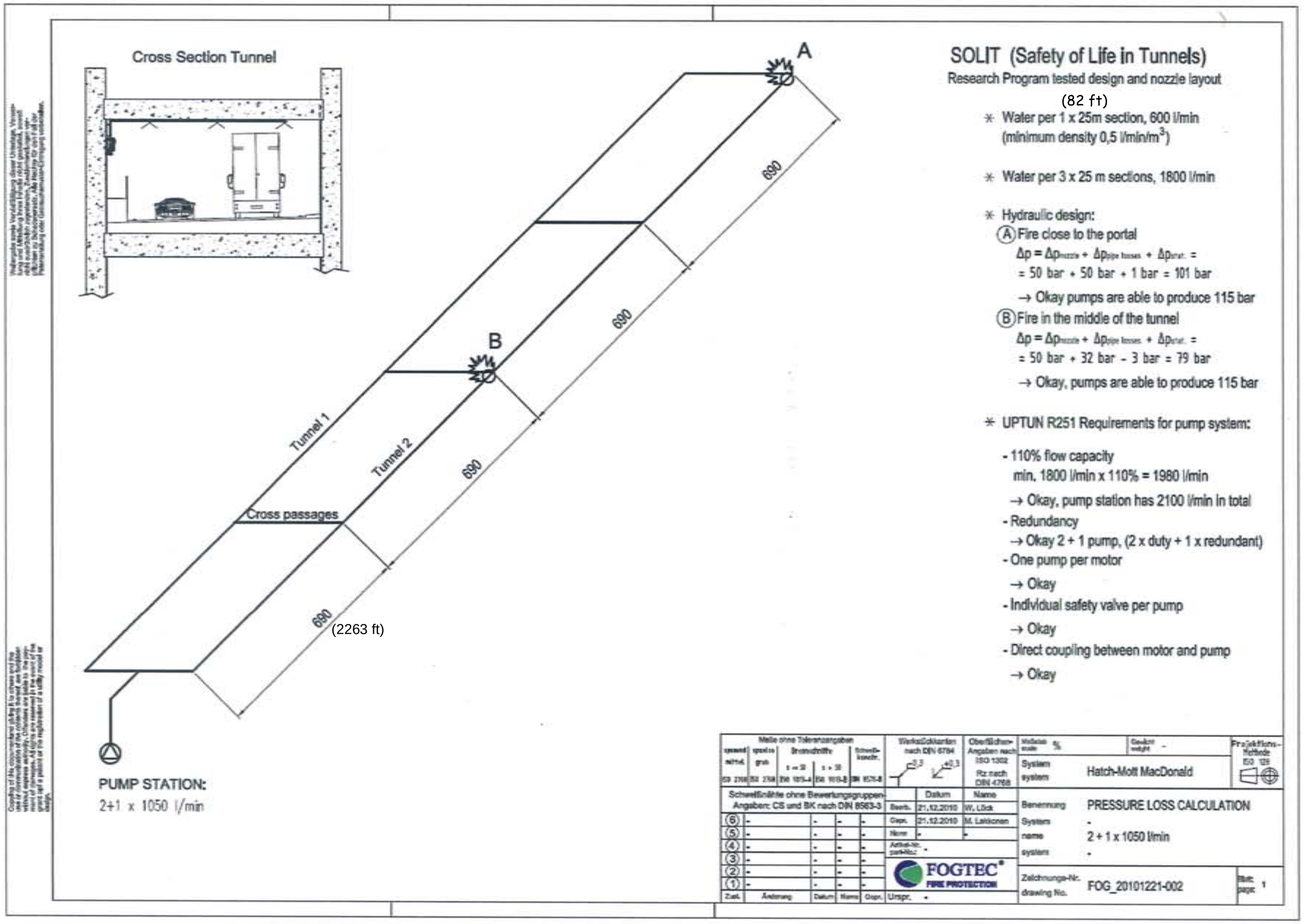
1. Nozzle Layout (Cross Section)
2. Hydraulic Design
3. Pump Room Layout
4. Section Pipes
5. Trace Heating

13 Annex 2 – Preliminary technical documentation

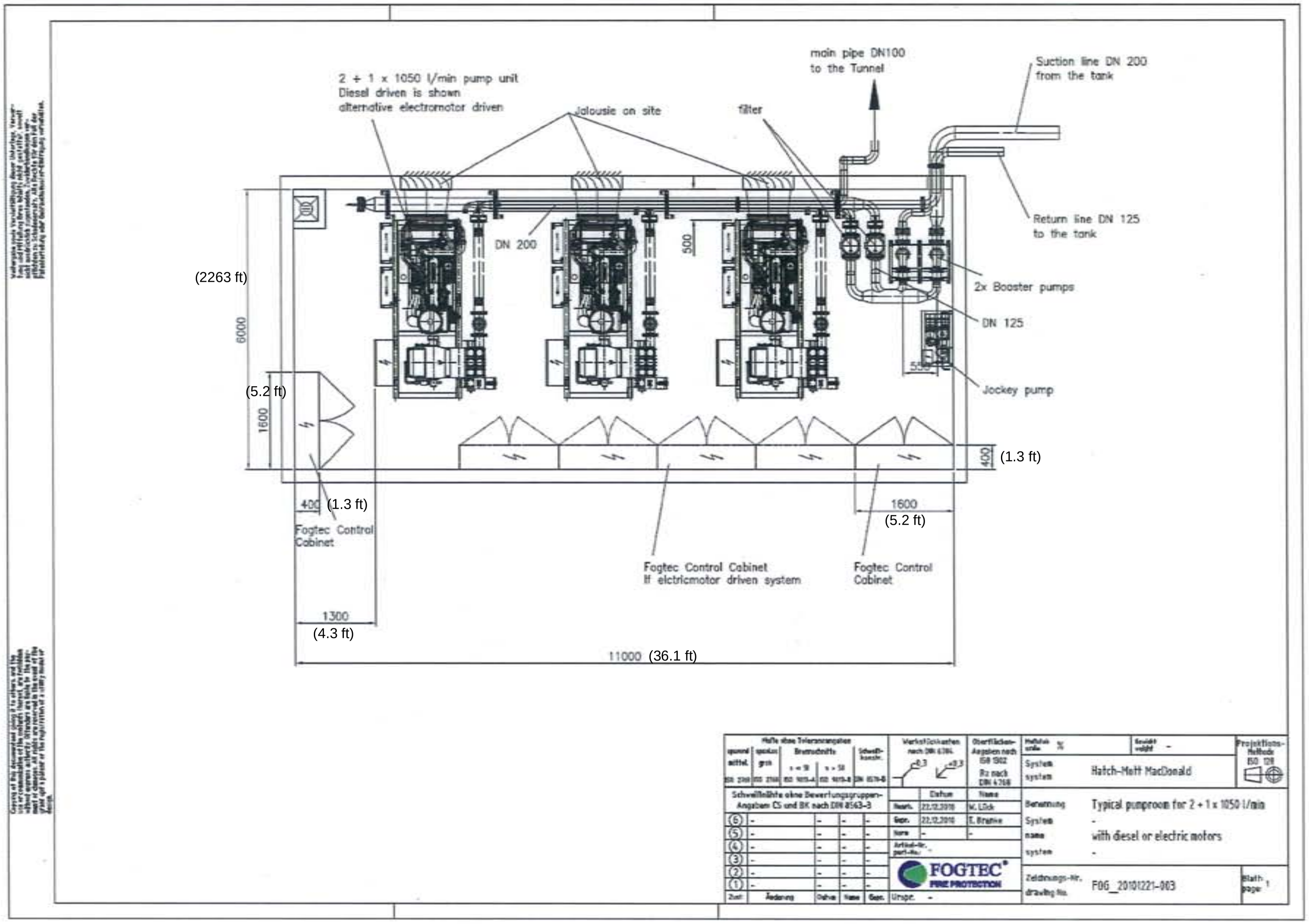
13.1 Cross section



13.2 Hydraulic design

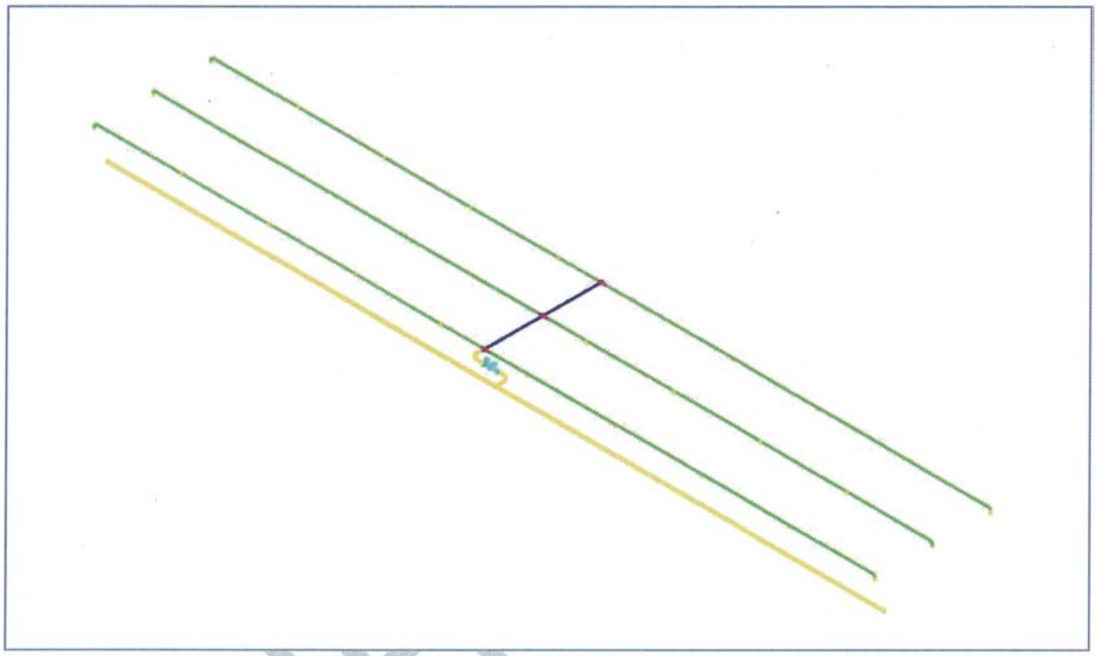


13.3 Pump room lay-out

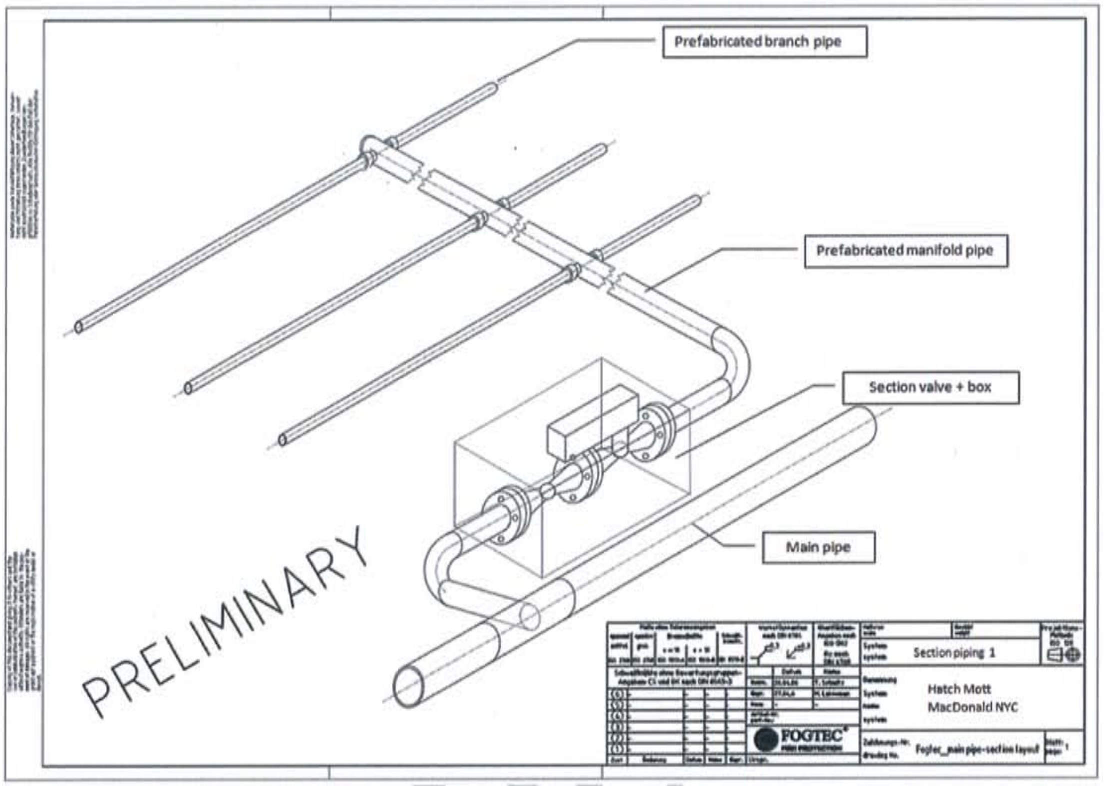


13.4 Section pipes

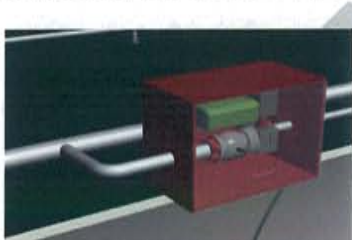
The schematic section design is presented in the following picture. The yellow pipe is the main pipe and the rest are section pipes. Nozzles are installed with the regular intervals to the longitudinal branch pipes (green colour). The length of one section is 25 meters (82 ft). The picture below demonstrates the typical section. There are 6 nozzles in 25 meter (82 ft) installed to every branch pipe of meter tunnel. This equals to 21 nozzles per section. The distance between nozzles is 4.17 meters (13 ft).



The sections are normally built with offsite prefabricated pipe kits in order to make installation in the tunnel faster. The following picture shows the main parts in larger view.



Additionally few details of pipework 3D models are shown in the following.



Section valve + fire protection box

Connection of branch pipes to the manifold

13.5 Trace heating

FOGTEC FIRE PROTECTION	TECHNICAL DATA SHEET	*TDS-TC+INS Eng v02*	24.05.2006
	Trace heating and insulation *(General Description)*		

Trace heating and insulation (Option)

Description

Pipe work with water in areas that might be influenced by cold temperatures needs to be protected. This can be done only by insulation if the freezing risk is small. Normally, the trace heating has to be installed in addition to the insulation. FOGTEC recommends using both trace heating and insulation for wet pipes in areas of temperatures below 0°C.

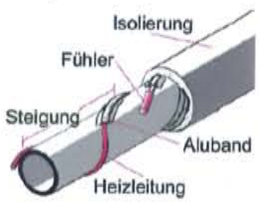
Applications

Road tunnels, rail tunnels, cable tunnels, garages and all outdoor applications.

General properties

Insulation:
Pipe insulation is available in different sizes, materials and thicknesses. Normally special glass wool insulation is used for FOGTEC pipe work. The insulation is manufactured to the tube profile and it is available with surface coating on request. The used insulation materials are classified to be non-combustible according to *DIN4102-A2* and *DIN EN 13501-A1*.

Trace heating:
Trace heating is arranged in FOGTEC systems with heating cable that is installed around the pipe before insulation. The heating power is available between 8-40W/m and normal power requirement is 230V AC. The temperature control is included to the FOGTEC supply, but customer has to supply the needed electric power which is dependent on the chosen solution and size of the system.

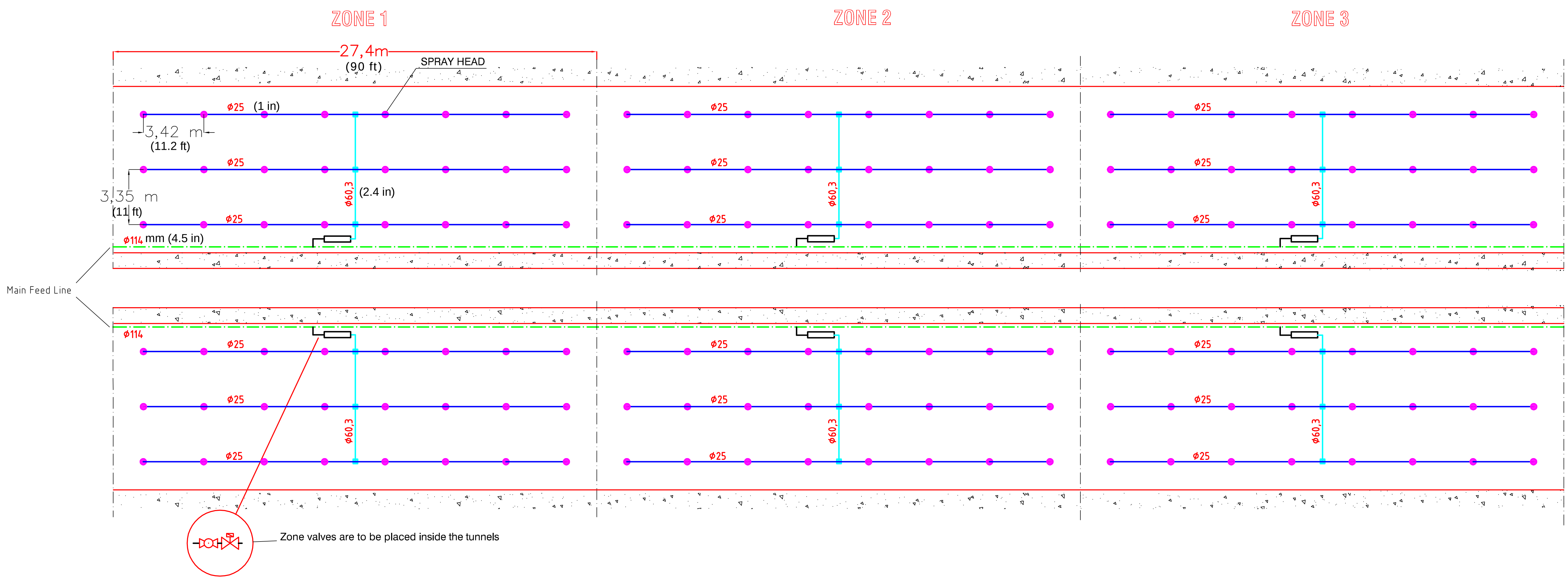


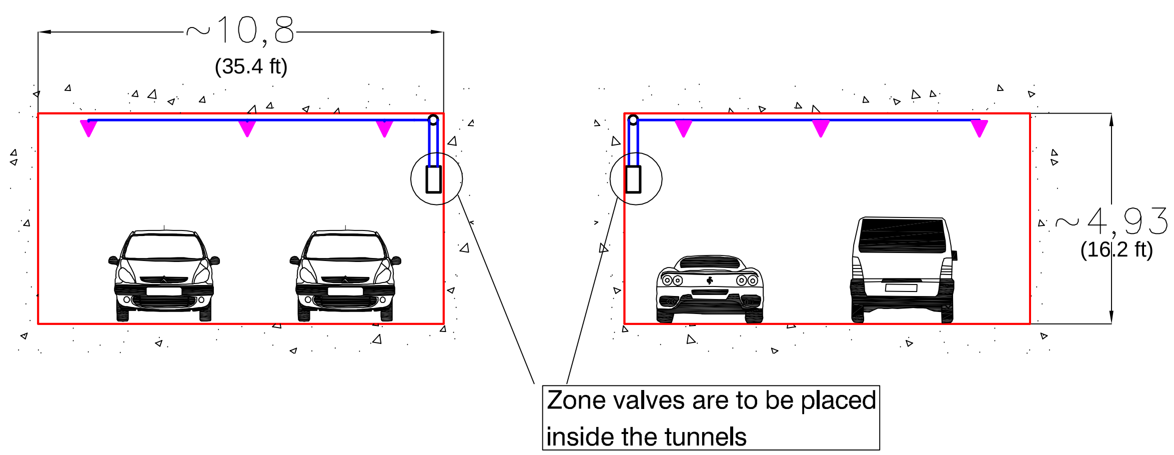
Insulation protection:
Pipe insulation is recommended to be sometimes protected with other materials in harsh environments. For example stainless steel metal cover is used often in traffic areas of road tunnels and some industrial applications with harsh environment. Proper covering of the insulation helps also in the cleaning of pipes.

Appendix C: Preliminary Design Drawings and Specification of a Water Mist System for EJMT: HI-FOG System

Drawings include

1. Nozzle Layout for EJMT
2. Nozzle Head Characterics (4S 1MD 6MD 1000)
3. SPU Pump Unit for North America (Specification)
4. Pump Room Layout
5. Valve Cabinet
6. Assembly Body
7. Specification for Water in HI-FOG Systems





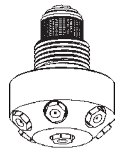
DRAFT

PROJ.NO: SYSTEM: HI-FOG	HI-FOG Marioff P.O.BOX 86 FIN-01301 Phone+358-9-870851 Fax +358-9-87085374 www.hi-fog.com	DESIGNER AMU	SCALE NONE	A3	SHEET
		CHECKED		THIS DRAWING IS DESIGNED WITH AUTOCAD 2004LT FOR WINDOWS	
		APPROVED		This drawing is our property. It is not to be traced, copied or published without our written consent, not to be misused in any way.	
	DRW. NAME HI-FOG ARRANGEMENT SPRAY HEAD SYSTEM		DRW. NO. Eisenhower		REV. 01

HI-FOG ®

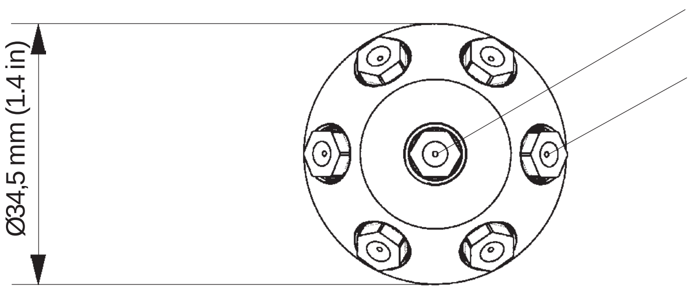
Technical Data Sheet TC9840

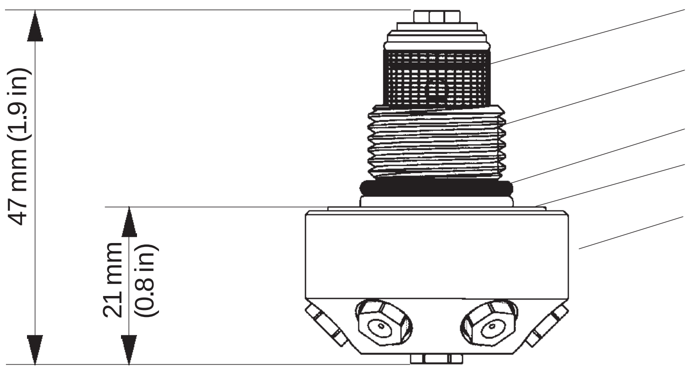
Spray Head Type 4S 1MD 6MD 1000



Stock code C31102

17 Nov 2006





General	Body material	Stainless steel
	Mass	0,139 kg
	K-factor	5,5 lpm/bar ^{0,5}
Installation	Location*	Tunnel ceiling and/or walls
	Max. spacing*	4 m (13.1 ft)
Typical application	Road and railway tunnels.	

*) Application specific

Marioff Corporation Oy, P.O. Box 86, Virnatie 3, FIN-01301 Vantaa, Finland,
tel +358 9 870 851, fax +358 9 8708 5399, e-mail info@marioff.fi, www.hi-fog.com

Pump Unit for North America

Overview of SPU products

TECHNICAL DATA SHEET DOC0004nnn **REVISION** Draft 1 **DATE OF ISSUE** Aug 2010

Description

The Sprinkler Pump Unit (SPU) for North America is designed to meet the requirements HI-FOG® Water Mist Fire Protection Systems on land-based applications, and is especially suited for systems requiring project specific approvals by NFPA. The SPU pump modules are started sequentially upon activation to reduce the electric power peak loads. In stand-by position the system pressure is maintained at 25 bar by means of a stand-by pump.

The SPU for North America can be started automatically, manually or remotely. The automatic start is activated by flow or by low pressure, both of which are continuously monitored. The manual start is activated from the pump controllers. The remote release can be included to allow activation by release panel or third party signal (such as a fire detection system, FDS).

The SPU for North America is stopped manually by pressing the STOP button on each pump controller after the section valve of the release area has been closed. Closing the section valve stops the water release and allows the pressure in the pipes to rise back to 140 bar.

Service area requirement

Reserve free space around the unit available for service and maintenance work per the instructions provided in the Marioff Installation Manual.

Starter Cabinet (pump controllers)

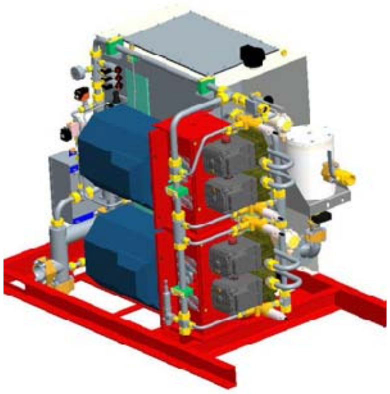
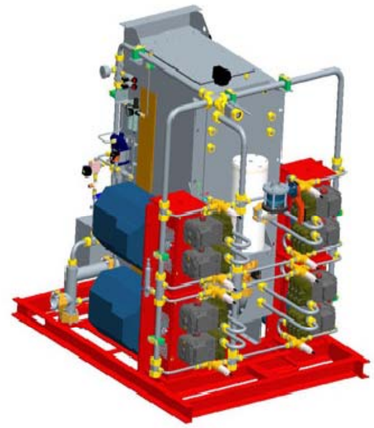
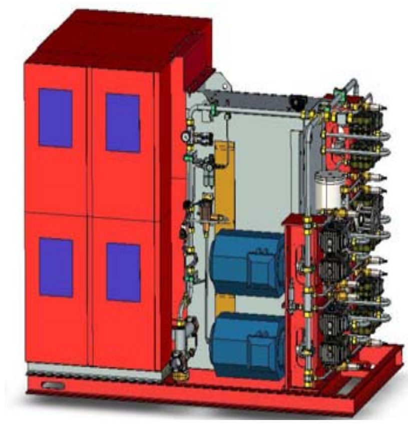
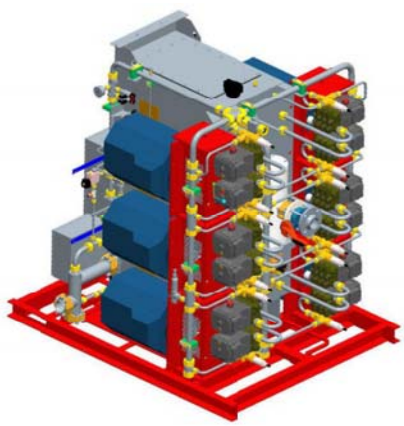
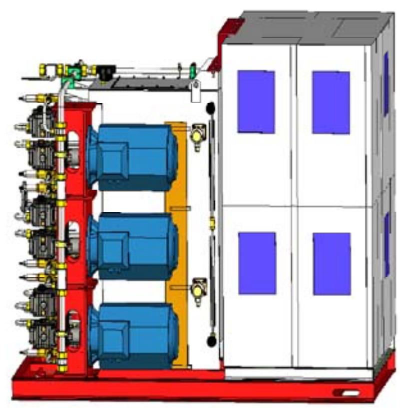
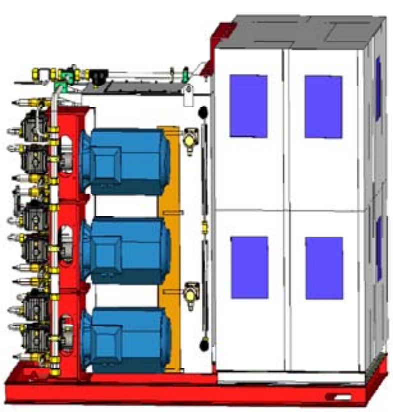
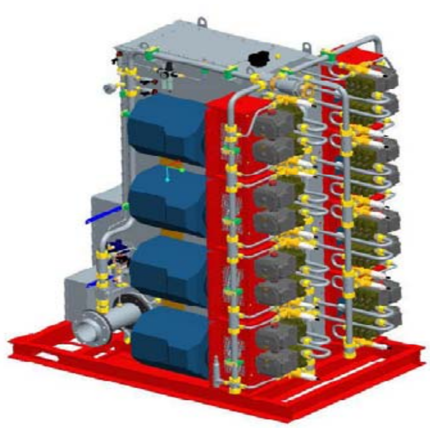
The Starter Cabinets for SPU for North America products consists of power supply section, control section, and a specified number of controller sections. The Starter Cabinet is used to monitor, operate, and control the SPU pump unit. It indicates all operation and fault signals concerning the pump unit.

The SPU for North America may include the following signals out for use by a third-party system:

- PUMP RUNNING – HI FOG ACTIVATED
- PUMP UNIT – PLC FAULT
- SYSTEM PRESSURE LOW
- POWER AVAILABLE
- PHASE REVERSAL
- LOW WATER SUPPLY

For the manufacturer's product details, please visit; www.tornatech.com or www.cutlerhammer.com.
For more information, see Technical Data Sheet DOC000nnnn.

Pump Configurations

E01234.3 SPU-2 Remote Cutler Hammer Controller 	E01235.2 SPU-3 Remote Cutler Hammer Controller Picture Not Available	E01236.2 SPU-4 Remote Cutler Hammer Controller 
E01237.3 SPU-5 Skid Mounted Tornatech Controller 	E01238.2 SPU-6 Remote Cutler Hammer Controller 	E01238.3 SPU-6 Skid Mounted Tornatech Controller 
E01238.4 SPU-6 (Canada Supply) Skid Mounted Tornatech Controller 	E01058.2 SPU-8 Remote Cutler Hammer Controller 	E01058.3 SPU-8 Skid Mounted Tornatech Controller Picture Not Available

Technical Specifications

Pump Unit	Electric Supply Options (60hz)	Discharge Flow LPM (GPM)	Discharge Pressure BAR (PSI)	Inlet H2O Pressure BAR (PSI)	Inlet H2O Flow LPM (GPM)	Inlet Air Pressure BAR (PSI)	Inlet Air Flow NL/MIN (CFM)
SPU-2	600V 3PH 60HZ 460V 3PH 60HZ	195 (51)	140 (2,030)	2-7 (29-101)	195 (51)	4-7 (58-101)	150 (5.3)
SPU-3		292 (77)		2-7 (29-101)	292 (77)	4-7 (58-101)	150 (5.3)
SPU-4		390 (103)		2-7 (29-101)	390 (103)	4-7 (58-101)	150 (5.3)
SPU-5		487 (128)		2-7 (29-101)	487 (128)	4-7 (58-101)	150 (5.3)
SPU-6		584 (154)		2-7 (29-101)	584 (154)	4-7 (58-101)	150 (5.3)
SPU-7		682 (180)		2-7 (29-101)	682 (180)	4-7 (58-101)	150 (5.3)
SPU-8		779 (205)		2-7 (29-101)	779 (205)	4-7 (58-101)	150 (5.3)

Pump Unit	Water Inlet	Water Outlet	Air Inlet	Drain Outlet	Overflow	Running Load Amps (RLA)	Lock Rotor Amps (LRA)
SPU-2	BSP R1,1/2" Female	30X2.5 DN2353	BSP R1/4" Female	BSP R3/4" Female	SAE 2 1/2" Flange	42	225
SPU-3	DN50 DIN2642	30X2.5 DN2353			SAE 2 1/2" Flange		
SPU-4	BSP R 2" Female	38X3 DIN2353			SAE 2 1/2" Flange		
SPU-5	DN65 DIN2646	38X3 DIN2353			SAE 2 1/2" Flange		
SPU-6	DN65 DIN2647	38X3 DIN2353			SAE 2 1/2" Flange		
SPU-7	DN100 DIN2633	SAE 2"			DN125 DIN2642		
SPU-8	DN100 DIN2633	BSP R2" Female			DN125 DIN2643		

Pump Unit	Width mm (in)	Length mm (in)	Height mm (in)	Mass (Dry) Kgs (lbs)	Mass (Wet) Kgs (lbs)
SPU-2	1000 (39.3)	1739 (68.5)	1248 (49.2)	N/A	N/A
SPU-3	1000 (39.3)	1739 (68.5)	1694 (66.7)	1770 (3902)	2300 (5071)
SPU-4	1410 (55.5)	1800 (70.9)	1800 (70.9)	1890 (4167)	2450 (5401)
SPU-5	1410 (55.5)	1800 (70.9)	1800 (70.9)	2400 (5291)	2960 (6525)
SPU-6	1410 (55.5)	1800 (70.9)	1800 (70.9)	2700 (5953)	3260 (7187)
SPU-7	1410 (55.5)	1925 (75.8)	2322 (91.5)	N/A	N/A
SPU-8	1410 (55.5)	1925 (75.8)	2341 (92.2)	3100 (6834)	N/A
SPU-5 (S)	1442 (56.7)	2456 (96.7)	2044 (80.5)	2600 (5732)	3160 (6967)
SPU-6 (S)	1442 (56.7)	2456 (96.7)	2044 (80.5)	2894 (6380)	3454 (7615)

*(S) denotes a SPU unit to be delivered as a skid with Tornatech cabinets mounted to a larger base

*Power requirements shall be based on the running load amps for all but 1 pumps running plus the lock rotor amps for one pump.

*RLA and LRA are calculated based on 460V-3PH-60Hz motors

SPU – x Sequence of Operations

The SPU-x installation and operation are governed primarily by NFPA 20 as well as the approval documentation of Factory Mutual for light-hazard applications. There are two ways that an idle pump unit can be started; they are by the automatic sequence and by manually starting and stopping each motor. The first operation to be covered is the starting and stopping each motor manually.

On each motor controller within the cabinet, there is separate start and stop push buttons that control each motor independent of the PLC programming. The PLC does, however, receive a signal each time the button is pushed. This is done to keep the PLC from activating the automatic sequence while a motor is being run for maintenance purposes or for other reasons. A signal will still be sent to the fire alarm panel (if option exists) that the system has been activated which is done for obvious reasons, you do not want someone to inadvertently run the pumps without someone else who is monitoring the system knowing about it. Once a pump is run and system pressure is high on the pipe network, the system will automatically reset the system pressure down to its standby pressure and return to auto-ready mode.

The automatic sequence mode is rather simplistic in concept although can be somewhat complex to try to end once started. If significant work is to be done on a system, it is often best to take the PLC out of run mode by flipping a hidden switch under a cover on the face of the PLC to the opposite position (off). Altering the position of this switch will automatically send a 'PUMP UNIT FAULT' to the monitoring fire panel to alert those monitoring the system of an error. It is very important to note that this switch must be returned to the 'RUN' position once the work is completed and the standby pressure is back to its normal pressure of 25-30bar. Failure to do so may activate the automatic mode once the PLC switch is set to 'RUN'. The automatic mode once activated will run for a minimum of 10 minutes per NFPA 20 before it will shut down and reset itself. Activation of the automatic sequence can be accomplished in two ways, either by a detection of steady flow or by a drop in system pressure.

<u>Flow Start:</u>
There is at least one flow switch on the pump unit that is located on the output of the standby pump. There may be other flow switches installed throughout the system if so required. These flow switches all have a programmable set-point that will close the circuit when the flow reaches that set-point. If flow is detected at any PLC monitored flow switch for a period of 4 seconds, the PLC will start the motor sequencing.

<u>Pressure Start:</u>
There is an analog pressure switch that is being monitored by the PLC that will give the exact pressure of the system at all times. The low pressure start is typically set to start the motor sequencing when the system pressure drops below 17bar. Once this signal has been received, there is a 10 second delay to protect against false starts and accidental trips. If the pressure remains below 17bar for the complete 10 seconds, the PLC will start the motor sequencing.

<u>Motor Startup Sequencing:</u>
Once either of the two ways to start the auto sequence has been initiated, it is recommended that the system be allowed to cycle through its sequence. Any disruption to this sequence may cause the motors to inadvertently start again within 10 seconds of being shut down. This occurs partly due to the NFPA 20 directive that states the pump must run for a minimum of 10 minutes once it has been activated and also may be the result of low system pressure or a flow switch still showing a flow condition. If it becomes absolutely necessary to stop the sequence, the safest way is to reset the PLC using the RUN/STOP switch discussed previously and not to turn back to RUN until the system is in standby mode, meaning no flow and system pressure at 25-30bar.
Once a signal is received to start the lead motor, the PLC will activate the pump run contacts on the controller relevant to Motor 1. The PLC will then monitor the pressure on the analog pressure switch for a period of 4 seconds following the startup of motor 1. If this pressure stays below the set-point of 90bar (typically), the PLC will then signal the controller for Motor 2 to start the motor. This sequence will continue for the number of motors installed on the pump unit. The motors will continue to run as long as the pressure remains below their individual shutdown set-points as described in the section below.

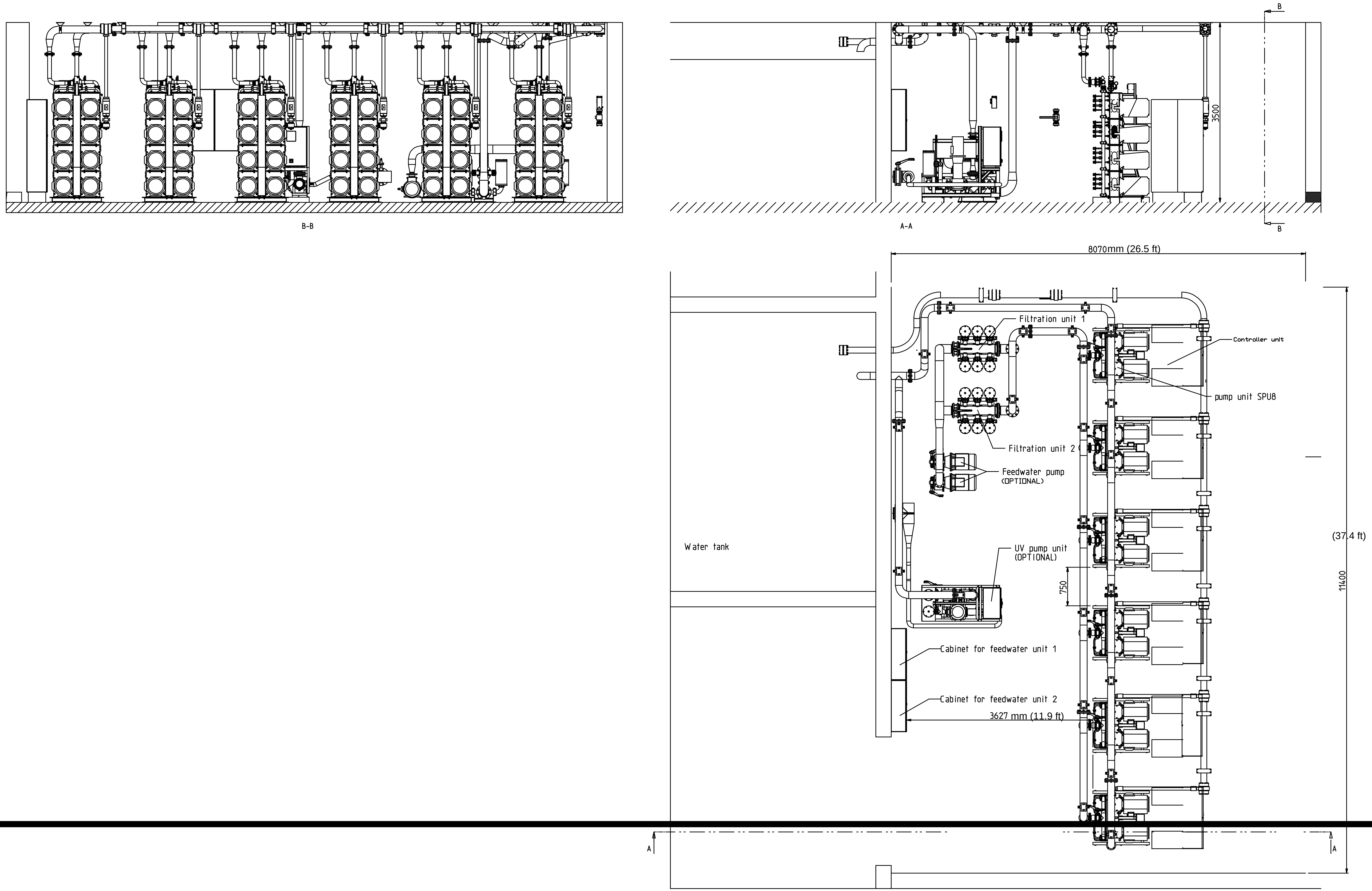
Motor Shutdown Sequencing:

Each motor installed on the pump unit is powering two individual pumps. These pumps have separate unloader valves that are to be set at varying pressure levels upon system commissioning, or if preset at factory, verified at commissioning. Typically the two pumps are set in tandem to the same pressure for each motor. The PLC program will have a preset value for the shutdown pressure of each pump. The pressure of the system must reach the highest set-point for the last motor that was started for the system to start shutting down motors. The set-point must be kept for a period of one minute before the PLC will discontinue its run signal to that motor controller. If once the PLC shuts the motor down, the system pressure drops below the 90bar set-point, the PLC will restart the motor. Once the system has been closed, and the flow and pressure have been stabilized, the PLC will shut down any remaining motors in sequence with 1 minute intervals between each motor. The final motor (motor 1) will run for a time period that is a minimum of 10 minutes from the shutdown of the last pump.

System Reset:

Following an automatic shutdown, the system will remain static for a period of 30 seconds before opening a stabilization valve which will return the system pressure to its original 25-30bar.*

*note: some systems have an optional manual reset which will flash calling for someone to push a button to reset the system.



Marioff Marioff Corporation Oy, P.O.Box 25, FIN-01511 Vantaa, Tel. +358-9-870851, Fax +358-9-87085399

Name: LAYOUT FOR PUMPROOM 6 X SPU8

Mass: 0.000 kg
Made: JSA 191208
Chkd:
Appd:
Release level: WIP

Scale: 3:100
Drw no: DOC0003554B
Product:
Replaces:
Tolerance: [redacted]
Drawing: 0003554
Model: 0003554

This drawing is a property of Marioff Corp. It is not to be disclosed, traced, copied or published without our written consent. Not to be misused in any way

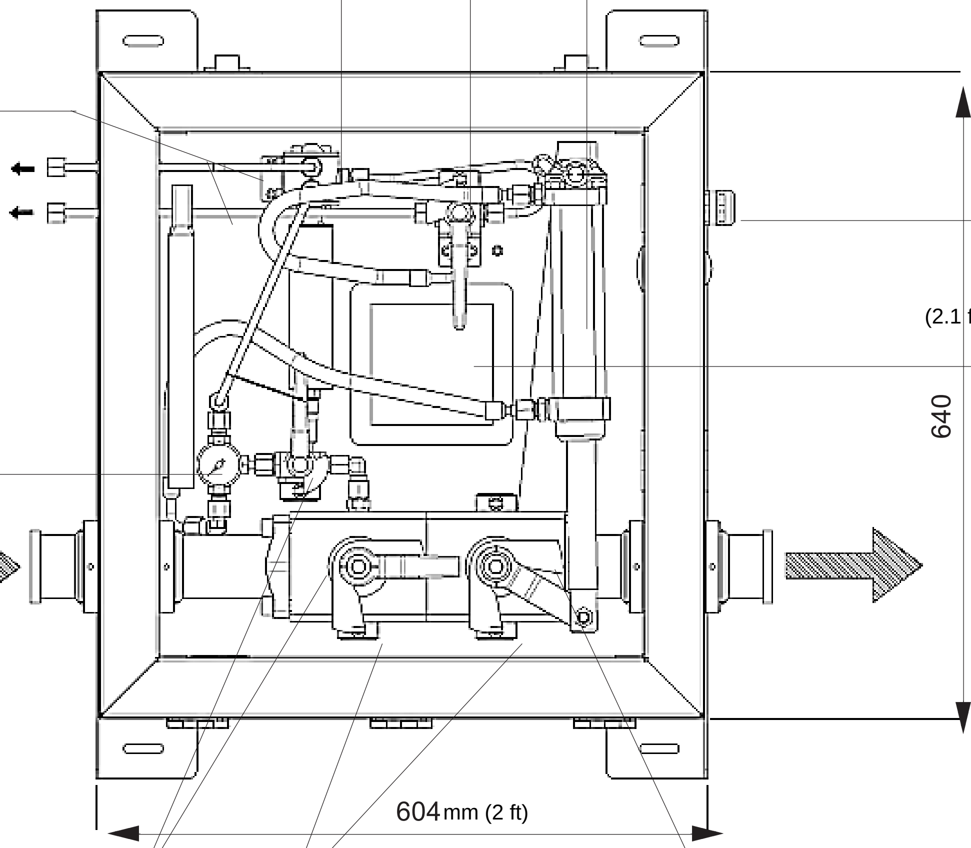
HI-FOG® water mist fire protection

Technical Data Sheet DOC0002339

Valve cabinet SAE 2” – SAE 2”

Product D90022

5 May 2008



Valve cabinet	The valve cabinet is used to protect the valves. It has a lockable door to prevent any unauthorized access to the valves. The manual shut-off valve is operated by using a handle inside the cabinet.	
General	Box material	Stainless steel plate 1.4301 EN (AISI 304), thickness 1 mm (0.04 in)
	Box size (mm)	width 604 (2 ft), height 640 (2.1 ft), depth 322 (1.1 ft) (box 200 (0.66 ft), door 120 (0.4 ft))
	Fastening holes (mm)	width 30 (0.1 ft), height 9
	Thermal isolation	Ceramic fire protection wool 2 x 30 mm, material Paroc FPS 14 Ceramic fire protection cord 25 x 25 mm (0.08 ft), product Finlon ceramic cord
Specifications	The cabinet design is validated in the following conditions: + 400 °C continuous temperature outside, duration > 1 hour + 800 °C continuous temperature outside, duration > 0,5 hours	

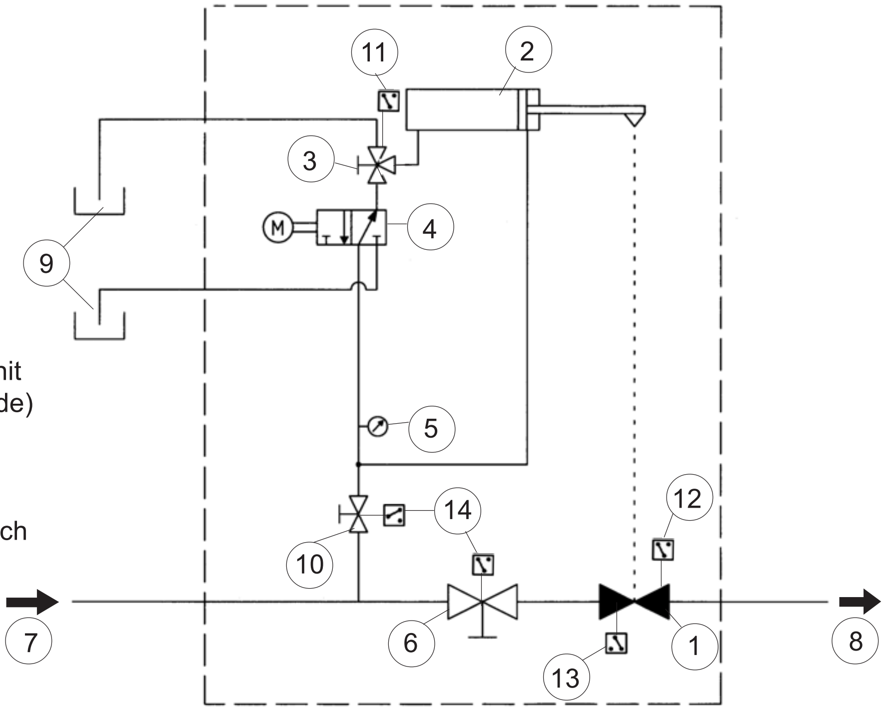
Marioff A UTC Fire & Security Company
Marioff Corporation Oy • Virnatie 3 / P.O.Box 86, FI-01301 Vantaa, Finland
Tel. +358 (0)9 870 851 • Fax +358 (0)9 8708 5399 • www.marioff.com

Valve cabinet SAE 2” – SAE 2”

Product D90022

5 May 2008

Valve cabinet components
1. Hydraulically operated section valve (closed in stand-by mode)
2. Hydraulic work cylinder
3. Manual release valve
4. Electric motor driven directional valve
5. Pressure gauge
6. Shut-off valve (normally open - closed during test work)
7. Main distribution pipe from the pump unit
8. Pipe to the section (dry in stand-by mode)
9. Overflow
10. Shut-off valve (normally open - closed during maintenance)
11. Manual release valve position limit switch
12. Section valve open limit switch
13. Section valve closed limit switch
14. Shut-off valve position limit switches



Operation principle
In stand-by mode, the pipe from the main distribution pipe (7) to hydraulically operated section valve (1) is pressurized by stand-by pressure. Water pressure effects (via shut-off valves (6) and pipe section in question) in a hydraulical work cylinder which operates the section valve (1) and in other components inside the valve cabinet.

1. Manual release
In manual release, a manual release valve (3) is turned to manual release position, thus generating a pressure difference in the hydraulic work cylinder (2) and forcing the piston to open the hydraulically operated section valve (1) which allows water flow to section pipe (8).

2. Remote release from control panel
The electric motor driven directional valve (4) can be remotely operated. In remote release, the directional valve (4) is turned to remote release position, thus generating a pressure difference in the hydraulic work cylinder (2) and forcing the piston to open the hydraulically operated section valve (1) which allows water flow to the section pipe (8). In case of electric black-out, the valve will stay in its last position.

Pump unit start
The pump unit is started by the start signal from the hydraulically operated section valve (1). Once started, the pump unit produces the full water pressure in pipe section(s) in question.

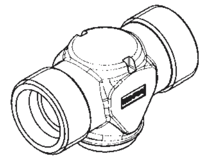
Valve cabinet reset
Hydraulically operated section valve (1) – closed
Manual release valve (3) – in automatic position
Electric motor driven directional valve (4) – closed
Shut-off valves (6) – open

Marioff Corporation Oy • Virnatie 3 / P.O.Box 86, FI-01301 Vantaa, Finland
Tel. +358 (0)9 870 851 • Fax +358 (0)9 8708 5399 • www.marioff.com

HI-FOG®

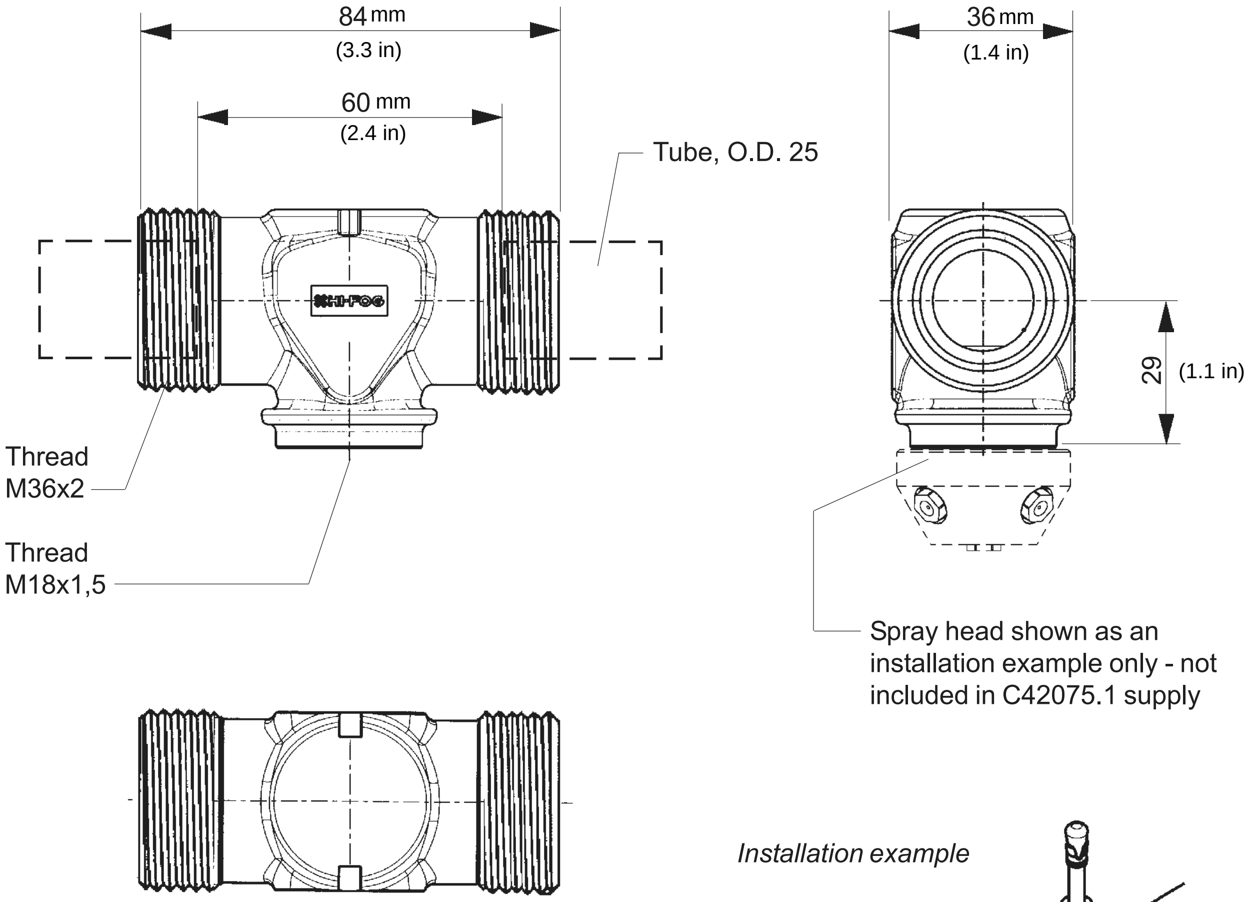
Technical Data Sheet TC9838

Assembly Body RA 715F-S00D25S10

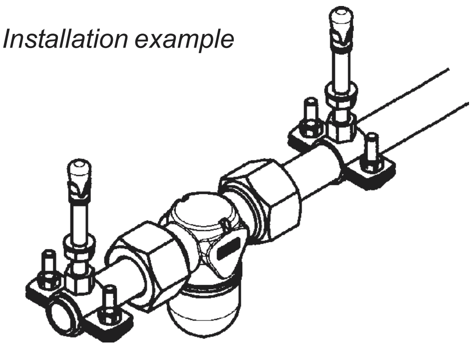


Stock code C42075.1

23 Jan 2006



Installation example



General	Body material	Cast stainless steel (CF8M)
	Mass	0,45 kg
Connection	Thread for cutting ring connection DIN2353	
Installation	Location	Ceiling or wall
	Projection	Pendent or horizontal

Marioff Corporation Oy, P.O. Box 86, Virnatie 3, FIN-01301 Vantaa, Finland,
tel +358 9 870 851, fax +358 9 8708 5399, e-mail info@marioff.fi, www.hi-fog.com

HI-FOG®
water mist fire protection

Technical Data Sheet

Specification for water in HI-FOG® systems

TECHNICAL DATA SHEET DOC0002101 **REVISION** C **DATE OF ISSUE** 20 Oct 2011

If the water requirements below cannot be reached, the water used for the HI-FOG® system may be treated, as described below in *Water treatment*, to enhance the HI-FOG® system lifetime.

A. Water requirements

- Equivalent of a potable supply
- Colourless and odourless
- Non corrosive
- Chloride concentration < 50 ppm (= 50 mg/l)
- pH value 7.0 – 9.0
- Iron (Fe) and Manganese (Mn); sum < 0.3 mg/l
- No free chlorine
- The fill line is routed through a < 100 µm filter (normally supplied with the unit). Suspended solids to be as low as possible.

B. Water recommendations

- Conductivity < 400 mS/cm
- Total hardness 1 – 3 mmol/l (5 – 16 °dH)
- Suspended solids, TSS < 10 mg/l
- Sulphate < 50 mg/l
- TOC < 2 mg/l (Total organic carbon)

If pH < 7.0 then alkalinity should be 1 – 4 mmol/l, pH shall never be below 6.5.

The amount of organic material shall be kept to a minimum. The biological and bacterial growth should be regularly monitored.

Distilled, demineralised, de-ionised or reverse osmosis water should not be used without adjustment of the alkalinity (or pH-value to ~8).

C. Water treatment

Fire suppression additives shall not be applied. The HI-FOG® system is not to be shock chlorinated.

Bacteriological growth

If bacteriological growth is found the water should be either changed through thorough flushing, or treated. The treatment may not be corrosive. Chlorine dioxide treatment may be used. Vernagroup's Purogene or Sanogene are possible treatment alternatives. The manufacturer's instructions and recommendations and applicable authorities' requirements are to be complied with.

Shock chlorinated water may be used only after ensuring that there is no free chlorine and the other parameters are within the specification (note: chlorination increases chloride content).

Specification for water in HI-FOG® systems

Corrosion

If the water is found corrosive an inhibitor may be used. The inhibitor may not contain nitrates or sulphates. It is also to be ensured the inhibitor complies with applicable authorities' health and other regulations. Nalco's Silazur 100 is a recommended alternative. Other inhibitors may also be used provided they are suitable for the materials used and not dangerous to people if they are exposed to the water mist.

D. Other aspects

If sea water or other water not complying with the specifications has entered the system (for example, in an emergency situation), the HI-FOG® system including all affected branch piping, is to be thoroughly flushed. The use of an inhibitor should be considered.

Marioff
A UTC Fire & Security Company

Marioff Corporation Oy • Virnatie 3, 01300 Vantaa, Finland • Tel. +358 10 6880 000 • Fax +358 10 6880 399 • www.marioff.com

Appendix D: Discussion of Fire Suppression Methods and Recent Data: Logic behind the decision on the use of conventional water sprinkler systems in tunnels of the Alaskan Way Viaduct (AWV) Project

This appendix summarizes the pros and cons of different fire suppression systems for tunnels and the factors affecting the choice of systems in tunnels, along with the most recent test data. The studies carried out in 2006 in support of the Alaskan Viaduct (AWV) project are discussed with regard to the choice of a conventional sprinkler system. The major findings of large scale tests of mist systems, carried out since the AWV studies, are then summarized.

The Alaskan Way Viaduct & Seawall Replacement Project

The Alaskan Way Viaduct and Seawall Replacement Project involved the construction of a new road tunnel, the Waterfront Tunnel, and the retrofit of the existing Battery Street Tunnel. The Waterfront tunnel is a 5300 ft (1615m) long double-deck bored tunnel; each road way in the Waterfront Tunnel is designed for three lanes of traffic and is approximately 50 ft wide and 21 ft high. The Battery street tunnel is an existing vehicle tunnel consisting of two-lanes of traffic and is approximately 2100 ft long and 62 ft wide. Both tunnels will have fixed fire suppression systems. For the Battery Street Tunnel, a complete replacement of the existing fire suppression system will be undertaken.

Transport of hazardous materials including flammable liquids and dangerous chemicals will be restricted from the future AWV Tunnel by the Seattle Fire Code; therefore a bulk fuel tanker, and hence a large pool fire, is not considered as the design standards.

In the studies carried out for the Seattle projects two types of fixed fire suppression systems including the traditional sprinkler deluge system and high pressure water mist deluge system were considered. A fire size considered of 100 MW was proposed, this being a typical value reflecting normal vehicle traffic through a tunnel including cargo trucks but excluding bulk transport of flammable liquids.

For the tunnel tenability evaluation study, only 410 ft (120 m) long section of the proposed Waterfront Tunnel with the similar cross section was modeled, as modeling a longer tunnel (5300 ft) would be difficult because of the significant computational requirement. For the fire suppression and extinguishment tests, a scale model of 90 ft long by 30 ft wide and 20 ft high is used. Simulations of both shielded and unshielded fires were performed.

For the traditional sprinkler nozzles study, 800-1400 microns water droplet diameter and a water density of 0.2 gpm/ft^2 was used, and for the high pressure water mist system study, a 50 microns water droplet diameter and a water density of 0.076 gpm/ft^2. With the prescribed water flow rates and droplet diameter, and the 100MW solid fuel fires, the simulation results were carried out for a section of tunnel 410 ft long. These showed that:

- Temperature reduction resulting from the fire suppression was good with both the standard drop sprinkler system and high-pressure mist system; both systems reduced the air temperatures to manageable levels and prevented the spread of fire, but the large drop system was less effective at reducing the air temperature.
- Visibility was improved upstream of the fire in the simulations. Downstream visibility was reduced when suppression was activated. For some cases if the tunnel ceiling was low, there was no stratification of smoke; the application of mist could improve the visibility.

- The high pressure mist system had the most significant reduction in thermal radiation. The standard sprinkler systems also reduced the thermal radiation, allowing firefighters to get closer to the fire.

In terms of the performance of fire suppression and extinguishment, the simulations showed that for the shielded solid fuel fires, roughly equal reductions in HRR with either system were possible. For unshielded solid fuel fires, the simulations showed that dramatic reductions in HRR occurred with a standard drop sprinkler. For the mist system, simulation showed that the reduction in HRR of unshielded fires was not significantly better than that for shielded fires.

Based on these findings, a traditional standard sprinkler system was recommended for the Alaskan Way tunnel. It was felt that both standard sprinkler systems and water mist systems were virtually equal in most aspects of the criteria. Both systems have the same ability to reduce the HRR of shielded fires; the standard system is superior for unshielded solid fuel fires. It was also believed that high pressure mist fire suppression in tunnels was a new technology while standard sprinkler system has been commonly used in tunnels (in Japan and Australia) for many years. Before switching to a more complex and unproven technology, it was believed that a substantial benefit would have to be shown.

The comparative study for the Alaskan Way tunnels had several limitations which would affect the accuracy and applicability of their findings:

- Due to significant computational requirement for modeling the existing 5300 ft long tunnel, the study only modeled a 410ft long section of the tunnel for the tenability condition study and a scaled model tunnel (90 ft long by 30 ft wide and 20 ft high) for the fire suppression model simulations.
- The tenability conditions of the tunnels are influenced by the tunnel length and the ventilation, the outcome of the tenability evaluation study may not entirely applicable to a 5300ft long tunnel. Also, and the conclusions drawn from a scaled model for the fire suppression/extinguishment simulations may also not be applicable for a 5300 ft long tunnel with different dimensions of tunnel cross sections.
- Since transport of hazardous materials including flammable liquids and dangerous chemicals will be restricted from the future AWV Tunnel, the fuel tanker fire has not been considered. Therefore the findings of the study are not applicable to the tunnel fires involved fuel tankers.

At the time of this study (2006), no full-scale test programs had been carried out to compare the traditional sprinkler and water mist system and very few tunnels had been installed with the water mist system. In addition, the traditional sprinkler system is very effective for solid fuel fires. Therefore the recommendation on the use of a traditional sprinkler system for the Alaskan Way tunnels was reasonable.

However, a drawback of traditional sprinkler systems effect on pool fires was identified in the Ofenegg Tunnel petrol fire test in 1965. The action of the large droplets caused an increase in fire size due to the disturbance of the fuel pool. In the Ofenegg petrol fire test, deflagration created by re-ignition caused extensive damage to the test setup and the ventilation installation in the tunnel (see EJMT fire suppression report, Jan 2011).

Full scale fire tests with the use of traditional sprinkler system for large truck fires (200MW) have been performed in Europe and results will be available to the public in the near future. Based on the experiments, for large truck fire, the water sprinkler system with high application rate can enhance life safety of the tunnel but the system cannot give good protection for tunnel structure. With the low-

application flow rates (same as used as design specification in Japan), the system cannot prevent fire spread from one HGV to another, which is one of the main requirements for a fixed fire suppression system.
There are also more tunnels in Europe that have been installed with the water mist systems (see Appendix A) since the time of the AWV study. Some of these tunnels have been retrofitted with water mist systems and some of the tunnels equipped with mist systems to allow dangerous good passing through.

Summary of Fire Tests Carried Out since the AWV Study

It is evident from the more recent tests carried out in Europe since the Alaskan Way Study that mist systems had a substantial mitigating effect on the fires studied. Pool fires were of short duration, in the order of a few minutes, and the high temperatures and high CO levels decrease significantly within minutes after the system was activated. Solid fuel fires took much longer to extinguish, in particular the 200 MW pallet fire, the conditions downstream remained untenable for the duration of the fire.
No special negative effects of the water mist system were observed beside the reduced visibility downstream of the fire during operation. The relative humidity in the tunnel downwind of the fire arises as an effect of activating the water mist system. The negative effect of higher humidity is small compared to the direct positive effect of suppressing the fire.

Early detection and a quick response of the suppression system should be incorporated in the future designs of the suppression system in tunnels.

Mist systems are more affected by ventilation. In the SOLIT tests the droplet sizes were significantly less than 1 mm in diameter, the smallest were produced by the high pressure system. It is advantageous to discharge the system upstream of the fire and allow the droplets to be transported by the air flow into the fire. Due to the critical effect of ventilation just before and during the activation of the suppression system, detailed studies are necessary to identify ventilation system operating strategies.
It can be concluded that the suppression effectiveness of both low and high pressure water mist systems are fairly equal. High pressure water mist uses less water and suppresses fires more in the gas phase by cooling hot gases, while low pressure is more effective in cooling the fuel surfaces. The low pressure systems achieve best results for the pool fires tested, while the high pressure systems achieved best results for the wood pallets fires. The thermal exposure is significantly reduced by both systems for the fires tested.

All the tests with a HRR larger than 10 MW result in a significant back layering within the first minute (before the activation of the suppression systems). By applying the suppression system, the capability of the ventilation system to avoid back layering was significant, even at low ventilation rates. The ventilation system and the water mist system were mutually mitigating the fire and the back layering disappeared with minutes after activation of the water mist system.
From the above, it is concluded that a mist system is probably better for pool fires, though less effective for solid fuel fires.

Appendix E: Examples of water mist systems installed in road tunnels (UPDATED DATA as of Jan 2012)

AQUASYS

- Mona Lisa tunnel (775 m, Austria, installed in 2004)
- Felbertauern tunnel (at an altitude of 1632-1650m, exposed to temperatures of -30°C at cold winter in Austria, 5034m long, high wind speed up to 1968 fpm ,i.e. 10m/s, system installed in 2006)
  - (Note: the Felbertauerntunnel and the Mona Lisa Tunnel have both been existing tunnels which have been retrofitted with water mist systems.)
- Roertunnel, NL, and Tunnel Swalmen, NL (A73, Roertunnel is 2.45 km long, longest road tunnel in Netherlands; a sister tunnel , Tunnel Swalmen, 400 m long; both are new tunnels and installed mist system in 2008)
  - (Note: both tunnels are equipped with mist systems to allow dangerous goods passing through)
- Gleinalmtunnel Austria (selected areas only)
- Öresund Tunnel DK-SE (service gallery only)

FOGTEC

- Virgolo tunnel (887m, dual lane, main link through the Alps from Italy through Austria to Germany, especially for cargo transport, 30% traffic is Heavy Good Vehicles, Italy)
- Critical sections of M30 Tunnels, Madrid (2006, Spain)
- Silver Forest Tunnel (Moscow, Russia, 2.1km, 2006)
  - (The tunnel design comprises two parallel tubes, each measuring 2.1km long with a diameter of 14.2m and double-deck construction)
- New Tyne Crossing (Newcastle, UK, 2009)
  - (Two under-river tunnels are the vital part of the Tyne and Wear road network)
- Dartford crossing (M25, London K, 2 tunnels, 1.43 km, 2010)
- Train tunnel projects (metro Budapest, Hungary)
- Eurotunnel (channel tunnel), France/UK
- Cable tunnels in various countries

HI-FOG

- 2 x NDIA Taxiway tunnels (road tunnels, 2x340m), 2009-2010, Qatar
- Helsinki Service Tunnel (road tunnels, 850m; 2000m) 2009-2010 Finland
- A86 Duplex Tunnel in Paris (road tunnels) 2005-2009

Appendix F Connections

Alternative 1

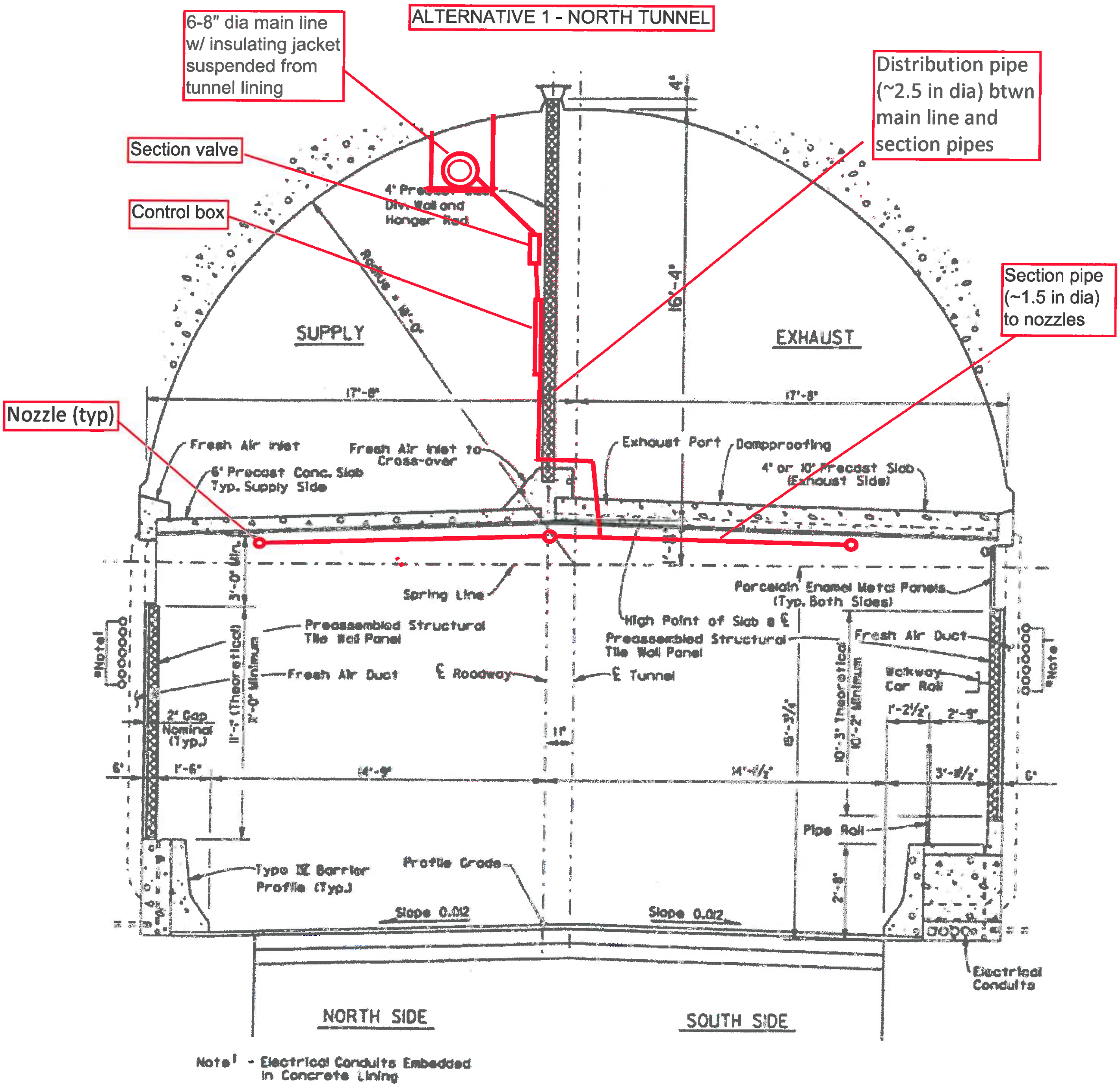
The HMM report notes that installation of pipes in the lower parts of the tunnel walls should be avoided to reduce the possibility of damage to pipes from accident events in the tunnel; because the system is expected to have high reliability, safe locations for critical components are desired. The report proposes to install the main pipe, the section valves, and the control boxes in the supply air duct, with section pipes and nozzles suspended from the tunnel ceiling. This requires hanger attachments from the curved plenum crown or from the vertical divider walls for the main pipe, valves, and control boxes, and penetrations of the precast plenum floor panels. The nozzle lines would be affixed to or suspended from the underside of the plenum floor.

Advantages:

- Relative isolation of the system's trunk elements (main line, section valves, control boxes) away from accident events in the tunnel
- Servicing the main line can be done without disrupting traffic in the tunnel.

Disadvantages

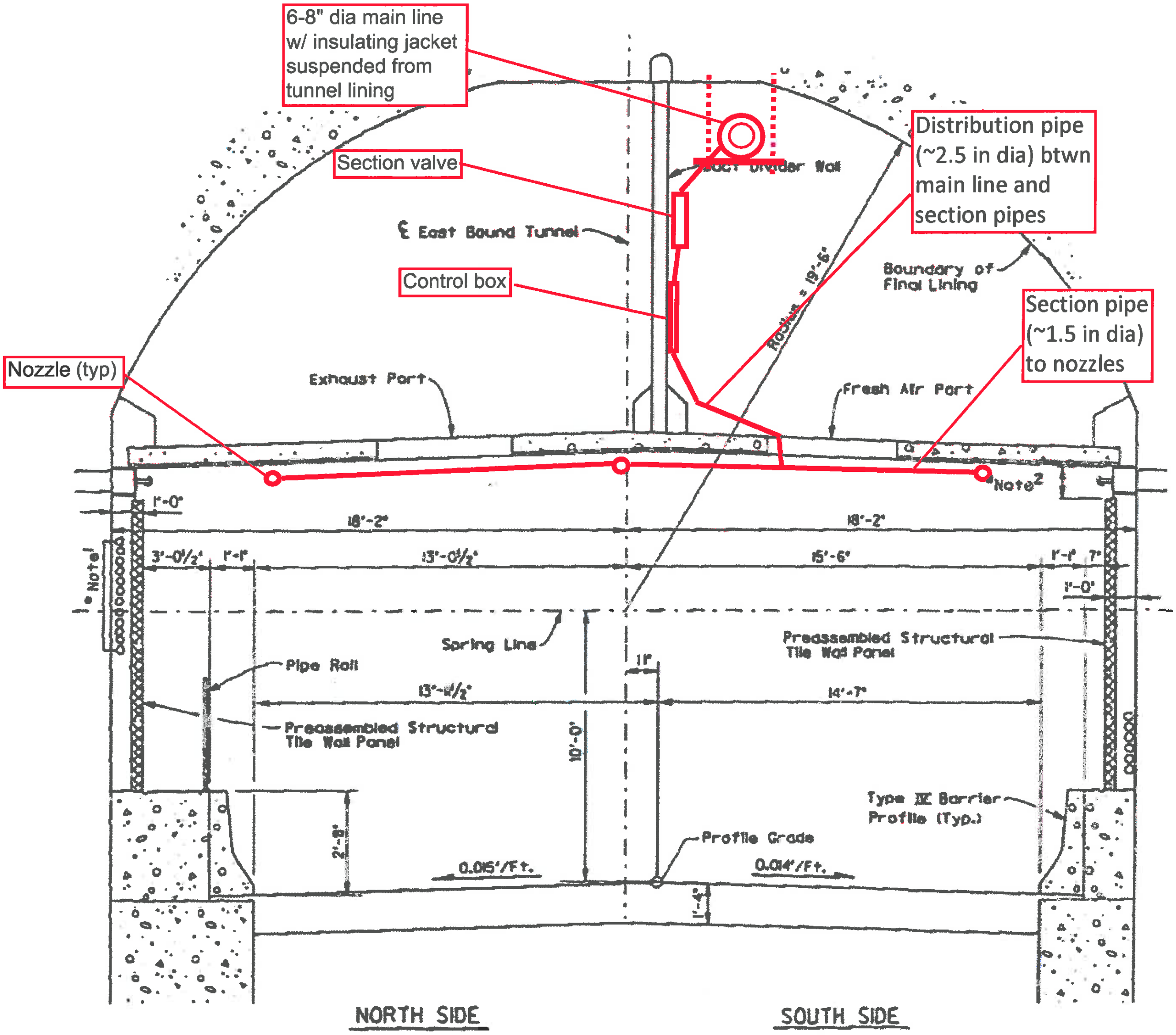
- If the system's main components (estimated at 50-70 plf) are supported by the plenum divider wall, they will reduce the divider wall's safe load capacity.
- Suspending the system's main components from the plenum ceiling is difficult and requires drilling into the tunnel lining and using anchoring systems that are typically not intended for curved surfaces.
- Getting flow into the section pipes requires multiple (90-110) cored holes (estimated 4-6" diameter) through the plenum precast floor elements and through the porcelain enamel metal panels on the ceiling of the traffic area; the alternative routing of water lines through existing ports in the plenum floor may reduce the capacity of the ventilation system.
- Access to the plenum will make construction very time consuming and difficult.



NORTH TUNNEL CROSS SECTION
(LOOKING EAST)

INSTALL MAIN PIPE, SECTION VALVES, AND CONTROL BOXES IN SUPPLY SIDE OF PLENUM, WITH SECTION PIPES AND NOZZLES SUSPENDED FROM TUNNEL CEILING

ALTERNATIVE 1 - SOUTH TUNNEL



Note[1] - Surface Mounted Conduits
Note[2] - 1'-2" Clearance Except In Suspended Ceiling Area

SOUTH TUNNEL CROSS SECTION
(LOOKING EAST)

Alternative 2

An alternative configuration is to install the main pipe, the section valves, and the control boxes above the wall panels and below the ceiling in the tunnels, in the area that includes longitudinal lighting units in the tunnel traffic area. This configuration places the critical components above and to the walkway side of the traffic area, eliminates attachments to the plenum curved ceiling or on the divider walls, and eliminates penetrations of the plenum floor; it still requires suspending nozzle lines from the underside of the plenum floor, by attachment hardware through the PE ceiling panels. However, it may require some reconfiguration of the lighting attachments and possible loss of some of the vertical PE metal panels above the wall panels in the westbound tunnel. The eastbound tunnel doesn't include similar PE panels above the wall panels, and it includes a void space below the lights and above the wall panels. In both bores, a closer look at the as-built condition is warranted to determine if this alternative is reasonable.

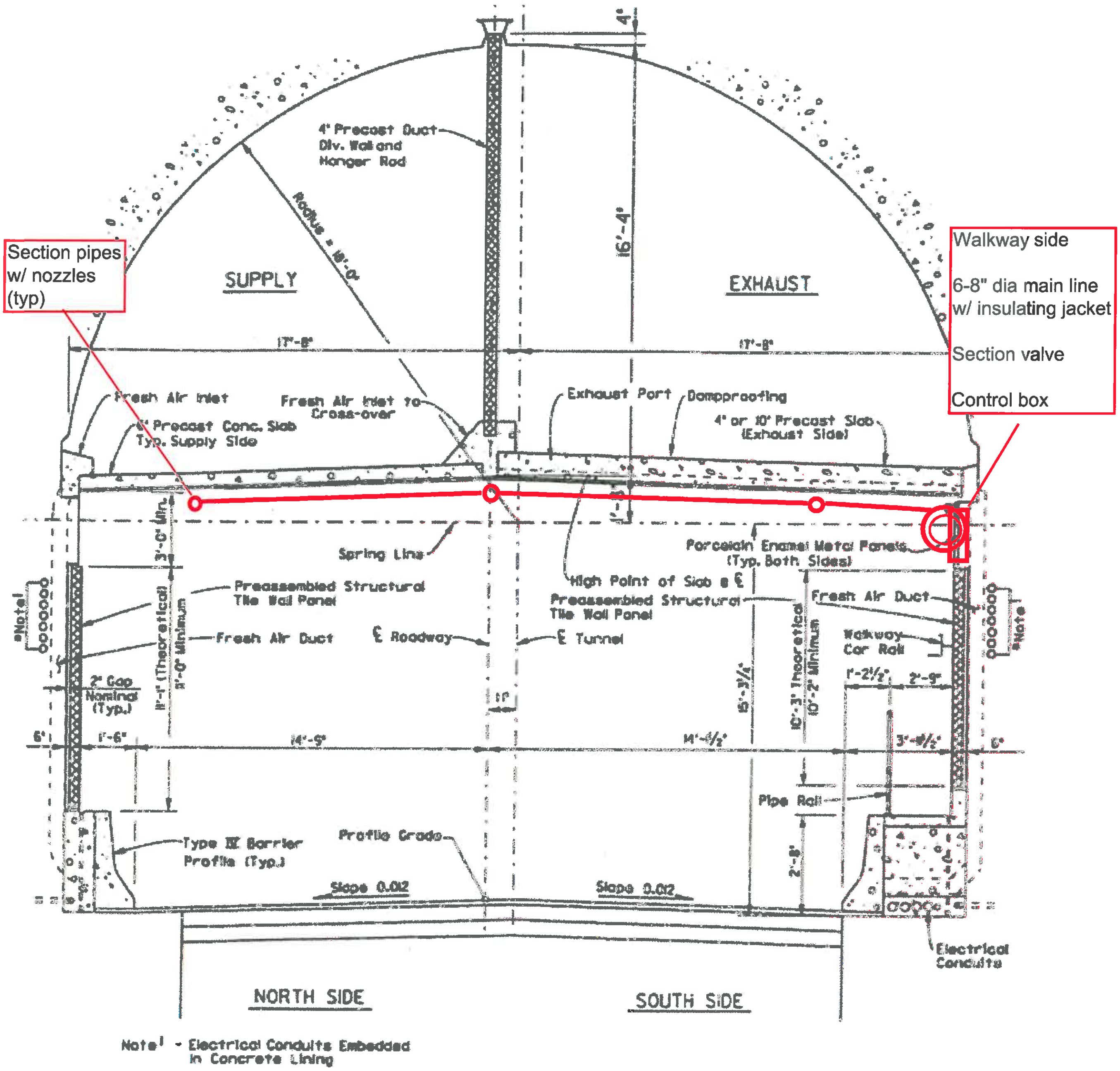
Advantages:

- Closer to water reservoirs and pump stations.
- Short connections from main line to distribution lines.
- Does not require holes through plenum precast floor elements or routing water lines through existing ports in the plenum floor.
- Attachment of system trunk elements to tunnel wall is simpler than attachments within the plenum above the traffic area.

Disadvantages:

- System's trunk elements are somewhat exposed to accident events in the tunnel.
- Servicing system's main line may require lane closure next to walkway.
- Requires integration with existing tunnel lighting and may necessitate reconfiguration of some of the lighting attachments at the tunnel wall panel / tunnel ceiling interface.

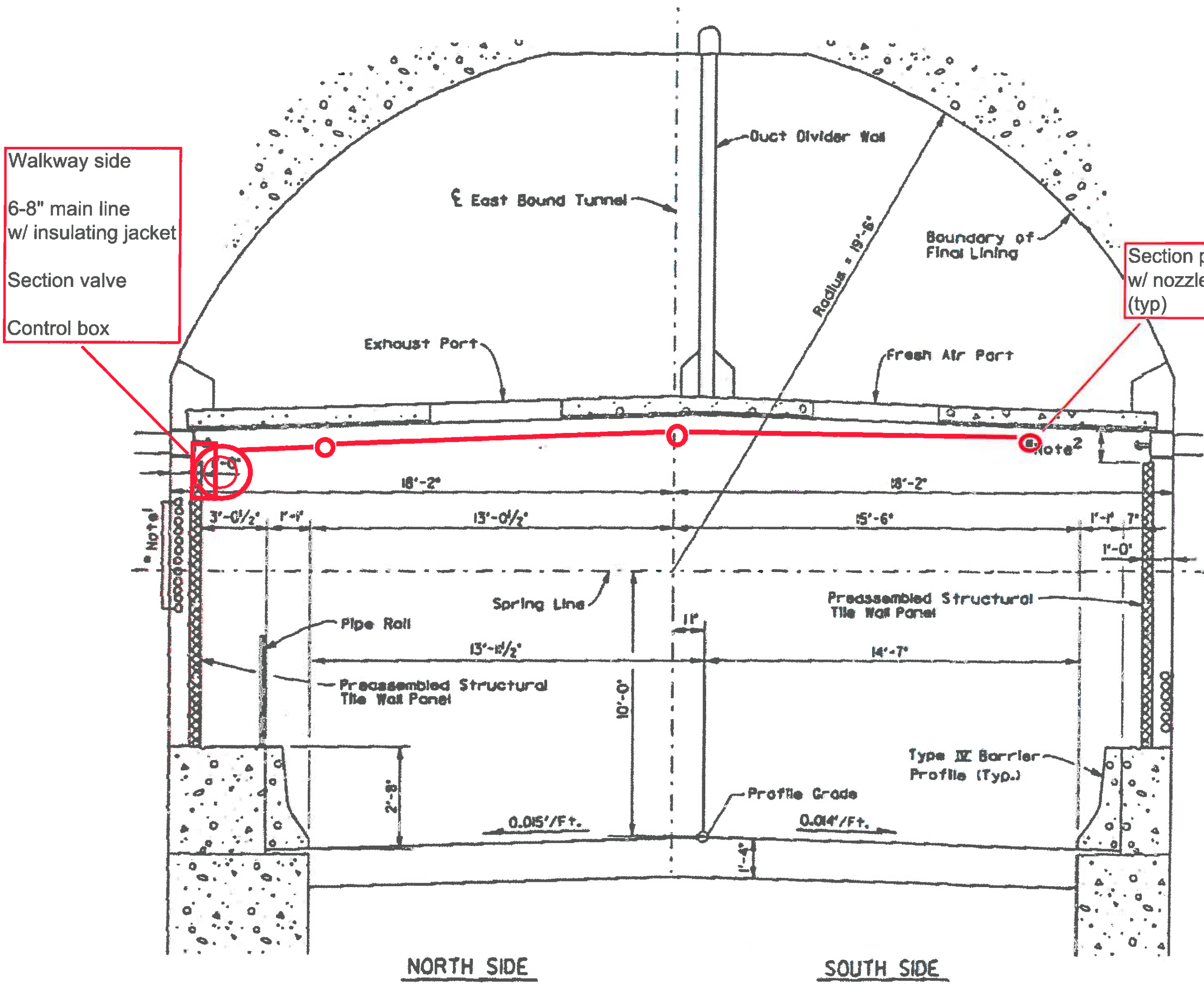
ALTERNATIVE 2 - NORTH TUNNEL



NORTH TUNNEL CROSS SECTION
(LOOKING EAST)

INSTALL MAIN PIPES, SECTION VALVES, AND CONTROL BOXES ABOVE THE WALL PANELS / BELOW THE LIGHTS ON THE WALKWAY SIDE OF THE TRAFFIC AREA, WITH SECTION PIPES AND NOZZLES SUSPENDED FROM THE TUNNEL CEILING.

ALTERNATIVE 2 - SOUTH TUNNEL



Note[1] - Surface Mounted Conduits
Note[2] - 1'-2" Clearance Except in Suspended Ceiling Area

SOUTH TUNNEL CROSS SECTION
(LOOKING EAST)

Alternative 3

A third alternative configuration is to install the main pipe below the elevated walkway and behind the barrier at the inside lane in the tunnels, route the distribution pipes behind or between wall panels, and place the section valves and control boxes in wall panel cut-outs. This configuration places the main line in a protected space but may expose section valves and control boxes to possible traffic damage. It will require reworking the space below the walkway and behind the barrier, and will require removal and sawcutting some wall panels along one face of the tunnel to accommodate the hardware between the main line and the section pipes. It mostly eliminates attachments to the tunnel lining but will probably require extensive concrete coring or demolition for all the plumbing runs; it still requires suspending nozzle lines from the underside of the plenum floor, by attachment hardware through the PE ceiling panels. It places the mainline close the probable water sources.

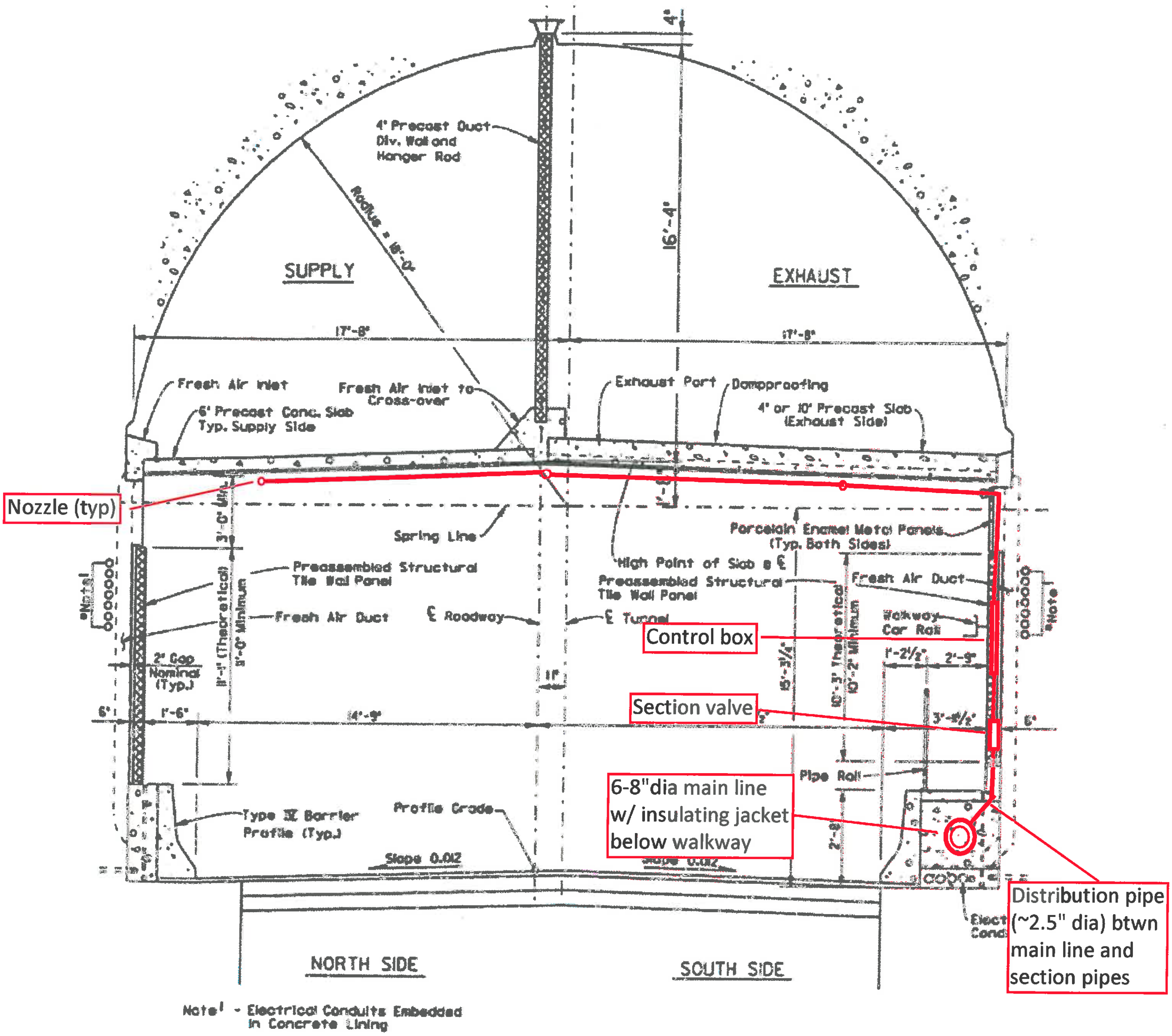
Advantages:

- Probably closest to water reservoirs and pump stations.
- Short connections from main line to distribution lines.
- Does not require holes through plenum precast floor elements or routing water lines through existing ports through the plenum floor.
- Attachment of system trunk elements to tunnel wall is simpler than attachments within the plenum above the traffic area.

Disadvantages:

- System's sensitive valves and control boxes are somewhat exposed to accident events in the tunnel.
- Servicing system's main line may require lane closure next to walkway.
- Requires removal and sawcutting of some tunnel wall panel to keep system elements recessed from the exposed plane of the wall surfaces.
- Requires major reconfiguration of the walkway and barrier to accommodate the main line for the system.

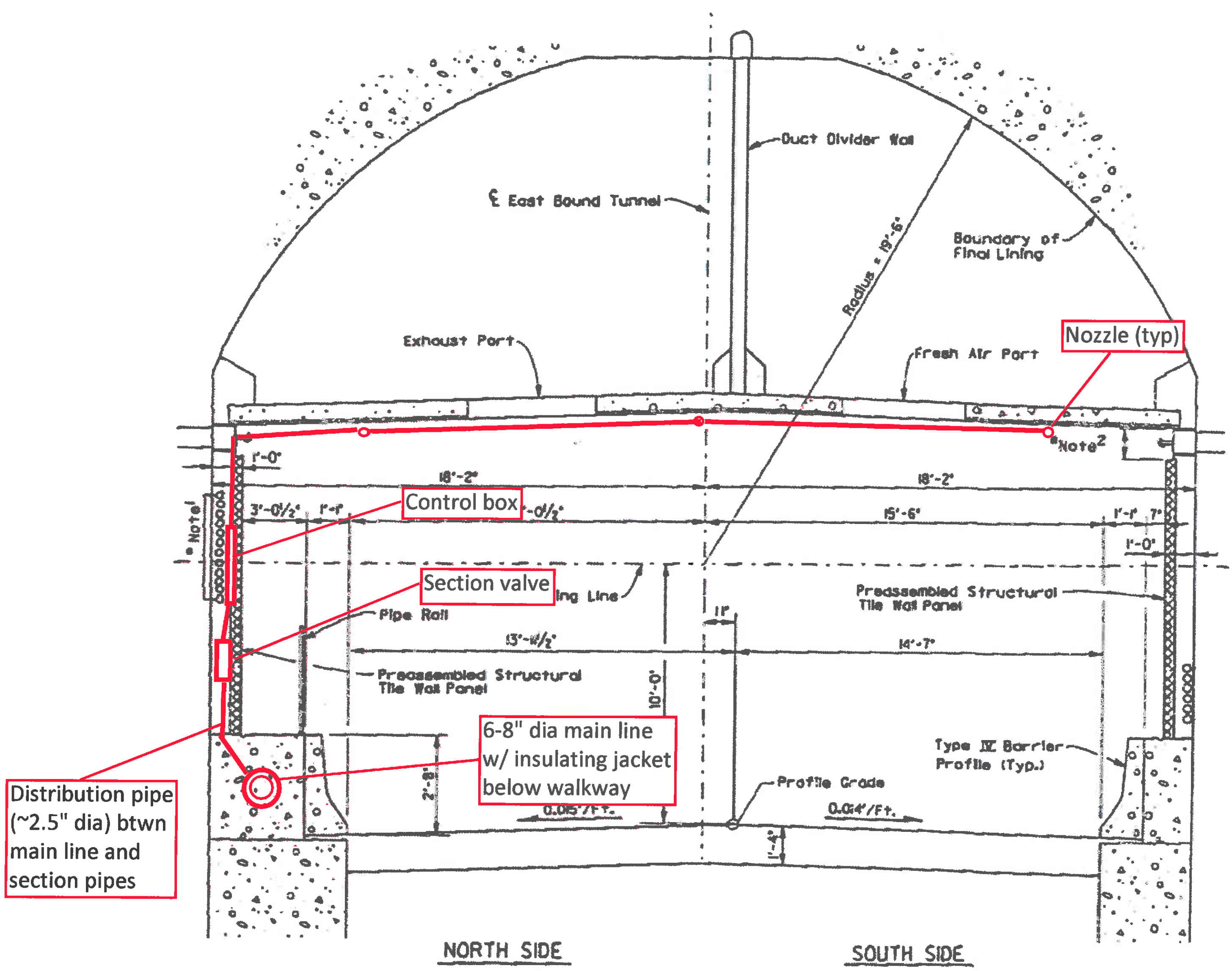
ALTERNATIVE 3 - NORTH TUNNEL



NORTH TUNNEL CROSS SECTION
(LOOKING EAST)

INSTALL MAIN PIPE IN SPACE BELOW WALKWAY. ROUTE DISTRIBUTION PIPE BEHIND OR BETWEEN (CUT) PANELS. PLACE SECTION VALVES AND CONTROL BOXES BETWEEN (CUT) WALL PANELS. SECTION PIPES AND NOZZLES SUSPENDED FROM TUNNEL CEILING.

ALTERNATIVE 3 - SOUTH TUNNEL



Note1 - Surface Mounted Conduits
Note2 - 1'-2" Clearance Except in Suspended Ceiling Area

SOUTH TUNNEL CROSS SECTION
(LOOKING EAST)

Appendix G: Answers to April 2012 CDOT Questions

	Questions From CDOT April 2012	Responses from Consultant
1	Given the standards in Part 2.3.8, filtration and water quality standards, where would the water treatment facility be located and how would the existing water treatment plant and fire hydrant system be incorporated?	The need for a water treatment plant depends on the quality of the water source. If potable water is available, no treatment is necessary. FOGTEC suggested to make use of the existing water tank. Usage of the existing fire hydrant system is presumably ruled by the local authorities and regulations. Possible interactions and operations with WM system need to be clarified together with the local safety authorities. Naturally, if both systems will be used simultaneously, the adequate size of the water reservoir needs to be ensured.
2	Is the method of last resort in Part 2.3.6 of flooding the waste water plant really an alternative at all? The electrical shorting caused by flooding would likely shut down the entire facility and would be an undesirable scenario.	The flooding approach is described in the report of "risk analysis study of Hazmat Trucks through EJMT", 2006. It may be worthwhile to design a by-pass for the wastewater plant and direct drainage from the water mist or a major spill to an external sedimentation pond.
3	3. Do the power requirements of the pumps exceed power available in the 480v system? If the 2400v system is used, what engineering will be required to provide this as essential power?	As described in section 2.3.4 of the design report (pump stations), the electrical power requirement for the pump units are 460KW, 510KW, and 1080KW depending on the system used. If this power is not available in the 480V system, a transformer 2400v to 480V is more cost effective than using 2400V pumps. Both AQUASYS and FOGTEC suggested that the diesel powered pumps can be used. As the water mist pump systems only run for emergency cases and a few times a year for maintenance purposes, the environmental impact of the diesel pumps is minimal.
4	What requirements does the power consumption put on the Emergency Generators, existing and future?	The electrical power supply for the water mist pumps shall be redundant. This can be accommodated by either redundant power supply with transfer switches or by an emergency generator providing the same power. May need to upgrade the emergency power system. Again Both AQUASYS and FOGTEC suggested that the diesel powered pumps can be used (see the reasoning in Q.3)
5	Is recessing the nozzles in the ceiling panels feasible to accommodate tunnel wash?	**From AQUASYS**: Due to the design of the nozzles (in-line with the piping) tunnel wash is not hindered. Installation of the nozzles behind the ceiling panels requires headroom of at least 100mm and complicates installation. **From FOGTEC**: The tunnel wash will not affact the nozzles; no protective cups for nozzles are necessary as the FOGTEC discharge holes are relatively large and will not be afftected by dirt. **From HIFOG:** The designed open spray heads, which are connected to the pipes using special assembly body will tolerate normal washing operations (which removes also possible dirt from the surfaces of HI-FOG components). As an option, nozzles can also be covered with protective cups. The cups could provide additional protection during the washing and also protect the spray heads against external dirt and mechanical damage.
6	Water supply main pipe will be located in the supply side duct ceiling?	Yes (for AQUASYS'S design)
7	Where would pumps and associated housing be located? Pg.10 states pump house would be next to the water reservoir (within 15 meters) at the west portal and should be kept from freezing. Is this feasible? Is this an underground structure? Has this been looked at in context (maintenance and operations vs. avalanche path). Is this electric? Is diesel shown as a backup only?	The pump house shall be heated to slightly above freezing point. The energy to accommodate this temperature is rather low especially if the pump house is underground or half underground. (The pump house must have adequate ventilation to maintain appropriate temperature and to prevent the formation of excessive humidity; low pressure pipes between the water tank and pump room can naturally be equipped with electrical heating trace cables with thermal isolation to protection them against freezing. The construction of the pump room and its equipment are not included to the scope of WM suppliers.)
8	Are intermediate pumps required?	No.
9	CDOT's diversion water right is 0.03cfs. With a 120,000 gallon tank, it takes over 6 days to fill once it is drained. Do we need to account for this in the design?	The water tank will not need 6 days to refill after a fire incident. If this is still unsatisfactory, either the water supply has to be upgraded or the tank has to be refilled by water trucks.
10	Is a new tank required per number 9 and number 1?	Depends on answer to Q9
11	Are intermediate tanks required?	Depends on answer to Q9
12	Where should tanks be located? Is this certain?	The design will assume the existing water tank located at the west end of the tunnels.
13	Can we make sure entire report has SI units in addition to metric units?	Imperial Units and SI units will be used.

	Questions From CDOT April 2012	Responses from Consultant
14	Are maintenance and operation costs known?	According to the PIARC 2008 (road tunnels: assessment of fixed fire fighting systems), the maintenance costs of the FFFS per year are estimated to represent around 1 to 2.5% of the installation costs. **From AQUASYS:** we have a maintenance contract for the water mist system for a similar tunnel; yearly maintenance cost are app. € 30,000. **From FOGTEC,** the yearly maintance cost is €30,000 to 50,000 in addtion to some spare parts; if remote valves are used, maintenace cost can be reduced significantly**. From Hi-fog:** the maintenance cost consists of spare parts and maintenance work. Since the system is not constantly being used a number of consumable parts remain minor considering to the total investment being mostly the parts for the pump units. Based on HI-FOG experience with the other tunnel projects, the estimated annual costs would be approximately 0.5-1,0% of the purchase price. There might be certain local maintenance and service requirements, which could have an effect on the final maintenance scope and price. More detailed cost calculations need to be done later on based on final system configuration and requirements.
15	Is the existing drainage system adequate? What improvements would be needed?	As indicated in design report (2.3.6 Drainage requirement), the maximum demand on the drainage capacity for a water mist system proposed for EJMT is in the range of 126m3(33286 gallon) to 234m3 (61817 gallon) depending on the type of water mist system. The adequacy of the existing drainage system would need to be evaluated. Normally the drainage system shall have sufficient capacity to remove fire-fighting water, storm water, tunnel wash water, carryover from the tunnel approach trench drains, vehicle drippings, and ground water infiltration from the roadway and tunnel. The travel lanes of the roadway shall not be used as a conveying system for water.
16	The wind that we could create in the air ducts if we have to run 600h.p. motors may affect the way they design for support and also the way we heat the water "wind chill"- can this be factored in?	Yes. There are two issues here, one is the structual issue and the another is the heat transfer. As for the heat transfer issue, the design of the insulation and water temperature maintained will consider the the high wind influence at the winter time during the fire incident. As for the wind load on the structural design of the water pipe support, that should be considered at the structural design stage.
17	We assume we need to have access to the water tanks during winter months, making location a critical design issue	Whether we use the existing water tank or propose a new water tank, the tanks can be located at the west portal (the location for the existing water tank).

APPENDIX H - Portal Schematics

User: p0083853 Date: 6/23/2012 Pen Table: CDOT-PenTable.tbl Plot Config: CDOT-PDFHighQuality_V8i.pltcfg

Print Date: 6/23/2012
File Name: 617545_DES_Plan02.dgn
Horiz. Scale: 1:100 Vert. Scale:

PARSONS
1700 Broadway Suite 900
Denver, CO 80290
(303) 863-7900

Sheet Revisions		
Date:	Comments	Init.

Colorado Department of Transportation
Eisenhower Tunnel, West Portal P.O. Box 399
Dumont, CO 80436
Phone: 303-512-5601 FAX: 303-512-5675
Region 1 GA

As Constructed
No Revisions:
Revised:
Void:

EJMT East Portal FFSS Drainage Modification Schematic Layout

Designer:
Detailer:
Subset:
Structure Numbers
Subset Sheets: of

Project No./Code
17810
C 0703-360
Sheet Number 1

User: p0083853 Date: 6/23/2012 Pen Table: CDOT-PenTable.tbl Plot Config: CDOT-PDFHighQuality_V8i.pltcfg

Print Date: 6/23/2012	Sheet Revisions	Colorado Department of Transportation	As Constructed
File Name: 647545_DES_Plan01.dgn	Date: / Comments / Init.	Eisenhower Tunnel, West Portal P.O. Box 399 Dumont, CO 80436 Phone: 303-512-5601 FAX: 303-512-5675	No Revisions:
Horiz. Scale: 1:200 Vert. Scale:			Revised:
PARSONS 1700 Broadway Suite 900 Denver, CO 80290 (303) 863-7900		Region 1 GA	Void:

EJMT West Portal FFSS Supply System		Project No./Code
Designer:	Structure Numbers	17810
Detailer:		C 0703-360
Subset:	Subset Sheets: of	Sheet Number 2

APPENDIX I

Estimate Summary for EJMT FFSS at 10 % design level-06/27/12

ITEM	COST		
Hi-FOG estimate (Highest of three systems, use)	$ [redacted]		
FOG-TECH estimate		$ [redacted]	
AQUA SYS estimate		$ [redacted]	
East Portal-tank and drainage for effluent	$ [redacted]	see spreadsheet	
West Portal-water filtration system	$ [redacted]	see spreadsheet	
pumps (included in contingency)	n/a		
control systems (Included in contingency)	n/a		
Linear heat detectors	$ [redacted]	see spreadsheet	
generators	$ [redacted]	see document	
subtotal	$ [redacted]		
Contingency @ 25%	$ [redacted]		
Subtotal	$ [redacted]		
CE and indirects @ 20%	$ [redacted]		
Total	**$** [redacted]		

East Portal EJMT-Tank and Drainage for Effluent

Item #	Description	Price	Quantity	Units	Cost
206	Structure Excavation	[redacted]	[redacted]		[redacted]
206	Structural Backfill (Class 1)	[redacted]	[redacted]		[redacted]
515	Waterproof Coating	[redacted]	[redacted]		[redacted]
601	Concrete Class D	[redacted]	[redacted]		[redacted]
602	Reinforcing Steel	[redacted]	[redacted]		[redacted]
603	8" Ductile Iron Pipe	[redacted]	[redacted]		[redacted]
603	24 Inch RCP (CIP)	[redacted]	[redacted]		[redacted]
604	Vane Grate Inlet (Double)(5 Foot)	[redacted]	[redacted]		[redacted]
	Total				[redacted]

West Portal-EJMT Water Filtration Costs

ITEM	UNIT	QTY	May 2012 Cost Estimate Unit Cost	Total
1 Mechanical Filtration Equipment				
Automatic duplex strainer (2 units) based on the following: 304 Stainless steel interior and exterior Design pressure 1200 psi @ 100 deg. F ASME code Sec. VIII Div. 1 8" 600# Flanged inlet & outlet designed to accept 1000 gpm water with a pressure drop of 2 psi motorized scraper assembly 460v/3 ph/60 hz 1/2 hp TEFC motor 150 micron slot wedgewire SS316L screen NEMA 4X FRP control panel Installation upstream of existing tank	[redacted]	[redacted]	$ [redacted]	[redacted]
2 Piping tie-in, pipe installation (8" diameter), pressure gauges, electrically actuated butterfly valves (3)	[redacted]	[redacted]	[redacted]	[redacted]
3 Subcontractors				
Electrical/Instrumentation Subcontractor Cost	[redacted]	[redacted]	[redacted]	[redacted]
Coating/Painting Subcontractor Cost	[redacted]	[redacted]	[redacted]	[redacted]
Filtration vault	[redacted]	[redacted]	[redacted]	[redacted]
Insulation/Heat Tracing Subcontractor Cost	[redacted]	[redacted]	[redacted]	[redacted]
SUBTOTAL				[redacted]
Contractor Overhead & Mark-Up [redacted]		[redacted]	[redacted]	[redacted]
Taxes, Bonds & Insurance [redacted]		[redacted]	[redacted]	[redacted]
TOTAL ESTIMATED CONSTRUCTION COST (2012 DOLLARS):				[redacted]

Clarifications:

Assumed that existing water source is sufficient and can be utilized
Estimate based on the assumption that the existing water line at the point of tie-in is 8" diameter
New Pumps are not included for the existing water source (assumed that they are not needed)
New Tanks are not included (assumed that existing tank is sufficient)
Assumed that the existing electrical power source is sufficient
Normal access to installation site is assumed

Linear Heat Detectors

	Project No.	ESTIMATE NO:	
LOCATION:		SHEET NO:	1
ARCHITECT / ENGINEER	HATCH MOTT MACDONALD	DATE:	Revised:
SUMMARY BY:		PRICES BY: Protectowire/Sanders	CHECKED BY:

ITEM	DESCRIPTION	QUANTITY	UNIT	MATERIAL UNIT PRICE	TOTAL MATERIAL COST	UNIT LABOR HOURS	TOTAL LABOR HOURS	LABOR RATE	TOTAL LABOR COST	EQUIPMENT COST	TOTAL DIRECT COST	Comment
1	Linear heat detection cable Protectowire	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	Vendor qoute
2	Boxes for end of line resistors	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	Vendor qoute
3	Zone boxes	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	Vendor qoute
4	Fire panel with alarm point location meter	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	Estimated
5	Fastener clips	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	
6	Power feed to new panel XHHW-2 #16AWG	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	
7	GRS Conduit 3/4"	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	
8	Testing and commissioning						[redacted]	[redacted]	[redacted]		[redacted]	
	SUB TOTAL				[redacted]		[redacted]		[redacted]	[redacted]	[redacted]	

Contingency factor for design phase	[redacted]	[redacted]
Bonds & insurances	[redacted]	[redacted]
Overhead & profit	[redacted]	[redacted]
TOTAL		[redacted]

Cost of Diesel Generators

FROM Norm Rhodes; 5/17/12 email

AQUASYS system (electrical power requirement for the water mist pump units is [redacted]

Fogtec system (electrical power requirement for the water mist pump units is [redacted]

Hi-fog system (electrical power requirement for the water mist pump units is [redacted] : assume diesel-engine-generator at [redacted] which costs [redacted])