FIRE AND SECURITY CONSULTING SERVICES
http://fscs-techtalk.com

17 McKenna Court
NOOSAVILLE
QUEENSLAND, 4566
AUSTRALIA

Phone: +61 (0)7 5455 5148, Mobile: 0409 399 190, Email: rafoster@bigpond.net.au

WATERSPRAY SYSTEMS FOR FIRE PROTECTION – V1

A number of Fire and Security Consulting (FSCS) clients have expressed interest as to where and when waterspray systems are used in fire protection.

Readers of this paper are advised that it is written in the context of Australian Standards although references are made to NFPA Codes as applicable.

Appendix 1 to this paper contains references to the cited Codes and Standards, technical papers, web links to Companies and their equipment, these are marked with numbered references in parenthesis in the body of the paper thus - **[ ]**.

Whilst the concept of fire control and suppression effected by automatic sprinklers designed and installed under AS2118.1 **[1]** is generally well understood, waterspray systems are less so.

In a sprinkler protected property, only those sprinklers above and / or adjacent to the fire are actuated, with statistics from Harry Marryatt's book – "*Fire – A Century of Automatic Sprinkler Operation in Australia and New Zealand 1886 – 1986*" **[2]** indicating that more than 86% of fires are controlled by 3 sprinklers or less, with 93% of fires being controlled by 5 sprinklers or less.

Contrary to sprinkler systems, all the nozzles in a waterspray system, sometimes referred to as a "deluge or drencher system", are designed to discharge simultaneously.

TYPES OF SYSTEM

Waterspray systems are most commonly used to protect the following:-

- High Velocity (HV) systems for coal conveyors, cable trays, diesel engines, turbo alternator lube-oil systems, oil and pulverized coal fired boilers, electrical equipment such as transformers, oil switches and rotating electrical machinery and similar hazards.

  These systems contemplate fire suppression and / or control dependant on application.

- Medium Velocity (MV) systems for piping and equipment, LPG (including Propane and Butane) tanks and spheres, general fuel tanks, drum filling sheds, LPG cylinder filling sheds, LPG tanker loading bays, fixed and floating roof storage tanks, cooling tower decks, structural steel, steel doors and munitions compartments on Naval ships.

  These systems contemplate cooling of the subject equipment and surrounds to reduce radiant heat flux and consequential equipment damage and process interruption.

In consideration of the applications discussed above, the two basic types of waterspray systems are:-

High Velocity (HV) Waterspray

As the name implies, High Velocity nozzles discharge a jet of water at a high velocity and momentum. The internal design of this nozzle is such that the jet takes the form of a cone of coarse spray of uniform density.

The coarse spray issued from this nozzle is desirable when used on fires involving heavy and medium oils, and similar products in order to penetrate the flame zone and so reach the surface of the burning oil or the rupture area of the equipment.

The principal contributor of extinguishment on hazards of this type is the oil-in-water emulsion formed on the surface of the oil. Secondary assistance to extinguishment is given by the effects of vapour dilution, cooling and smothering.

To provide adequately for the wide range of application requirements of water spray systems various types of nozzles have been developed, each differing in flow rates and discharge characteristics. The types are discussed later in this paper.

Medium Velocity Waterspray (MV)

Medium Velocity sprayers discharge water in the form of a spray of finely divided droplets at medium velocity. These sprayers utilise an external deflector to achieve the desired discharge angle and spray characteristics.

Due to the discharge characteristics given by the medium velocity sprayer, the spray issued has a high heat absorption rate, making it ideal for the protection of hazards involving light oils where emulsification is not possible although unless applied as part of a foam system, it is generally not possible to extinguish flammable liquid fires with medium velocity (MV) waterspray systems.

These same discharge characteristics are also desirable where controlled burning and/or exposure protection is required.

A number of types of medium velocity sprayers are available with various orifice sizes, each being available with varying discharge patters. The types of nozzles used are discussed later in this paper.

The Myths of Water and Oil

The use of water on flammable liquid fires often raises questions of safety. While it is true that a straight stream of water when applied to a flammable liquid fire can actually spread the burning liquid, water is an excellent fire suppression agent used to successfully control and extinguish flammable liquid fires, if properly applied and in the appropriate density. Every flammable/combustible liquid has a flash point-the temperature at which the liquid gives off a flammable vapor in sufficient concentration with ambient air to generate an ignitable mixture - **Note 1**.

Another important aspect of flammable liquid fire control is proper spill containment. If a pool or "burning" liquid flows outside a sprinkler-protected area, no sprinkler system will be effective. Therefore, containment must be limited to the areas protected by the fire suppression system.

Note 1 Testing carried out by Mather and Platt (Previously Wormald owned and ownership now unsure) in the mid 1900s determined the density rate of application according to the flashpoint of the combustible liquid. This is depicted in Figure 8 below showing the three curves*, extinguishment, controlled burning* and *minimum.*

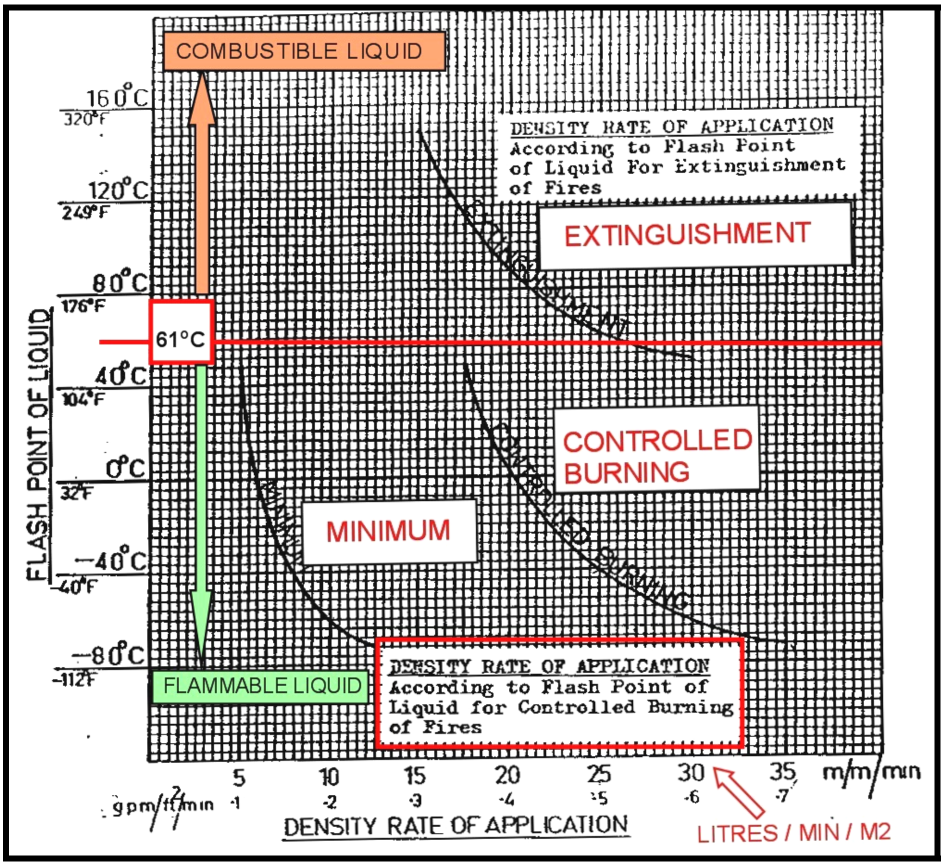

Figure 1 – Design Density

Whilst the Australian Standards [3], NFPA [4] and API [5] Codes specify waterspray application rates, designers should be aware that these are the minimum. D

For those wishing to design fire suppression (extinguishing) systems from first principles as applicable to the flash point of the flammable or combustible liquids, the design densities shown in Figure 1 can be used as long as these equal or exceed the design densities specified in the Standards or Codes.

Note that the term "flash point" is defined in AS 1940 [6] as being "*The lowest temperature, corrected to a barometric pressure of 101.3 kPa, at which application of a test flame causes the vapour of the test portion to ignite under the specified conditions of test*."

The Queensland Government publication "*A guide for flammable and combustible liquids under the Work Health and Safety Act 2011"* [7] provides guidelines for differentiating between flammable and combustible liquids. Generally flammable liquids have a flash point =/<60^{o}C and combustible liquids have a flash point =/>61^{o}C. This is generally equivalent to the temperatures cited in NFPA 30 [8].

APPLICATIONS

Extinguishing – Combustible Liquid Fires

Extinguishment of fires associated with combustible liquids such as transformer oil and the like can be achieved with the correct system design and nozzle selection. Considering that flame plumes from oil fires exhibit a significant upwards velocity, the first requirement is that the spray should have sufficient droplet size and velocity to penetrate the flame plume. This causes an emulsion to be formed which makes the surface of the material temporarily non-combustible. In some liquids the emulsification is extremely temporary, being present only during actual application of water. With other more viscous liquids the emulsification may persist for some time and thus offer a safeguard against the danger of flashback. To obtain the emulsifying effect, a relatively strong, coarse spray is needed to give surface agitation and "High Velocity" nozzles are used.

Figure 2 below shows a transformer fire at the Hume Weir Power Station which, not having waterspray protection resulted in its total loss and interruption to power supply in the community.

Figure 2 – Hume Weir Transformer Fire

Close examination of Figure 2 (behind the visible flames on the left) shows that there is a masonry wall at the rear of the transformer. This wall protected the other transformer and is a commonly used practice for the protection of multiple transformer installations

Whilst the dividing wall protection concept is widely used, the installation of a "High Velocity" water spray system is generally used in Australian power stations. Figure 3 below is the commissioning test of the main generator transformer at Wallerawang power station in NSW.

Figure 3 – Wallerawang Generator Transformer Waterspray System

Extinguishing – General Combustible Materials

Extinguishment of fires associated with general combustible is sometimes desirable when an automatic sprinkler system may not achieve the required results. These typically include power station coal conveyors where the heat from a seized roller bearing can ignite coal dust and thence the coal on the conveyor resulting in a fire that will continue to move within the conveyor housing.

Figure 4 shows conveyor protection and Figure 5 showing the conveyor header, conveyor end protection is vital to stop any burning product such as coal from being transferred to the downstream process line.

Figure 4 - Conveyor Protection

Figure 5 - Conveyor Head protection

Exposure protection

Exposure protection is accomplished by application of waterspray directly to the exposed structures or equipment to cool and reduce heat transfer from adjacent fire. The application of the spray cools the structure by absorbing the radiant and conducted heat.

Exposure protection of structural steel can be effected with medium velocity waterspray to reduce the temperature of the steel to below the critical level for integrity. Most steel design criteria such as in AS4100 [9], use a design strength of steel of 60% of its yield strength, which equates to a temperature of ~600^{o}C

Note 1 Refer to the paper "*Performance of Steel Sections in Fire Conditions*" [10]

Exposure protection of LPG tanks (often referred to as "bullets") is affected with medium velocity nozzles arranged such that all surfaces and associated equipment (relief valves, access openings) etc. are property covered with the spray.

Even with proper protection, there have been some instances where the intent of protection has failed. Figure 6 below shows the result of a fire at the Boral, St. Peters NSW, LPG storage facility on April 1st 1990. There were a number of 100 tonne capacity horizontal LPG tanks, each protected with a waterspray system.

The subsequent "BLEVE" (**Note 1**) dislodged the tank from its foundations and it was "propelled" some 150m into a nearby creek. The remaining waterspray pipework can be seen on the other tank(s)

The subsequent enquiry determined, amongst other findings that a small leak of propane started somewhere on a manifold below the tank and the escaping vapour formed a cloud at ground level, which eventually came into contact with an ignition source.

Features which compromised the safety of the facility included:-

- The fire and leak alarms that were installed were not connected to the Fire Brigade.
- The signs for the controls of the "drencher" system where not able to be read, so that the Fire Brigades could activate the waterspray system which could have cooled the tank(s).
- The orientation of the hydrostatic relief valves on the liquid propane manifold projected vapour in the direction of pipes also containing propane, and so caused progressive failures to pipes and escalation of the fire.

Further investigation revealed that the waterspray system relied on manual operation and that even if the Fire Brigade was able to determine the correct operation process, by that time the waterspray system control valve(s) were irreparably damaged.

FSCS advises that based on this and the failure of other manually operated systems, that an automatic function should be provided and that regular testing with the attendance of the local Fire Brigade.

Note 1 - *a BLEVE is a **b**oiling **l**iquid **e**xpanding **v**apour **e**xplosion that occurs when the structural integrity of a pressure vessel fails, generally due to fame impingement on the vessel shell or ends. The results include dislodgement of the vessel and a fireball. To give readers an ides of the effect, a butane cigarette lighter can generate a momentary fireball of approximately 2m in diameter.*

Figure 6 – Results of a LPG Tank Fire

Figure 7 below shows the commissioning test of an automatic waterspray system on an LPG tank at the Amcor packaging plant at Taree NSW.

Figure 8 below shows the commissioning test of an automatic waterspray system on a LPG tanker loading bay for Boral at Port Botany NSW.

Figure 7 - LPG Tank

Figure 8 - LPG Tanker Loading Bay

Figure 9 below shows the arrangement of a fixed waterspray system covering the shell and roof of a fuel oil tank at a UK Power Station. Note the red distribution pipework around the shell and on the roof.

Figure 10 below shows the arrangement of a fixed waterspray system covering a floating roof tank.

Figure 9 - Protection of a Vertical Cylindrical Tank

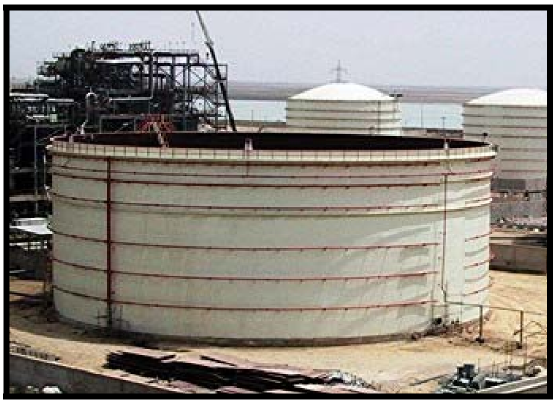

Figure 10 - Protection of a Floating Roof Tank

Note that Figure 9 shows the correct protection of the tank top but only one row of nozzles for the shell. This arrangement relies on "run down" of the water to cool the shell – not really an effective system.

Figure 10 however, shows the correct protection of the shell with multiple rows of nozzles achieving correct application. Note also that floating roof tanks do not require roof protection because, being shielded by the shell, they will not be unduly affected by radiant heat flux.

Figure 11 – Floating Roof Tank Shell Protection

Figure 11 above shows a waterspray system on a floating roof tank during testing and commissioning. Whilst this is a particularly good example of spray coverage, the absence of spray in the red circle indicates nozzle blockage and the unusual downward jet of water in the blue circle indicates either a missing nozzle or a leak in the pipe / joint. This emphasises the importance of a proper testing regime.

Protection of Butane and Propane Spheres

Exposure protection of spheres takes is the same as horizontal LPG tanks discussed earlier. The main difference is that AS1596 does not provide a required design waterspray density for spheres. In that case, FSCS suggests that NFPA 15 be used with a design density 10.2 litres per minute per square metre over the surfaces which is consistent with the AS1596 design density for horizontal tanks.

Figure 12 shows a typical arrangement of a Butane sphere showing the waterspray nozzles arranged in rings around the sphere. Figure 13 however, shows direct spray protection only on the lower “hemisphere” with the upper “hemisphere” reliant on “run down” from a single nozzle at the top. FSCS considers that this method of protection is prone to failure with the “run down” obstructed by tank fittings and wind displacing the thin water film.

FSCS considers that cooling water shall be sprayed on both the upper and lower “hemispheres” of the shell because “run down” is not possible below the “equator”.

Note that in Figures 12 and 13; the support structures are concrete encased to prevent structural steel failure from radiant heat flux.

Figure 12 - Correct Sphere Protection

Figure 13 Poor Sphere Protection

Extinguishing and Control

One application that FSCS was involved in was the protection of the Sydney Harbour Tunnel in the early 1990s. This application contemplated various fire scenarios and whilst extinguishment was desirable and achievable in many fire scenarios, a minimum of *control was* considered as vital so that fire fighters could approach and successfully extinguish any fire. Figure 14 below shows one of the commissioning tests.

The project was written up in “Fire Australia” and “Fire International”. The complete published paper is on the FCSC web site – http://fscs-techtalk.com.

Figure 14 – Sydney Harbour Tunnel Commissioning Test

Cooling of structural building elements including structural steel and roller shutters.

Figures 15 and 16 below show waterspray being applied to a steel roller shutter required to have an FRL being part of the separation wall between sprinklered and non sprinklered compartments.

Steel roller shutters have an FRL of -/-/60, Tests by CSIRO demonstrate that with a water density of 0,2litres per second per square meter (12 litres/second per square meter) that the temperature rise of the unexposed face of the shutter is limited to 120^{o}C at 120 minutes (2 hours). This is lower than the allowable 140^{o}C permissible when testing fire doors.

This project used Multiple Jet Controls (MJC) each side of the door with open spray nozzles spraying water at the required design density over the door face.

Although the MJCs had independent glass bulb release elements – see Figure 29 on page 16, an electric actuator was used to activate both MJCs with the signal coming from a flow switch monitoring the sprinkler system on one side of the door.

Consequently a protected roller shutter can meet the required FRL of -/120/120 cited in AS2118.1.

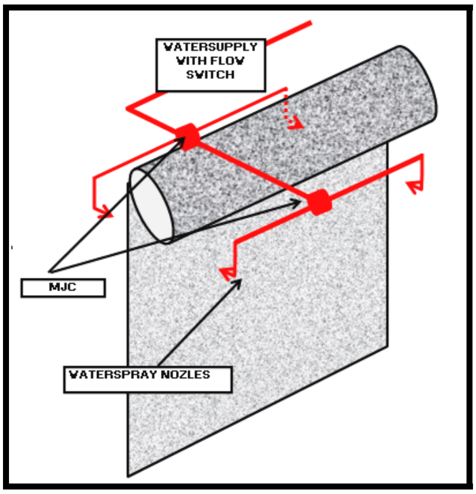

Figure 15 - System Arrangement

Figure 16 - Roller Shutter

CODES AND STANDARDS

There are two Australian Standards which specify waterspray cooling systems:-

- **AS1596** [11] which specifies cooling systems for certain LPG tanks within certain distances from another in order to reduce radiant heat flux. The Standard specifies a design density of 10 litres per minute per square metre (10 mm/min) across the exposed surfaces. An example calculation is provided later in this paper.
- **AS1940** [12] which specifies cooling systems for vertical fixed and floating roof tanks containing flammable or combustible liquids within certain distances from another in order to reduce radiant heat flux. The Standard specifies a design flow in litres per minute based on algorithms set out in the Standard. An example calculation is provided later in this paper.
- **NFPA 15** [13] specifies the requirement for waterspray systems as follows:-

Note - ¶ is for exposure control (cooling) and ¶ is for extinguishing.

- ¶ For oil filled transformers, a design density of 10.2 litres per minute per square metre (10.2 mm/min) over the projected area of a rectangular prism envelope for the transformer and 6.1 litres per minute per square metre (6.1 mm/min) over the expected non-absorbing ground surface of exposure. An example calculation is provided later in this paper.
- ¶ For cable trays, a design density of 12.2 litres per minute per square metre (12.2 mm/min) over the projected horizontal and vertical areas containing the cables.
- § For vertical or horizontal vessels or spheres, a design density of 10.2 litres per minute per square metre (10.2 mm/min) over the surfaces.

- ¶ For conveyors over the drive unit rolls, take up rolls, power units, hydraulic oil unit, top belt and bottom belt a design density of 10.2 litres per minute per square metre (10.2 mm/min).
- § For horizontal structural steel, a design density of 4.1 litres per minute per square metre (4.1 mm/min) over the surfaces.
- § For vertical structural steel, a design density of 10.2 litres per minute per square metre (10.2 mm/min) over the surfaces.
- § For metal pipes, tubing and conduits a design density of 6.1 litres per minute per square metre (6.1 mm/min) over the surfaces.

- **NFPA 850** [14] *Fire Protection for Electric Generating plants and High Voltage Direct Current Converter Stations* specifies the requirement for fire extinguishing waterspray systems as follows:-
  - For boiler fronts, a design density of 10.2 litres per minute per square metre (10.2 mm/min) over the surfaces.
  - For lubrication lines and oil reservoirs, a design density of 10.2 litres per minute per square metre (10.2 mm/min) over the projected surfaces.
  - For horizontal generator rotors and stators, a manually operated system delivering a design density of 24.5 litres per minute per square metre (24.5 mm/min) over the projected surfaces.
  - For vertical generator rotors and stators, a manually operated system delivering a design density of 12.25 litres per minute per square metre (12.25 mm/min) over the projected surfaces.

  NFPA provides free access (read only) to the general public for all its Codes and Standards [5].
- **API 2510** [15] specifies the requirement for waterspray systems as follows:-
- Fixed water spray systems shall be designed to protect against pool fire exposure to the vessel with a minimum fire water application rate of 0.10 US gallons [US] (4.1litres) per minute per square metre.

WATER SUPLIES

Water supplies for waterspray systems may be drawn from a municipal reticulated supply or from dedicated tanks and pumps on site. Refer to the FSCS paper titled *Water Supplies for Fire Services V4a* [16] for further guidance.

It should be noted that the water quantity should also include that for fire hydrants and fire sprinkler systems if applicable.

WATER DISTRIBUTION

The distribution pipework for the waterspray system, commonly called an *installation* in the fire protection industry, is normally dry with the water being retained by means of an automatic deluge valve or manual valve on the supply connection. Operation of the valve feeds water into the distribution system to allow for the simultaneous operation of all nozzles on the system.

The action of the deluge valve opening and the subsequent water flow causes an alarm to be actuated and relayed to a suitable remote location. In most cases this will be the Fire Indicator Panel. The Fire Brigade ASE which normally relays detection and sprinkler alarms to the Fire Brigade can be programmed to include transmission of a *deluge installation* alarm.

Each *installation* is controlled by a separate set of automatic deluge valves or manual valves. In the majority of cases, automatic operation of the respective systems is achieved by means of electrical fire or gas detection systems but in many instances, a fixed temperature detection system can be utilised with pilot sprinkler heads on either water or air lines.

DETECTION & CONTROL

Regular Deluge Valves

Automatic operation of the waterspray system can be initiated by a number of means:-

1. The most common system is where separate water filled detection piping with regular sprinkler heads is used, see Figure 17 below.

   In this arrangement, detector sprinklers are fixed to a water charged pipe arrangement.

   A water tapping from below the lower isolating valve is connected via a restricted orifice to the array of sprinkler detectors and also to the deluge valve diaphragm. In the event of fire when one or more sprinkler detectors are activated, water from the tapping below the deluge valve through the restricted orifice cannot make up the flow discharging from the actuated detector sprinklers and thus the water pressure is released from the deluge valve diaphragm allowing the valve to open.

   Local manual release is provided by a valve on the sprinkler detection line and a pressure switch provides alarm indication.

   Sometimes a bypass valve is provided to enable local operation.

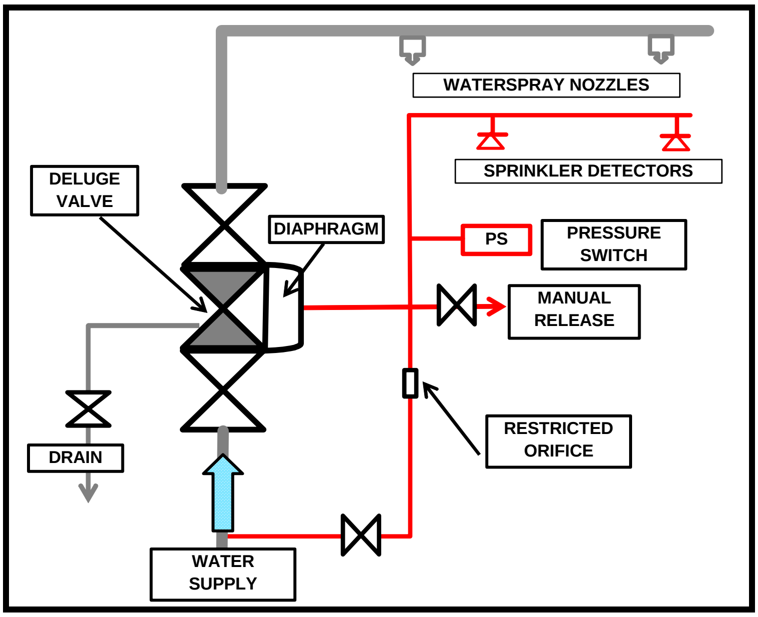

Figure 17 – Deluge Valve with “Sprinkler” detection charged with water

2. Where freezing might be an issue, air filled detection piping with regular sprinkler heads is used, see Figure 18.

   In this arrangement detector sprinklers are fixed to an air charged pipe arrangement. The air supply is taken from either a “plant” or dedicated supply with a reservoir (see Figure 18 on page 11 and Figure 26 on page 15) to maintain pressure in the event of air supply failure. This air pressure maintains a pilot diaphragm valve in the closed position. A water tapping from below the lower isolating valve is connected through a restricted orifice to this pilot diaphragm valve.

   In the even of fire when one or more sprinkler detectors are activated, the air pressure is released from the pilot diaphragm valve.

   Water from the tapping below the deluge valve cannot make up the flow discharging from the pilot diaphragm valve and thus the water pressure is released from the deluge valve diaphragm thus allowing the valve to open.

   Local manual release is provided by a valve on the sprinkler detection line and a pressure switch provides alarm indication.

   Sometimes, in “mission critical” installations, a bypass valve is provided to enable local operation when the deluge valve is being serviced.

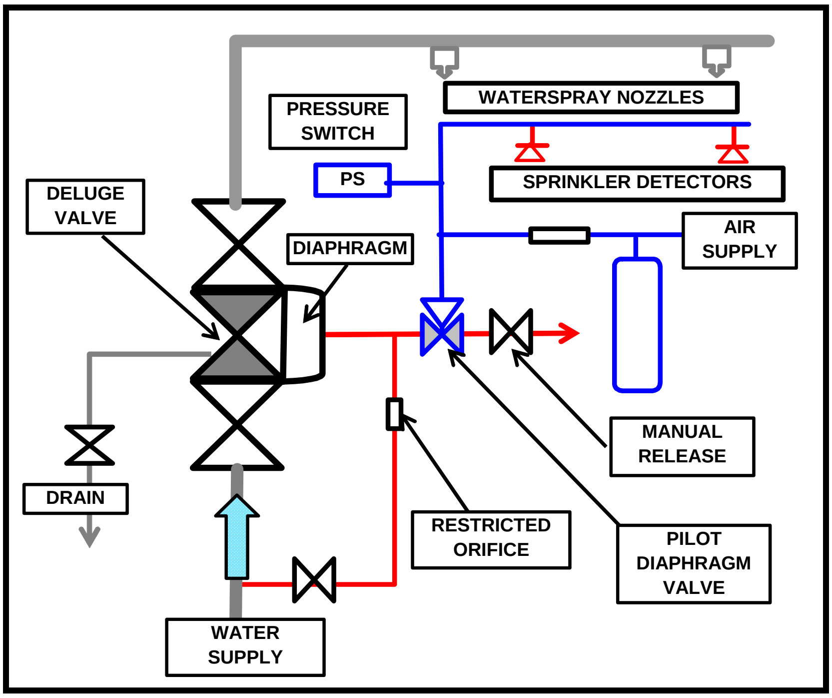

Figure 18 – Deluge Valve with “Sprinkler” detection charged with air

3. In this arrangement “electric” detectors (**Note 1**) are used with heat and flame being the most common – see Figure 19 below and Figure 26 on page 15.

   A water tapping from below the lower isolating valve is connected via a restricted orifice to the deluge valve diaphragm. In the event of fire when one or more detectors are activated, a signal from the Fire Indicator Panel (FIP) opens the solenoid valve. Water from the tapping below the deluge valve cannot make up the flow draining from the actuated solenoid valve and thus the water pressure is released from the deluge valve diaphragm allowing the valve to open.

   Local manual release is provided by a valve on the sprinkler detection line and a pressure switch provides alarm indication.

   Sometimes, in “mission critical” installations, a bypass valve is provided to enable local operation when the deluge valve is being serviced.

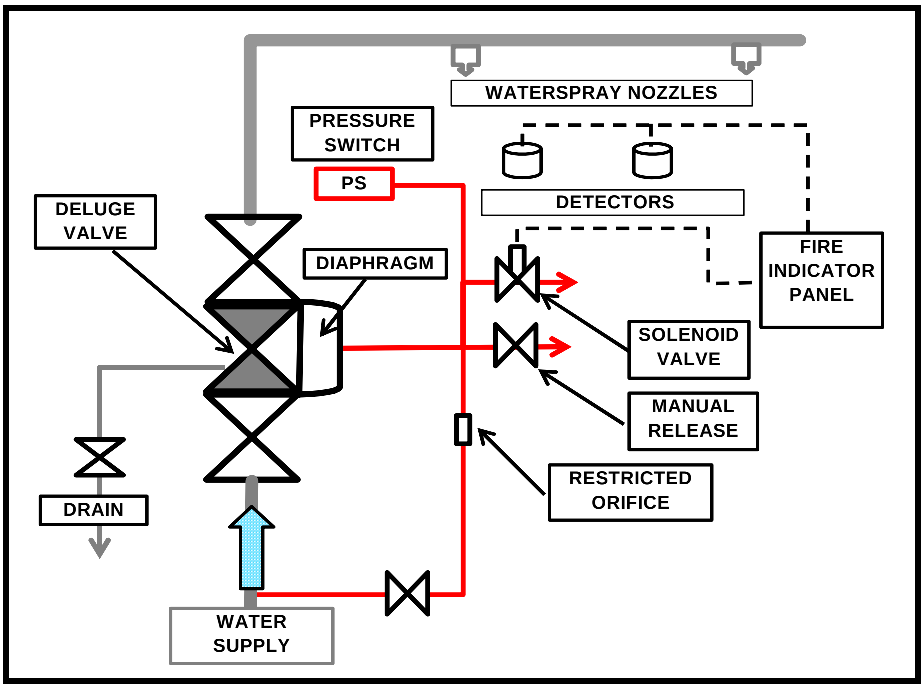

Figure 19 – Electric Detection

4. In this arrangement, a Multiple Jet Control (MJC) as described on Page 16 and shown in Figure 29, is used. This is a control valve with inbuilt glass bulb or soldered strut detection element, similar to that in a sprinkler head where, when the glass bulb or solder strut is dislodged, the valve will open.

   MJCs are available in various sizes and configurations from 25mm single outlet right angle type sup to 80mm multiple outlet types. The arrangement shown in Figures 20 and 29 is a "straight through" type.

   For indoor applications, the MJC is located within the compartment being protected and for outdoor applications; the MJC is located above the equipment or plant being protected.

   MJCs can also be electrically activated by a "piston actuator" initiated from selected detection inputs to the Fire Indicator Panel.

   In the arrangement shown, the water supply enters the MJC and when released, water flows directly through. Systems without electric detectors rely on the "glass bulb" or "soldered strut" element activating by heat. Temperature ratings are generally available in a range similar to those for sprinkler heads.

   Now, using Figure 29 on page 16 as a reference, it is shown that when the detection element actuates, the internal valve disc is dislodged thus releasing water to the waterspray nozzles.

   Where electrical detection is used, a "piston actuator" is fitted to the MJC (note that only glass bulb MJCs can accommodate this feature) is "fired" thus shattering the glass bulb detection element and opening the MJC as previously described. This requires the provision of an MJC to process the detector inputs and generate the required output for actuation.

   Local manual release can only be provided by a bypass valve as shown. A pressure switch provides alarm indication.

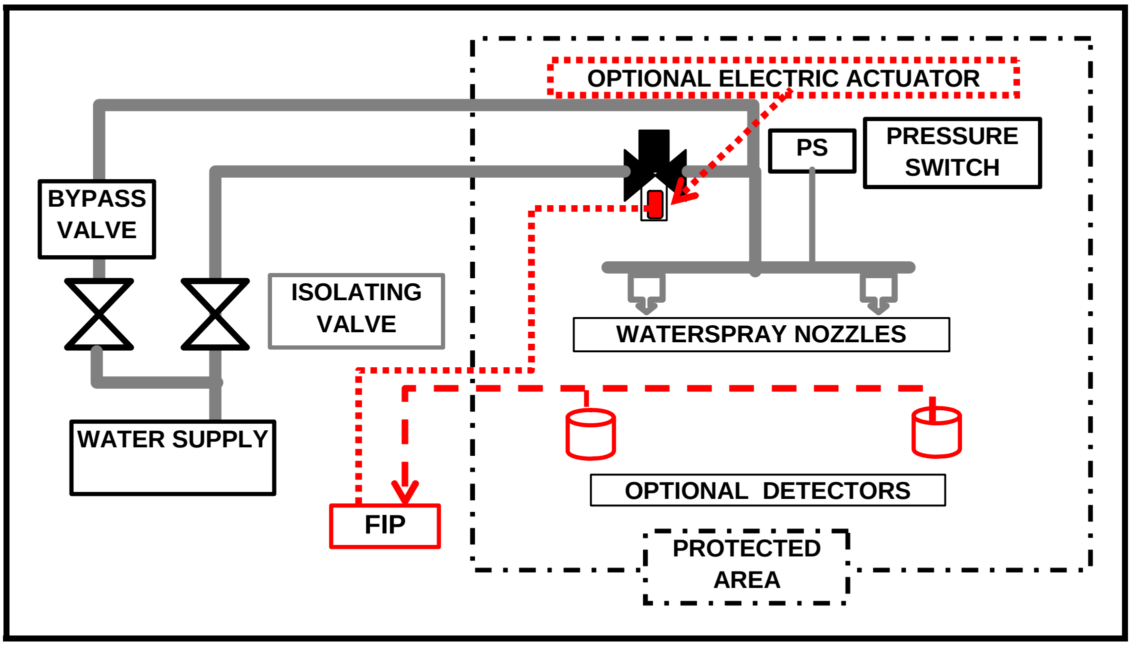

Figure 20 – MJC Operation

Note 1 Weatherproof, flame proof and intrinsically safe detectors are available to suit both external and hazardous area locations. Refer to the FFSCS paper "*Protection of Electrical Equipment*" [17] for further information.

Other MJC Uses

1. AS2118.1 permits sprinklers to be omitted from switchboard rooms and the like provided that the room is provided with a detection system complying with AS1670.1 [24] or, "multiple" jets for alarm purposes only, with the drain discharging to an open tundish or fitted with a sight glass".

   This feature was, and can still is, a common feature in sprinkler protected buildings. Furthermore, activation of the system will operate the sprinkle system hydraulic bell and the Fire Brigade ASE alarm as applicable. Figure 21 below shows a typical system.

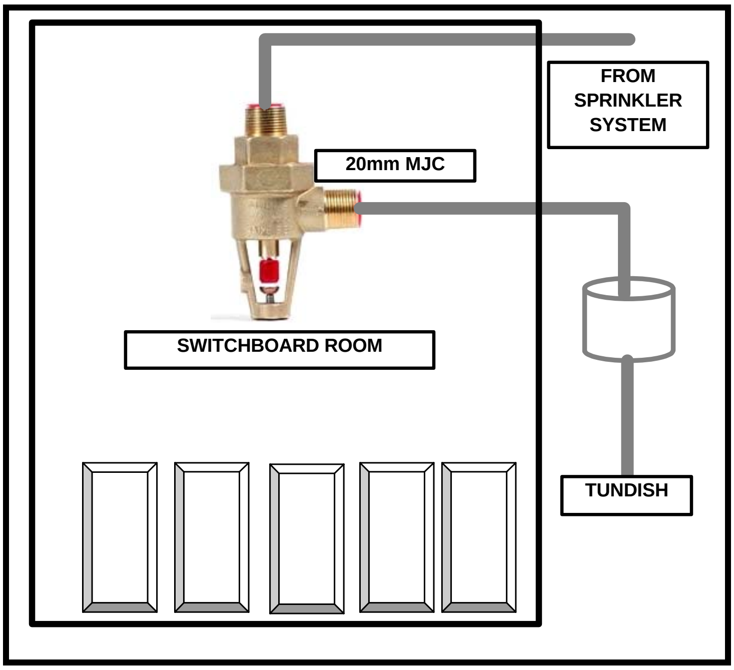

Figure 21 – MJC in Switchboard Room

In an otherwise sprinkler protected building, there may be specific areas or equipment that cannot be adequately protected by a conventional sprinkler system. These areas may include small LPG tanks, bio-fuel equipment, large flammable liquid stores etc.

In these cases protection can be achieved, either with cooling using MV waterspray nozzles or extinguishment using HV waterspray nozzles. Instead of installing a dedicated waterspray system these areas can be protected with a MJC operated system as shown in Figure 22 below with the water supply being sourced from the sprinkler system. This is commonly called as a "tail end" system.

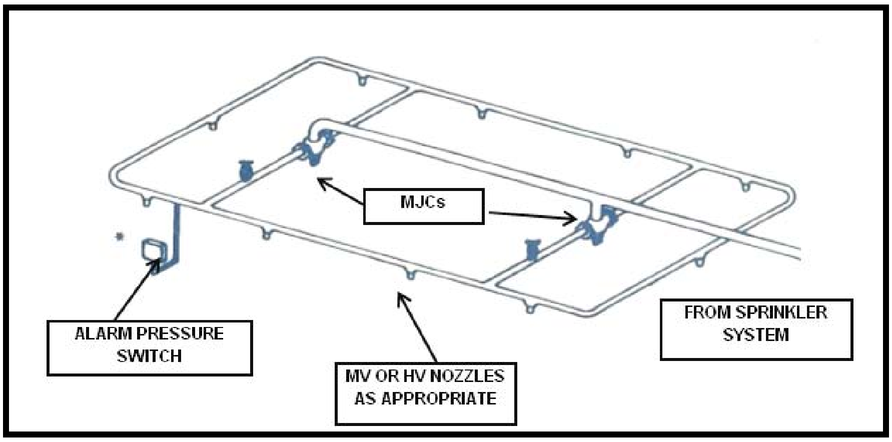

Figure 22 – Tail End MJC System

NOZZLES

The discharge nozzles for both high and medium velocity waterspray nozzles are unique to each of their applications. Furthermore each of the major fire equipment manufacturers will have their own registered / patented designs.

Readers should refer to the contact details in Appendix 1 to this paper for the principal fire equipment Companies that are able to supply waterspray equipment.

High Velocity Nozzles

A typical HV nozzle shown in Figure 23 has a machined body with an internal "swirl plate" which, with the appropriate flow and pressure, produces a coarse spray with large droplets and high velocity projection.

The two variables driving the flow rate are the final orifice size indicated by the blue circle and the dimensions and angle of the internal machined shape indicated by the red line.

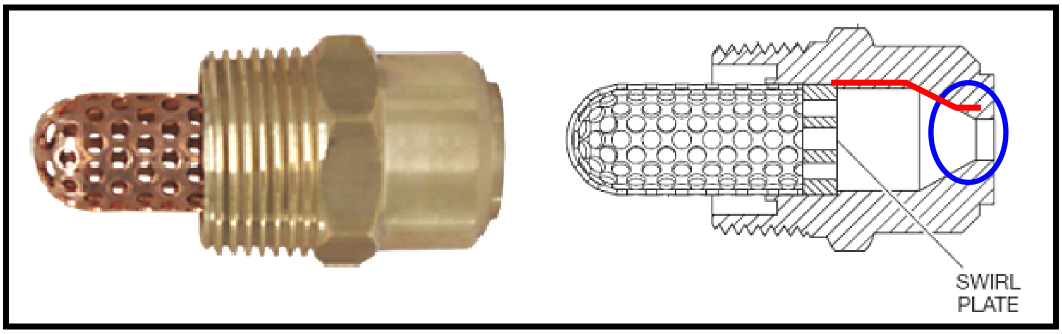

Figure 23 – High Velocity Waterspray Nozzle

Designers select the nozzles to be used based on the required flows, distances and orientation from the equipment to be protected.

Whilst the spray patterns (angles) are available for each nozzle at the optimum pressures, the pattern will differ dependant on the discharge orientation, i.e. pointing down, sideways or upwards. Each manufacturer will have provided their accredited designers with appropriate design data so that the required waterspray coverage can be achieved.

Later in this paper is a generic worked example for the protection of an oil filled transformer

Medium Velocity Nozzles

A typical MV nozzle shown in Figure 24 has a cast or pressed body with an external deflector which, with the appropriate flow and pressure, produces a fine spray.

Figure 14 shows the two variables in a MV nozzle, the defector angle and the orifice insert which determines the flow rate for the nozzle.

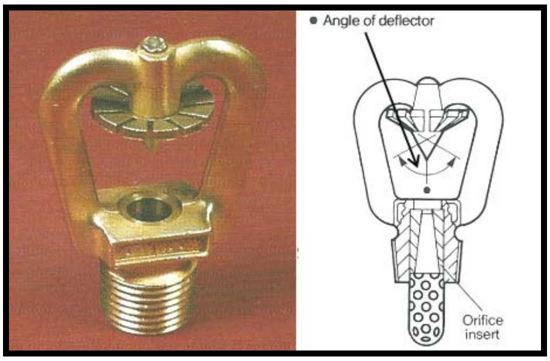

Figure 24 – Medium Velocity Waterspray Nozzle

Other Medium Velocity Nozzles

Some manufacturers can supply specialist nozzles with the following characteristics:-

- Reverse action nozzles, useful in positioning protection piping close in to the equipment being protected with the nozzle facing outwards. These have similar spray patterns to regular MV nozzles.

- Tank top nozzles, useful in positioning protection piping close in to the equipment being protected with the nozzle installed on a "candle stick" allowing for a wide spray pattern.
- Glazing nozzles designed to spray water on glazing with the spray pattern covering the entire projected area. This overcomes the unacceptable issue of having dry – unprotected upper corners of the glazing.

CONTROL VALVES

As discussed earlier, actuation of a waterspray system is generally achieved by the automatic opening of a deluge valve. However some jurisdictions permit manual operation.

All manufacturers have a selection of deluge valves suitable for water, air or electric detection. Many have self resetting and remote resetting valves.

Latching Valve

Figure 25 below shows a typical latching deluge valve. The valve is shown in the closed position with the "clack" holding back the water by being latched.

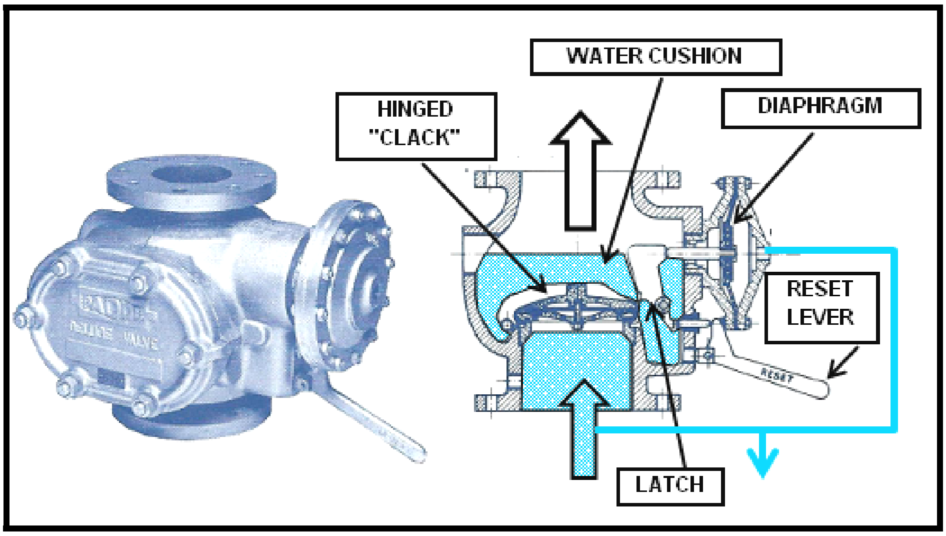

Figure 25 – Latching Deluge Valve

Note the shading showing water above the "clack" being required to dampen the forces developed when the "clack" hits the internal part of the valve casting when the valve is opened.

Figure 26 Deluge Valve Skid

Figure 26 shows the same model of valve assembled on a factory assembled "skid" for the Mobil "Beryl B"North Sea oil platform. This valve arrangement has electrical detection using flame detectors but with air to the diaphragm. Note the small air reservoir provided as a stand-by air supply.

Note also that all the electrical equipment has been selected for an aggressive marine use.

Diaphragm Type Valves

Figures 27 and 28 below show a typical diaphragm type deluge valve. The area of the diaphragm subject to the water pressure is greater on the top than on the bottom. Therefore with equal pressure on the top and the bottom, the diaphragm will be in the closed position.

If the water pressure on top of the diaphragm is released, and not permitted to rise, the valve will open. The water pressure is controlled by a restricted orifice.

Figure 28 is from the Sydney Harbour Tunnel where 156 150mm deluge valves of this type were installed in FRL -/120/120 (2 hour) rated enclosures. The requirement for remote resetting from the control room was achieved without the need to access the valves.

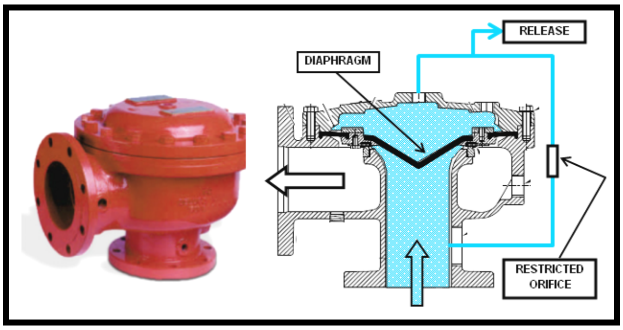

Figure 27 – Diaphragm Type Deluge Valve

Figure 28 - Sydney Harbour Tunnel Deluge Valves

Multiple Jet Control

Figure 29 below shows the principle of the operation of an MJC. In this figure, the water is held back by the function of the glass bulb, the valve stem and the valve disc. When the glass bulb is shattered either by heat or the Metron piston actuator, the valve disc and stem are forced down allowing water to flow through the valve.

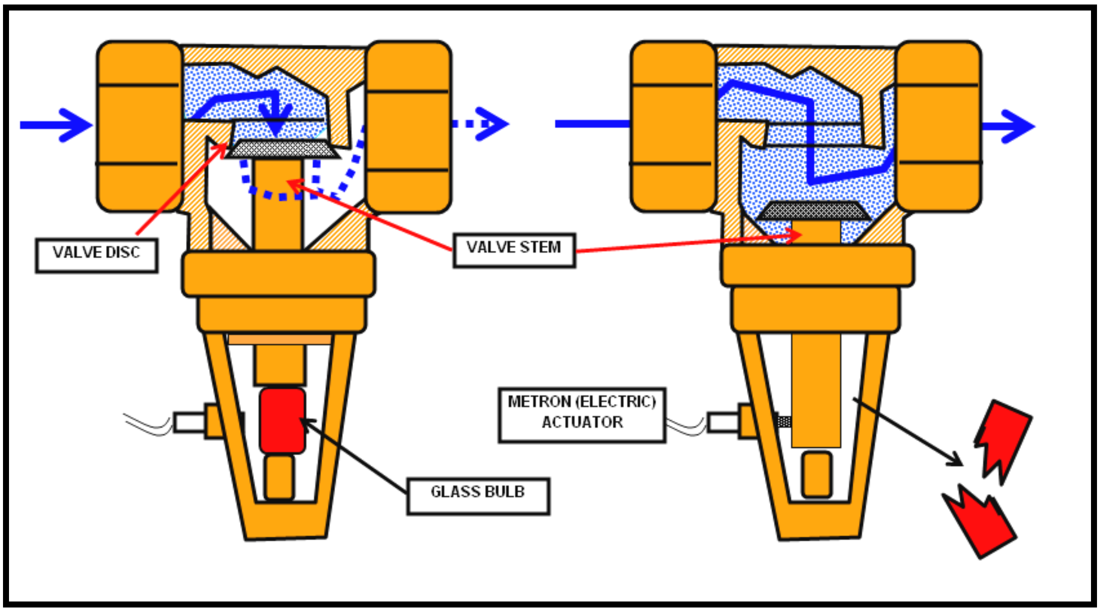

Figure 29 – Principle of MJC Operation

Figure 30 below show an enclosed transfer bridge between tow factory buildings which has a product transfer conveyor within. Because the two buildings are required to be fire separated, Figure 31 shows a water curtain activated by two MJCs supplying open medium velocity sprayers.

Figure 30 - Transfer Bridge

Figure 31 - Water Curtain MJCs

EXAMPLES OF PROTECTION

The following are examples of different protection systems using both HV and MV nozzles. Readers should not use the information herein to design systems.

LPG Tank Protection

Figure 32 hereunder is an example of the protection of a horizontal LPG tank for compliance with AS1596. The pale blue shaded areas represent the approximate coverage of waterspray.

The dark blue lines represent the waterspray distribution piping with the red lines representing the water filed detection piping and detector sprinklers.

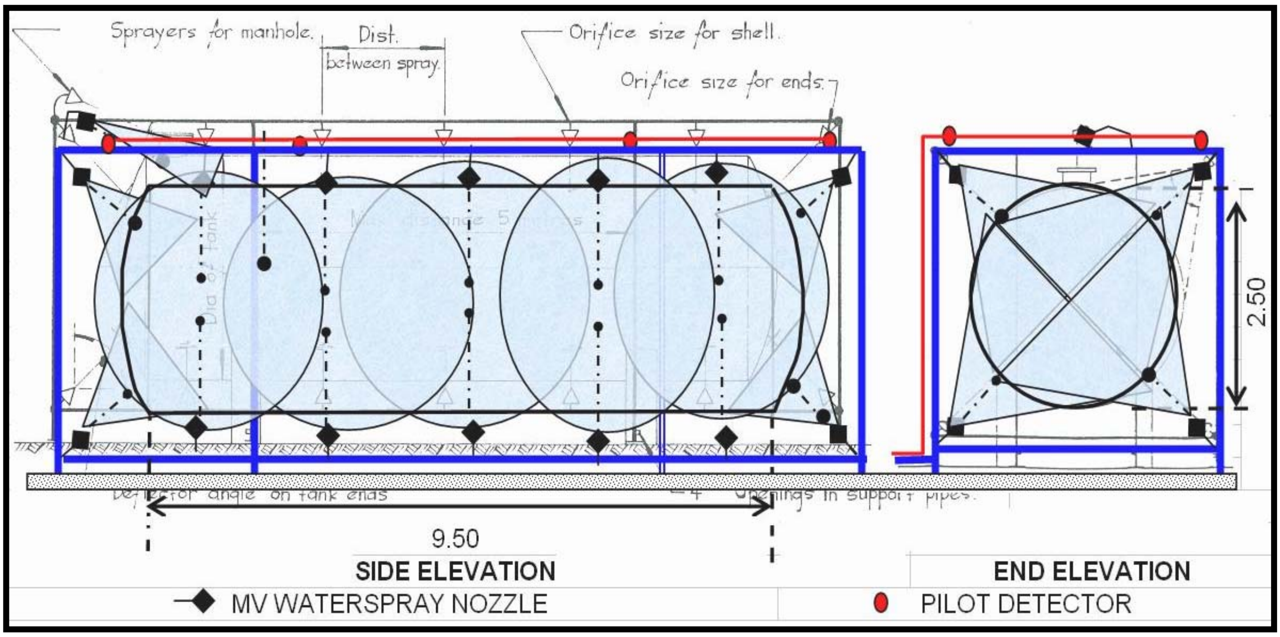

Figure 32 – MV Waterspray Protection of an LPG Tank

Calculations for the required amount of water are based on the total surface area of both ends and the shell in square metres multiplied by 10 to give a result in litres per minute.

The locations and spray patterns of the nozzles shown in Figure 32 are indicative only and the designer, using skill and experience will select various types of nozzles according to coverage, spray angle and flow such that all surfaces are covered.

Table 1 below shows the calculations for this 2.5m diameter x 9.5m long tank with dished ends.

To that should be added "hydraulic gain **[Note 1]** at 10%", with an additional 15% for overlap and windage.

Note 1 - The FSCS paper entitled "*Hydraulic Gain in Sprinkler Systems*" **[23]** on the FSCS web site at http://fscs-techtalk.com provides further explanation.

PROTECTED AREA	DIMENSIONS	AREA M^2	SPRAY APPLICATION – L/M
Shell	9.50m long x 2.5m diameter	74.6	746
Manhole / Safety Valves	2.0 – **Note 2**	2.0	20
Ends x 2	1.69 x 2.5m diameter **Note 3**	8.45	84.5
Total			**850.5**

Table 1 - Calculations

Note 2 – A nominal 2.0m^2 is added for this protection.

Note 3 – For the Torispherical ends, the area is taken as 1.69 x the diameter

Based on the above and including the 10% for overlap and 15% for hydraulic gain, the total required flow is 943 litres/minute.

Figure 21 shows typical wet pilot detection with the general rule is that detectors should be above the tank spaced at about 3m apart down each side as shown in Figure 32. The location of nozzles and detectors is required to be carried out by an experienced designer.

Transformer Protection

Figure 33 hereunder is an example of the protection of a Generator Transformer with High Velocity nozzles. The pale blue shaded areas represent the approximate coverage of waterspray.

The dark blue lines represent the waterspray distribution piping.

The calculations shown are carried out to meet NFPA requirements for a design density of 10.2mm/min (10.2 litres/minute/square metre) as discussed earlier.

Note 1 – allows for additional water flow to cater for the "hydraulic gain" **[23]** where in order to meet the minimum flow from furthest nozzle on the system, a higher pressure is required. This higher pressure means that nozzles nearest to the supply will flow more water than the minimum design requirement.

Note 2 – allows for wastage of the water from overlap, slippage and windage as explained below:-

- All nozzles discharge a generally circular spray pattern and in order not to have dry unprotected areas, the nozzle discharges have to overlap.
- Slippage is the action of the waterspray, after hitting the target area, slipping or running off the surface to be protected.
- Windage is a factor that should be allowed on external transformers to allow for wind displacement of the discharge pattern.

Aiming the nozzles in order to obtain proper protection requires skill and experience and some manufacturers such as Tyco provide discharge pattern templates for each type of nozzle.

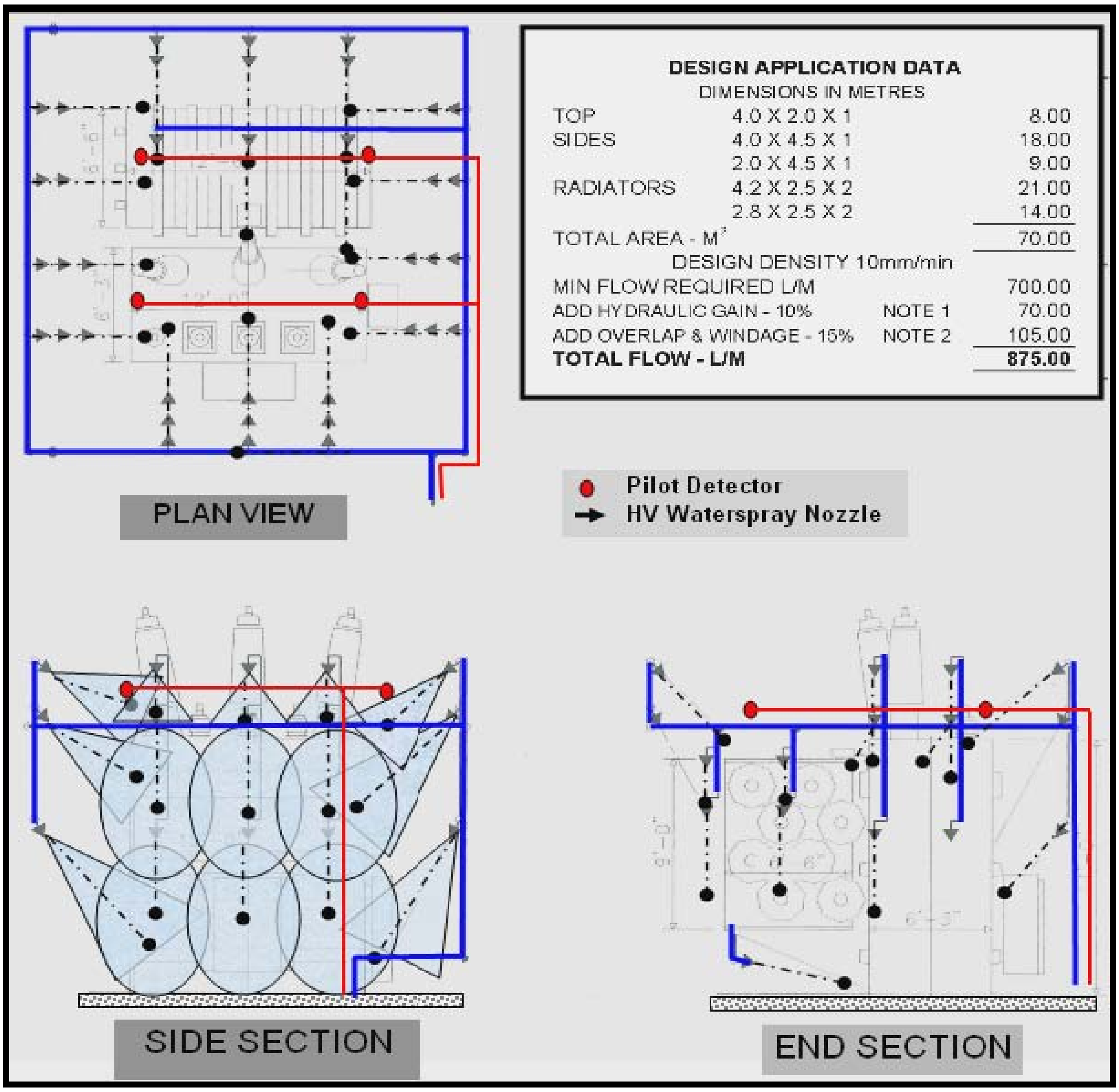

Figure 33 – Typical Generator Transformer Protection

Note that the nozzle spray pattern is indicative only and is only provided for the side section.

Figure 34 below is a typical template called a “rangefinder” which provides various affect ranges dependant on the angle that the nozzle is installed. This one is for a Tyco HV37 nozzle.

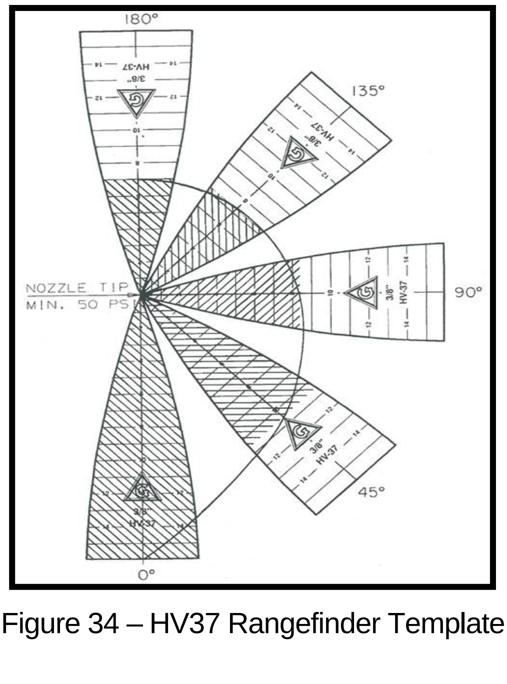

Figure 34 – HV37 Rangefinder Template

The locations and spray patterns of the nozzles shown in Figure 33 are indicative only and the designer, using skill and experience will select various types of nozzles according to coverage, spray angle and flow such that all surfaces are covered.

NFPA15 provides the required clearances from the high and low voltage bushings according to the voltage. Compliance with these clearances will ensure no arcing from the bushings to the waterspray pipework. Interestingly, the conductivity of High Velocity waterspray is less than that achieved in a standard rain test.

Figure 33 does not include the locations of the elected type of detection being water, air or electric. However the general rule is that detection should be above each section of the transformer and sometimes beneath radiators etc where their bulk tends to shield detectors.

Protection of Flammable Liquid Tanks

Figures 35, 36 and 37 below show the calculation methodology carried out to comply with AS1940 for the protection of tanks similar to that shown in Figures 9 and 10.

The following notes should be read for the example. The AS1940 requirements are shown in italic typeface whilst the FSCS comments are shown in blue regular typeface:-

1. *AS1940 specifies that If one of the tanks is more than 6 m but neither is more than 20 m in diameter, the distance between them shall be at least one-half of the diameter of the larger tank. This example has 12.0m separation.*

2. *The maximum capacity of tanks in a single compound of fixed roof tanks shall not exceed 60,000m^3. This example complies.*

3. *Cooling water is required for this tank installation applied by hydrants, monitors or fixed pipe systems.*

   FSCS considers that hand held hose / nozzle streams would not be acceptable for the arrangement shown below.

4. *Where monitors are used to effect the required tank cooling systems, they shall be located such that in use, the operator shall not be subjected to a radiant heat flux greater than 4.7kW/m^2.*

   Based on the tank arrangement shown and with the advice in AS1940 that monitor streams will not effectively reach further than 45m, FSCS considers that monitors will not be able to effectively cover Tank 5 nor the surfaces of the other tanks facing inwards.

   Additionally it is doubtful if any attending Fire Brigade would be able to muster the necessary numbers of fire fighters to man the monitors <u>and</u> provide for their protection.

5. *AS1940 advises that any vertical fixed roof tank should be considered as a tank-on-fire and a potential source of radiant heat flux to adjacent tanks. The intent of the waterspray requirement is to control the temperature rise of an adjacent tank by applying cooling water to that portion of the tank shell or roof that might be exposed to radiant heat.*

6. *The algorithms for calculating the required waterspray density of application the surface of the tank subject to radiant heat flux is taken as 1/3rd the tank circumference multiplied by its height plus any corresponding surface of the roof.*

   FSCS advises that the “1/3rd area of shell and fixed roof” is part of the waterspray calculation regime and does NOT mean the waterspray need only be applied to a third of the tank. The waterspray application is required to be applied to all surfaces subject to radiant heat flux exposure, i.e. in line of sight from the tank-on-fire.

7. *Where the adjacent tank is separated from the tank-on-fire by more than 1.5 times the latter tank diameter there is no need for cooling water.*

8. *The algorithms in AS1940 assume that the water quantity supplied reaches the tank surface where it is required.AS1940 advises that special circumstances such as wind may require an increase in water.*

Example

The example detailed below is for a flammable liquid storage depot comprising nine 18m diameter by 11.5m vertical fixed roof tanks.

The arrangement is shown in Figure 35 below with 12m separation between each tank.

Figure 25 shows the two scenarios for protection calculations. **Scenario 1** where the red dashed circles around Tank #1 encompass the least number of tanks within 1.5D of Tank #1, those being Tanks 2, 4 and 5; and **scenario 2** where the blue dashed circles around Tank #5 encompass the greatest number of tanks within 1.5D of Tank #5, those being Tank # 1, 2, 3, 4, 6, 7, 8 and 9, i.e. all the tanks in the cluster nit "on fire".

Calculations have to be carried out for both scenarios to determine the maximum flow rates and storage capacity, although in this paper, only the first of the calculations has been carried out.

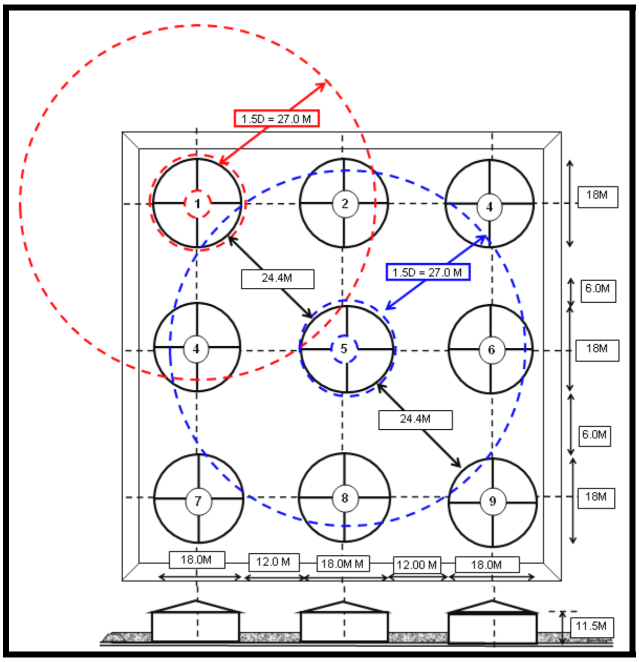

Figure 35 – Tank Arrangement

For this example, the total capacity of the tank installation with product depths of 11.0m § in the tanks is 25,195.7m^3.

§ The overall tank heights are 11.5m and the 0,5m "ullage" allows for the installation of the foam system discharge devices.

The required waterspray flow is calculated by:-

a Cooling water for tank shell = qv = dhW where:-

Qv =	litres per minute applied to that part of the tank shell facing the tank-on-fire
d=	diameter of tank being protected - metres
h=	height of tank being protected – metres
W=	Cooling water factor from Figure J1 in AS1940 – litres per minute

b For cooling water for the tank roof, firstly determine S/D ratio with:-

S being the separation distance from the tank on fire

D being the diameter of the tank on fire

For any tank within one diameter of the tank-on-fire add water quantity equal to 0.25 x d2 x W for roof cooling.

The value of W, being litres per minute per square metre is taken from Figure J1 in AS1940 which is a “log – log” function of S/D and envisages a protected silhouette area of the tank.

Designers often develop a Microsoft Excel spreadsheet to calculate the cooling water quantity with data entry of tank numbers, diameter, height and separation distance. Figure 36 below is the FSCS edition of such a spreadsheet based on the tank and layout details in Figure 37.

As1940 provides for the calculation of required waterspray base on the formulae described in dot point 6 above, or a simpler formula based on the total capacity of the installation in m^3 multiplied by a factor given in the Standard.

TANK COOLING CALCULATIONS TO AS1940 INSTALLATION CAPACITY = 20,615 M^3	CALCULATED VALUES	CALCULATIONS BY	DATE
	REQUIRED INPUT	RICK FOSTER	N/A

TANK ON FIRE		TANKS WITHIN 1.5D			SEPARATION	COOLING WATER FOR TANK SIDE			TANK TOP COOLING IF S=<D	TOTAL COOLING
No.	Dia (D) M	No.	DIA (d)M	HEIGHT h(M)	(S)M	S/D	W	Qv = (d x h x W) L/Min	Q= (0.25 x d x d x W) L/Min	WATER - L/Min
1	18.00	2	18.00	11.50	12.00	0.67	3.20	662.40	259.20	921.60
		4	18.00	11.50	12.00	0.67	3.20	662.40	259.20	921.60
		5	18.00	11.50	24.40	1.36	1.50	310.50	121.50	432.00
PRODUCT DEPTH IN TANKS - M				11.00					TOTAL COOLING WATER	2,275.20

MAXIMUM COOLING WATER REQUIREMENT TO J2.3(a) IS FOR TANK	1	BEING ON FIRE =	2,275.20	L / MIN	
					2,275.20
TOTAL CAPACITY OF INSTALLATION = M^3	25,195.70	APPLY BY FIXED SPRAYS AT 85% EFFICIENCY			2,616.48
			LITRES / SECOND		43.61

Figure 36 – Excel Spreadsheet Calculations

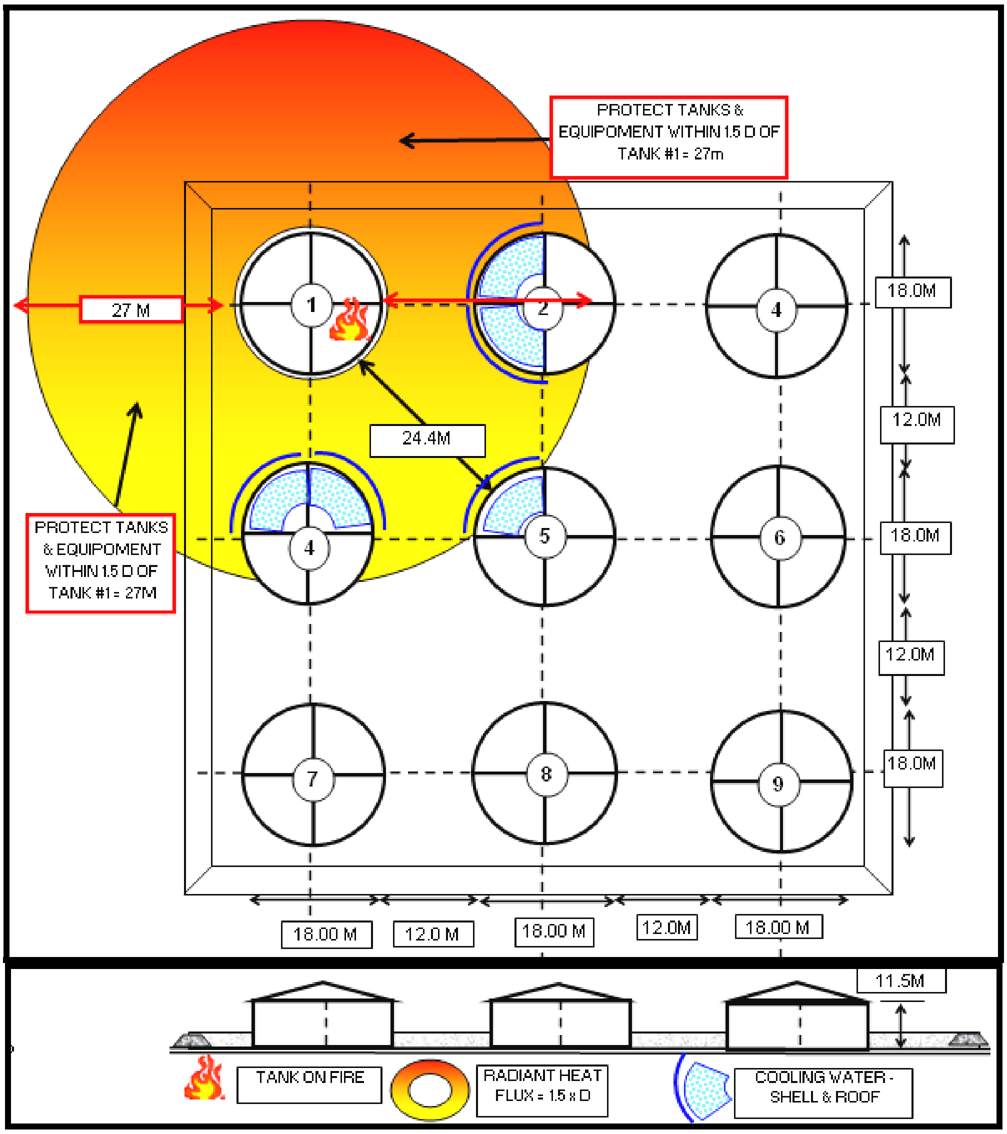

Figure 37 – Example Tank Protection Arrangement

Figure 37 above shows that for Tank 1 on fire, waterspray is required to be applied to the colour coded portions (shell and roof) of tanks 2, 4 and 5 being within the "1.5D" of (1.5 x 18.0m = 27m) distance from the tank-on-fire No. 1.

The arrangement shown provides for a suitable piping and valve arrangement so that cooling water can be applied to all the appropriate tanks, and portions thereof for all tank-on-fire combinations.

The example in Figure 37 divides the tanks into "quadrants" as shown although division into "thirds" as shown in Figure 38 might result in a neater design.

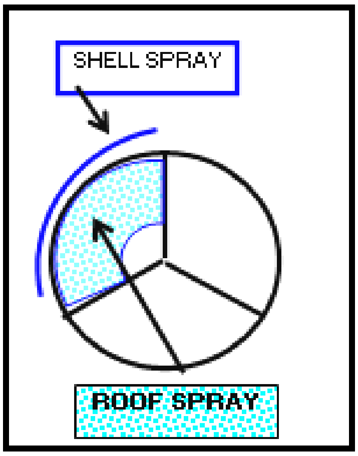

Figure 38 – Alternative Spray Arrangement

The locations and spray patterns of the nozzles required and the designer, using skill and experience will select various types of nozzles according to coverage, spray angle and flow such that all surfaces are covered.

Based on the AS1940 calculations in Figure 36 above, the waterspray requirement for **scenario 1** in this example using fixed nozzles is 2,616 litres per minute and with a requirement for the required 1.5 hour duration, a water quantity of ~235 m^3. This is in addition to the requirements for hydrant and foam systems.

The next calculation for **scenario 2** will result in an increased flow and capacity.

Note that waterspray system flow rates for tanks, and in particular clusters of tanks, will incur significant *"hydraulic gain";* and the final water flow and storage requirements will certainly be at least 25% greater than the raw calculations indicate.

----------- End of Document---------

I trust that this paper provides useful information on the design of waterspray systems.

Richard A Foster

Dip Mech Eng; Dip Mar Eng; MSFPE

Fire Safety Engineer

RPEQ Mechanical – 7753: Accredited by Board of Professional Engineers as a Fire Safety Engineer

Principal – Fire and Security Consulting Services

Web Site http://fscs-techtalk.com

Version 1 – June 1st 2016

APPENDIX 1

1. Referenced Codes and Standards

Readers are encouraged to obtain copies of the relevant Codes and Standards if they are contemplating designing systems described in this paper.

- [3] Standards Australia http://infostore.saiglobal.com/store/
- [1] AS2118.1 – Automatic fire sprinkler systems – Part 1 – General Requirements
- [6] AS 1940 – The Storage and Handling of Flammable and Combustible Liquids **Note 1**
- [9] AS4100 – Steel Structures
- [11] AS1596 – The Storage and Handling of LP Gas **Note 2**
- [12] AS1940 – The Storage and Handling of Flammable and Combustible Liquids
- [24] AS1670.1 - Fire detection, warning, control and intercom systems – System design, installation and commissioning
- 4] National Fire Protection Association http://www.nfpa.org/freeaccess
- [8] NFPA 30 – Flammable and Combustible Liquids Code https://www.nfpa.org/Assets/files/AboutTheCodes/30/FI30-2012.pdf
- [13] NFPA 15 Standard for Water Spray Fixed Systems for Fire Protection
- [14] NFPA 850 - Fire Protection for Electric Generating plants and High Voltage Direct Current Converter Stations
- [5] American Petroleum Institute www.api.org/
- [15] API 2510 - Design and Construction of LPG Installations https://law.resource.org/pub/us/cfr/ibr/002/api.2510.2001.pdf

Note 1 Unlike NFPA 15, AS1940 provides a comprehensive methodology for the calculation of waterspray systems. NFPA provides a baseline design density 10.2 litres per minute per square metre (10.2 mm/min) over the surfaces.

Note 2 AS1596 does not provide a required design waterspray density for spheres. In that case, FSCS suggests that NFPA 15 be used with a design density 10.2 litres per minute per square metre (10.2 mm/min) over the surfaces.

Referenced Australian Legislation

- [7] Queensland Worksafe Act https://www.worksafe.qld.gov.au/__data/assets/pdf_file/0007/82492/dgsm-infopaper11-fcl-licensing.pdf

2. Referenced Technical Papers

The FSCS papers referenced below are available for download from the FSCS web site at http://fscs-techtalk.com

- [10] Performance of Steel Sections in Fire Conditions
- [16] Water Supplies for Fire Services V4a
- [17] Protection of Electrical Equipment
- [23] Hydraulic Gain in Sprinkler Systems

3. Companies

Note that I am most familiar with the Tyco range of equipment having works with that Company and its subsidiaries for many years. As indicated in the introduction to this paper, there are many other International Companies that can provide either identical or similar approved and listed equipment for waterspray systems.

- [18] Tyco https://www.tyco-fire.com/index.php?P=product&S=S8
- Wormald – **Note 1** http://www.wormald.com.au/
- Wormald New Zealand http://www.wormald.co.nz/
- Reliable https://www.reliablesprinkler.com/
- Angus Fire (UK) www.**angusfire**.co.uk/
- Viking (USA) www.**viking**groupinc.com/
- Chubb Fire & Security Systems www.**chubb**.com.au/**fire**-products/ part of UTC Building & Industrial

Note 1 – As of March 2016, Wormald has returned to Australian ownership and management after its sale to Evergreen Capital - see https://www.wormald.com.au/media/iconic-australian-fire-brand-returns-to-local-management

FSCS is unsure about the split of product availability between Tyco and the new Wormald International Company. In the meantime the products referenced in this paper can still be viewed on the referenced Tyco site(s).

4. Books

- [2] *Fire – A Century of Automatic Sprinkler Operation in Australia and New Zealand* *1886 – 1986* Harry Marryatt – Australian Fire Protection Association ISBN 0 7316 4001 2.

5. Referenced Equipment

- [17] Pilot Detector https://www.tyco-fire.com/TD_TFP/TFP/TFP1388_10_2014.pdf
- [19] MV Nozzles https://www.tyco-fire.com/TD_TFP/TFP/TFP807_10_2015.pdf
- [20] HV Nozzles https://www.tyco-fire.com/TD_TFP/TFP/TFP815_12_2015.pdf

[21] MV Tanktop and Reverse Action Nozzles https://www.tyco-fire.com/TD_TFP/TFP/TFP809_02_2016.pdf

- [22] DV1 / F470 Deluge Valve - - Wormald New Zealand http://www.wormald.co.nz/__data/assets/pdf_file/0013/404320/Model_F470_Deluge_Valve.pdf