THE IMPROVEMENT OF THE FIRE PROTECTION IN A CANDU-6 TYPE NUCLEAR POWER PLANT BY THE USE OF WATER-MIST EXTINGUISHING SYSTEMS

Nicolae-Andrei BRANZEU[1], Daniela NECULA[2]

Abstract

This paper aimed to be an analysis on the possibilities to use the water- mist fire suppression systems in some areas in CANDU-6 type Nuclear Power Plant (NPP) showing a significant fire hazard. The analysis considered areas such as below turbogenerator (T/G) operating deck, areas in which the stand-by and emergency Diesel unit are located and the areas of the electric cable spreading and electrical panels and switchgears.

It is briefly presenting different water-mist fire suppression systems, such as HI-FOG system.

The comparative use of these water-mist fire suppression systems in significant fire hazard areas in a CANDU-6 type NPP, as well as the advantages versus the sprinkler systems, water spray systems and gas-based systems is also presented.

Keywords: water mist, fire suppression, CANDU-6 NPP.

1. Introduction

Water has favorable physical properties for fire suppression. Its high heat capacity (4.2 J/g-K) and high latent heat of vaporization (2442 J/g) can absorb a significant quantity of heat from flames and fuels. Water also expands 1700 times when it evaporates to steam, which results in the dilution of the surrounding oxygen and fuel vapors. With the formation of fine droplets, the effectiveness of water in fire suppression is increased, due to the significant increase in the surface area of water that is available for heat absorption and evaporation.

Water mist refers to fine water droplets in which 99% of the volume of the spray is in drops with diameters less than 1000 microns. As is show in Table 1, decreasing the droplet size by a factor of 10 increases the surface area (and evaporation rate) by a factor of 10 and the number of droplets by a factor of 1000. Advantages of water mist over gaseous agents are that water is non-toxic, readily available, and lower in cost than most chemicals or patented mixtures. Water mist

[1] Eng., Center of Technology and Engineering for Nuclear Projects, Bucharest, Romania
[2] Eng., Center of Technology and Engineering for Nuclear Projects, Bucharest, Romania

provides effective cooling for fuel and for the compartment that cannot be provided by the gaseous agents, potentially preventing re-ignition that may occur if a gaseous agent concentration cannot be maintained for a sufficient period of time. With effective cooling and less clean-up time, water mist allows the space to be reoccupied and operational in a short time following a fire. Advantages of water mist over conventional sprinklers include reduced water flow rates and therefore less water damage to sensitive equipment or occupancies. Low water flow rates also provide a clear advantage in terms of space and weight requirement for the water supply. In addition, water mist is able to control flammable liquid fires that conventional sprinklers cannot control due to splashing and spillage of the fuel.

2. Paper contents

The main difference between the well-known sprinkler/deluge water sprays and the water mist sprays is the droplet sizes. A large fraction of the droplets from water mist systems is in the size range that evaporates shortly after entering a fire plume. This leads to inert gas production (steam) which subsequently may be beneficial for fire suppression, provided that the inert gas is present where it is needed. The utilization of the latent heat of evaporation of water in the fire plume also adds to the suppression efficiency of water. On the other hand, when water droplets evaporate inside the fire plume, these droplets are not reaching the firebase to provide cooling and wetting of the burning substances or cooling of objects for extended service in a fire situation.

The main difference between gas systems and water mist systems is that water mist needs to be heated up and evaporate to become a gas, and will re-condense and form droplets when the mixture of water vapour and other gases are cooled below 100°C. Other inert gases used for fire suppression will stay as gases even at ambient temperature, and will diffuse into all parts of a compartment when released. To keep the inerting effect, it is required to close all openings and shut down ventilation systems. A certain extra supply of gas is often specified to count for leakage in a certain holding time.

Water mist systems can not make the atmosphere of a compartment inert without having a heat source. This means that the water mist normally has to be entrained into the fire plume to form inert gas. It also means that water mist has to be supplied to the compartment either continuously or at intervals to compensate for fall-out of droplets if protection criteria arc to be kept for a certain time. Since water droplets not perfectly follow airflow and diffuse into covered areas of a compartment, it is necessary to install the spray nozzles in a way to cover the fire risk areas. However, a well-designed water mist system is then functioning with a

certain ventilation rate of the compartment, either through open doors, leakage in the construction or by ventilation systems.

If the temperature of a compartment is kept above about 70°C, the inerting effect of water vapour is sufficient to suppress fires the same way as gas systems. This is due to the saturation pressure of water at atmospheric pressure, which allows about 30% volume of water vapour at 70°C.

Water Mist System Description. HI- FOG concept and characteristics.

Water mist systems are fire protection systems which use water in small droplets to extinguish fire. The mechanisms of extinguishment include flame cooling by droplet heating and evaporation, oxygen depletion by steam expansion and combustion products, and wetting of surfaces. The design of commercially available systems (see Table-2) are distinctly different. Generally they can be categorized as follows:

1. Type of atomization method: single fluid, twin fluid.
2. Delivery type: wet pipe, dry pipe, pre-action and deluge system.
3. Pressure supply method: gas propellant, pumps.
4. Operation pressure level: low pressure (≤12.5 bar), medium pressure (>12.5 bar and <34.5 bar), high pressure (≥34.5 bar).
5. Water source: self-contained water tank/cylinders, private water source, public water source.
6. Mist discharge type: continuous discharge, cyclical discharge.

HI-FOG water mist is always generated by a high pressure. The systems are powered by constant pressure electric or diesel pumps (pressures up to 140 bar) ,or by pressurized gas cylinders (pressures up to 200 bar). All the drop sizes usually fall in the range below 200 µm (Dv90 < 200 µm). The penetration length may be up to 7 – 8 m horizontally, and even longer distances are reached vertically. The good penetration also contributes in spreading the mist throughout the space, even past obstacles.

Owing to the optimal drop size distribution and good penetration the HI-FOG systems have a very high cooling, inerting and radiant heat blocking efficiency. Gas temperatures around the fire drop abruptly within seconds after discharge, and the fire is quickly surrounded by a dense cloud of small droplets. The radiant heat is blocked so effectively that at a few meters distance from the fire people do not feel any heat. The adjacent structures are well protected, even if the fire is still burning.

HI-FOG can replace not only conventional water spraying systems, but also gaseous extinguishing systems In “sprinkler-like” applications the HI-FOG systems are designed to suppress and control the fires. The HI-FOG performance has been proven to be better than or equivalent to that of conventional sprinklers.

The amount of water used is much less, though, resulting in smaller water damages.
Also, the water supply as well as the piping can be considerably reduced as compared to conventional sprinkler systems.
In "gas-like" applications the HI-FOG systems are designed to suppress or extinguish the fires. As compared to gases, HI-FOG has clear benefits of being completely safe to people and of not requiring enclosure integrity. These two benefits sum up to the superior advantage of immediate activation of the system without any delay.
HI-FOG systems are unique water mist systems, and their capabilities cannot be generalized to any other water mist system. HI-FOG systems, components and methods are also well protected by patents. The present patent portfolio contains over a thousand granted patents and patent applications worldwide.
HI-FOG is a registered trademark of Marioff Corporation Oy.
In Figure 1 a typical HI-FOG system for engine room fire protection is presented.
In Figure 2 synthesis between HI-GOG and traditional sprinkler performances is presented.

Reliability Analysis

The quantitative analysis of water mist systems requires knowledge of the reliability data associated with the failure modes for each component considered. A reliability study of water mist fire protection system conducted by FM Global [4]. Due to the relatively short use of commercial water mist fire protection systems, no specific reliability data were found during this study. Therefore, the reliability data from outside sources and other field applications were used by assuming that the failure data of the components in water mist systems components are equal to those of the same components when used in other applications.

The reliability of water mist systems is assessed by using FMEA and FTA techniques and compared with that of automatic sprinkler systems. The importance analysis has shown that problems with human error, control panels, cables, and fire detectors are the most significant contributors to the water mist system failure to perform adequately in a fire event.

Set up of CANDU-6 NPP fire zones where water mist systems might be employed

As presented in Ref.[1] in the following areas in CAND-6 NPP with fire hazard, it is assumed as necessary to develop a detailed analysis to substitute the

classical fire extinguishing systems (sprinkler, water spray) with high performant systems employing water mist:

- area below turbo-generated (about 1500m2surface; fire load is due to the lubricating oil and electric cables);
- cable spreading rooms in Service Building (about 800m2surface; fire load is due to electric cables), Electrical Bay (about 500m2surface and 800 m2; fire load is due to electric cables);
- Emergency and Stand-by Diesel generators areas (about 80m2 and 400m2 surface; fire load is due to Diesel fuel, the lubricating oil and electric cables);

3. Tables

Table 1

The properties of one liter of water

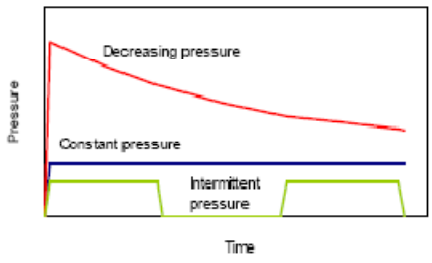
	Droplet size (mm)	Number of droplets	Surface area (m^2)
Conventional sprinklers	10	1.9×10^3	0.6
	1	1.9×10^6	6
HI-FOG®	0.1	1.9×10^9	60
	0.01	1.9×10^{12}	600
	0.1 x	1000 x	10 x

Water mist

Tabel 2

Water mist system types

FLUID AND PIPING	
Single fluid system	Discharge of plain water.
Twin fluid, twin pipe system	Discharge of water and gas. Water and atomising gas are separately supplied to separate nozzles or mixed at a common water mist nozzle.
Twin fluid, single pipe system	Discharge of water and gas. Water and atomising gas are separately supplied to and mixed in the common discharge pipework.
DROPLET SIZE	
Class 1	D_{v90} < 200 µm
Class 2	D_{v90} < 400 µm
Class 3	D_{v90} > 400 µm
WORKING PRESSURE (AT THE NOZZLE)	
Low pressure	< 12 bar
Intermediate pressure	12 … 35 bar
High pressure	> 35 bar
DISCHARGE PRESSURE CURVE	Examples of water mist discharge pressure curves
Constant pressure	
Decreasing pressure	
Intermittent pressure	



DRIVE UNIT	
Electric pump	External water and power supply
Diesel pump	External water supply
Gas-driven pump (HI-FOG only)	External water supply OR water tank included
Accumulator unit	Self-contained, gas operated system

4. Figures

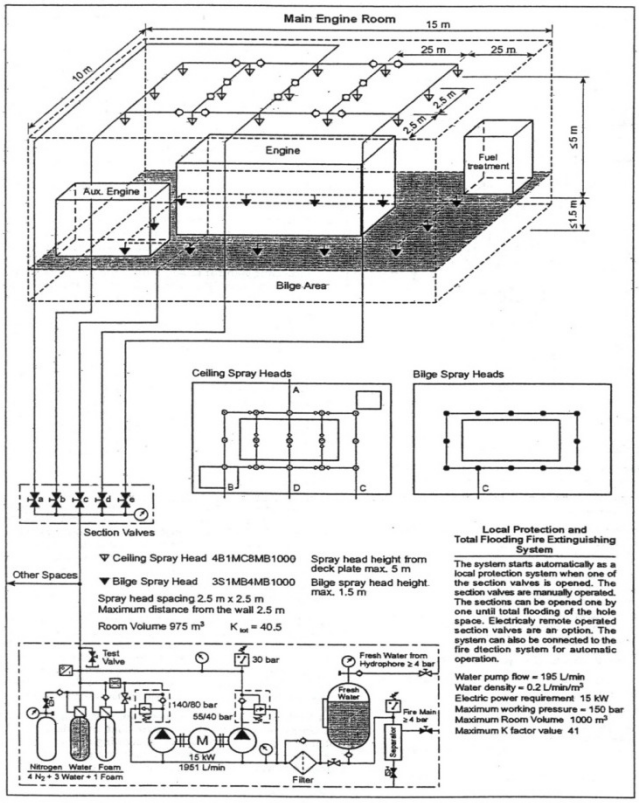


Fig. 1. Typical water mist plans. (Courtesy of Marioff)

	Traditional sprinkler	HI-FOG
Time required for action	Medium	Fast
Suppression of solid fire	Excellent	Excellent
- liquid fire	Low	Excellent
- floor fires	Excellent	Excellent
- wall fires	Medium	Excellent
- ceiling fires	Low	Excellent
- concealed fires	Low	Excellent
Prevention of toxic gas formation	Medium	Good
Cooling effect	Low	Excellent
Radiant heat blocking	No	Excellent
Smoke scrubbing	No	Good
Fire suppression capability	**Medium**	**Excellent**
Total fire damage	Medium	Low
Water damage to fire area	High	Low
Water damage to other areas	High	Low / No
Other damage	Black water	No
Short circuits	Yes	No
Total damage	**High**	**Low**
Aesthetics	Obtrusive	Small & hideable
Tank space requirement	High	Low
Lifetime costs	Medium	Low
VDS and FM approved	Yes	Yes
OVERALL SCORE	**Medium**	**Excellent**

Fig. 2. HI-FOG® vs. traditional sprinklers

5. Conclusions

The great advantages of the water mist fire suppression system compared with the classical fire suppression systems are:

- fast cooling-down of the flame;
- significantly lower water floors for fire suppression (about 30lpm in compare with 1000 lpm);
- redaction of water negative impact/effect on electrical and I & C equipment;
- smaller number of water sources for the system supply.

R E F E R E N C E S

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