AN ANALYTICAL APPROACH ON PROBABILITY OF SUCCESSFUL PERFORMANCE OF SPRINKLER SYSTEM

Won K. Kim. PE
Principal Consultant in *TÜV SÜD Korea*
29F, Two IFC, 10 Gukjegeumyung-ro, Yeongdeungpo-gu, Seoul, Korea, 07326
won-kook.kim@tuv-sud.kr

Though sprinkler system is installed as a main tool to mitigate the effect of fire occurring in the structure, it does not perform successfully all the time. Papers reviews show that the successful performance of sprinkler system ranges from 88% to 99%. Those numbers are analyzed both from statistics and fault tree analysis. And also found that the studies have limitation, as it was focused on the actuation of the system. Even if the system is actuated, if the water spray from sprinkler heads is not good enough to suppress the fire, fire will not be extinguished or controlled under its allowable size. Method of estimating the probabilities of actuation and suppression was studied to estimate the successful performance of sprinkler system in this paper. Correct estimation of probability of successful performance of sprinkler system is keen to fire risk assessment, as it is the most important mitigation tool in structural fire. Hope this paper would add accuracy in assessing a fire risk.

I. INTRODUCTION

Fire PRA in nuclear power plant requires probability of successful performance of sprinkler system. And in many cases the probability is taken from statistics which are framed under the condition that the sprinkler system operated in the event of fire. In reality many conditions must be met to suppress the fire after sprinkler system actuated. The conditions are fire size, fire growth, location of fire origin, size of the room, ceiling height, actuation time of sprinkler head, fire water spray density, obstacles of fire water spray and etc. And the probability of operation of sprinkler system heavily depends on the maintenance condition, too. Edward K. Bundnick[1] estimated the probability of operation of sprinkler system from 86.4% to 97.9% in his paper, “Automatic Sprinkler System”. He used Fault Tree Analysis method with limited statistical data, and the result of his analysis agrees with John R. Hall and William E. Koffel’s[2] NFPA statistical data analysis. This study shows that the probability of successful operation of sprinkler system has a quite wide range. And if we consider the probability of suppression in addition to operability, then the probability of successful performance of sprinkler system shall have even wider range. In this study the successful performance of sprinkler system was estimated based on its operation and suppression.

II. METHODOLOGY

To suppress or control the fire successfully the sprinkler system has to be operated first and the system must be capable of suppress or control fire. The procedure for estimating successful performance of sprinkler system is illustrated in the following flow chart.

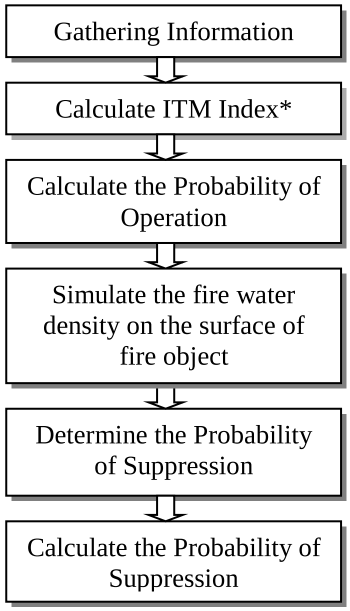

Fig. 1. Flow chart for estimating the successful performance of sprinkler system
Note *: ITM Index means Inspection, Testing & Maintenance Index

III. PROBAILITY OF OPERATION

The range of successful operation of sprinkler system is suggested as 88%~98% by combining the result of analytical research and statistical research of the sprinkler operability. The probability of operation is based on the ITM Index. ITM Index is calculated by checking activities of inspection, testing and maintenance. The following table shows the items of activities and their weight factor.

TABLE 1. ITM Index

Category	Frequency	Items		ITM Index
Inspection (54)	Daily	Temperature of valve room		1
	Weekly	Monitoring of control valve		1
		Fire water supply line valve		1
		PIV		1
		Spare sprinkler heads		1
		Air pressure		1
	Monthly	Monitoring of control valve		1
		Fire water supply line valve		1
		PIV		1
		Spare sprinkler heads		1
		Alarm		1
		Water pressure gage		1
		Alarm valve		1
		Pressure plate on sprinkler riser		1
		Valves		1
		Air pressure		1
	Quarterly	Pressure plate on sprinkler riser		1
		Alarm system		1
		Fire Department Connection	Fire truck approach	1
			Integrity of connection	1
			Cap	1
			Gasket	1
			Sign plate	1
			Check valve	1
			Drain valve	1
	Semiannually	Sprinkler head	Corrosion	1
			Spray obstruction	1
			Painted	1
			Damage	1
		Installation direction (upright, pendent, wall)		1
		Pipeline	Installation condition	1
			Physical damage	1
			Leaking	1
			Corrosion	1
			Deforming	1
			Outside load	1
		Hangers & braces	Installation condition	1
			Physical damage	1
			Corrosion	1
		Icing for wet sprinkler system		1
		Spare sprinkler heads		1
	5 years	Alarm valve inspection		1
		Check valve inspection		1
		Pipe plugging	Filter in pump suction side	1
			Foreign materials during flow test	1
			Sprinkler head plugging	1
			Aboveground pipe plugging	1
			Underground pipe plugging	1

			Repair work for pipe rupture	1
			Increment of valve malfunction	1
			No supply of fire water more than one year	1
			Sodium silicate in pipe	1
			Foreign material during pipe repair work	1
			Change of fire water color during water flow test	1
Test	Quarterly	Flow test at main drain test		2
		Flow alarm test		2
		Low air pressure alarm test		2
		Priming water level test		2
	Semiannually	Fire detector test		2
	Annually	Fire water specific gravity test for anti-freezing agent		2
		Pre-action system test		2
		Pre-action valve test		2
		Air compressor test		2
		Valve room low temperature alarm test		2
		Control valve test		2
	5 years	Sprinkler head test		2
		Gage calibration		1
		Pipe cleaning		1
	20 years	Fast response sprinkler head test		2
	50 years	Sprinkler head test		2
	75 years	Sprinkler head test		2
Maintenance	Monthly	Protection from spray coating		2
	Quarterly	PIV & OS&Y valve test		2
	Annually	Lubricating valves & stems		1
		Cleaning strainer		2
		Open drain valve for dry type sprinkler		1
Records	Record all the ITM activities			2
	Tag all the control valves			2
	Tag alarm valves, dry pipe valves, pre-action valves and deluge valves			2
Total				100

The probability of operation shall be calculated by the following table.

TABLE 2. Estimation of operation of sprinkler system

Range of Operation (%)		ITM Index			Estimated operation (%)
88 - 98	X	Very high	91<	=	>98 (98)*
		High	81 ~ 90		95~97 (96)*
		Normal	71 ~ 80		92~94 (93)*
		Low	61 ~ 70		89~91 (90)*
		Very low	<60		<88 (88)*

(xx)* presents the mean value

IV. ESTIMATION OF SUPPRESSION

Sprinkler system uses water to suppress the fire. Thus, the fire water spray density on the surface of fire origin is the most important factor contributing to suppression of fire. And the water spray density on the surface of fire origin shall be affected by the water delivery from the sprinkler head, response time index of sprinkler head, water droplet size, fire size, room configuration, height of fire origin, and obstruction under sprinkler heads. The fire water density on the surface of fire object can be simulated by FDS[3].

Spray densities of fire water for each different classification of fire load are shown in the following table.

TABLE 3. Spray density for each fire hazard occupancy from NFPA 13.

Fire Hazard Classification	Description of Classification	Spray Density (gpm/ft^2)
Light Hazard	Low fire load & low heat release rate; office	0.1
Ordinary Hazard (Group 1)	Low fire load & normal heat release rate. Height of combustibles is lower than 2.4m; parking garage, electronic products manufacturing plants, restaurant (excluding kitchen), laundry shop	0.15
Ordinary hazard (Group 2)	Normal fire load and heat release rate. The height of combustibles is between 2.4m and 3.66m; chemical plant, shops, mechanical maintenance shop	0.20
Extra Hazard (Group 1)	High fire load and heat release rate. Small amount of inflammable liquid; airplane hangar, hydraulic oil, plywood manufacturing plant	0.30
Extra Hazard (Group 2)	Considerable amount of inflammable or combustible liquid; process using asphalt, spraying inflammable liquid, coating	0.40

When the simulated density on the surface of fire origin meets or exceed the required density, the probability of successful suppression would be 1. And the probability of suppression would be lowered, if the simulated density is lower than required density. In this paper the different rage of probability is suggested in the following table.

TABLE 4. Probability of successful suppression of fire for varied design density

Designed Density	Light Hazard	Ordinary G1	Ordinary G2	Extra G1	ExtraGroup2
	0.1 [gpm/ft^2]	0.15 [gpm/ft^2]	0.2 [gpm/ft^2]	0.3 [gpm/ft^2]	0.4 [gpm/ft^2]
≥100%	1.0	1.0	1.0	1.0	1.0
91%≤D<100%	0.9	0.9	0.9	0.9	0.9
81%≤D≤90%	0.8	0.8	0.8	0.8	0.8
<80%	0	0	0	0	0

Note: The probabilities of successful suppression in grey area are arbitrary numbers and they shall be decided through the actual fire test

Real probability of successful suppression of the sprinkler system can be decided by real fire test. In the Table 4, probability of 0.9 and 0.8 are suggested as an example. Unless the probabilities of successful suppression of the system under design density can be found by the test, only the probability 1 and 0 shall be used.

V. Calculation of Probability of Successful Performance of Sprinkler System

The probability of successful performance of sprinkler system can be estimated by multiplying probability of operation by probability of successful suppression of sprinkler system.

$$P(P) = P(O) \times P(S) \qquad (1)$$

Where, P(P), probability of successful performance of sprinkler system, can be determined from Table 1 & 2
P(O), probability of operation of sprinkler system, can be determined from Table 4
P(S) is probability of successful suppression of sprinkler system

For example, if the IMT index is 90 for some sprinkler system, then the expected probability of operation of sprinkler system shall be come 0.97 from the Table 2. And if the simulated fire water spray density meets the required design density, then the probability of successful suppression shall be "1". Spray density on the surface of fire object can be obtained from simulator, FDS[3]. The probability of successful performance of sprinkler system shall be "0.97" from (1).

P(P) = 0.97 x 1 = 0.97

TABLE 5. Probability calculation example 1

	Factors	Design Requirement	Result
Operability	IMT Index		90 points
	Probability of Operation		0.97
Suppressibility	Fire Load Classification	Extra Hazard Gr. 1	Extra Hazard Gr. 1
	Design Density	12.2 lpm/m^2	12.2 lpm/m^2
	Minimum Area	232.2 m^2	240 m^2
	Simulated spray density on the surface of fire object	12.2* lpm/m^2	12.5 lpm/m^2
	Probability of Suppression		1
Probability of Performance	P(P) = 0.97 x 1		0.97

Note: * is a given number

When the simulated fire water spray density does not meet the required design density of the current fire load, then the P(S) shall be "0". Then the probability of successful performance of sprinkler system shall be "0" from eq.1.

P(P) = 0.97 x 0 = 0

TABLE 6. Probability calculation example 2

	Factors	Design Requirement	Result
Operability	IMT Index		90 points
	Probability of Operation		0.97
Suppressibility	Fire Load Classification	Extra Hazard Gr. 1	Extra Hazard Gr. 1
	Design Density	12.2* lpm/m^2	12.2 lpm/m^2
	Minimum Area	232.2 m^2	240 m^2

	Simulated spray density on the surface of fire object	12.2 lpm/m^2	10.7 lpm/m^2
	Probability of Suppression		0
Probability of Performance	P(P) = 0.97 x 0		0

Note; * is a given number

VI. Conclusion

Probability of successful performance of sprinkler system can be estimated by considering operability and suppressibility. Operability can be estimated by IMT Index which reflects the performance of inspection, maintenance and testing. Suppressibility can be determined by estimating the spray density on the surface of fire object with FDS. Then, the probability of successful performance of sprinkler system can be obtained by multiplying probability of operation by probability of successful suppression of sprinkler system. Testing with different ratio of spray density on the surface of fire object shall verify the probability of successful suppressibility. In conclusion it is possible to estimate the probability of sprinkler system by reviewing its design factor and considering its maintenance activities.

REFERENCES

1. Edward K. Budnick, “Automatic Sprinkler System Reliability”, Fire Protection Engineering, Society of Fire Protection Engineers, Winter 2001
2. William E. Koffel, Reliability of Automatic Sprinkler Systems, Revised, 2005
3. Fire Dynamics Simulator (FDS) is a computational fluid dynamics (CFD) model of fire-driven fluid flow developed by NIST. The software solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow, with an emphasis on smoke and heat transport from fires.