Aspects of Clean Agent Fire Extinguishing System Reliability

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Halon 1301 systems have been utilized to protect very high value assets or functions in the past. These systems were installed at relatively large expense and were often additional fire protection over and above the requirements of building or fire codes. Now, Halon 1301 use in new applications has been greatly reduced and may come under regulatory control in the near future. **As** a consequence, a number of clean fire extinguishing agents have been introduced and commercialized as replacements for Halon 1301.

The primary measure of success of a clean agent system is fire extinguishment. To insure fire extinguishment, the concentration developed in the protected enclosure at the seat of the fire, the local delivered concentration, must exceed the extinguishing concentration for the particular fuel and fire hazard protected.

The reliability of Halon 1301 systems was established over two decades of use. A significant reason for the reliability of Halon 1301 systems was the use of design concentrations that were from 50% to 100% greater then the extinguishing concentration for the hazard being protected. This large safety factor for Halon 1301 systems helped to insure that enough agent was actually delivered from the installed system to extinguish a fire.

The current design practice allows for design concentrations that are as small as **120%** greater then the extinguishing concentration, a 20% safety factor. This is a significant reduction in the safety factor that has been generally employed for Halon 1301 systems. There has not been a corresponding specific effort to improve the reliability of systems utilizing the new agents, although general system design and installation has improved.

Therefore, the question is will the local delivered concentration, at the seat of the fire, actually be high enough to extinguish the fire when using a 20% safety factor. The issues can be broken down into the establishment of the extinguishing concentration and design concentration, the actual average concentration delivered to the enclosure, and the local concentration in the enclosure at the fire.

This paper will only consider systems that are designed, installed, and maintained per current codes, standards, listings, and approvals. It is recognized that a greater proportion of system failures will occur for systems outside of this realm. Examples of these include: lack of enclosure integrity, failure of a cylinder valve to operate, plugging of a nozzle orifice or an obstruction of system piping, and improper installation.

Determination of the Extinguishing Concentration and the Minimum Design Concentration

The minimum design concentration for an agent is determined by demonstrating the extinguishing concentration through testing for the fuel involved and adding a 20% safety factor. An extinguishing concentration of 8.0% would result in a minimum design concentration of 9.6%. For Class B fuels and gases, the flame extinguishing concentration is determined with a cup burner laboratory apparatus. For Class A fuels, the extinguishing concentration is determined by test, as part of a listing program. Both of these methods are described in NFPA 2001.[1]

For Class B fuels and a given agent, variation exists in the reported values for cup burner extinguishing concentrations. NFPA 2001 reports cup burner values from up to seven laboratories. The variation in cup burner values for an agent can range from 5.0% to 5.9% for a single fuel (FC-3-1-10 and heptane) to 12.0% to 12.7% (HFC-23 and heptane). The variation for Halon 1301 is also reported and ranges from 2.9% to 3.9%. This degree of variation is typical of all the reported values for agent/fuel combinations.

The cup burner apparatus, and the procedure for operating it, have not been standardized. The differences in reported values are most likely due to differences in apparatus, differences in technique, and some natural variation in the experimentally determined numbers.

For hazards that require inertion, where conditions for subsequent reflash or explosion exist, the inertion concentration must be determined by test. For inertion, only a 10% safety factor is used.

For Class A fuels, the extinguishing concentration is determined by a full-scale wood crib fire test. The concentration selected for this test is generally a cup burner concentration for heptane. (A heptane concentration is selected to simplify other test requirements in UL 1058.[2]) The extinguishing concentration data are for a single Class A material, in a single configuration, and is extrapolated to other Class A materials and configurations.

However, other fire testing has found that the heptane cup burner concentration is generally greater then the concentration required for extinguishing Class A materials.[3] Use of the heptane cup burner concentration would therefore be conservative, providing a greater then 20%, but undetermined, safety factor.

The protection of hazards that are not powered down when the system is discharged require further evaluation of the design concentration. The presence of an electrical current can supply an energy source that will continue to volatilize fuel and lower the required energy feedback from a flame to sustain combustion. These hazards require higher concentrations of agent. Some test data have been made available by Niemann.[4]

The determination of the extinguishing concentration for a given fuel and a given fire hazard has some variability and uncertainty. However, for a given fuel, a single concentration is selected and used as the basis for setting the minimum design concentration. The minimum design concentration is set as 120% of the extinguishing concentration (20% safety factor) or 110% of the inerting concentration (10% safety factor). The actual safety factor may be different.

Average Enclosure Concentration

The actual quantity of agent delivered into an enclosure and the concentration developed can vary from the design for a number of reasons. Some of these reasons have been discussed in a recent paper:'

1) Some agent vapor is left in the cylinder and piping after the discharge is complete, possibly 2% of the initial charge.
2) The agent that is delivered to the enclosure may be diluted by a slug of nitrogen coming from the cylinder (only for agents using nitrogen gas for super-pressurization), possibly 1% of the design concentration.
3) The system is allowed to leak up to **5%** of the agent from the cylinders before being required to be refilled.

The concentration may also tend towards higher values then the design concentration. The reasons for this include the equation for determining the agent mass required from the design concentration **is** conservative and does not account for non-fixed material that occupies space in the enclosure.

The actual effect on the delivered concentration of the factors listed above is dependent on the particular system. While these effects are not individually large, they could become significant if they are additive for some particular system.

Two other issues have been identified that may affect the delivered concentration: repeated tee splits and pipe variability. When using flow calculation software, there is uncertainty in the calculation of how the agent splits at a tee. The software may predict that 30 pounds goes out one branch of the tee and 70 pounds goes out the other branch, when the actual measured split is 29 pounds and 71 pounds. This uncertainty can compound the more times the agent flows through tee splits. The result could be that the quantity of agent from a nozzle at the end of a run of pipe that includes many tee splits would be poorly predicted. If this nozzle was in an separate enclosure, the delivered concentration could be significantly lower, or higher, than expected.

The variability in pipe internal diameter could also result in unexpected flow behavior. Recent testing with 3/8 inch diameter Schedule 40 pipe was generating unpredictable results. The pipe was cut apart and the internal diameter measured. The measurement showed an average internal diameter of 0.474 inches compared to the nominal internal diameter 0.493 inches, a reduction of **8%** in the flow area. **A** pipe manufacturer has indicated this amount of variability in internal diameter is not unusual. This uncertainty in the actual pipe diameter for an installed system could result in unexpected splits of the agent at a tee. The effect of variability in pipe internal diameter becomes less important for larger pipe sizes.

Local Enclosure Concentration

The concentration developed in the enclosure is not necessarily completely uniform. Local areas of higher or lower concentration can form depending on the configuration of the enclosure, obstructions in the enclosure, nozzle locations, enclosure temperature, nozzle pressures, etc. The local concentration in the vicinity of the fire, not the gross or average enclosure concentration, must be greater then the extinguishing concentration for fire extinguishment.

The ability of an agent to satisfactorily disperse, vaporize, and mix in an enclosure is also dependent on the nozzle design. UL requires a test of a nozzle's maximum allowable area coverage and another test of a nozzle's maximum allowable height. These tests require the construction of an enclosure, at the maximum area or height, and the extinguishment of heptane "tell-tale" fires (small cans of heptane placed strategically throughout the enclosure). These tests are pessimised by running at the heptane cup burner concentration (not the heptane minimum design concentration) and at the maximum discharge time (10 seconds). The average nozzle pressure recorded in this test becomes the minimum allowable nozzle pressure, for this particular nozzle design, that can be used in system design.

The actual average node pressure during the discharge of an installed system can vary depending on the cylinder storage pressure. For nitrogen pressurized systems, the cylinder can lose up to 10% of the specified storage pressure before being required to be serviced. The effect of this loss of storage pressure on average nozzle pressure is system dependent. The effect of average nozzle pressure being **less** than the minimum, from **loss** of storage pressure or other reasons, on the local delivered concentration is also system and hazard dependent, but is not expected to be large for the majority of systems.

Implications for System Design

As discussed above, the actual extinguishing concentration may vary from the value used to establish the design concentration. For discussion purposes let's suppose, for a particular fuel in a particular hazard, this variability can be represented by a curve; see Figure 1. For concentrations **less** then **"A,"** the fire will not be extinguished; for concentrations greater then "B," the fire will always be extinguished. For concentrations between "A" and "B," there is a probability that the fire will be extinguished as shown on the curve. The selection of the extinguishment concentration from the available test data will be greater then "A," but not necessarily greater then "B." **An** example of an extinguishing concentration as established by ***test*** is shown in the figure.

The minimum design concentration is set as 120% of the extinguishing concentration. The average enclosure concentration and the local delivered concentration can vary, as discussed in this paper. Suppose that the probability for the local delivered concentration can be represented by a bell curve; see Figure 2.

The two probability curves could be plotted together, as in Figure 3. Overlap between the two probability curves would represent potential failures of the system to extinguish the fire. If the local delivered concentration is less then the actual extinguishment concentration the fire would not be extinguished. As plotted, this would require both the local delivered concentration and the actual extinguishment concentration to be on the low probability "tails" of the curves.

The overlap area, if it even exists, in Figure 3 can be reduced in several ways. First, the concentration established as the extinguishing concentration can be assured to be conservative, tending towards, or past, the point "B" in Figure 1. Second, the "distance" between the extinguishing concentration and the minimum design concentration, the safety factor, in Figure 3 could be greater. And third, the variability of the local delivered concentration could be reduced.

The systems that have been identified that may have large variations in the local delivered concentration are those that have repeated tee splits and those employing small pipe diameters. These effects have not been quantified well enough to establish probability curves like the one shown in Figure 2. If these types of systems have significant overlap of the probability curves that could result in fires not being extinguished, then changes in the design procedure are recommended.

A possible change that could be considered is an increase in the safety factor. The safety factor may not need to be increased for all system designs, but only for those that are believed to have unacceptable likelihood of failure. The increase in the safety factor could be implemented on a system-by-system basis by raising the design concentration higher then the current minimum. The amount to increase the safety factor should be evaluated on both a technical basis and a cost/benefit basis.

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[1] National Fire Protection Association. "NFPA 2001 Standard on Clean Agent Fire Extinguishing Systems," 1996 Edition.

[2] Underwriters Laboratories Inc., "UL 1058 Halogenated Agent Extinguishing System Units," Third Edition. Underwriters Laboratories Inc., Northbrook, IL.

[3] P. J. DiNenno, "Development of an Alternative Class A Fire Test Procedure for Clean Total Flooding Gases," presented at the International Conference on Ozone Protection Technologies, Washington, DC, October 1996.

[4] R. Niemann, "Evaluation of Selected NFPA 2001 Agents for Suppressing Class "C" Energized Fires," Halon Options Technical Working Conference, New Mexico Engineering Research Institute, Albuquerque, NM, May 1996.

[5] C. Hanauska, "Considerations for Achieving Extinguishing Concentrations," Halon Options Technical Working Conference. New Mexico Engineering Research Institute, Albuquerque, NM, May 1996.

Figure 1. Probability of a fire not being extingushed.

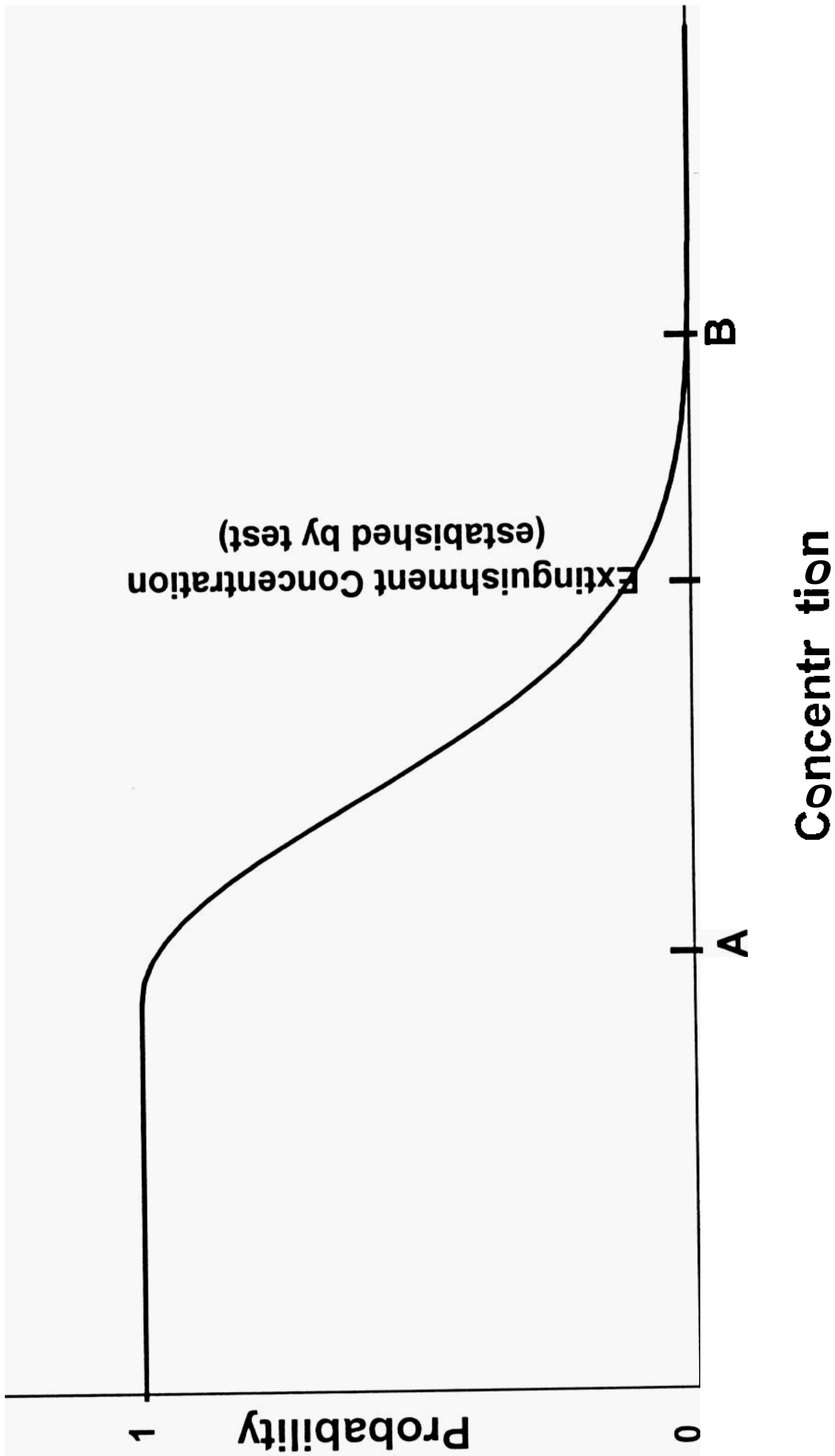
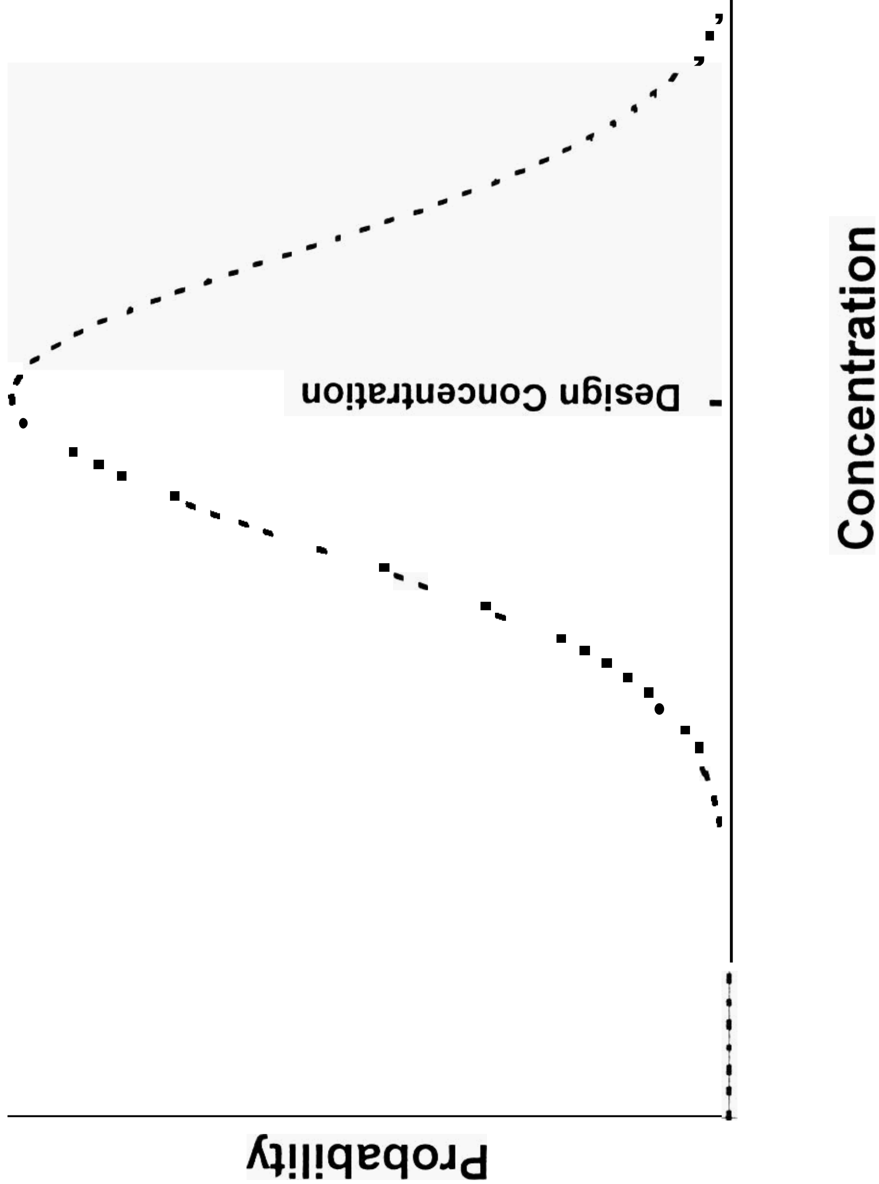


Figure 2. Probability distribution for local delivered concentration.



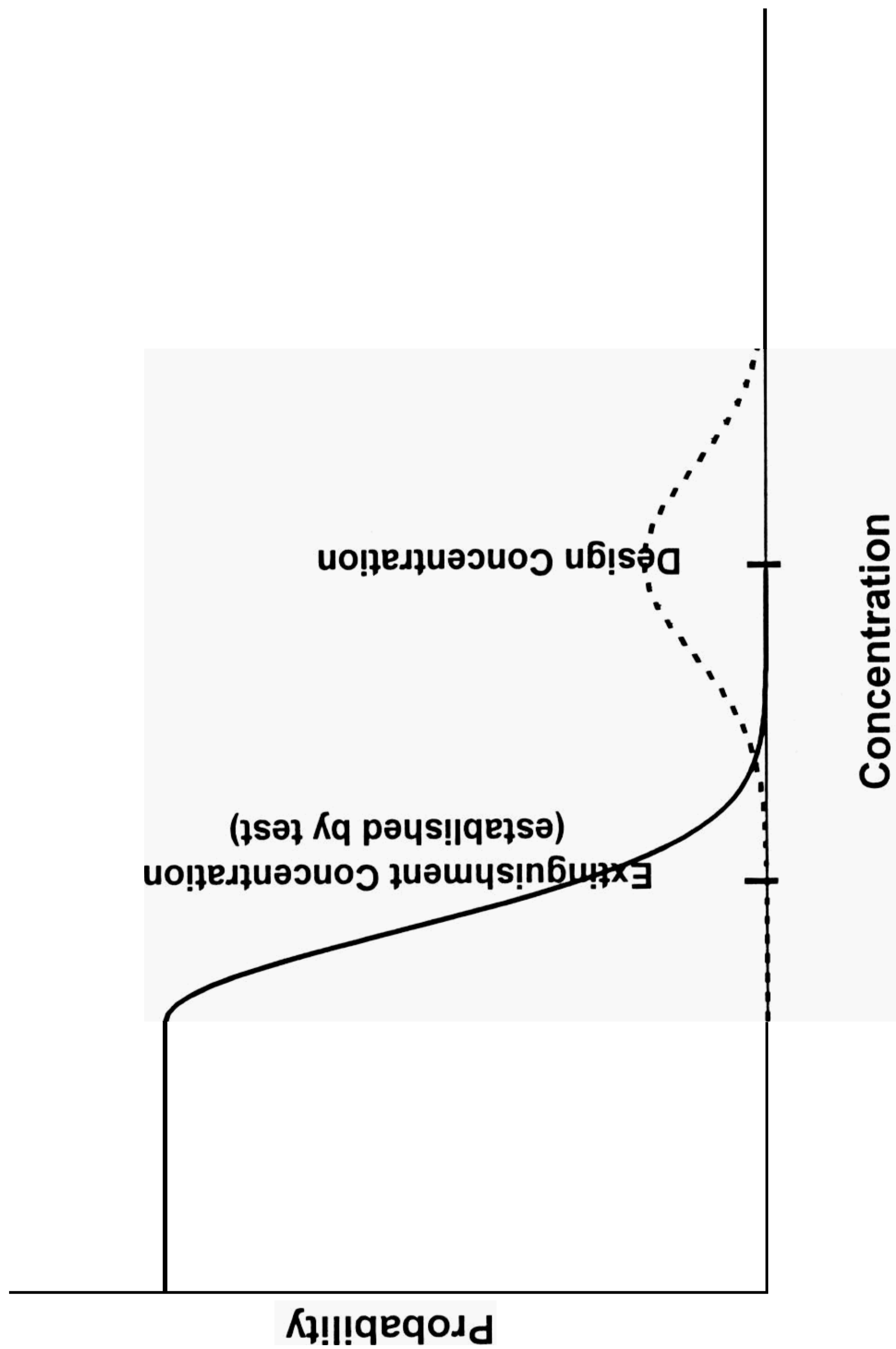


Figure 3. Potential for system failure.