PACKAGED, SELF-CONTAINED, FIRE SUPPRESSION
SYSTEM FOR USE IN REMOTE AREAS WHERE A
NORMAL WATER SUPPLY IS NOT AVAILABLE
FOR STRUCTURAL FIRE FIGHTING

SERIAL NO. 15974

MAY 14, 1965

CONTRACT NO. NBy-32287

U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

FACTORY MUTUAL RESEARCH CORPORATION

LABORATORY REPORT

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1151 BOSTON-PROVIDENCE TURNPIKE, NORWOOD, MASS. 02062

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Abstract

Five packaged, self-contained fire suppression systems were devised after a comprehensive review of pertinent material. Eighty-one references are attached. The two most promising concepts, as recommended by FMRC and approved by the Navy, are a multi-cycle, total flooding system using Bromotrifluoromethane and an automated sprinkler system using water.

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I INTRODUCTION

A. The Problem. The basic problem is that of providing optimum fire protection for buildings, to safeguard both shelter and supplies.

B. The Objective. The objective as stated in the contract is "to obtain engineering data on packaged, self contained fire sprinkler systems for use at any location on a global basis where a normal water supply is not available for structural fire fighting."

C. Definitions. Our working definitions of the individual components of the statement of objective follow:

"Obtain" - To secure information through a search of existing data and literature and by conversation with knowledgeable persons.

"Engineering Data" - Any information concerning the equipment or application anticipated which is necessary to evaluate systems.

"Packaged, Self Contained" - All components necessary to fire suppression are supplied as part of the system, except that in some cases, water may be obtained locally or transported separately.

"Fire Sprinkler System" - Any device or collection of devices and materials whose end purpose is the suppression of fire.

D. The Mission. The mission assigned was to:

1. Acquire information on the conditions under which the equipment will be used and the performance required.

2. Survey the literature pertinent to existing systems and review the patent status of likely ideas.

3. Choose or develop at least three applicable system concepts. A concept is a system differing from others in any one or more of the following areas: suppressant, arrangement, method of actuation, cycles of operation, other major functional areas - such as power supply. The concepts chosen must be reducible to hardware.

4. Evaluate on the basis of initial cost, maintenance cost, effectiveness and reliability, the three to five most promising concepts and rank these in order of promise.

5. Prepare drawings and specifications for prototype modules of the two most promising systems as approved by the Government.

E. Design Criteria

1. The Building

a. Types - Construction

Emphasis is placed on lightweight buildings of the prefabricated type for use at advanced bases or temporary locations. Specific data such as leakage and infiltration rates must be determined when needed for each type of construction. The building types outlined in the contract are (1) steel siding and roof (Butler Type), (2) wood panel walls and composition roof, (3) metal clad panel walls and roof.

b. Size - Geometry

The lateral dimensions of the building are specified as ranging from 20 ft x 48 ft to 40 ft x 100 ft and the height from a minimum of 8 ft to a maximum of 20 ft.

c. Cost

The erected cost of a building is estimated as a minimum of about $15 per square foot including a minimum of fixtures and equipment. To allow for the presence of operational equipment and supplies a total of $30 per square foot will be used for comparison purposes.

2. Occupancy - Fire Potential

The buildings under consideration will be used for sleeping, messing, operational activities and the storage and maintenance of equipment and supplies. Combustible storage will consist primarily of cellulosic materials stored to a maximum height of 12 ft. It is to be expected that some measures can be taken to control the arrangement of storage to minimize the fire hazard involved. Only small quantities (5-10 gallons) of flammable liquids are expected inside buildings. Where greater quantities occur, modification of the basic protection system may be necessary.

3. Environmental Conditions & Related Problems

a. General

The contract requires that the basic or modified systems be suitable for use at any location on a global basis.

The temperature range specified is -65°F to 140°F.

When a single universal, all climate system is impractical it is considered satisfactory to provide one, two or more systems modified to fit a group of environments.

The suppressant must be non-toxic.

b. Tropic

Temperatures are expected to range up to 140°F and in all cases will be above the freezing point of water.

High humidity will make necessary special precautions to combat fungus, rot and corrosion.

c. Arctic

The temperature will be above 50°F for less than 2 months per year and can reach a minimum of -65°F. Buildings will in most cases be heated during occupancy. A few may be unheated for part or all of the year. Storage tanks, batteries, etc. can be buried under five feet of snow to keep the temperature to a minimum of -10°F.

The humidity in arctic locations is expected to be quite low, therefore, external corrosion will be minimized. The behavior of fires in cellulosic materials would be influenced to a presently undetermined degree by extremely low humidity.

A layer of permafrost of indeterminate depth with an active layer of about one foot can be expected. In the winter snowfall will total four to five feet.

4. <u>Size - Weight Limitations</u>

For shipping, the cube dimension is more important than weight. For air lifting, consideration must be given to the cargo dimensions. A typical cargo space of 8 ft x 8 ft x 40 ft with a capacity of 20-30,000 lbs. does not place a serious restriction on size. Shipment by sea imposes even less of a restriction. Transport over land can be accomplished by means of trailers or sleds capable of carrying up to 110 tons. There are no systems being considered at the present time which would be difficult or impossible to ship or transport. Minimum size and weight will, of course, facilitate transportation and installation and generally result in decreasing total cost. Size and weight are therefore considered as important criteria having flexible limits.

One of the most important reasons for minimizing size and weight is to overcome priority restrictions on the shipment of materials to advanced bases, particularly in a wartime situation. It is highly desirable to reduce the lag time between erection of a building and installation of its protective equipment.

5. Limitations Due to Lack of Power

In line with the concept of a self contained system, provision of an independent power supply will be considered as a necessity even though base power may in many cases be available for auxiliary use.

6. Maintenance Limitations

Maintenance personnel trained in installation and maintenance of specialized equipment may not always be available. The equipment should therefore be as simple to install, maintain and replace as possible. This would include plug-in, number coded connections for wiring, slip-on pipe connectors and easily replaceable, plug-in, sub modules. Since this work may of necessity be done under adverse conditions the operations should be simple and easily accomplished with a minimum number of tools. Most locations will be either continuously occupied or visited at intervals of not more than one month. Special analyses will have to be made where buildings are unattended for longer periods.

7. Cost of Protection

An acceptable cost for fire protection is considered to be about 10% of the total value of a building and its contents. For a 20 ft x 20 ft module this would amount to an acceptable protection cost of $3 per square foot or $1200. Where more expensive equipment is present or where remoteness warrants greater effectiveness or reliability, a greater expense may be justified. This total cost will consist of equipment cost, transportation and installation.

8. Effectiveness

To achieve maximum effectiveness the fire must be detected at its inception and an optimum quantity of the most efficient suppressant delivered instantaneously and only on the fire. There should be no resultant fire or agent damage of any kind. The fire would be instantaneously extinguished and the agent flow would be shut off automatically. There are practical problems in achieving this type of effectiveness, therefore the following somewhat more realistic performance standard is proposed.

a. Detection (initial and any subsequent) and agent delivery must be rapid enough to prevent damage to the structure and its protective equipment.

b. The fire should not spread outside the bounds of the volume which it occupied at the time suppression was begun.

c. The system should deliver the minimum quantity of agent necessary at the optimum rate and in the optimum manner and then should shut down automatically to prevent waste of agent.

d. The system should recycle promptly if the fire regenerates to the size which initially actuated the system. This would mean that the operating characteristics of the components should not change after exposure to the maximum permissible fire or suppressant discharge (or conversely the fire should be suppressed before the detectors, etc. are affected).

e. The system should be capable of a minimum of two effective cycles of extinguishment. Where value, remoteness or degree of hazard warrants additional cycles should be provided, the number being based on an engineering review of the specific situation.

f. Efficiency will be measured by the time required for extinguishment, quantity of suppressant used and total damage caused by the event. Statements regarding absolute or comparitive effectiveness must be substantiated during a test program.

3. Reliability

a. Where other criteria do not prevail, redundancy of functions and critical components should be provided. Where redundant components are to be provided, functionally equivalent devices from two or more separate manufacturers could be used to further randomize the probability of failure from basic design or manufacturing features.

b. The system should be capable of recycling and suppressing two or more separate fire incidents.

c. The operating condition of the system should be easily discernible at all times.

d. The equipment should not be subject to malfunction due to normal cycling, shock, vibration, corrosion, humidity, temperature or normal variations in the quality of either the actuating media or suppressant for a minimum of ten years. The equipment should be capable of operation after long periods of quiescence as well as frequent operation at short intervals.

II LITERATURE REVIEW

A. SEARCH AREAS -

A literature search was conducted to investigate the areas cited in Paragraph II of the proposal supplement dated Oct. 20, 1964. The attached bibliography summarizes the results of this search.

The following areas and sources were utilized:

1. FMRC Technical Information Files -

a. Chemical Abstracts Covering the years 1954 to 1960.

b. Fire Research Abstracts and Reviews (1958-1964). Several complete articles were obtained and reviewed.

c. Fire Research (1947-1962).

d. National Fire Codes. Ten Volumes in the 1964-65 series were studied with special attention given to alarms and special extinguishing systems.

e. ASME Technical Papers.

2. Defense Documentation Center, Bedford, Mass. -

Channels were opened with the DDC after submitting a Field of Interest Register, Form 20. Personnel at the Center organized a list of some four hundred related documents for our review. Thirty of these documents were photographed and used later for reference purposes. The documents were obtained using the following descriptors; sprinklers, spray nozzles, conical nozzles, fire alarm systems, temperature warning systems and fire extinguishers.

3. U. S. Patent Office -

A state-of-the-art search regarding packaged, self-contained fire suppression systems was conducted by our attorneys in Washington. The final report consisted of seventy-five patents which are considered to be a representative sampling of prior patent disclosures. These patents were cited under the following group headings:

Receptacle Type -

a. Frangible Receptacle

b. Receptacle Inverted or Moved

c. Follower Type

d. Fused Sprinkler head or opening

e. Fluid Pressure Developing Expelling Means

f. Striker or Container Rupturing Means

Systems -

a. Gas Extinguishant

b. Gas Pressure Discharge of Non-Gaseous Extinguishant

c. Chemical Pressure Generating Automatic

d. Automatic Chemical Pressure Generating-Pressure Controlled

e. Foam

f. Special Application

No information was received which seriously altered the five existing system concepts.

4. NCEL Library, Port Hueneme, Calif. -

A number of Technical Reports and Technical Notes were studied during our visit at Port Hueneme January 18-22, 1965. Several of these publications are listed in the bibliography.

B. RELATED SYSTEMS

1. A fire sprinkler control system (C-2) was of particular interest because of its ability to restore protection after a fire has been extinguished. Water flows in the system for a predetermined period after the fire out signal has been received to insure against re-ignition. The multi-cycle operation is accomplished by means of time delay relays, solenoid valves, thermostats and a restricted orifice.

2. A new vapor-securing foam (C-1) has been developed by the U.S. Naval Research Laboratory, Wash. D.C. Although this agent is primarily intended for the extinguishment of burning, low-flashpoint, flammable fuels of the gasoline type, it did indicate possibilities for other applications. System #3 is indirectly based on this concept.

3. Mr. J. C. King of NCEL has developed a self-contained sprinkler system designed to prevent fires caused by thermal radiation (C-6). It features a self-activating deactivating operation using a photoelectric flame detector. Water additives are fed into the line to increase the extinguishing ability of water.

4. Reference (C-5) describes in detail a packaged fire sprinkler system developed to protect 20 ft x 48 ft advanced base buildings. It has a 370 gallon storage tank connected to a twelve head loop. The distribution

system is normally dry. In the event of a fire the supervisory pressure maintained in the loop escapes allowing water to flow through the system. The design criteria are based on a five minute operating time in which large fires are to be held in check until fire fighters can arrive.

In our opinion, the main disadvantage of such a system is its inherent slow detection and operation. Valuable time is lost while the fusible links melt, air escapes from the loop and pressure builds in the tank to a level sufficiently high to rupture a flangible disc. Larger fires can therefore be expected to develop reducing the chance of total extinguishment.

5. Packaged, limited supply water spray systems are also commercially available (Ref. C-7 is a typical system) and offer protection for short periods of time. The major components are: Spray Nozzles, Supply Tanks, Pressure Regulators, Fire Detectors and Nitrogen Cylinders. In general, these systems operate on the deluge principle i.e. all nozzles discharge when a fire is detected. The estimated cost for protecting the average 20 ft x 20 ft x 10 ft high modules and 40 ft x 100 ft x 20 ft high Butler Building is $2000 and $6500, respectively.

C SUPPRESSANTS

Water -

The most commonly used suppressant for the extinguishment of burning Class A combustibles is water. Extinguishment is accomplished through cooling and the reduction of the oxygen concentration due to the generation of steam. When water at ordinary temperatures strikes burning wood it will not boil instantaneously, consequently initial wetting usually occurs (A-2). In general, the ratio of the amount of water to the amount of wood necessary for extinguishment can be taken as 1/7 by volume. Theoretically this ratio can be improved to the 1/150 range. Since the self-contained suppression system is to have a limited supply of agent, it is desirable to use this agent in the most efficient manner.

The fire-fighting characteristics of water have been improved with the use of additives (See Reference A-22). This report consideres two phases of improvement, the increase of viscosity and the reduction of radiant energy transmission. Small scale and large scale laboratory fire tests as well as field fire tests were conducted to yield the following conclusions:

Small Scale Tests

All viscosity additives tended to improve fire-fighting properties of H_2O by decreasing the runoff. Opacifiers in combination with viscosity additives improve properties further. However, the majority of the improvement is attributed to the viscosity additives. The overall results indicate optimum viscosity to be about 10 cp.

Large Scale Fires

Almost all viscosity additives improved fire-fighting properties. The more effective additives were: DOW ET-460-4, DOW ET-570 and CMC. Improvements obtained were in the order of 50% to 75% at a viscosity of 5.5 cp. The optimum viscosity was not determined. It was also found that fires extinguished with viscosity additives seldom reignited, where almost all reignited when plain water was used.

Field Fire Tests

DOW ET-570 was found to be the most effective additive because of its low shear sensitivity, thus possessing the ability to maintain its viscosity. Spray patterns varied with viscosities from full cone-patterns with plain water to hollow cone-patterns as the viscosity increased. The low viscosity solution can be expected to penetrate deep seated fires more readily than a high viscosity solution. Whereas exposed fires which are accessible by direct spray can be extinguished most effectively with high viscosity solutions.

Another method of improving the extinguishability of water is application in the form of finely divided particles, i.e. fog or spray. The cooling effect is enhanced through an increased rate of evaporation; hence a more rapid exclusion of oxygen.

The production of large quantities of fine spray (0.1 mm dia.) has been successful with high water pressures in combination with air-water nozzles (A-8). It was found that the sprays contain nearly equal weights of droplets and air. Fire tests with 5 lbs of wood indicated that particle sizes in the range of 260 to 340 microns could be taken as optimum (A-35). This conclusion was supported further by references (A-36 and A-34).

Tests conducted by J. E. Malcom (A-32) indicate that particles under 100 microns appear to be acceptable from the standpoint of fallout rate and ability to reach the desired point of application. In general, fog or spray is considered by many to be approximately 10 times as effective as a solid stream of water (A-37 and D-16).

Non-freeze water solutions have been developed for low temperature first aid fire fighting. One of the most promising is the water-base alkali-earth-metal-salt solution. Mr. R. J. Zablodil (A-5) found that the extinguishing ability of plain water was also improved by the inclusion of this compound. He recommends the use of waterbase lithium chloride and waterbase lithium chloride-calcium chloride solutions. With the addition of 0.5% sodium dichromate in a water solution of lithium chloride, corrosion can be satisfactorily inhibited when contained in a drawn brass extinguisher (A-16).

Halogenated Hydrocarbons -

Many halogenated hydrocarbon agents exhibit a high degree of effectiveness in fighting fires in Class A, B and C fuels. Extinguishment is attained through cooling, exclusion of oxygen and a combustion chain breaking mechanism (A-3). The presence of bromine tends to increase the effectiveness of a halogen compound. However, if one bromine is already present in the molecule the addition of another is not always beneficial (A-7). Florine, on the other hand, tends to increase stability and reduce toxicity. Halon 1301* combines these two elements and was considered a logical choice for further investigation.

Halon 1301 is a noncorrosive, relatively nontoxic (A-41) extinguishing agent with freezing and boiling points of -270°F and -72°F, respectively. Tests indicate that Halon 1301 is two to three times as effective as CO_2 in fighting equal Class A combustible fires (A-44). Mr. W. F. Haessler (A-43) suggests an even greater degree of superiority.

See suppressant rating chart (Appendix A) for general summary of suppressant characteristics.

D. ADDITIONAL REFERENCE ANNOTATION

Reference (A-10)

Two basic units, capable of generating foam by inert gas injection, were devised and tested, data was accumulated regarding friction losses in small pipe due to the flow of foam.

Reference (A-13)

The problem of compaction and the resulting discharge characteristics of dry chemical extinguishing agents was investigated. It was established, with the use of X-ray techniques, that the degree of compaction caused by vibration is considerably less in extinguishers of the stored pressure type. Further studies indicate a good powder does not necessarily resist vibration packing but does release readily once packing has occurred.

Reference (A-14)

A pneumatic conveying system driven by a commercially available vacuum cleaner was devised to facilitate the loading of dry chemical extinguishing agents. It was found that Purple-K-powder dry chemical could be transferred at a rate of 1.14 lbs/sec with a 5% reduction in the powders specific surface area using a 1-1/2 hp unit. The concept seems to be very

*Halon 1301 (Bromotrifluoromethane)

promising from the standpoint of field application.

Reference (B-1)

This report evaluates the operation of high metallic strip rate-of-rise detectors. Above the minimum rate-of-rise of temperatures, the operating temperature of the detector decreases as the rate-of-rise is increased. Furthermore, the operating time of a comparable fixed temperature detector is greater at rates-of-rise above the minimum.

Reference (B-2)

Four detectors and five Freon 1301 extinguishers were tested, some of the results are as follows:

1. Smoke detectors operated sooner than tube and strut detectors in the presence of a slow developing fire.

2. Tube and strut detectors were superior against rapidly developing fires.

Reference (B-6)

This report consists of a comprehensive study of recent advances in detection by light and heat.

Reference (A-41)

The life hazard of heat - decomposed Halon 1301 was studied by exposing guinea pigs to various concentrations in air. Animals subjected to concentration of 20%, by volume, for two hours showed no significant pathological change during a 10 day observation period. Halon 1301 decomposition products are essentially HF acid, HBr acid, halides and in some cases free bromine.

Reference (A-44)

The following recommendations could give improved results when conducting total flooding fire tests:

1. Ventilate thoroughly between fire tests.

2. Ventilate during preburn time.

3. If the threshold concentration of a gas is to be determined separate flames must be located at several levels in the test enclosure.

Reference (D-2)

Air temperatures required for ignition of most wood is approximately 700°F in atmospheres containing 19% to 20% oxygen and 1000-1100°F in atmospheres of 14% to 15% oxygen. The approximate heat energy required for ignition is 135 Btu/Ft^2/min.

Reference (D-14)

The following are some of the conclusions regarding protection of high piled storage:

1. A stable pile resists control by automatic sprinklers to a much greater degree than an unstable pile. Pile collapse permits more water to reach the seat of the fire.

2. Ceiling temperatures can be controlled by water spray application rates.

3. At low density applications, the tendency for the fire to spread horizontally to the edges of the pile increases.

4. Ordinary sprinkler discharge at practical application rates cannot be expected to extinguish a fire that is well established in stock below the top two pallets in the pile.

5. In a dry pipe system a fire may be expected to establish itself deeper into the piles and open a larger number of sprinklers.

6. Under conditions of slow fire development, combined with generation of large quantities of smoke and relatively slow sprinkler operation, a smoke detection system would be of value.

7. Fire can be expected to communicate from one pile to another when the aisle space between piles is less than 30% of the height of the highest adjacent pile and may communicate where clearance is less than 50% of the height of the highest pile.

8. The vertical and horizontal rate of spread of fire increases as the clearances between piles diminish. As thermal updraft increases, pressure develops between closely spaced stacks, and the flame is pushed out in all directions.

III DISCUSSION

A. CHOICE OF DETECTION SYSTEMS

The tube- and strut-type heat detector is being recommended for four of the five listed systems. This detector is in some cases somewhat slower to operate than other types, but it was chosen because of its simplicity, low cost, low power consumption, ruggedness, reliability and freedom from false alarms. The detailed outline of devices considered and the reasons for choosing this device and the ionization-type combustion gas detector used in one system follows.

a. Convective Heat Detection.

1. Fusible links, plugs.
2. Eutectic tubing.
3. Fusible conductor, film or line type.
4. Fusible insulation separating conductors.
5. Pneumatic tubing with or without auxiliary chambers.
6. Liquid expansion devices.
7. Thermoelectric, thermocouple, thermopile.
8. Temperature-dependent resistance elements, thermistors.
9. Curie point magnetic-effect devices.

b. Flame Radiation Detection.

1. Photoconductive - infra-red and ultraviolet.
2. Photoelectric - infra-red and ultraviolet.
3. Convective heat detectors having high emissivity surface coatings to increase sensitivity to thermal radiation.

4. Heat detectors with radiation collecting mirrors.

5. Flame oscillation frequency detectors.

c. Combustion Gas-Smoke Detection.

1. Transmission types.

2. Spectrophotometric, infra-red analyzer type.

3. Reflective type.

The following are the performance criteria on the basis of which the detector was chosen.

1. Sensitivity, speed of response.
2. Cost, total, initial, installation, maintenance and replacement.
3. Simplicity, of construction and operation.
4. Durability, resistance to mechanical and fire effect damage.
5. Reliability, both long term with few operations and short term with many operations.
6. Adjustability, to achieve optimum sensitivity under a wide range of conditions.
7. Recycle capability.
8. Selectivity, no false alarms, monitors only desired area.
9. Stability, no change due to ambient conditions of heat, vibrations, corrosion, humidity or fungus growth.
10. Flexibility, capable of using a wide range of a-c or d-c electric currents, possibilities of increasing sensitivity.
11. Miscellaneous, safe, unobtrusive, small, available.

The mechanism of burning wood has been described as occuring in three stages (A-1), ignition, combustion and glowing. During the combustion stage the temperatures are relatively low as much of the heat is used to convert solid wood to gases and the burning activity is essentially at the wood's surface. Mr. Adler (A-1) maintains that wood of ordinary dimensions has a combustion stage which lasts approximately 10 minutes. Extinguishment is considered to be significantly easier when initiated during this stage. The more established a fire becomes the more suppressant action is needed.

The problem with respect to detection is that for maximum efficiency the sensor must be both sensitive and selective. Basically it must detect a fire in its beginning stages but should only detect fire in the specific area assigned to it. For example, either a combustion gas or smoke detector is the first choice for sensitivity but the convection column from a low rate of gas or smoke evolution is highly susceptible to drafts and ambient air currents and flow patterns and the gas or smoke may reach a detector in an adjacent or even distant module before reaching that directly above. Also, when suppression commences, additional smoke and gas will be generated which will operate other adjacent or distant devices. In addition, where recycling is desired, the smoke may persist and the sensor will be unable to determine when the fire is out.

Where one shot complete flooding or deluge type suppression is feasible the smoke or combustion gas detector is undoubtedly the optimum choice from the standpoint of speed of operation.

Where local application is feasible and recycling capability is desired a detector with more selectivity is necessary. An infra-red sensing device with optics to limit the area scanned to 20 x 20 would be the most sensitive. In the present ease where ambient heat sources or light preclude use of this, the rate-compensated fixed-temperature structural tube type detector for instance (Fenwal Detect A Fire) would be a suitable choice.

B. FIVE PRELIMINARY SYSTEM CHOICES

Appendicies B through F, which are attached, contain detailed descriptions of each of the five systems which we consider to be most promising. Each is discussed and evaluated on a basis of initial cost, maintenance cost, effectiveness, and reliability as required by the contract. The five systems we have chosen are in the order of their promise, most promising first, follow:

1. Halon 1301, multiple shot recycling. Total-flooding with detection by strut and tube heat detectors. (See Appendix B).

2. Automated sprinkler system. Water (with Lithium Chloride added for low temperature application), recycle as required, detection by both standard automatic sprinklers and strut and tube type heat detectors. (See Appendix C).

3. High-expansion (1000 to 1) foam filled with an extinguishing concentration of Halon 1301, local application, recycle as required with strut and tube type heat detectors. (See Appendix D).

4. Halon 1301, single shot, total-flooding, with a smoke detection system. (See Appendix E).

5. High pressure (100 to 1000 psi) water fog (with Lithium Chloride added for low temperature application), local application of a simultaneous four nozzle discharge, recycle as required with detection by strut and tube type heat detectors. (See Appendix F).

The suppressants used have been chosen on the basis of the rating chart in Appendix A plus consideration of other factors such as availability and compatibility of systems to apply these suppressants.

The cost of any of these systems chosen falls within the range considered acceptable, e.g. 10% of the total cost of an erected building.

Appendix G constitutes the rating chart which we have used to rank system concepts in order of most to least promising as required by the contract.

It must be understood that the over-all ranking may vary somewhat with changes in the relative importance of adaptability to specific applications or situations. For instance, we have taken into consideration the adaptability to arctic conditions with an expected low temperature of minus 65°F in unheated buildings. The amount of construction in the arctic regions is, however, comparatively small and information we have obtained leads us to expect that a considerable number of arctic buildings will be heated. On the other hand, in tropic locations buildings may have high leakage rates or perhaps no sides at all which would rule out a concept strictly confined to total flooding with a gaseous suppressant.

For purposes of rating we have considered adaptability to tropic, temperature and arctic conditions to be weighted equally since the temperature range minus 65° to plus 140°F was specified in the contract.

A low ranking of a particular system for a particular category means only that the system can be adapted to that condition only with difficulty or additional expense or that the specific technical information or performance und r th t condition is lacking.

The system cost for each concept is influenced by the total amount of suppressant storage. This amount depends on whether one uses total flooding or local application concepts. The reasons for the amounts in storage is explained in the respective appendices.

IV CONCLUSIONS

The multi-cycle, total flooding system using Bromotrifluoromethane as a suppressant and the automated sprinkler system were chosen as the two most promising system concepts.

V RECOMMENDATIONS

1. The two most promising systems should be fire tested to determine the extinguishing ability of the suppressants and the reliability of the system components under typical fire conditions.

2. Future remote area structures should incorporate a fire protection system as an integral part of the structure.

RLP/jb

REPORT BY : J. B. Smith, E. W. Cousins, J. S. Slicer, M. J. Miller and R. L. Pote,Jr.

APPENDIX : A-G

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APPENDIX A
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SUPPRESSANT RATING CHART

CODE: 3 EXCELLENT
2 GOOD
1 FAIR
0 POOR

	CLASS A FUEL ×2	CLASS B FUEL	NON-TOXIC	NON-CORROSIVE	SUITABLE FOR ALL CLIMATES	NO MESS	SELF-PROPULSIVE	TOTAL
HALON NO. 1301	4	3	2	2	2	3	1	17
WATER PLUS 24% LITHIUM CHLORIDE	6	1	3	1	3	1	0	15
ABC DRY CHEMICAL	4	3	3	2	2	0	0	14
WATER PLUS LiCl AND $CaCl_2$	6	1	3	0	3	1	0	14
WATER PLUS $ZnCl_2$	6	1	3	0	3	1	0	14
CO_2	2	2	1	2	1	3	2	13
NITROGEN, ARGON	0	2	0	2	3	3	3	13
WATER (SPRAY OR FOG)	6	2	3	1	0	1	0	13
WATER PLUS DETERGENT	6	1	3	1	0	1	0	12
HIGH-EXPANSION FOAM	6	1	3	1	0	1	0	12
FOAM (PROTEIN & INSOLUABLE SOAP BASE)	5	2	3	1	0	1	0	12
WATER (SOLID STREAM)	6	0	3	1	0	1	0	11
WATER AND THICKENING AGENT	6	0	3	1	0	1	0	11
LOW EXPANSION FOAM	5	1	3	1	0	1	0	11
CHEMICAL FOAM	5	1	3	1	0	1	0	11
WATER SLURRY	6	0	3	1	0	1	0	11
HALON NO. 1211	0	3	1	2	2	2	0	10
HALON NO. 1201	0	3	1	2	2	2	0	10
HALON NO. 1011	4	3	0	0	2	1	0	10
HALON NO. 1202	4	3	0	1	1	1	0	10
HALON NO. 2011B	4	3	1	0	1	1	0	10
SODIUM BICARBONATE BASE DRY CHEM.	0	3	3	2	2	0	0	10
POTASSIUM BICARB. BASE DRY CHEM.	0	3	3	2	2	0	0	10
HALON NO. 1002	4	3	0	0	1	1	0	9
HALON NO. 10001	2	3	0	1	1	1	0	8
HALON NO. 2312	2	3	0	1	1	1	0	8
HALON NO. 2202	2	3	0	1	1	1	0	8
HALON NO. 2002	2	3	1	0	1	1	0	8
SYNTHETIC FLUIDS	5	0	0	1	0	1	0	7
HALON NO. 1001	0	3	0	0	2	2	0	7
HALON NO. 104 (CCl_4)	2	2	0	1	0	2	0	7

DEFINITIONS

1. Class A Fuel X2 - Refers to the ability of the suppressant to extinguish fires in ordinary combustibles i.e. cellulosic materials. Since 90% of the fuels are expected to be Class "A" combustibles this rating is increased by a factor of two thereby increasing its relative affect on the total. References used: A-3, 4, 5, 17.
2. Class B Fuel - Refers to the ability of the suppressant to extinguish flammable liquid fires. References used: A-3, 4, 5, 8, 17.
3. Non-toxic - Relative toxicity at extinguishing concentrations in normal and heat-decomposed state. Estimated for some suppressants where data was not available. References used: A-3, 4, 23, 41.
4. Non-corrosive - Stability of suppressant in contact with ordinary materials used in storage tanks and distribution systems. References used: A-4, 7, 16, 19, 20, 27.
5. Suitable for All Climates - Suppressants ability to resist freezing at temperatures down to -65°F and maintain its discharge characteristics in the temperature range -65°F to 140°F. e.g. Carbon dioxide can be expected to discharge as a frost-vapor mixture at temperatures in the -40°F range resulting in a decrease in effectiveness. References used: A-5, 7, 13, 17.
6. No Mess - Minimum suppressant damage to buildings and contents. References used: A-3, 23.
7. Self-Propulsive - Rated on the basis of vapor pressure at low temperatures (0°F to -65°F). References used: A-3, 7.

System No. 1 - Halon 1301 Multicycle Total Flooding System

I DESCRIPTION

A. Basic Module

The system is to consist of two or more supply tanks of Halon 1301 pressurized with nitrogen. If a fire should rekindle or a second fire occur after the initial soaking period, a second dose will be applied to combat the situation. A tube and strut thermal switch will activate an explosive value, which in turn discharges the initial supply. A timer will be started simultaneously with the initial fire signal and set to operate a second explosive valve 20-30 minutes later. With the exception of the detection components, the system is basically the same as the Halon 1301 single-shot total-flooding concept.

B. Necessary Modifications

There will be only minor changes between an arctic and tropic system, i.e., the low arctic temperature range will require that the storage tank be pressurized with a greater quantity of nitrogen. Optimum pressures and orifice sizes will have to be determined during the test program.

C. Means for Protecting Larger Areas

The basic module need only be expanded to fit larger buildings, e.g., Butler Building, 40 ft x 100 ft x 20 ft high. In this case two - possibly three - detectors with at least four nozzle assemblies would be required.

II DISCUSSION

A. General

Halon 1301 is a relatively nontoxic, noncorrosive vaporizing liquid fire suppressant. Its freezing and boiling points are -270°F and -72°F respectively. Halon 1301 has a vapor pressure of 200 psi at 70°F, thereby eliminating the need for expensive pressure containers. Extinguishment is accomplished through cooling, exclusion of oxygen, and a combustion chain-breaking ability (A-3). Fire tests conducted by W. M. Haessler of Fyr-Fyter Co. (A-43) indicate that complete extinguishment of burning cellulosic materials can be attained with one pound of Halon 1301 for each 50 cu ft of volume coupled with a minimum soaking time of 15 minutes. To apply this protection to a particular volume will require that the space be completely closed.

B. Effectiveness

It is necessary to use the somewhat slower acting, fire-resistant, tube and strut detector in order to achieve a successful multicycle operation. By comparison, the ionization-type detector can be damaged by fire, thereby eliminating its effectiveness from a multicycle standpoint. The expected effectiveness of this system is therefore assumed to be less than the single-shot system due to abovementioned slow action.

C. Reliability

The reliability is considered to rank higher than the single-shot system since the threat of a rekindled fire does not pose as serious a problem.

D. Initial Cost

The estimated initial cost is in the $1400-$1500 range. This figure can be expected to decrease if (a) Halon 1301 is produced in large quantities, (b) local application of Halon 1301 proves to be practical.

E. Maintenance Cost

The system should be inspected on a regular schedule, possibly every two months, to check the strength of the battery, weight of the Agent storage and general condition of fittings, valves and electrical components. It is impossible, at this time, to estimate the cost of such an inspection program, other than to say it would require approximately 14 man-hours per system per year.

F. Disadvantages

The normally open electrical circuit does not allow a trouble-indicating signal.

The system's effectiveness relies on a reasonably well sealed space to maintain the required suppressant concentration. In many tropic areas this may not be practical or even possible, thereby reducing the probability of extinguishment.

G. Calculations

As stated one pound of Halon 1301 is required for each 50 cu ft of volume. Assume that there will be one air change (exclusive of ventilation)/hour. (D-21).

1. Module Volume - 20 ft x 20 ft x 10 ft high = 4000 ft^3
   Lbs Halon 1301 (ideal) = 4000 ft^3/50 ft^3/lb = 80 lb

2. Agent make-up required
   Due to one air chg/hr

   Air chg = 4000 ft^3/hr or 1000 ft^3/15 min (required soaking time)

   Lb Halon 1301 (make-up) = 1000 ft^3/50 ft^3/lb = 20 lb

3. Total lb agent = 80 + 20 = 100 lb
   Two-shot system requires 2 x 100 = 200 lb

4. Approx. cost = 200 lb x $3.00/lb = $600 (20'x20'x10' module)

   Actual protected Vol/lb = 4000 ft^3/100 lb = 40 ft^3/lb

5. (Cyl.) Tank Size -
   Assume Loading Density = 60 lb Halon 1301/cu ft (Ref. A-43, A-28)

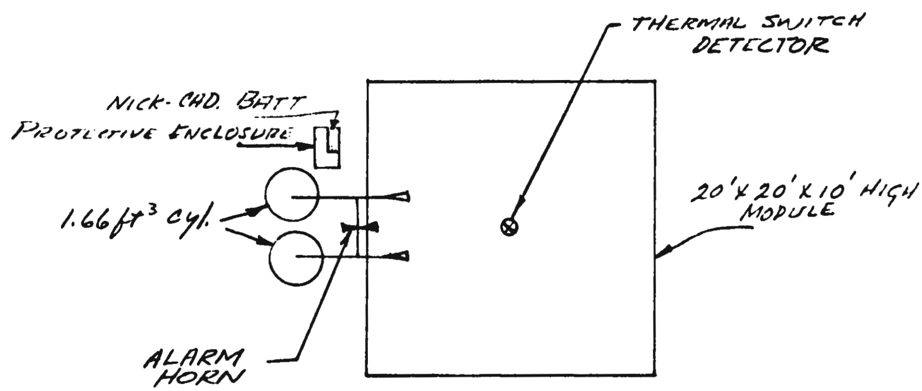
(20 x 20 x 10) (module)	100 lb/60 lb/ft^3 - 1.66 ft^3 (12.3 gal)
(40 x 100 x 20) (But. Bldg.)	80,000 ft^3/40 ft^3/lb = 2000 lb 2000 lb/60 lb/ft^3 = 33.4 ft^3 (247 gal)

6. The degree of pressurization necessary to maintain adequate discharge characteristics will depend on the temperature range of the area in question, i.e. an environment which has a minimum annual temperature never less than 70°F will require no pressurizing since the vapor pressure of Halon 1301 will be sufficient (see Ref. A-28).

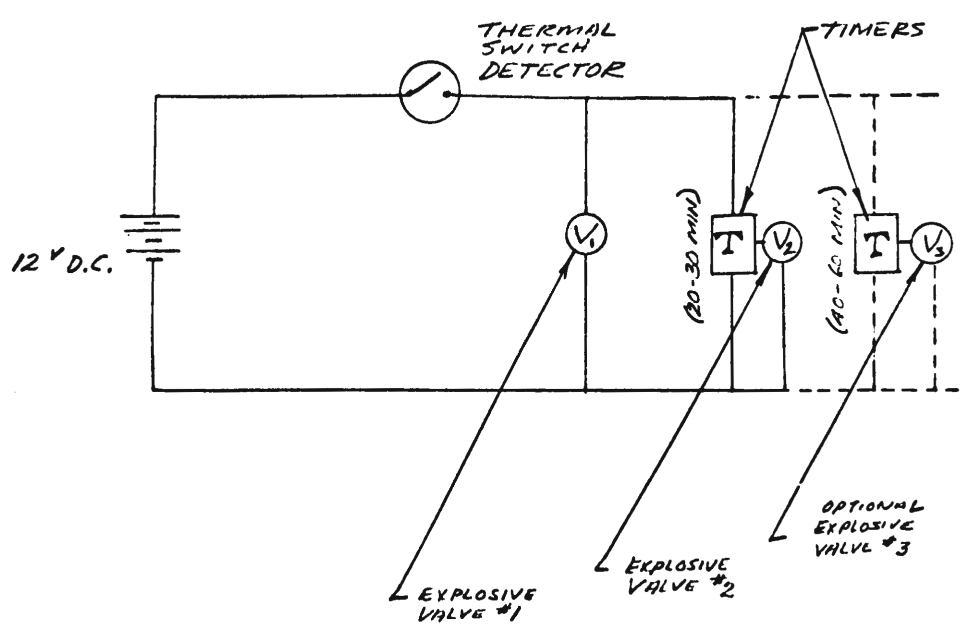
III DETAILS OF COST ESTIMATE

		(2 Shot) Module (20 x 20 x 10)	(2 Shot) Butler Bldg. (40 x 100 x 20)
1.	Nick-Cad Batt Cold Climate 12 v	$ 150	$ 150
2.	(2) 1.66 ft^3 Cyl.	100	
	(2) 33.4 ft^3 Tank		500
3.	Nitrogen	10	100
4.	Thermal Switch	20	120
5.	Pressure Reducing Valve 50/ea.	100	100
6.	Tubing & Fittings	20	80
7.	Alarm Horn	20	20
8.	MI Cable $.66/ft	30	90
9.	Quick Operating Valve (Explosive) 100/ea.	200	200
10.	Timers 100/ea.	100	100
11.	Nozzle Assembly 10/ea.	20	40
12.	Halon 1301	600	12,000
	TOTAL	$1,370	$13,500

SYSTEM LAYOUT

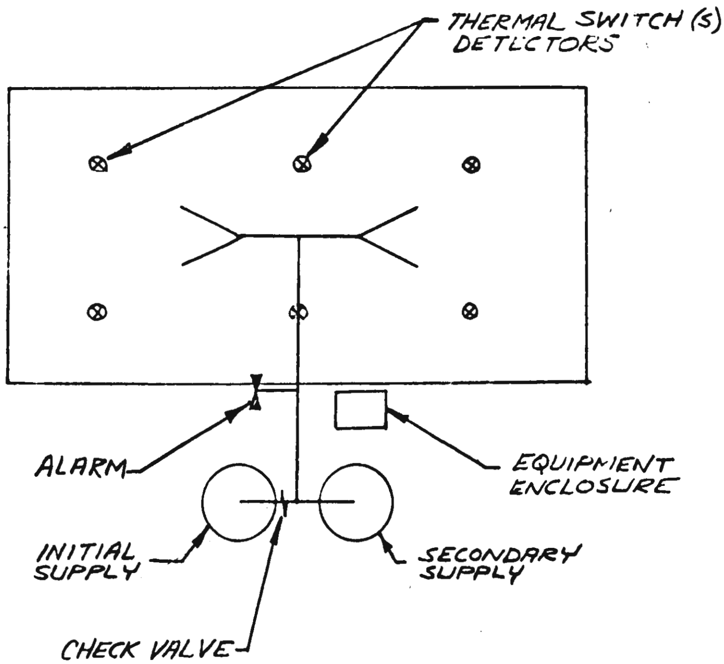


ELECTRICAL SCHEMATIC



TWO SHOT MULTI-CYCLE SYSTEM

(ADAPTED TO BUTLER BLDG.)



SPECIFICATIONS

(SYSTEM NO. 1)

1. Battery - Nickel-Cadmium, 12 volt, 100 amp-hour rating. Cold climate rating (-65°F).
2. Cylinder - 2 cu. ft. capacity steel cylinder, maximum allowable pressure (working pressure) 1000 psi at 200°F. Construct and label in accordance with Interstate Commerce Commission regulations.
3. Tank - 35 cu. ft. steel tank, 1000 psi working pressure at 200°F. Construct and label in accordance with Section VIII, Unfired Pressure Vessel, ASME Boiler and Pressure Vessel Code. Spray one coat (Mil-C-15328) and one coat (Jan-P-735) and 7 top coats of Micro-filled asphalt emulsion.
4. Nitrogen - Standard "T" size cylinder, 2600 psi.
5. Detector - Thermal switch capable of withstanding momentary overshoot of 2000°F at the probe and 800-1000°F at the body. Sensitivity within ± 1°F, 12 volt d.c., 2 amp, adjustable in the field.
6. Pressure Reducing Valve - Inlet pressure range 0-3000 psi, delivery pressure range 25-400 psi. Flow rate 500 cu. ft. per minute (minimum).
7. Tubing - 3/8 inch and 1/2 inch nominal diameter copper tubing, Type K.
8. Fitting - Wrought copper.
9. Brazing - Copper phosphorous alloy, Class BCuP-3.
10. Cable - MI cable, 2-#16 gauge.
11. Quick Operating Valve - 12 volt d.c., Squib operated.
12. Timers - Repeated cycle timer, capable of giving "on" signal at 20-30 minute intervals as long as timer is energized. D.C. operation.
13. Nozzle Assembly - To be determined.
14. Halon 1301 - ($CBrF_3$) Bromotrifluoromethane.

System No. 2 - Automated Sprinkler System

I DESCRIPTION

A. Basic Module

A schematic layout and list of components is attached. This is a system consisting of four standard automatic sprinklers or spray nozzles of 165°F rating supplied with water from a pressure tank with an on-off operation provided by normally open circuit strut and tube type detectors of 140°F rating connected to a solenoid actuated water control valve. In operation only those sprinklers affected by the fire would open. Water would be discharged through the affected sprinklers as long as the strut and tube detector senses the presence of fire and for a selected time thereafter. The time delay would be accomplished by sizing an orifice to delay the filling of the upper chamber of the water control valve after closing of the chamber venting solenoid valve. The system would be capable of instantaneous recycle. The question of optimum pressure, flow rate, time delay and sprinkler orifice size will have to be resolved during the test program for the expected range of fire types. Except for extra automatic control features this system is similar in many respects to previous systems considered to have some potential (C-5, D-18). The general performance characteristics also correspond to those necessary for the anticipated applications (C-5, D-18, D-19, D-20).

B. Necessary Modifications

1. Arctic Application. For application where ambient temperatures reach -65°F water with 24% lithium chloride will be used, with a corrosion inhibitor if necessary. Since this suppressant solution is viscous at -65°F, consideration will have to be given to balancing pressures, pipe size and orifice size and design to accomplish the optimum flow and degree of atomization. If necessary, consideration can be given to providing

an atomizing gas supply at each sprinkler. Oscillatory pumping, produced by a continuously cycling solenoid, could also be investigated if found necessary.

2. Tropic Modifications. The only modification foreseen is the use of sprinklers and detectors with higher temperature ratings.

3. Where control to only a single module or system is needed, a solenoid can be provided on the gas line rather than the liquid line. A smaller solenoid using less power might then be feasible. Control on the liquid side will, of course, be necessary where a number of systems are supplied from a single tank. Control of the liquid line would also facilitate connection to base water supplies should these be provided.

4. At least one manufacturer now makes available spray nozzles which are precalibrated for median drop size and drop size distribution. This would facilitate investigation of the relationship between drop size and suppression efficiency.

5. The feasibility of pressure compensation for changes in viscosity should be investigated.

C. Possible Modifications - Not Planned

1. Fully automatic sprinklers, which would detect fire and individually and independently recycle as needed, would offer maximum protection efficiency. A system of this type would however involve considerable development and be more expensive than the basic module described in this section.

2. Sensitivity of the strut and tube detector might be increased by providing a blackbody coating on the tube and a parabolic reflector for the collection of thermal radiation.

3. The number of detectors could be increased.

4. If only a single 20 x 20 or 20 x 40 module is to be protected or should protection of a larger area be desired by complete replication of

20 x 20 modules with independent control of each it might be advisable to effect control by means of individual solenoid valves rather than the solenoid actuated diaphragm valve specified herein.

5. The modification of the automatic sprinklers to provide a lower fusing or operating temperature rating might be investigated, e.g. a 0°F rating for use in locations continuously at -65°F.

6. Should sprinkler operating temperatures be modified to provide increased sensitivity at low temperatures, the detector operating temperature would also have to be lowered.

7. Additives such as thickeners or surface-active agents might be added to improve the fire-fighting characteristics of water at above freezing temperatures (D-22).

8. Direct pressurization of the supply tank by solid rocket fuel has been shown to be feasible (NRL Report 5332).

9. Solid fuel might also be used to provide heat to nitrogen cylinders for low temperature applications, possibly increasing the effectiveness.

10. Pumper connections can be provided.

11. It is quite possible that collapsible (inflatable) water storage tanks could be used. Something of the nature of the standard F I Pneumatic Lifting Bag (D-18, P 409) appears applicable.

12. Should a collapsible storage tank be used, it is quite possible that pressurization could be provided by (a) placing normal storage on top of a platform resting on the bag, (b) constructing the building on top of the bag, (c) for emergency or auxiliary use by running a vehicle on to a platform resting on the bag.

13. A fog or spray could be provided by explosive dispersal of a liquid in independent containers hung in each module. Dispersal from individual pressurized high-rate discharge bottles in each module could be used.

14. Consideration should be given to designing an entire building from the ground up to incorporate fire protection features such as water storage and distribution which are combined with or integrated into the structural elements.

D. Means for Protecting Larger Areas

Since the contract requires that the system be capable of protecting building areas to 40 x 100 consideration must be given to the means by which this is accomplished. Four general methods are possible. In each the water storage capacity needed is estimated on the basis of four automatic sprinklers operating.

1. Total Replication. This would duplicate all equipment described herein for each 20 x 20 module of the building. This is considered impractical.

2. Partial Replication. This would provide a single central storage tank with supply and control to individual modules in each 20 x 20 ft area.

3. Partial Expansion. This would be the same as 2 except that the size of the module would be increased to 20 x 40, 40 x 40 or larger. The automatic sprinklers offer some selectivity with respect to the quantity of water discharged and therefore this is considered the most promising method.

4. Total Expansion. A single supply and control would be provided for single sprinkler system covering the entire building. This would be most economical and perhaps sufficiently effective in areas of low hazard where a large number of sprinklers would not be expected to open during any given fire or whose personnel are available to replace sprinklers after a fire.

II DISCUSSION

A. General

Automatic sprinklers have proven their effectiveness and reliability with increasing frequency in the last 75 years. This is not to say that the effectiveness cannot be improved and this is one attempt to do so. The basic concept is that described in U.S. patent 3,100,017 dated August 6, 1963 for a "Fire Sprinkler Control System" issued to Joseph E. Johnson, assignor to Viking Fire Protection Company. It is expected that the system would be revised for the purposes of this contract, since many of the supervisory features would not be needed in a remote, unattended area. Where it is necessary to limit power consumption supervisory and fail safe features would have to be sacrificed.

The effects of changes in pressure should be investigated during testing of this system to determine optimum flow rates and spray qualities.

B. Effectiveness

The fact that the amount of water used is controlled both by the number of sprinklers opened and by the number of detectors which operate should lead to application of water only where it is necessary. Automatic shut off of water when its use is no longer indicated also leads to conservation of water supplies. Use of relatively high (100 psi) pressure should result in prompt extinguishment with a minimum number of sprinklers opened.

C. Reliability

Total system reliability with respect to extinguishment is enhanced by the recycling capability. Additional operational reliability can be provided by duplicating critical components. All operating components are of relatively simple construction and operation.

D. Initial Cost

Cost data for a 20 x 20 module and for a 40 x 100 area are contained on the system schematic which is appended.

E. Maintenance Cost

Total maintenance should consist of periodic checks of the batteries and replacement of sprinklers should a fire occur.

F. Disadvantages

Since individual sprinklers cannot themselves reclose after operation they will operate (after fusing) each time water is supplied to them. Considering a four sprinkler module if one sprinkler operates and puts out a fire and then a second fire requiring only one sprinkler for extinguishment starts at the opposite corner of the array then both sprinklers would operate. Theoretically a fire could start at the juncture of four modules and open 16 sprinklers. If the fire rekindled sufficiently to affect the four detectors then all 16 sprinklers would again operate regardless of the need. This same principle must be taken into consideration when deciding whether to increase the protection area by replication of independently controlled modules or by provision of a single control and detection system for an entire building.

The thermal lag and higher temperature rating of automatic sprinklers will make them slower in operation than the strut and tube detector. The fire will therefore be more established when suppression commences. This is counterbalanced to some extent by the greater selectivity of discharge and the possibility of cost savings by providing a single control and detection system for an entire building.

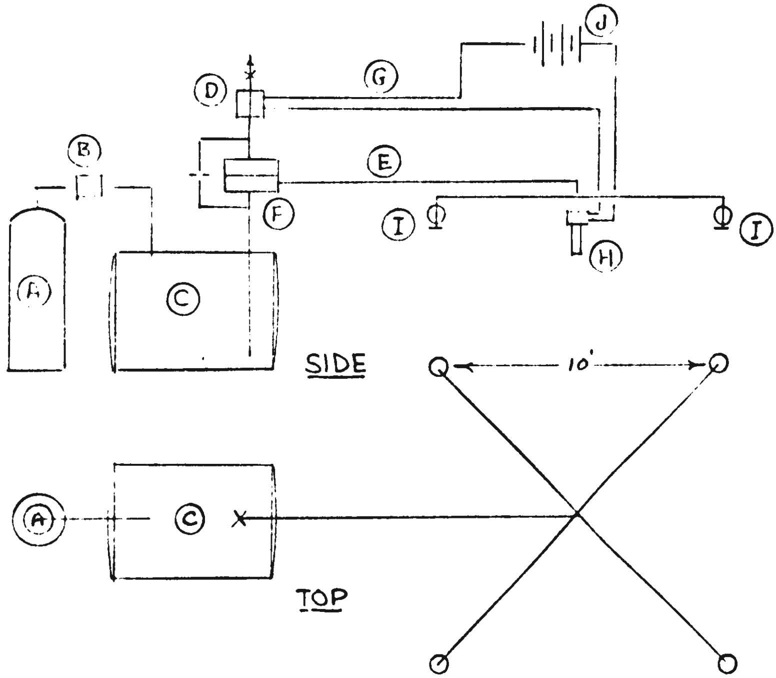
III CONCLUSIONS

This system most nearly approaches systems which are currently available for general application in fire protection. The demonstrated effectiveness and reliability of standard automatic sprinkler system is coupled with additional control features to improve overall system efficiency.

The overall usefulness of this system is perhaps most easily and optimistically predicted of the five systems listed and is the one which should require the least development. It may however produce water damage and requires a corrosive anti-freeze water solution at temperatures below 32°F.

The problems of decreasing water damage and of minimizing corrosion will require additional investigation.

SYSTEM NO 2 , AUTOMATED SPRINKLER SYSTEM



		20 × 20		40 × 100 (2, 40×50 SYSTEMS)
A	Nitrogen Cyl's (4)	100	× 2	200
B	Regulator	50	× 1	50
C	Water Stge 500 gal	300	× 2	600
D	Solenoid	50	× 2	100
E	Tube	50	× 10	500
F	Control Valve	100	× 2	200
G	Elect. Cable	20	× 10	200
H	Detector	20	× 10	200
I	Automatic Sprinklers	10	× 10	100
J	NiCd Battery	150	× 1	150
	ESTIMATED COST	$ 850		2300

SPECIFICATIONS

(SYSTEM NO. 2)

1. Nitrogen - Standard "T" size cylinder 2600 psi.
2. Regulator - Inlet pressure range 0-3000 psi, delivery pressure range 25-400 psi.
3. Water Tank - 70 cu. ft. steel tank, 100 psi working pressure at 200°F, construct and label in accordance with Section VIII, Unfired Pressure Vessel, ASME Boiler and Pressure Vessel Code. Spray one coat (Mil-C-15328) and one coat (Jan-P-735) and 7 top coats of Micro-filled asphalt emulsion.
4. Solenoid Valve - 3/8 inch to 1/2 inch diameter pipe size, 12 volt d.c. Working pressure 1500 psi, stainless steel body.
5. Tubing - 3/8 to 3/4 inch nominal diameter copper tubing, Type L.
6. Control Valve - 2 inch cast iron, pilot actuated, direct loaded, diaphragm valve.
7. Cable - MI Cable, 2-#16 gauge.
8. Detector - Thermal switch capable of withstanding momentary overshoot of 2000°F at the probe and 800-1000°F at the body. Sensitivity within ± 1°F, 12 volt d.c., 2 amps, adjustable in the field.
9. Automatic Sprinklers - UL and FM Approved 3/8 and 1/2 inch diameter orifice sprinkler head.
10. Battery - Nickel-Cadmium, 12 volt, 100 amp-hour rating, cold climate (-65°F).

System No. 3 - High Expansion Foam and Halon 1301.

I DESCRIPTION

A. Basic Module

A schematic layout and list of components are attached. Essentially, this is a system for local application using high expansion foam generators suspended at the ceiling. Tube and strut thermal switches (four in parallel) will activate an explosive operated diaphragm closure to release gas for foam generation.

As now conceived there would be four foam generators (Figs. 1 and 2) located at the ceiling of each 20 ft x 20 ft module. These generators would be spaced 10 ft on centers. The generators would be a modification of the operating principle developed by the Lawrence Radiation Laboratory (A-11) for gloved box protection or a smaller version of the presently Factory Mutual approved (D-17) portable units using electric motor driven fans. The generators for this project would not require an elbow (A-11) and special closure (A-11) but would require a conical diffuser (Fig. 2).

The foaming agent and water would be stored in a pressurized tank and would be forced through a tube to a spray nozzle located so as to discharge the mixture against the net of the foam and generator. This discharge would occur upon actuation of an explosive operated diaphragm closure by the detection system.

By connecting the tube and strut detectors to a stepping type relay it is possible to provide for recycling. Each time the detectors of a module call for suppressant the relay would advance and open the explosive operated valves on another bank of tanks of gas and foaming agent and water. A time delay of at least five minutes would be provided between discharge of suppressant in a single module building.

B. Necessary Modifications

1. Arctic Application. The water and foaming agent solution is subject to freezing. Work by others (C-1) indicates that ethylene glycol can be added to prevent freezing down to -20°F without serious adverse effect on foam generation. There is some indication (C-1) that water solutions that will not freeze at lower temperatures do not have good foaming characteristics. This area needs further investigation.

2. Tropic Modification. No problems are foreseen in applying this system in areas where temperatures reach 140°F, except that the ratings of detectors must be increased.

C. Means For Protecting Larger Areas

The basic module need only be expanded to fit larger buildings, e.g., Butler Buildings, 40 ft x 100 ft x 20 ft high. In the case where there were more than 4 modules the amount of gas provided to generate the foam would need to be for four modules (See II Discussion A. General.)

D. Possible Modifications

The existence of a portable 3000 cfm high expansion foam generator given by a 1/3 hp electric motor indicates that it would be entirely practical to use an electric motor (1/6 hp or smaller) driven fan instead of the gas inspirator unit to generate foam in quantities required for this application. The power requirements would be in the order of 150 watts per unit (746 watts per hp x 1/6). The greatest demand foreseen would occur in a multi-module building with a fire starting at the junction of 4 modules and causing 16 units to operate. The power requirement would then be 2400 watts or 100 amps from a 24 volt source. Manufacturer's catalog data indicates that this can be obtained for 5 minutes with two 12 volt, 150 amp units in series. These units have a total weight of 50 lb.

II DISCUSSION

A. General

Tests by Factory Mutual Engineering Division (D-17) and others (A-11) (A-12) have shown the effectiveness of the so-called high expansion, e.g. 1000 to 1 expansion, foam as a fire suppressant on cellulosic materials. As dicussed in Appendix B, II A. General, Halon 1301 has been shown effective in total flooding situations. Tests by R. L. Tuve (C-1) have also shown the effectiveness of another halon in a foamed surfactant on flammable liquids.

B. Effectiveness

It is the intent of this system to combine the properties of both these extinguishing agents into a suppressant that would be superior to either one. The persistence of the foam is intended to be the vehicle for maintaining a concentration of Halon 1301 near the burning material and not allow the Halon 1301 to be quickly dissipated by air currents or by run-off.

Tests by others (B-8) have shown that the speed of response of the tube and strut detector is much faster than the ordinary sprinkler and operation of this system would be expected to occur when a fire in a cellulosic material is much smaller than with the normal sprinkler system. Thus the expectation would be for the use of a minimum amount of suppressant (estimated at 1/4 filling per module) and that the worst condition in a multi-module building would be from a fire that caused the systems of 4 modules to operate.

This system is intended to provide one filling of a module in 5 minutes. It is estimated that 30 gallons of foaming agent and water would be required for each module.

The estimated one filling for a 20 ft x 20 ft x 10 ft high module would require 4000 cu ft of foam or 1000 cu ft from each generator. Thus each generator would need to generate 200 cu ft per minute of foam to give a filling time of 5 minutes. This would require a flow rate of gas through the net of 250 to 300 cfm (A-11) or a total of 1200 to 1500 cu ft of gas.

Taking the higher figure, this gas could be made up of 75 cu ft of Halon 1301, 200 cu ft of nitrogen and 1225 cu ft of air. Nitrogen stored in a standard cylinder would be used to inspirate the air helped by the Halon 1301 as it expands from liquid to gas (Fig. 1). Venturi inspirators will, according to catalog data, probably do the job if 3 in. units are used for the nitrogen and 1-1/2 in. units are used for the Halon 1301. This assumes a high back pressure. If the nitrogen alone must supply the total 1225 cu ft of air, this 6 to 1 mixture is within the ragen of these mixers at 30 to 40 lb per sq in. nitrogen pressure. Of course, for this application much lighter weight Venturi units of a similar size could be used.

As now visualized sufficient Halon 1301, atomizing gas, and water-foaming agent mixture would be provided for a single module building to completely fill the building once. The control system would be arranged to discharge this in four shots in quick succession if the fire was severe enough or in a maximum of four well spaced (weeks apart) intervals if there were successive fires.

In multi-module buildings sufficient Halon 1301, atomizing gas, and water-foaming agent mixture would be provided to completely fill four modules. The control system would be arranged to discharge this in full module increments. Thus for the best condition where the fire operated detectors of only one module, there would be sufficient suppressant for four shots on four fires. The worst condition would be where the fire operated the detectors of four modules. This would exhaust the suppressant in one shot.

C. Reliability

All operating components are of relatively simple construction and operation. Failure of heating unit in arctic regions could render the system inoperative. This concept cannot, however, combat a second fire or a fire that has rekindled unless the protection is manually restored or the detection system and suppressant quantity are designed for recycling operation.

D. Initial Cost

The estimated initial cost is in the \$1000 to \$1100 range for a 20 ft x 20 ft module and \$4000 to \$4500 for a 40 ft x 100 ft building.

E. Maintenance Cost

The system should be inspected on a regular schedule, possibly every two months, to check the strength of the battery, weight of the storage and general condition of the fittings, valves and electrical components. It is impossible, at this time, to estimate the cost of such an inspection program, other than it would require approximately 15 man-hours per system per year.

F. Disadvantages

The state of the art has not advanced to the extent that foaming performance can be accurately predicted at extremely low temperatures (-20^{o}F to -65^{o}F). Although no actual foam generators of the size contemplated are currently being marketed, several have been specifically fabricated and tested (A-11) (A-42) for other applications.

III CONCLUSIONS

This system concept has the advantage of being "a local-application" type when in a large building. The suppressant does considerably less damage to the occupancy than water type systems. In fact data (A-11) (A-42) indicate that damage approaches that of a system using gas as a suppressant.

IV DETAILS OF COST ESTIMATE

The cost of the materials for protection for a 20 ft x 20 ft module or a 40 ft x 100 ft building is estimated as:

		20 x 20	40 x 100
Venturies 8 @ $10.00	=	$ 80.00	$ 800.00
Detector 4 @ 20.00	=	80.00	800.00
Tubing-copper @ 10¢/ft	=	20.00	200.00
Wiring & relays	=	100.00	200.00
Batteries (these could supply more than 1 module)	=	150.00	150.00
Foam generator 4 @ $20.00	=	80.00	800.00
Explosion opp. release	=	30.00	300.00
Nitrogen Cylinder X3	=	150.00	300.00
Foaming Agent	=	5.00	10.00
Halon 1301	=	250.00	1000.00
		$1095.00	$4560.00

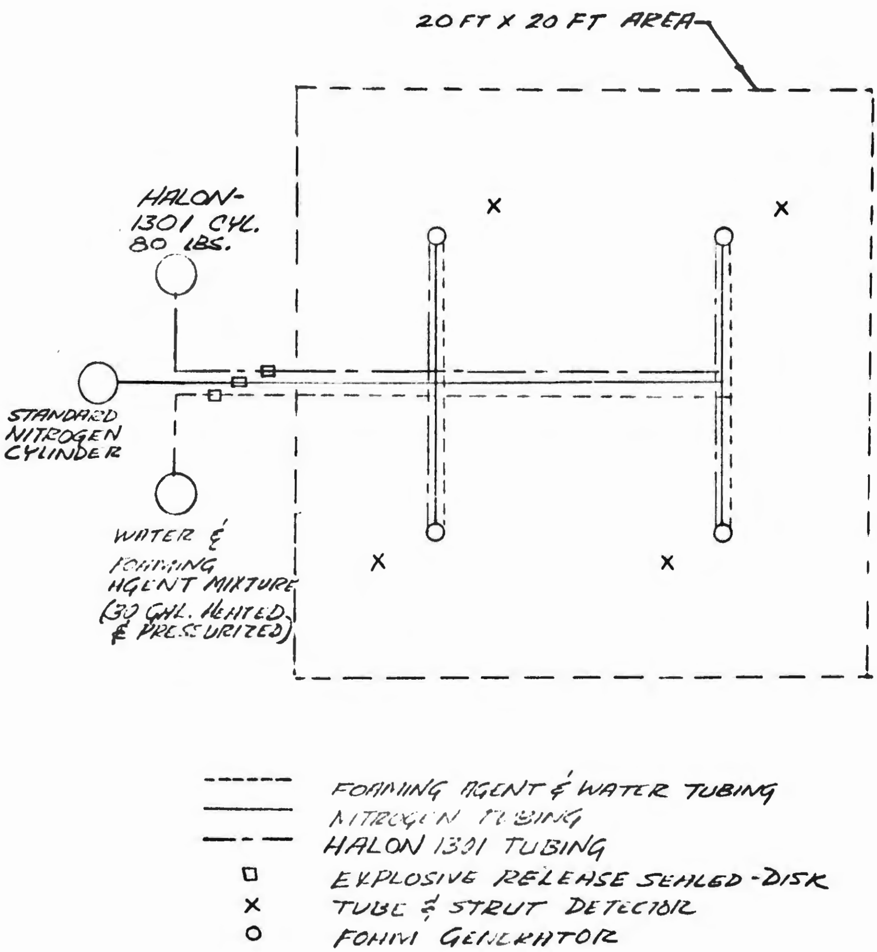


FIG. #1 COMBINATION HIGH EXPANSION FOAM AND HALON 1301 SUPPRESSANT SYSTEM.

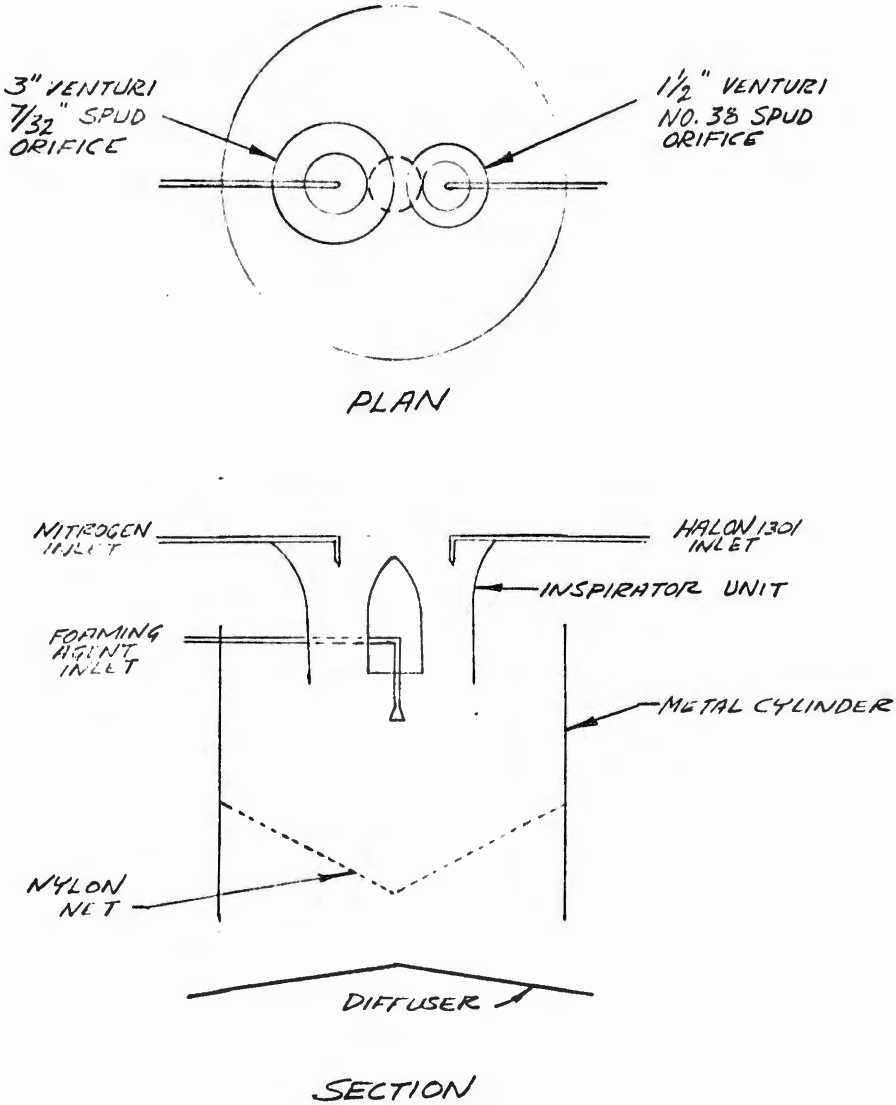


FIG #2 FOAM GENERATOR

THE GAS INSPIRATOR COULD BE REPLACED BY AN ELECTRIC MOTOR DRIVEN FAN WITH THE HALON AND FOAMING AGENT BEING DISCHARGED INTO THE AIR STREAM.

System No. 4 - Halon 1301 Single Shot Total Flooding System

I DESCRIPTION

A. Basic Module

This relatively simple concept consists of a single supply tank of Halon 1301 arranged to discharge completely when activated by an ionization type detector. The discharge nozzle will be located just below the ceiling at one wall of the 20 ft x 20 ft x 10 ft high module. An explosive-type valve will release the agent which is to be stored under nitrogen pressure. It is intended to maintain approximately 200 psi at the nozzle assembly to give adequate dispersal. Pressure will be controlled with a pressure-reducing valve. A small quantity of escaping gas can be used to sound an alarm. The system will receive power from a nickel-cadmium battery.

B. Necessary Modifications

There will be only minor changes between an arctic and tropic system, i.e., low arctic temperature range will require that the storage tank be pressurized with a greater quantity of nitrogen.

Optimum pressure and orifice sizes will have to be determined during test program.

C. Means for Protecting Larger Areas

The basic module need only be expanded to fit larger buildings, e.g., Butler Building, 40 ft x 100 ft x 20 ft high. In this case two - possibly three - detectors with at least four nozzle assemblies would be required.

II DISCUSSION

A. General

Halon 1301 does no damage of itself to property. It is a relatively nontoxic, noncorrosive vaporizing liquid fire suppressant. It has the highest suppressant ability per unit weight and unit volume. Its freezing and boiling points are -270°F and -72°F respectively. Halon 1301 has a vapor pressure of 200 psi at 70°F, thereby eliminating the need for expensive pressure containers. Extinguishment is accomplished through an apparent combustion chain-breaking ability (A-3) exclusion of oxygen, and cooling. Fire tests conducted by W. M. Haessler of Fyr-Fyter Co. (A-43) indicate that complete extinguishment of burning cellulosic materials can be attained by means of total flooding with one pound of Halon 1301 for each 50 cu ft of volume coupled with a minimum soaking time of 15 minutes. To apply this protection to a particular volume will require that the space be completely closed.

B. Effectiveness

The ionization-type fire detector has proved to be a very responsive device in detecting ordinary fires in the early stages. When used in conjunction with an explosive, squib-operated system and a highly pressurized agent, the resulting system can be expected to operate very quickly. Early detection and operation increase a system's effectiveness (Ref. A-1, A-2).

C. Reliability

From the standpoint of simplicity of operation and the nonfreeze ability of the agent, this system appears to be quite reliable. The concept cannot, however, combat a second fire or a fire that has rekindled without manually restoring the protection.

D. Initial Cost

The estimated initial cost is in the $1000-$1100 range. This figure can be expected to decrease if (a) Halon 1301 is produced in large quantities, (b) local application of Halon 1301 proves to be practical.

E. Maintenance Cost

The system should be inspected on a regular schedule, possibly every two months, to check the strength of the battery, weight of the agent storage and general condition of fittings, valves and electrical components.

It is impossible, at this time, to estimate the cost of such an inspection program, other than to say it would require approximately 14 man-hours per system per year. Some of the more vulnerable components are the battery and the fire-indicating cabinet, both of which are relatively expensive.

F. Disadvantages

The system's effectiveness relies on a reasonably well sealed space to maintain the required agent concentration. In many tropic areas this may not be practical or even possible, thereby reducing the probability of extinguishment.

G. Calculations

As stated one pound of Halon 1301 is required for each 50 cu ft of volume. Assume that there will be one air change/hour (exclusive of ventilation) (D-21).

1. Module Volume - 20 ft x 20 ft x 10 ft high = 4000 ft^3
   lbs. Halon 1301 (IDEAL) = 4000 ft^3/50 ft^3 lb = 80 lbs.

2. Agent make-up required due to one air chg/hr.

   Air chg = 4000 ft^3/hr or 1000 ft^3/15 min (required soaking time)
   lbs Halon 1301 (make-up) = 1000 ft^3/50 ft^3/lb = 20 lbs.

3. Total lbs Agent = 80 + 20 = 100 lbs.

4. Approx. Cost = 100 lbs x \$3.00/lb = \$300 (20' x 20' x 10' module)

   Actual protected vol/lb = 4000 ft^3/100 lb = 40 ft^3/lb

5. (Cyl.) tank size -
   Assume loading density = 60 lbs Halon 1301/cu ft (Ref. A-43, A-28)

   (20 x 20 x 10 Module) 100 lbs/60 lbs/ft^3 = 1.66 ft^3 (12.3 gal)

   (40 x 100 x 20 But.Bldg.) 80,000 ft^3/40 ft^3/lb = 2000 lbs.
   2000 lbs/60 lbs/ft^3 = 33.4 ft^3 (247 gal)

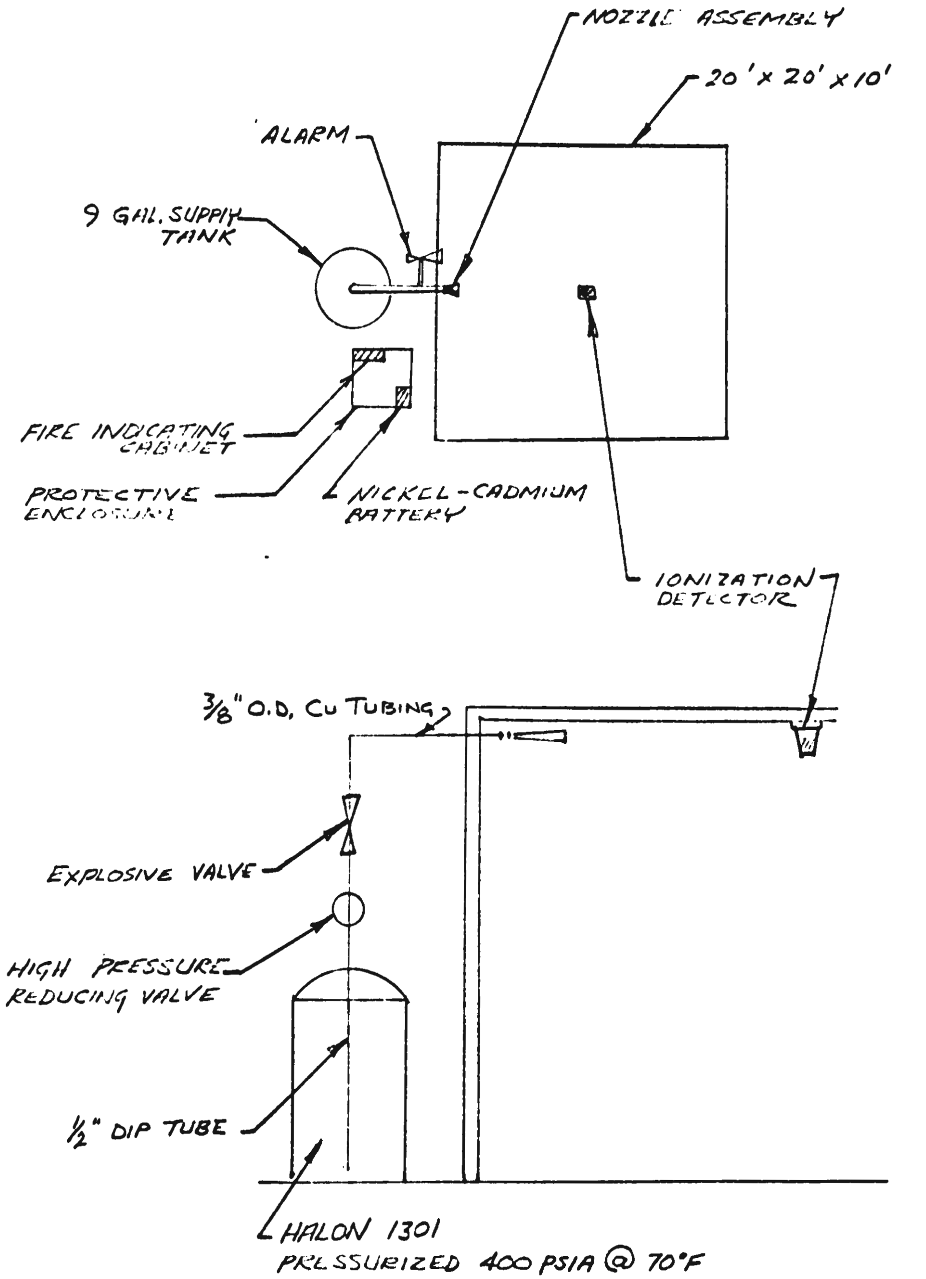
6. The degree of pressurization necessary to maintain adequate discharge characteristics will depend on the temperature range of the area in question. i.e., An environment which has a minimum annual temperature

never less than 70°F will require no pressurizing since the vapor pressure of Halon 1301 will be sufficient (A-28).

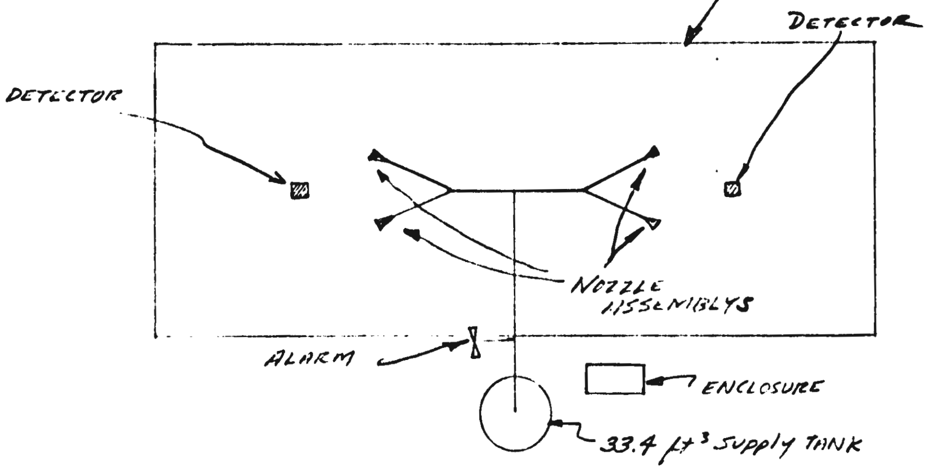
III DETAILS OF COST ESTIMATE

		Module (20 x 20 x 10)	Butler Bldg. (40 x 100 x 20)
1.	Nick.-Cad Batt. Cold Climate 12	150	150
2.	1.66 ft^3 cyl.	50	-
	33.4 ft^3 tank	-	250
3.	Halon 1301	300	6000
4.	Nitrogen	5	50
5.	Ioniz. type detect. & Fire Indicat. cabinet	325	400 (2 detectors)
6.	Press. reducing valve	50	50
7.	Tubing & fittings	10	40
8.	Alarm horn	20	20
9.	MI cable $.66/ft	20	70
10.	Quick operating valve (explosive)	100	100
11.	Nozzle assembly	10	40 (4 nozzles)
	Total	$1040	$7170

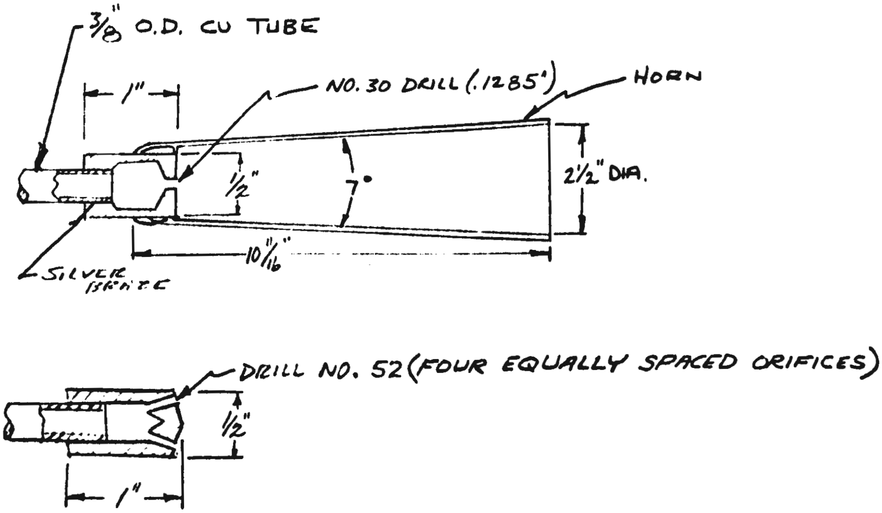
SYSTEM LAYOUT



SYSTEM ADAPTED TO BUTLER BUILDING



POSSIBLE NOZZLE ARRANGEMENTS (REF. A-29, A-30, A-31)



System No. 5 - High Pressure Water Fog

I DESCRIPTION

A. Basic Module

A schematic layout and list of components is attached. Essentially this is a system using relatively high (100 to 1000 psi) pressures for the local application of water fog (mean diameter of droplets less than 500 microns) simultaneously through a fixed array of four spray nozzles. Actuation is by means of normally open circuit strut and tube type detectors arranged to energize a normally closed solenoid valve in the event of fire. A time delay relay would provide for a minimum of 30 seconds (or optimum time as determined by test) discharge with instantaneous recycle capability.

B. Necessary Modifications

1. Arctic Application. For application where ambient temperatures of -65°F are expected water with 24% Lithium Chloride will be used. A corrosion inhibitor.

Since the water-lithium chloride mixture is highly viscous it may be found that to get optimum drop sizes, gas atomizing nozzles must be used. If such is the case additional nitrogen (or other gas) will be needed. Additional tubing will also be necessary to get the gas to the nozzles and solenoids to control the gas flow.

2. Tropic Modification. No problems are foreseen in applying this system in areas where temperatures reach 140°F except that the rating of detectors must be increased.

C. Possible Modifications - Not Planned

1. The use of gas-liquid atomizing nozzles for normal service has not previously been used in fixed fire protection systems to our knowledge. Their use could result in smaller drops and more uniform sprays.

2. If gas-liquid atomizing nozzles are found necessary to atomize the viscous water - LCl_2 solution it is possible that there may be some advantage in using Freon 1301 as the atomizing gas. This would add the combustion inhibiting capabilities of Freon to the cooling-coating effects of the water and perhaps result in a beneficial synergistic effect.

3. It may be possible to speed the response of the tube and strut detector by adding a reflective thermal radiation collector arranged to focus on the tube which would in turn be coated to increase its absorption of radiation. The angle of view of a parabolic reflector might make it advisable to use more detectors in the 20 x 20 module.

4. More standard detectors could be supplied in the 20 x 20 module to increase the speed of detection. The optimum number for a given fire situation would have to be determined experimentally.

D. Means for Protection of Larger Areas

In all of these it is assumed that no more than a maximum of four modules (16 nozzles) could operate simultaneously.

1. Total Replication. All equipment including storage tanks could be provided for each 20 x 20 ft module of the maximum size 40 x 100 ft building.

2. Partial Replication. This is considered the most satisfactory. A single central storage tank and pressure supply would provide the suppressant supply to each of ten protection modules each having independent detection and control.

3. Expansion. The system could be arranged to discharge simultaneously through all nozzles in a 40 x 100 ft area. This is considered wasteful and unnecessary except perhaps for certain highly hazardous situations where a total flooding deluge type operation might be needed.

II DISCUSSION

A. General

A number of investigations by others (D-16, A-33, A-34) have suggested that the extinguishing efficiency of water is dependent on many cases on the degree of atomization of the water. Zablodil (A-35) and Underwriters' Laboratories (A-36) have indicated an optimum drop size of the order of 300 microns. At least one manufacturer (A-37) has made claims that fire control with high pressure (600-800 psi) water fog hand lines requires only a tenth of the total quantity of water required to establish control using solid stream delivery. A statistical study (D-17) of the effect of pressure on the number of sprinklers opened during actual fire losses indicates an optimum pressure of about 50-100 psi for standard sprinklers. This is of course a combination effect since median drop size not only diminishes with increased pressure but the flow rate of each sprinkler will increase as the square root of the pressure. As Rasbash (A-33) has stated the increase in extinguishing and heat transfer efficiency must be balanced against the ability of the drops to reach the fire site. Since in normal industrial applications where ceiling heights may vary up to 100 ft this is a problem which has limited the consideration of fine fogs. In this contract however the ceiling height is specified as varying only from 8 ft to a maximum of 20 ft. This fact coupled with the use of a detector which will operate considerably in advance of standard automatic sprinklers leads to a more optimistic expectation that the fog will reach the fire in its early stages and effect control and extinguishment with optimum efficiency and minimum usage of water. For the smaller buildings (20 x 48) the efficiency should be improved even more by the confining, concentrating and smothering effects provided by enclosing the fog. Water damage should also be significantly decreased.

B. Effectiveness

1. Availability of pressures over a wide range to 1000 psi means that spray characteristics can be tailored to individual applications.

2. The design is such that the effectiveness may be increased easily by increasing the number of nozzles, flow rates and the number of detectors.

C. Reliability

1. Control using an open circuit detection system means that power is required only for actuation during a fire.

2. If additional reliability is desired redundant components may be added easily.

3. The ability to recycle in event of a rekindle or a later fire increases the probability of successful suppression.

D. Initial Cost

1. Cost estimate data is included on the system schematic.

2. Water will be available in one form or another at most of the locations anticipated making the transport of suppressant to remote locations unnecessary.

3. The total quantity of water required is minimized by automatic control recycling features.

4. The use of high pressure would result in decreasing the size of piping necessary.

E. Maintenance

Total maintenance should consist of checking and recharging the battery at periodic intervals of one to 12 months and replenishment of the suppressant and pressure cylinders should a fire occur.

F. Disadvantages

1. As presently set up, four nozzles will discharge simultaneously. Supposedly the ultimate in efficiency would be complete automatic on-off-

recycling control of individual nozzles. However, it is likely that the additional expense could be justified only for rare, special cases.

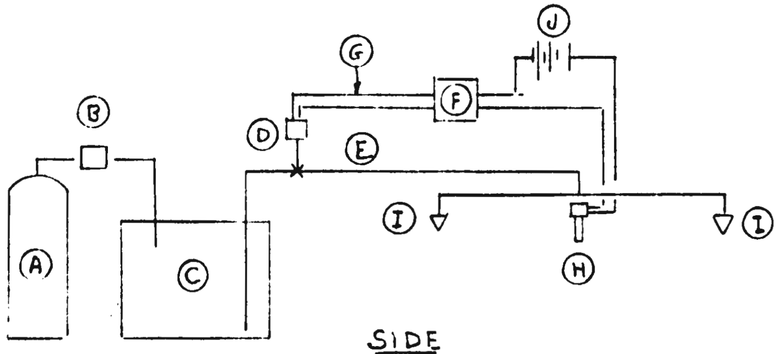
2. The use of high pressures will require vessels which are normally heavier than those used for lower pressure. Where this is a serious disadvantage, however the expense of lighter designs using more exotic metals, special configurations, etc. such as filament winding, etc. may be justified.

3. Use of an open circuit detection system makes continuous electrical supervision of components impossible. In remote areas the power drain is a more important criterion and in many cases there will be no personnel present. For less remote bases where base power is available, more complete supervision and additional fail safe features may be justified.

III CONCLUSIONS

This system shows considerable promise, however, specific performance standards require experimental work for verification. The cost figures which are given are only approximate since optimum pressures, storage quantities and specific design features will have to be verified during the test and development stage.

SYSTEM NO 5, RECYCLING WATER FOG



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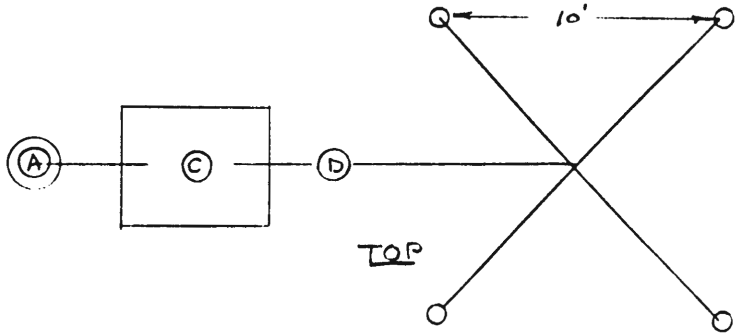

TOP

		20 x 20		40 x 100
A	Nitrogen Cyl's (4)	100	x 2	200
B	Regulator	50	x 1	50
C	Water Stge 250 gal	200	x 2	400
D	Solenoid	50	x 10	500
E	Tube	50	x 10	500
F	Timer, Relays	100	x 10	1000
G	Elect. Cable	20	x 10	200
H	Detector	20	x 10	200
I	Nozzles	50	x 10	500
J	N. Cd Battery	150	x 1	150
	ESTIMATED COST	$ 790		3700

SYSTEM RANKING CHART

		SYSTEM #1 HALON-1301 RECYCLE	SYSTEM #2 AUTOMATED SPRINKLER SYSTEM	SYSTEM #3 HALON-1301 FOAM	SYSTEM #4 HALON-1301 SINGLE SHOT	SYSTEM #5 WATER FOG
COST	20X20 INITIAL COST	5	3	1	4	2
	MAINT. COST	ESSENTIALLY EQUIVALENT				
	40 X100 INITIAL COST	5	1	2	4	3
	MAINT. COST	ESSENTIALLY EQUIVALENT				
EFFECTIVE-NESS	SUPPRESSANT-OVERALL EFFICIENCY	ESSENTIALLY EQUIVALENT				
	DETECTION TIME	2	3	2	1	2
	DELIVERY TIME OF SUPPRESSANT AFTER DETECTION	ESSENTIALLY EQUIVALENT				
RELIABILITY	COMPLEXITY	3	2	2	1	3
	RECYCLE	1	1	1	5	1
MISC.	EASE OF INSTALLATION	ESSENTIALLY EQUIVALENT				
	POWER REQUIREMENT	1	2	5	4	3
	SIZE - BULK	1	3	2	1	3
	WEIGHT	1	3	2	1	4
	STATE OF THE ART (AMOUNT OF DEVELOPMENT REQUIRED	2	1	2	2	2
RELATIVE OVERALL RANKING		1	2	3	4	5

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13. ABSTRACT

Five packaged, self-contained fire suppression systems were devised after a comprehensive review of pertinent material. Eighty-one references are attached. The most promising concepts, as recommended by FMRC and approved by the Navy, are a multi-cycle, total flooding system using Bromotrifluoromethane and an automated sprinkler system using water.

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