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SELF-CONTAINED AFFF SPRINKLER SYSTEM.(U)
MAY 82 E J JABLONSKI, R E BURNS, J T HUGHES N00014-81-C-2221

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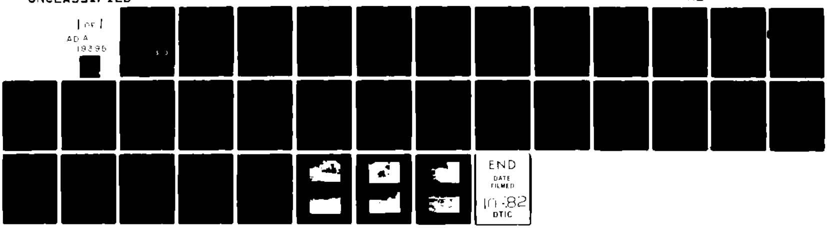

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SELF-CONTAINED

AFFF SPRINKLER SYSTEM

For

U.S. Naval Research Laboratory

Code 6180

Washington D.C. 20375

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EXECUTIVE SUMMARY

A self-contained foam-water sprinkling system was developed for combatting fires on and around diesel engine driven generators on submarines. The system recommended can effectively control fires on the engine and in the bilge area. Additional manual use of portable extinguishers is recommended for control of fuel and lube oil spray fires.

In the fire tests conducted, the AFFF sprinkling system produced control times (90% bilge fire out) of 5 to 7 seconds and total extinguishment times of 15 to 39 seconds using a 30 gallon foam-water storage tank and a piping system with six directional spray nozzles. Stored nitrogen was used to propel the agent. Automatic fire detection and extinguishing system actuation is recommended due to extremely rapid development of intolerable heat and smoke conditions expected in such a fire situation.

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BACKGROUND

Analysis of numerous shipboard fires and the results of related R&D projects led the Navy to adopt twin agent systems for combatting flammable liquid spray and spill fires. Twin agent systems combine the flame knockdown characteristics of potassium bicarbonate dry chemical (PKP) and the extinguishing and vapor securing characteristics of aqueous film forming foam (AFFF). Such systems are now in use on aircraft carriers (flight decks, hangar bays and machinery spaces) and in machinery spaces of other surface ships.

The original objective of this work was to design and evaluate a twin agent unit for extinguishing flammable liquid fires (Class B) and fires in ordinary combustibles (Class A) in submarines. The concept was to apply twin agent through hose reels much as done on surface ships. Further evaluation of hazardous locations on submarines concluded that the surface ship concept had several disadvantages including an "overkill" quantity of agent, obstruction of the twin agent units or inaccessibility of the seat of a fire for manual agent application to be effective. Other disadvantages considered were visual obscuration and breathing difficulty if PKP is used in larger quantities than 30 lb. portable extinguishers, and space and weight limitations. Therefore the approach was modified to provide protection for the diesel engine driven generator which was considered to be the major fire threat for purposes of this project. The revised approach, which was adopted, was to design and test a self-contained AFFF sprinkler system to combat a bilge fire beneath a diesel generator with spray fire control by portable 30 lb. PKP extinguishers. Previous studies (Reference 1) have demonstrated the effectiveness of PKP dry chemical in controlling Class B spray fires. Remote, manual actuation of the AFFF system was anticipated.

Diesel engine driven generators present a threat of fire from pressurized or spilled fuel or lubricating oil and hot surfaces in any installation. In the closed environment of a submarine the threat is magnified. Danger exists to the crew from rapid generation of heat and toxic products, and to critical electrical and electronic equipment installed adjacent to diesel generators. In such confined areas, rapid attack with manual suppression devices, if possible at all, would put the crew at greater risk. The possibility of loss of critical equipment in the same room and loss of the diesel generator from either fire or extinguishing agent use is also increased.

The Naval Sea Systems Command authorized NRL to proceed with development and testing of a self-contained AFFF sprinkling system for use on submarines. Work by Hughes Associates, Incorporated personnel was done under contract number N00014-81-C-2221 with the Naval Research Laboratory.

OBJECTIVE

The revised objective of this project was to be able to develop a fixed hardware system for applying AFFF foam-water agent to extinguish fires in submarine diesel generator areas. The system was to be self-contained and capable of extinguishing fires on the engine, except for spray fires, and in the bilge area beneath the engine. The system would be expected to cool the area around a spray fire which would be extinguished by portable PKP extinguishers and/or fuel supply shutdown. Factors to be considered in achieving the objective were use of available hardware (if possible, hardware already Approved for Service Use), selection of optimum agent discharge rates to achieve extinguishment, space and weight limitations, and avoidance of agent damage to electrical and electronics equipment installed in the same area. Naturally, reducing the hazard to the crew in the diesel generator room and other areas of the ship was of major importance as well as limiting damage to ship systems and preserving the ability to conduct essential operations.

TEST SET-UP

Simulated Diesel Engine and Bilge

Ship visits provided data for constructing the simulated diesel engine and bilge area shown in Figure 1 and the accompanying photographs. A diesel engine was simulated by a large steel tank. A bilge area of typical size (approximately 200 $ft.^2$) was constructed with sheet steel around the tank. Steel grate, representative of deck grating in a submarine, was installed between the top of the bilge area and the bottom of the tank. The tank and grate provided both obstructions to extinguishing agent flow and hot surfaces during the fire tests.

Fuel

The bottom of the bilge was covered with a layer of water approximately one inch deep. Fifty gallons of JP-5 fuel (equivalent characteristics to diesel engine fuel for purposes of these tests) was floated on the water base to provide a measured depth of 3/8 inch fuel. Five gallons of AVGAS were added to aid in complete and rapid ignition of the "diesel" fuel, and to simulate the rapid ignition that would be expected of a diesel fuel spray on a hot diesel engine surface. Actual ignition was accomplished by use of a torch saturated with AVGAS. Fuel quantity and burning rate were calculated to assure that no more than one-half of the fuel was consumed during any test run. The existence of remaining fuel was confirmed by observation and "burning off" after each test. The bilge was drained and flushed after each test to assure that no extinguishing agent remained from the previous test to affect the results of the next.

Extinguishing System Hardware

System components were selected to provide the maximum overall advantage, in the opinion of the project team and responsible Navy personnel, in terms of extinguishing capability, space and weight limitations, standardization of Fleet hardware, and avoidance of over-spray which could damage adjacent equipment. All components have, in some fashion, been approved for service use by the Navy. These are:

- 30 gallon and 50 gallon pre-mixed AFFF agent storage containers tested and specified for use on Coast Guard ships and similar to the 80 gallon containers supplied by the same manufacturer for Navy shipboard Twin Agent Units;
- air aspirating (Grinnell B-1) and non-air aspirating (Bete NF series) foam-water nozzles (both have been used in shipboard systems);
- nitrogen tank;
- on-off liquid agent selector valves;
- piping (all 1" galvanized used for tests);
- pressure gauges.

A general system layout is shown in Figure 2.

Previous research and development projects conducted by NRL (References 2 and 3) and others have shown that AFFF foam-water mixtures discharged through non-air aspirating nozzles are at least equal in fire extinguishing performance to the same mixtures discharged through air aspirating nozzles. Both types of nozzles were tested, however, a nozzle with the greatest directional ability was preferred due to the need to limit agent overspray beyond the actual bilge fire area. Grinnell B-1 air aspirating nozzles and Bete Fog Nozzle Series NF2000 non-air aspirating nozzles were tested. For comparison purposes, one test was conducted with a Bete nozzle having a conical spray pattern.

Hardware variables that were studied consist of type of nozzle, nozzle location, piping configuration, and agent storage container capacity. Some variation was permitted in quantity and pressure of the nitrogen propellant supply.

Extinguishing Agents

All fire tests were run with a pre-mixed solution of 6% aqueous film forming foam (AFFF) agent in accordance with MIL-F-24385B and fresh water. It is anticipated that fresh water would be used in charging submarine systems but either fresh water or sea water could be used as permitted by all applicable MIL SPECS.

Test Area

All tests were run out-of-doors in an area surrounded by an eight foot high partition installed to minimize the effects of wind. Wind conditions during the tests appeared to have little or no effect on fire suppression performance. Testing in open atmosphere eliminated rapid smoke build-up which would occur in an enclosure and obscure observation of fire suppression performance.

TEST PROCEDURE

In order to provide maximum agent coverage and extinguishment efficiency with minimum space and weight requirements, testing was begun with a single pipe run from the agent storage tank with nozzles placed above the centerline of the "engine" (Figure 3 - Configuration A). Four different piping configurations and 6 different nozzles were tested, until in the opinion of the investigators, an optimum arrangement was determined.

Initial test runs were made with each nozzle and piping configuration flowing water alone in order to observe nozzle patterns and flow rates and to confirm published data for the nozzles. Water was used from the facility main system at a pressure of 35 to 50 psi.

Fire tests were then conducted with at least three trained observers recording ignition, pre-burn, control, extinguishment and agent discharge (run) times, and agent tank and nozzle pressures.

A pre-burn of thirty to sixty seconds was provided during each fire test to assure that the entire fuel surface was ignited and had burned for at least 15 seconds prior to actuation of the extinguishing system. This provided a "worst case" condition for manual fire fighting and a severe fire for evaluation of the fixed system capability. Previous experience shows that longer pre-burn or greater quantity of fuel would have little effect on extinguishing capability of the AFFF system. They would, however, provide a more challenging situation to manual fire fighting. It was estimated that the ability to extinguish such a fire in a submarine by manual means was exceeded manyfold due to heat, flame and smoke generated in the first 30 seconds.

Based upon all observations, each system was evaluated and changes made in order to achieve the objectives of the project. Piping and nozzles were varied until it was clear that a practical balance of system hardware and control and extinguishment times had been achieved. Various system arrangements and nozzle types were tested as follows:

- Configuration A - Single run of pipe over centerline of engine as shown in Figure 3. Three fire tests were run, first with Grinnell air aspirating nozzles, second with Bete 15° pattern nozzles discharging so agent would flow over tank and into bilge area, finally with Bete 15° nozzles at an angle so as to wet a larger tank area.

- Configuration B (Figure 4) - Two pipe runs, 4 feet apart, with 2 nozzles above outside diameter of "engine" on each side. Bete nozzles with 90° fan angle, 120° fan angle and a conical rather than fan shaped pattern.

- Configuration C (Figure 5) - A total of six nozzles, 4 located as in Configuration B with the addition of 1 nozzle at each end of the "engine" directed into the bilge area with the discharge pattern oriented 90° to the side nozzles. Bete nozzles having 15°, 80° and 120° fan angles were used in order to determine maximum distribution with minimum overspray of the bilge.

- Configuration D (Figure 6) - A total of six Bete nozzles arranged as in Configuration C but spaced more evenly and with the piping looped to eliminate dead end pipe runs to any nozzle.

The majority of fire tests (14 out of 18) were run using a 50 gallon capacity agent storage container. As testing progressed and control and extinguishment times were significantly reduced, it was decided that a standard 30 gallon storage tank would provide an adequate quantity of agent. Four fire tests were conducted with piping Configuration D and the 30 gallon container.

During the fire tests initial nitrogen pressure, supplied from standard tanks, was allowed to vary from 130 to 168 psi. The variation in pressures observed had little effect on extinguishment results.

RESULTS AND DISCUSSION

Fire test data are shown in Figure 7, where the following are recorded:

- Test - Sequential number of test.

- Config. - Piping configuration A,B,C, or D as shown in Figures 3 through 6.

- Nozzle Type and Number Used - Manufacturer's designation and number of nozzles (in parentheses). In all but two tests, the nozzles used were NF type Bete nozzles with the pattern angle 15°, 80°, 90° or 120° noted as the final digits of the manufacturer's designation.

- Agent Tank Size - 50 gallon or 30 gallon pre-mixed agent storage container.

- T_c - Control time in seconds or the time after agent discharge began until 90% of the bilge fire was out as determined by at least two trained observers.

- T_x - Extinguishment time in seconds or time after agent discharge began until all fire was out.

- T_s - Total system run time or agent discharge time in seconds from time discharge observed from all nozzles to time agent flow ceased at the first nozzle (observed that all nozzles began and ceased flow almost simultaneously).

Initial pressure and average nozzle pressure during the fire tests were recorded and flow rates were calculated and compared with nozzle manufacturers published data. Eighteen fire tests were run with four different piping and nozzle configurations and six different nozzles.

Tests 1, 2 and 3

These three tests were conducted with three nozzles located directly above the centerline of the engine as shown in Figure 3. Control times of 10 to 18 seconds and extinguishment times of 21 to 35 seconds were considered reasonable but turned out to be the longest times recorded. Grinnell B-1 air aspirating nozzles used in test 1 resulted in the lowest control and extinguishment times of the three runs but were rejected due to significant overspray beyond the "bilge" area. Bete 15° pattern nozzles were employed in test 2 (fan pattern oriented along engine centerline) and test 3 (fan pattern oriented 45° to centerline). Control and extinguishment times were significantly longer than with the B-1 nozzle for the same flow rate although overspray was not a problem. In general, the results with Configuration A were considered marginal or unacceptable and the wisdom of, and need for, wetting the engine top questionable. It was decided to evaluate more direct application to the bilge surface.

Tests 4, 5 and 6

These tests were run with piping shown in Figure 4, Configuration B, with two nozzles on each side of and directly above the sides of the engine providing coverage over the side of the engine and into the bilge. Bete 90° pattern and 120° pattern nozzles were used to provide greater agent coverage in the bilge area. One run (Test 5) employed a non-air aspirating Bete nozzle with conical pattern. This nozzle was rejected due to overspray beyond the bilge and significantly increased extinguishment time. Fire knock-down and control was good with the two fan pattern nozzles as was the absence of overspray. The major problem was slow coverage by AFFF of the bilge area at the ends of the engine. Addition of end nozzles was the obvious next step.

Tests 7, 8 and 9

Figure 5 shows Configuration C with a total of six nozzles, 2 on each side of the engine and 1 on each end. A mix of 15°, 80° and 120° pattern nozzles was tried in the three tests. This resulted in reduction in control time and extinguishment time without significant overspray of agent outside of the bilge area. Foam coverage and depth in the bilge area was better than in previous tests.

Tests 10, 11 and 12

Configuration D (Figure 6) closed the pipe loop and provided more equal spacing between sprinkler heads (nozzles). Tests with this pipe configuration and 80°, 90° and 120° nozzles resulted in control times of 5 and 9 seconds and extinguishment times of 18 and 19 seconds. System run times of 34 seconds gave more than adequate margin of safety in the opinions of the investigators. It was decided that the looped configuration with Bete non-air aspirating 80° fan pattern nozzles on the engine ends and 90° fan pattern nozzles on the engine sides provided potential for the best system configuration.

Since all previous tests had used the 50 gallon agent container and total agent quantity seemed to be greater than necessary, subsequent tests employed the same 80° and 90° nozzles and a mix of 50 and 30 gallon agent containers.

Tests 13 through 18

These tests were designed to confirm previous control and extinguishment time observations and to evaluate agent storage container capacity needs in light of minimum space and weight requirements. In tests 14 and 18, the 50 gallon storage container was used as in all previous tests. All system discharge times were between 30 and 38 seconds, the variation being due to different nozzle and pipe configurations tested. The remaining four tests of this group were run with a 30 gallon agent storage container. While system run times (T_S) were reduced to 18 to 23 seconds, control times (T_C) remained between 5 and 7 seconds and extinguishment times were between 15 and 39 seconds. In the two out of four cases where extinguishment time (T_X) exceeded system run time (T_S) the fire was completely extinguished by the AFFF agent applied during the system run time.

Photographs included as Figures 10 through 15 show the rapid development of flame and smoke and rapid knock-down by the recommended system.

The final test configuration, using non-air aspirating nozzles with 90° fan patterns on the sides and 80° fan patterns on the ends of the engine resulted in control times of 5 to 7 seconds. The recommended system employs all 90° pattern nozzles which will not change system performance and will avoid any confusion in installation. The 30 gallon agent storage container is recommended simply to avoid additional space and weight penalties. The fact that the fire was fully extinguished after the agent supply was exhausted in 2 of the 4 fire tests with the 30 gallon container, is compensated by the recommendation that the system be actuated automatically by smoke and heat detectors. Due to the very rapid evolution of flame, heat, and smoke in these fires, automatic actuation would be recommended regardless of agent quantity available. In addition, automatic shut-down of the engine and fuel supply is recommended due to the severity of spray fires which would prohibit total extinguishment.

One alternative arrangement has been considered, using the onboard air supply to propel the agent rather than a separate nitrogen supply. This arrangement was rejected due to the need to shut-down the air supply immediately after the agent is exhausted. Otherwise, the potential for re-ignition or spreading a fire not yet extinguished is great.

RECOMMENDATIONS

The following is a summary of the recommendations resulting from this project. The general conclusion is that fully developed fires attendant to diesel engine equipment operation on submarines can be controlled and extinguished with the self-contained automatic detection and suppression system described, along with automatic engine shut-down and manual attack on spray fires with portable dry chemical extinguishers. The system recommended is for an engine and bilge size typical of those on submarines as described in an earlier section of this report. For larger or smaller areas the system can be scaled up or down or extended to protect supply pipe areas or day tanks as necessary. A general system layout is shown in Figures 8 and 9.

System Components

- Thirty gallon agent storage tank located ten feet or less from the diesel engine.

- One inch diameter pipe installed 0 to 12 inches above the top of the diesel engine.

- Six Bete NF20090 (90° pattern) nozzles, one on each end of the engine above the centerline and from 0 to 12 inches beyond the end of the engine, and two on each side of the engine equally spaced along the length and directly above the widest part of the engine.

- A nitrogen tank 110 cubic feet capacity at 2200 psi.

- A nitrogen supply regulator 2200 psi to 170 psi at 40 cubic feet per minute.

- Photoelectric and heat detectors (combined or separate), minimum of two each spaced evenly above the engine.

- Manual system release both within and outside of the protected space in the event of detection system or electrical power failure.

<u>Agent</u>

Six percent or three percent AFFF agent in accordance with MIL-F-24385C, pre-mixed with fresh water.

<u>System Actuation</u>

Fire extinguishing system automatically discharged by photoelectric and heat detectors installed above the engine and bilge area. No time delay between detection and system actuation should be permitted, nor should manual override of actuation be provided. Manual actuation should be provided both within and without the protected space. Shielding of engine components that could be rendered useless by AFFF spray and prevent later operation of the engine should be considered.

<u>Engine Shut-Down</u>

Common sources of fire at diesel engines are fuel or lubricating oil sprays ignited on hot surfaces. Due to the intensity of such fires, the high potential for a subsequent bilge fire and the very rapid build-up and spread of heat, smoke and toxic gases, it is recommended that engine shut-down be accomplished automatically upon actuation of the fire suppression system.

Manual Fire Fighting

PKP dry chemical is effective in controlling spray fires until the source of fuel can be shut off. While it appears unlikely that crew members could react before the automatic suppression and fuel shut-down functions, provision of PKP extinguishers in 20 or 30 pound size and appropriate training of crew members is prudent.

Additional Testing

The final extinguishing system configuration performed so well that little could be accomplished by testing additional designs. Agent quantity, hardware space requirements and extinguishing times might be reduced but the results would be marginal.

Since these fire tests were conducted in the open, it has been suggested that further testing in a closed environment, such as the NRL FIRE I Submarine Chamber, may be necessary. This would resolve questions regarding system performance in an atmosphere with rapidly increasing pressure which may be detrimental to extinguishing agent flow and suppression.

REFERENCES

1. Jablonski, E.J., Peterson, H.B., and Tuve, R.L., "A Comparative Testing Study of Fire Extinguishing Agents for Shipboard Machinery Spaces", NRL Memorandum Report 1696, April 15, 1966.

2. Darwin, R.L., and Jablonski, E.J., "Full Scale Fire Test Studies of Sea Water-Compatible 'Light Water' as Related to Shipboard Fire Protection", Department of the Navy Report, August 25, 1969.

3. Jablonski, E.J., "Comparative Nozzle Study for Applying Aqueous Film Forming Foam on Large-Scale Fires", Civil and Environmental Engineering Development Office (Air Force Systems Command) Report CEEDO-TR-78-22, April 1978.

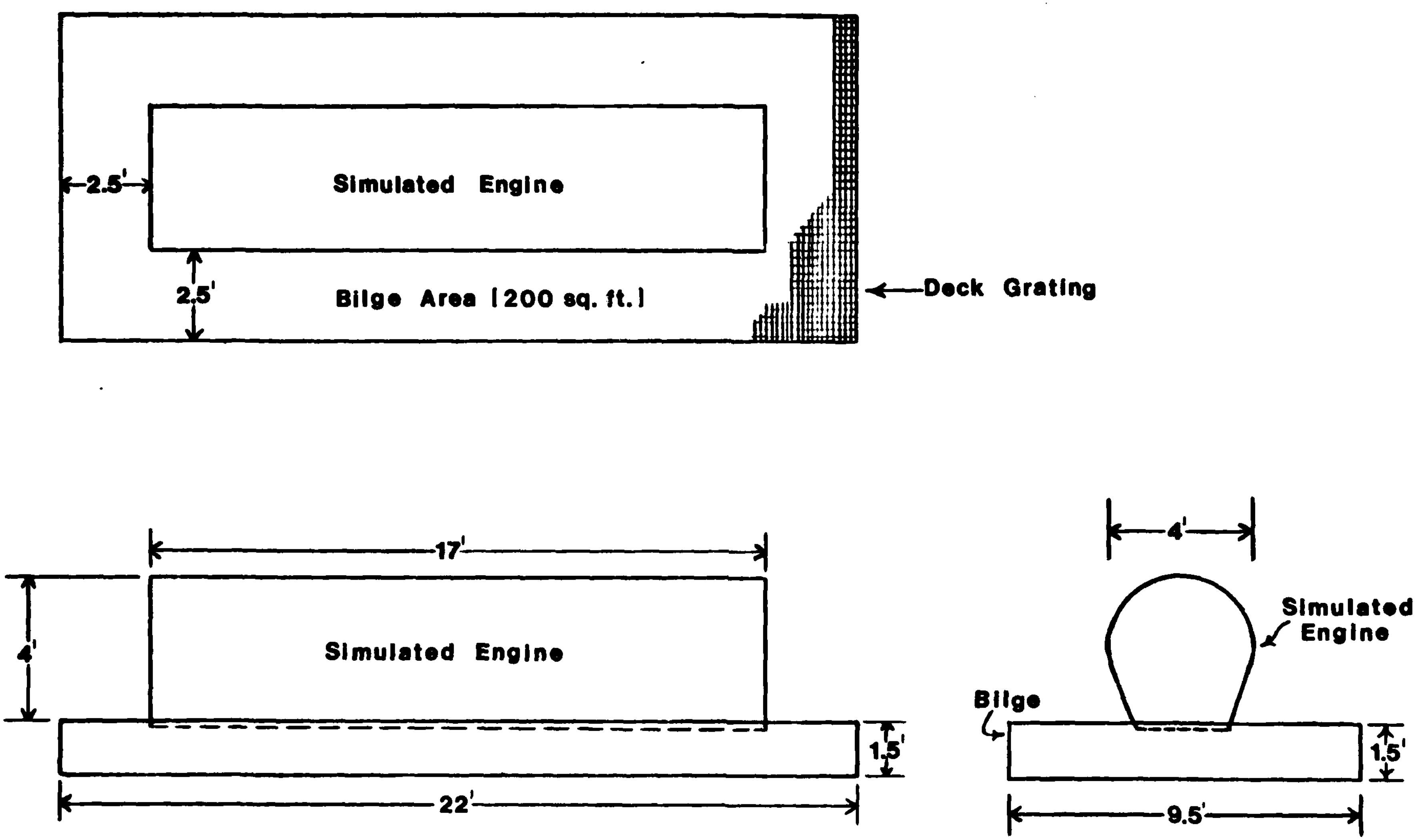


FIGURE 1 - Simulated Diesel Engine and Bilge Area

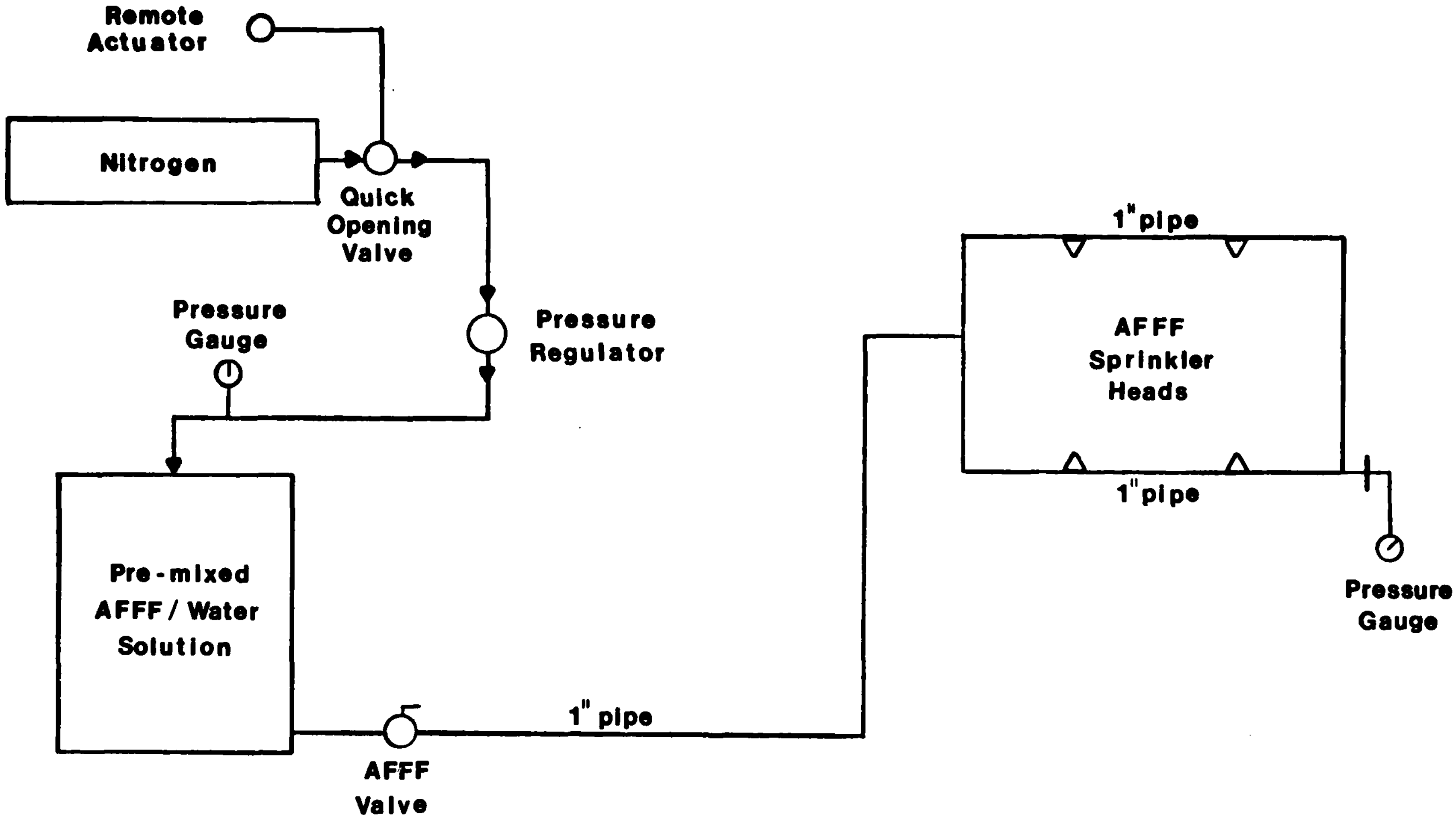


FIGURE 2 - General AFFF System Layout

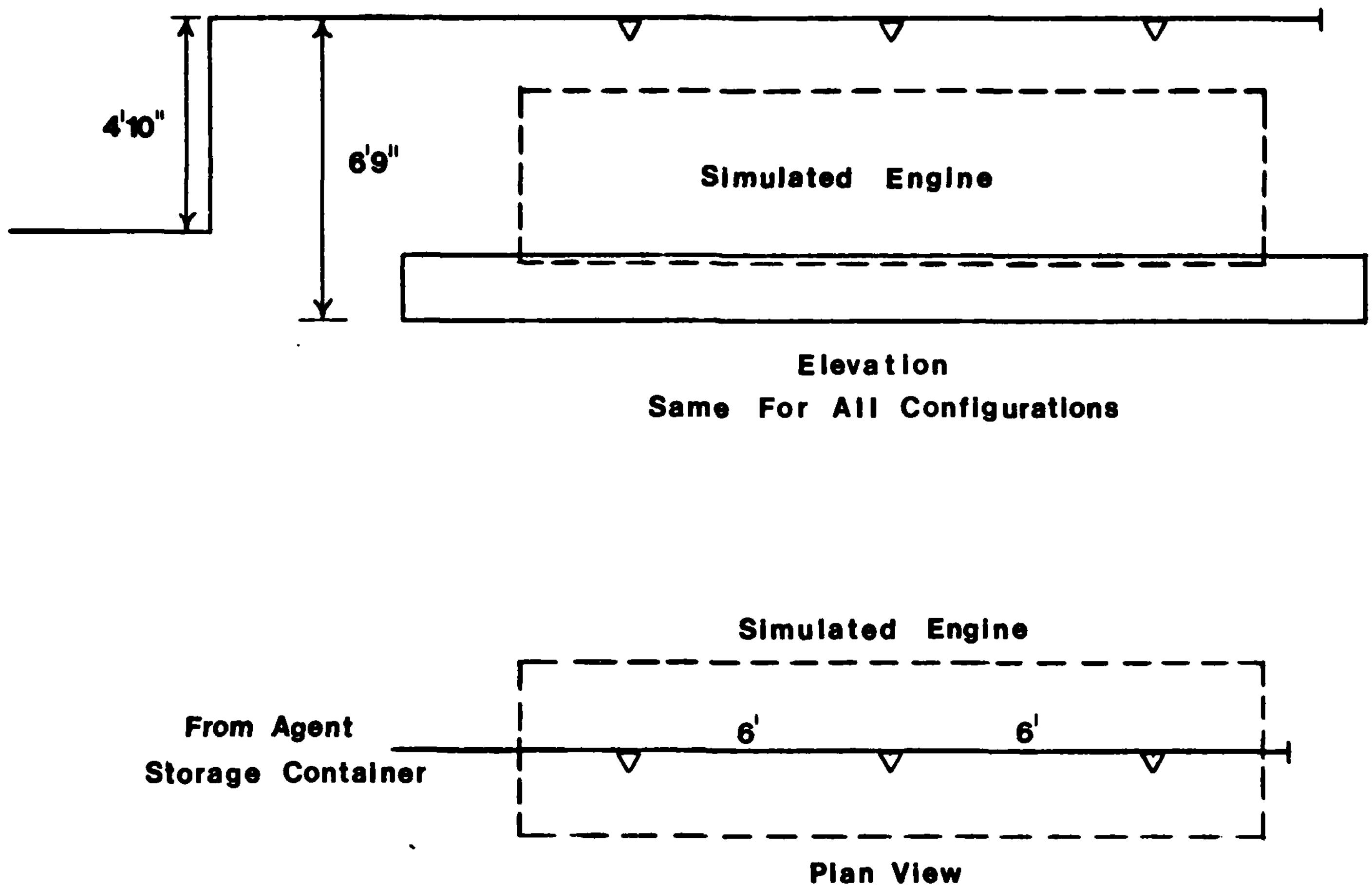


FIGURE 3 - AFFF Sprinkler System Piping and Head Arrangement
Configuration A - Tests 1,2,3

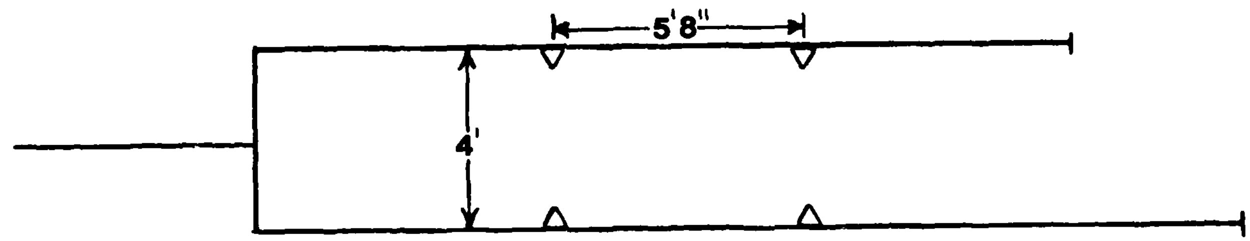


FIGURE 4 - AFFF Sprinkler Piping and Head Arrangement
Configuration B - Tests 4,5,6

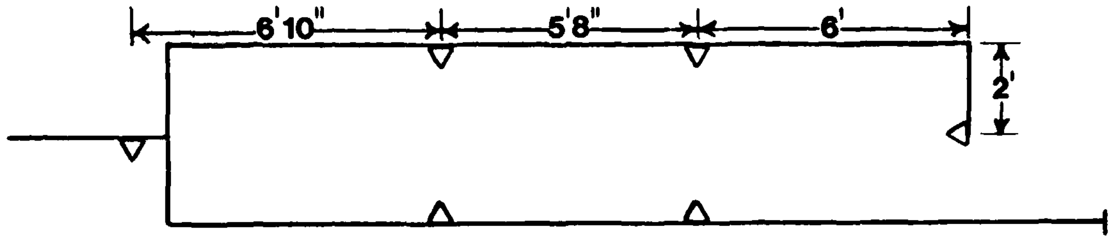


FIGURE 5 - AFFF Sprinkler System Piping and Head Arrangement
Configuration C - Tests 7,8,9

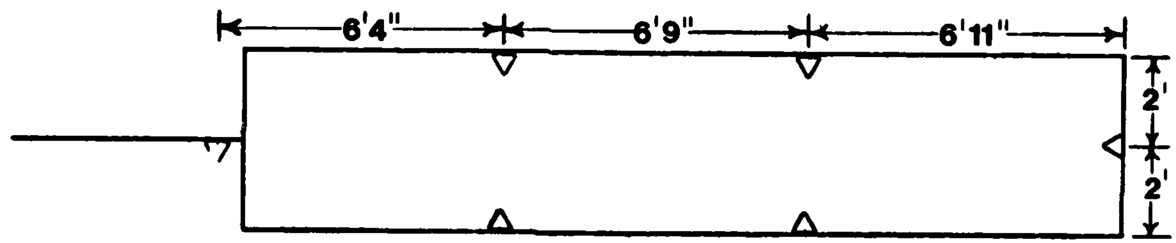


FIGURE 6 - AFFF Sprinkler System Piping and Head Arrangement
Configuration D - Tests 10 - 18

TEST	CONFIG.	NOZZLE TYPE & NUMBER USED ( )	AGENT TANK SIZE	TIME (SEC.) T_c	T_x	T_s
1	A	B-1 (3) Air Aspirating	50	10	21	36
2	A	NF 20015 (3)	50	18	26	36
3	A	NF 20015 (3)	50	15	35	36
4	B	NF 20090 (4)	50	12	22	37
5	B	TF 24XPN (4) Cone Pattern	50	14	45#	38
6	B	NF 200120 (4)	50	7	26	38
7	C	NF 20015 (2) NF 200120 (4)	50	6	20	31
8	C	NF 20080 (2) NF 200120 (4)	50	7	22	30
9	C	NF 20080 (2) NF 200120 (4)	50	12	22	34
10	D	NF 20080 (2) NF 200120 (4)	50	9	19	34
11	D	NF 20080 (2) NF 20090 (4)	50	5	18	34
12	D	NF 20080 (2) NF 200120 (4)	50	5	19	34
13	D	NF 20080 (2) NF 20090 (4)	30	6	39#	22
14	D	NF 20080 (2) NF 20090 (4)	50	7	19	30
15	D	NF 20080 (2) NF 20090 (4)	30	6	15	18
16	D	NF 20080 (2) NF 20090 (4)	30	7	22	23
17	D	NF 20080 (2) NF 20090 (4)	30	5	19#	18
18	D	NF 20080 (2) NF 20090 (4)	50	6	22	32

Fire 98% out within time system was exhausted (T_s); agent flow over surface extinguished completely at T_x

FIGURE 7 - Test Data

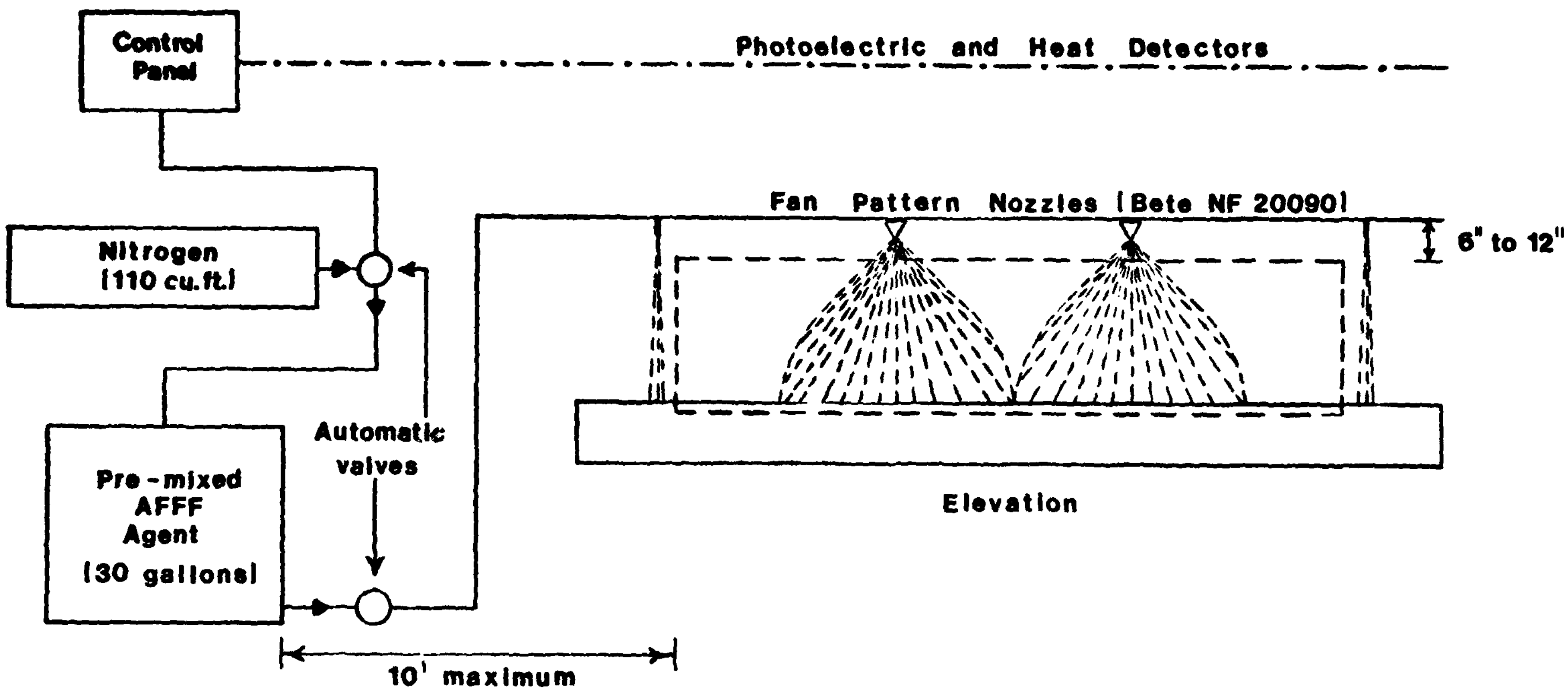
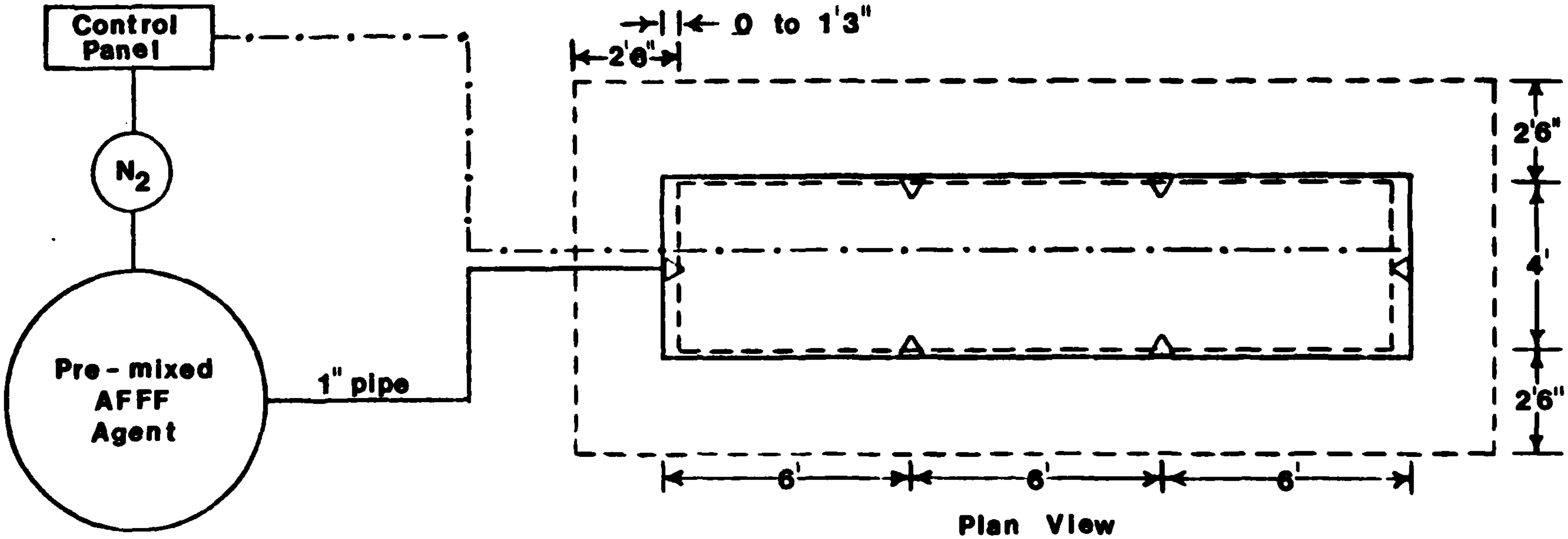


FIGURE 8 - General Recommended System, Elevation View



Dimensions based on test
set-up: "engine" 4' x 17'
"bilge" 9' x 22'

FIGURE 9 - General Recommended System, Plan View

Test 17 Preburn, 10 sec. after surface fully ignited

FIGURE 10

Test 17 System Operating, 3 sec. after system actuation

FIGURE 11

Test 15 Preburn

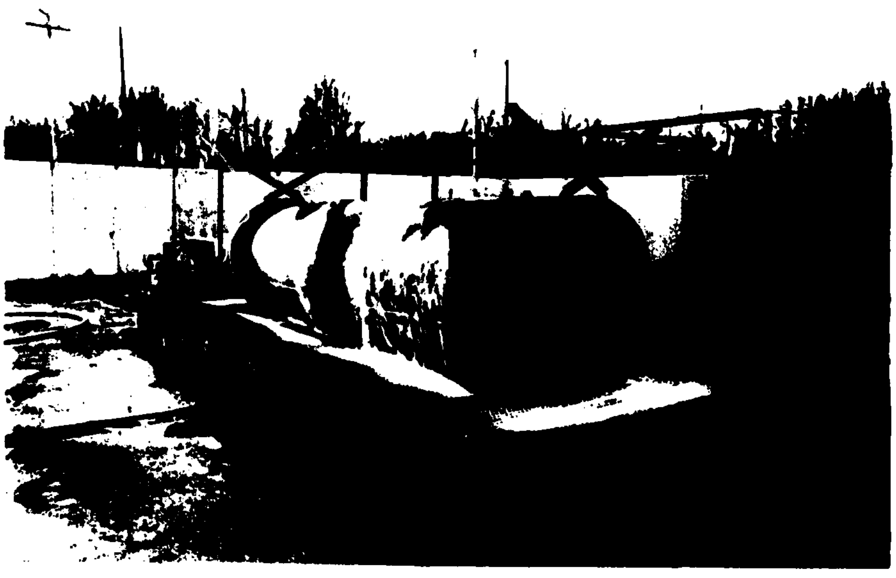
FIGURE 12

Test 15 System Operating, 3 sec. after system actuation

FIGURE 13

Configuration D - Nozzle Flowing, Note Fan
Shaped Discharge Pattern

FIGURE 14



Configuration D - Arrangement of Bilge, Tank
Piping, 6 Nozzles, Agent Storage and Nitrogen Supply
Foam Residue on Tank and Grate after test

FIGURE 15

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