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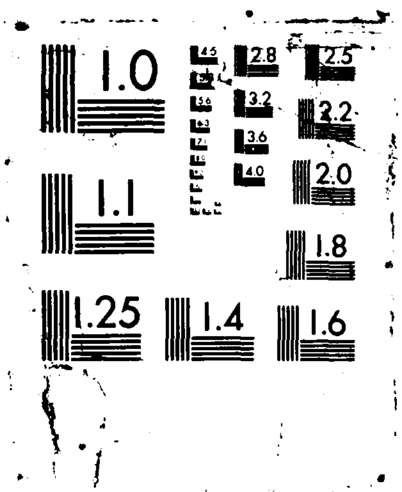
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EXTINGUISHING AGENT FOR MAGNESIUM FIRE: PHASES V AND VI

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This report documents the validation testing of the extinguishing system for metal fires developed as part of Phases I-IV. The results of this validation testing form the basis of information from which draft military specifications necessary to procure the agent and the agent delivery system may be developed. The developed system was tested against a variety of large-scale metal fire scenarios and the capabilities of the system assessed. In addition the response of the system to storage and to changes in ambient conditions was tested. Results of this testing revealed that the developed system represented a reliable metal fire extinguishing system that could control and extinguish very large metal fires. The specifications developed for the agent and for the delivery system are discussed in detail.

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PREFACE

This report was prepared by the New Mexico Engineering Research Institute (NMERI), University of New Mexico, Campus Box 25, Albuquerque, New Mexico 87131, under contract F29601-84-C-0080 (Subtask 3.07 "Extinguishing Agent for Magnesium Fire"), for the Engineering and Services Laboratory, Air Force Engineering and Services Center, Tyndall Air Force Base Florida 32403, and the Naval Air Systems Command, HQ NAVAIR, Washington, DC 20361.

Mr. Bryce Mason was the project officer for HQ AFESC/RDCF and Ms. Phyllis Campbell was the project officer for NAVAIR. This report summarizes work done between 14 December 1985 and 30 September 1986. This report was submitted for publication on 30 December 1986. The material reported herein represents a continuation of the effort described in ESL-TR-86-17, **Extinguishing Agent for Magnesium Fire: Phases I-IV.**

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

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Chief, Engineering Research Division

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SECTION I

INTRODUCTION

The final report for Phases I-IV on Extinguishing Agents for Magnesium Fires (Reference 1) describes the development of an extinguishing system for metal fires. The system is comprised of two major components: the agent and the agent delivery system. The agent recommended for use in the extinguishment of metal fires is a nonaqueous fire extinguishing agent, composed of the liquid boron-type fire extinguishing agent, trimethoxyboroxine (TMB), and the halogenated hydrocarbon type fire extinguishing agent, bromochlorodifluoromethane (Halon 1211). The agent delivery system consists of a 40-gallon (151.4-liter)-capacity agent tank and appropriate valves, rupture discs, agent discharge hose, nozzle, and nitrogen propellant system. The agent is placed inside the agent tank and isolated from the ambient air and moisture through the use of appropriate valves and rupture discs. The current effort involves the validation testing of the developed system (Phase V) and the development of a draft system specification (Phase VI).

A. OBJECTIVE

The objective of this effort is to perform validation testing of the TMB/Halon metal fire extinguishing system developed in Phases I-IV of this subtask.

B. BACKGROUND

Trimethoxyboroxine (TMB) has been found to be the most effective Class D fire extinguishing agent for general configuration metal fires (Reference 1). TMB does have the following limitations:

1. Because TMB is a flammable liquid, it produces a secondary Class B fire during extinguishment of Class D fires. The secondary fire is due, at least in part, to the release of methanol during the thermal decomposition of TMB.

2. It is susceptible to hydrolysis, which produces a precipitate that can interfere with the delivery system by plugging nozzles and valves. When

TMB was used by the United States Navy, the extinguishers developed for the agent (Reference 2) required an extensive amount of maintenance and even then were unreliable. Even slow TMB leaks or seepage past the main release valve of the converted 2.5-gallon stored pressure water extinguisher produced a crystalline deposit in the valve throat. This deposit restricted or prevented the release of the agenct, even when the pressure gage showed a full charge. Consequently, the extinguisher and valve mechanism had to be disassembled frequently and deposits cleaned out of the valve. Even after its mechanism had been reassembled, one could not be certain that the extinguisher would work a day or a week later.

3. On open-air aging or at low temperatures, TMB may exhibit unacceptably high viscosities.

4. TMB degrades certain polymeric materials.

5. It is relatively expensive [$10.47/kg ($4.75/lb) for industrial grade].

As reported in Reference 1, the reformulation of TMB and the development of an improved delivery system have solved many of the problems associated with the use of TMB as an extinguishing agent for Class D metal fires.

The addition of halogenated hydrocarbons, specifically halons, reduces or eliminates the problems associated with aging, low temperature viscosity, and flammability; and, depending upon the formulation, reduces the average cost of materials. A thorough investigation (Reference 1) found that the formulation which yielded the best overall improvement in physical properties without decreasing the effectiveness of the TMB is a mixture of 30 percent by volume Halon 1211 and 70 percent by volume TMB. This modified agent is referred to as Boralon-1-30V. Boralon is a term coined by investigators which is used to simplify the nomenclature associated with the deveoped agent. This nomenclature is explained fully in Section II.

Although the addition of halon improves on the physical characteristics of TMB, there are still problems associated with hydrolysis and agent incompatibility with nonmetalic materials. The development of a delivery system, such as that described in Reference 1 assures a high degree of reliability for agent use. A stored pressure system such as developed previously (Reference 2) forces the agent against valves and seats which will ultimately degrade and allow agent hydrolysis. The developed delivery system is externally pressurized, and agent contact with valves is minimized. In the developed system rupture discs are used at critical locations to isolate the agent from air and moisture during storage while not restricting flow during use. Every effort has been made in the development of the system (agent plus delivery system) to assure that once the delivery system is properly filled with agent the system will remain reliable with minimum maintenance for a 5-year period.

C. SCOPE

The scope of this task involves the operational validation testing of a TMB/Halon metal fire extinguishing system which has recently been developed. The final product of this effort will be a technical report detailing all work accomplished, conclusions, recommendations, and a draft specification to procure the metal fire extinguishing system.

SECTION II
TEST DESCRIPTION

A. TECHNICAL REQUIREMENTS

Tests were to be conducted to optimize and validate the fire extinguishing system performance. Tests were conducted regarding the optimization of application rates, throw range, throw pattern, nozzle design, and compatibility with other agents which might be used for extinguishment of either the metal fire or the hydrocarbon fuel fire.

Tests were also conducted relating to the reliability of the metal fire extinguishing system. Tests were conducted regarding system aging, system response to in-service stress due to handling and transporting the system, agent and delivery system components compatibility, and effects of extremes in ambient conditions on the system. Small scale prototypes or models were used to test some of these variables.

Based on the data collected in Phase V, draft military specifications were developed in Phase VI for the agent and for the delivery system. These specifications include information on agent compatibility, delivery system performance, and system reliability.

1. Problem Approach

To fulfill the technical requirements for Phase V of this effort a two-phase approach to the problem was pursued. In the first (field) phase additional prototypes were constructed to test throw range, throw pattern, nozzle design, and application rates. Initial tests were accomplished using a less expensive agent which modeled the properties of Boralon-1-30V. Based on these tests a nozzle was chosen which gave the best agent application. A series of large-scale fire tests were conducted modeling various scenarios to determine the effectiveness of the system and assess the limitations of the system. An additional prototype was filled with agent and mounted on a truck to assess the effects of aging and in-service stress on the delivery system and on agent effectiveness. In addition, the compatibility of the agent with other agents which might be used for the metal or liquid-fuel fire was evaluated.

In the second (laboratory) phase tests were conducted to evaluate the physical and chemical characteristics of the agent. The agent was subjected to freeze/thaw cycles and low-temperature viscosities determined to obtain information relating to the storage and use requirements of the agent. Agent and delivery system component compatibility tests were conducted to evaluate adverse effects of agent/hose material contact. The effects of extremes in ambient conditions were assessed. In addition room-temperature properties of vapor pressure, density, and viscosity were determined for the agent.

The results of the tests conducted in Phase V of this study, which are documented in Section III-VI of this report, form the base of information from which a system specification may be developed. The development of the draft military specifications necessary to describe and acquire the agent and the agent delivery system is described in Section VII. The Draft Military Specification for the "Fire Extinguishing Agent, Modified Boron Type, For Metal Fires" is contained in Appendix A; the Draft Military Specification for the "Agent Delivery System For Use With Modified Boron Type Fire Extinguishing Agent For Metal Fires" is contained in Appendix B.

B. NOMENCLATURE

Halons are halogenated hydrocarbons. When used generically, the word "halon" remains uncapitalized; however, when used as part of a designation for a specific compound, e.g., Halon 1211 or Halon 2402, it is capitalized.

Much of the work reported in this report covers mixtures of TMB with halons. Present nomenclature--for example, "90 percent TMB with 10 percent Halon 2402, by volume"--is cumbersome. In the following material and in the future reports from this laboratory, the designation "Boralon-1" and "Boralon-2" will be used to name TMB/Halon 1211 and TMB/Halon 2402 mixtures, respectively. The composition will be added as, e.g., 10V or 20W to denote the volume (V) or weight (W) percent of halon in the mixture. Thus, "Boralon-1-30V" is the designation for a mixture containing 30 percent Halon 1211 and 70 percent TMB by volume. It is important to distinguish carefully between weight and volume bases for the TMB/halon mixtures. Because of the large densities of most halons, the differences between weight and volume percentages are significant. The amount of Halon 2402 in Boralon-2-10V is 10 percent by volume but 16 percent by weight.

C. SYSTEM DESCRIPTION

The fire extinguishing system is composed of two parts: The first is the agent Boralon-1-30V. The second part is the agent delivery system. In Phases I and II, TMB was found to be the only agent which could effectively extinguish metal fires in both horizontal and vertical configurations. Other agents tested proved effective only on horizontal magnesium fires. TMB exhibits some adverse properties--primarily its flammability and poor aging characteristics. It was discovered in the Phase II effort that the addition of halons greatly decreases the flammability and improves certain other characteristics. In Phase III, Boralon-1-30V, a mixture containing 70 percent TMB and 30 percent Halon 1211 by volume, was shown to be a superior agent to all other agents tested against fires containing JP-4, JP-5, aluminum, and/or titanium in addition to magnesium. In Phase IV an agent delivery system was designed and a prototype constructed; final full-scale testing of Boralon-1-30V was performed.

The agent delivery system was designed to overcome two problems which still exist with Boralon-1-30V. First, if allowed to sit in the open air, this agent will hydrolyze, lose volatiles, and become viscous. The presence of Halon 1211 decreases the tendency toward these adverse characteristics; nevertheless, Boralon-1-30V, like all other boralon agents, will become too viscous to use if it is allowed to sit in the open. Second, Boralon-1-30V, like all other boralon agents, attacks most plastics and elastomers. The agent must be kept out of contact with such materials. Any elastomers used should be of a chemical-resistant type.

To eliminate the hydrolysis and aging problem, a sealed system was chosen for the agent. This system contains a nickel diaphragm rated at 1165 kPa (169 lb/in^2) that isolates the agent from ambient air. When a pressure of 1379 kPa (200 lb/in^2) is applied from an external nitrogen cylinder, the diaphragm ruptures, dispensing the Boralon-1-30V. The dimensions of the horizontal 151.4-liter (40-gallon) ASME code tank used in this extinguishing system is 463.6 millimeters (18.25 inches) in diameter by 1077 millimeters (42.4 inches) long. The length includes the domed end caps. The shell length--the length disregarding the end caps--is 838.2 millimeters (33-inches). The tank is rated at 1379-kPa (200-lb/in) working pressure. The system contains a 25.4-millimeter (1-inch) Schedule 80 dip tube, a 12.7-millimeter (0.5-inch) nitrogen inlet port, a nitrogen cylinder connected to the main tank by a steel braided line and isolated from the tank by a nickel diaphragm rated at 689.4 kPa (100 lb/in), a 1379-kPa (200-lb/in) fixed-pressure regulator, a 25.4-millimeter (1-inch) chemical firehose, a brass shutoff with nozzle, and a 25.4-millimeter (1-inch) union rupture disk at the top of the dip tube. A concept drawing of the system is shown in Figure 1.

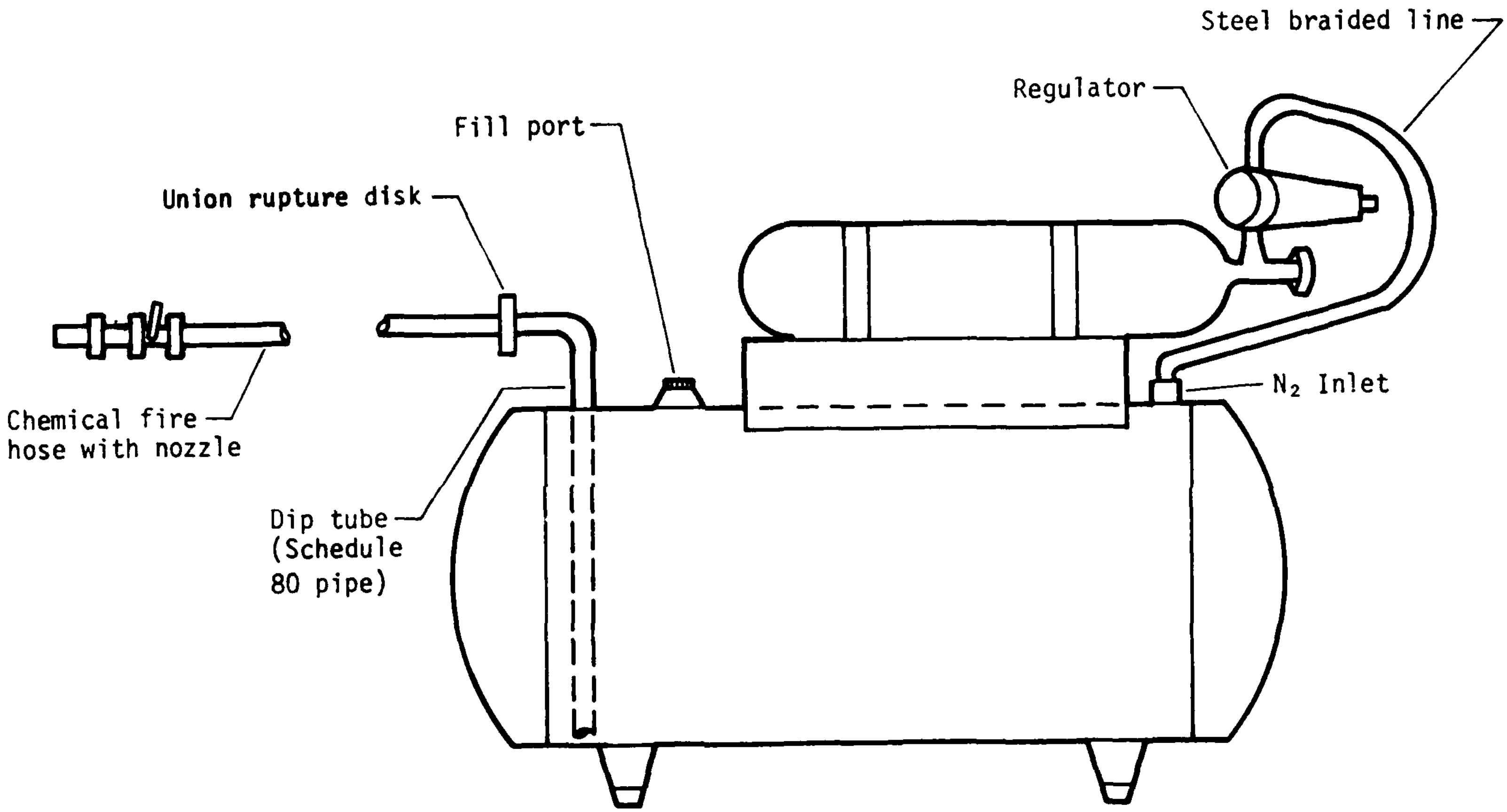

Figure 1. Concept Drawing of Agent Delivery System.

SECTION III
AGENT APPLICATION

Tests were conducted as part of the Phase V effort relating to agent application. Tests were conducted to quantify/optimize application rate, throw range, throw pattern, and nozzle design. To best obtain the desired information, the application rate, throw range, and throw pattern were determined as a function of nozzle design. In addition, calculations of flow parameters were done, based on the agents physical properties.

Because of previous difficulties encountered when boralon agents have been applied using nozzles with restrictive orifices, the recommendation was made in the Phase I-IV report (Reference 1) that only simple nozzles without such restrictive orifices be used with the boralon agents. This recommendation would rule out the use of most water of Aqueous Film-Forming hand-line nozzles, because of the baffle construction used to control the flow and spray pattern. Because of the above contraints, the nozzles considered for use with the extinguishing system were brass, straight-bore, plain-tip, nozzles. This type of nozzle would be expected to give the greatest throw range with no restrictive orifices. Nozzles with diameters ranging from 7.92 millimeters (0.312-inches) to 15.9 millimeters (0.625-inches) were used.

To conserve limited project funds, flow tests for the optimization of nozzle diameter, throw range, and application rate were conducted, using a fluid modeling the flow properties of Boralon-1-30V. The fluid used was water with hydroxypropyl methylcellulose added to increase the viscosity to that of the Boralon-1-30V agent. By using this alternate fluid, a larger number of flow tests were conducted at a savings of approximately $21,000.

Based on the results of these flow tests, a choice of nozzle may be made for the extinguishing system. The throw range, throw pattern, and application rate can then be quantified using Boralon-1-30V.

A. INITIAL FLOW TESTS

Initial flow tests were conducted using water with hydroxypropyl methylcellulose added to increase the viscosity. The target viscosity was chosen so that the ratio of density to viscosity was 0.093. The viscosity of Boralon-1-30V was taken to be that reported in the Phases I-IV report of 15 cP (Reference 1) while the density was determined as a result of this effort (Section V) to be 1.4 g/mL. This would result in a target viscosity of 12 cP for the hydroxypropyl methylcellulose-modified water. To attain this viscosity, 700 grams of Dow Mehtocel (Type E) were added to 189.2 liters (50 gallons) of water, along with 35 milliliters of ammonium hydroxide; the resulting solution was mixed well. The viscosity of the resulting solution was determined to be 13 cP at 21 °C, using a Brookfield viscometer.

The 151.4-liter (40-gallon) tank of the extinguishing system was filled with 121.12 liters (32 gallons) of modified water (water modified with hydroxypropyl methylcellulose); this resulted in an 80-percent fill ratio. The agent was discharged with 1379 kPa (200 lb/in) constant pressure through the extinguishing system described previously. The nozzle was secured to a test stand during flow test so that operator control was not a factor. The direction and angle of inclination were controlled externally in such a way that the maximum possible throw range was attained. The flow tests were conducted in winds of less that 8.04 km/h (5 mi/h) however, variation in throw range occured as the result of even light wind conditions. The results of these flow tests are contained in Table 1.

The data contained in Table 1 point out two trends. First, the maximum throw range does not vary to any significant extent with increasing mozzle diameter. Second, the increase in flow rate with increasing nozzle diameter plateaus above a nozzle diameter of 11.25 millimeters (0.438 inches). Flow calculations show that for the application rates observed for the 7.92-9.52, and 11.1 millimeter (o.312-, 0.375-, and 0.438-inch) nozzles, the exit velocities are similar (Table 2). The results of flow calculations reported in Table 2 will be explained later in this section). For nozzles producing similar fluid streams, the exit velocity is the determining component for throw range. That the exit velocities are similar partially explains the independence of nozzle diameter on throw range. The plateau in flow rate is probably caused by the inability of the constant nitrogen flow to keep up with the highter flow rates.

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TABLE 1. RESULTS OF INITIAL FLOW TESTS

Nozzle diameter, inches	Maximum throw, feet	Discharge time, seconds	Flow rate, lb/s
0.312	60	66	4.1
	90	[a]80	3.3
	75	67	4.0
0.375	80	50	5.3
	90	50	5.3
	70	[b]70	4.6
0.438	70	36	7.4
	60	30	7.9
	70	41	6.6
0.5	105	36	7.4
	85	34	7.8
	85	35	7.6
0.625	65	35	7.6
	70	34	7.8
	90	33	8.1

[a]Nitrogen cylinder ran out during testing resulting in long discharge time.

[b]Tank was overfilled.

TABLE 2. NOZZLE EXIT VELOCITY VERSUS FLOW RATE CALCULATED FOR EXTINGUISHING SYSTEM[a]

Flow Rate, lb/s	Nozzle exit velocity, ft/s				
	Nozzle diameter, inches				
	0.312	0.375	0.438	0.5	0.625
1	24.74	17.19	12.68	9.70	9.19
2	49.39	34.32	25.31	19.35	12.36
3	74.13	51.52	37.99	29.05	18.55
4	98.77	68.64	50.62	38.71	24.72
5	123.52	85.84	63.30	48.41	30.91
6	188.16	102.96	75.93	58.07	37.08
7	172.91	120.16	88.61	67.76	43.27
8	197.55	137.28	101.24	77.42	49.43

[a]Based on a 10-cP fluid.

To assess throw patterns 228.6-millimeter (9-inch) square catch pans were placed at 3.04-meter (10-foot) intervals for 30.4 meters (100 feet), and 3.04 meters (10 feet) on either side of the 12.2-meter (40-foot) marker. It was found from the results of these tests that with the nozzle at a 10-degree angle to horizontal all of the agent fell between 6.08 meters (20 feet) and the maximum throw distance with the majority of the agent falling between 12.2 meters and 18.2 meters (40 and 60 feet). In addition, little agent was found in the pans placed 3.04 meters (10 feet) on either side of the 12.2-meter (40-foot) marker and visual observation revealed that the discharge angle was approximately 20 degrees. It was also observed that the discharge pattern varied little with nozzle diameter.

To make an appropriate choice of nozzle diameter for the extinguishing system, the tradeoff between application rate and discharge time must be considered for two reasons. The first reason is that there is no appreciable difference in throw range as a function of nozzle diameter for the nozzles tested. The second reason is that the suggested method of application of the Boralon-1-30V agent is in short bursts, allowing the agent to coat the metal surface, with intermittent cooling of the metal using water or AFFF. Because of the second reason it is determined that the most efficient agent-delivery system would allow for a longer discharge time over an increased flow rate. For this reason the recommended nozzle for use with the metal fire extinguishing system is a 7.92-millimeter (0.312-inch) straight-bore, plain-tip nozzle.

B. FINAL FLOW TESTS

Upon completion of the initial flow tests the application parameters of the system were quantified using Boralon-1-30V discharged from the system under a constant pressure of nitrogen of 1379 kPa (200 lb/in). Four discharge tests were done. In the first three tests the nozzle was controlled by an operator and the angle adjusted to attain the maximum distance. In the last test the nozzle was controlled as described previously for the methylcellulose-modified water. The results of these discharge tests are contained in Table 3. Figure 2 shows the discharge pattern that resulted from agent discharge in Test 4.

TABLE 3. RESULTS OF DISCHARGE TESTS FOR BORALON-1-30V AGENT

Test	Discharge rate, lb/s	Throw range, feet	Max. cone width, ft	Wind direction, degree[a]	Wind speed, mi/h
1	N/A[b]	40	N/A[b]	310	7
2	5.47	96	9	180	3
3	6.33	80	19	120	3
4	6.02	70	10	165	5
Average	5.94	[c]82	13		

[a]Measured clockwise from tip of nozzle.

[b]Data not available.

[c]Does not include data from Test 1.

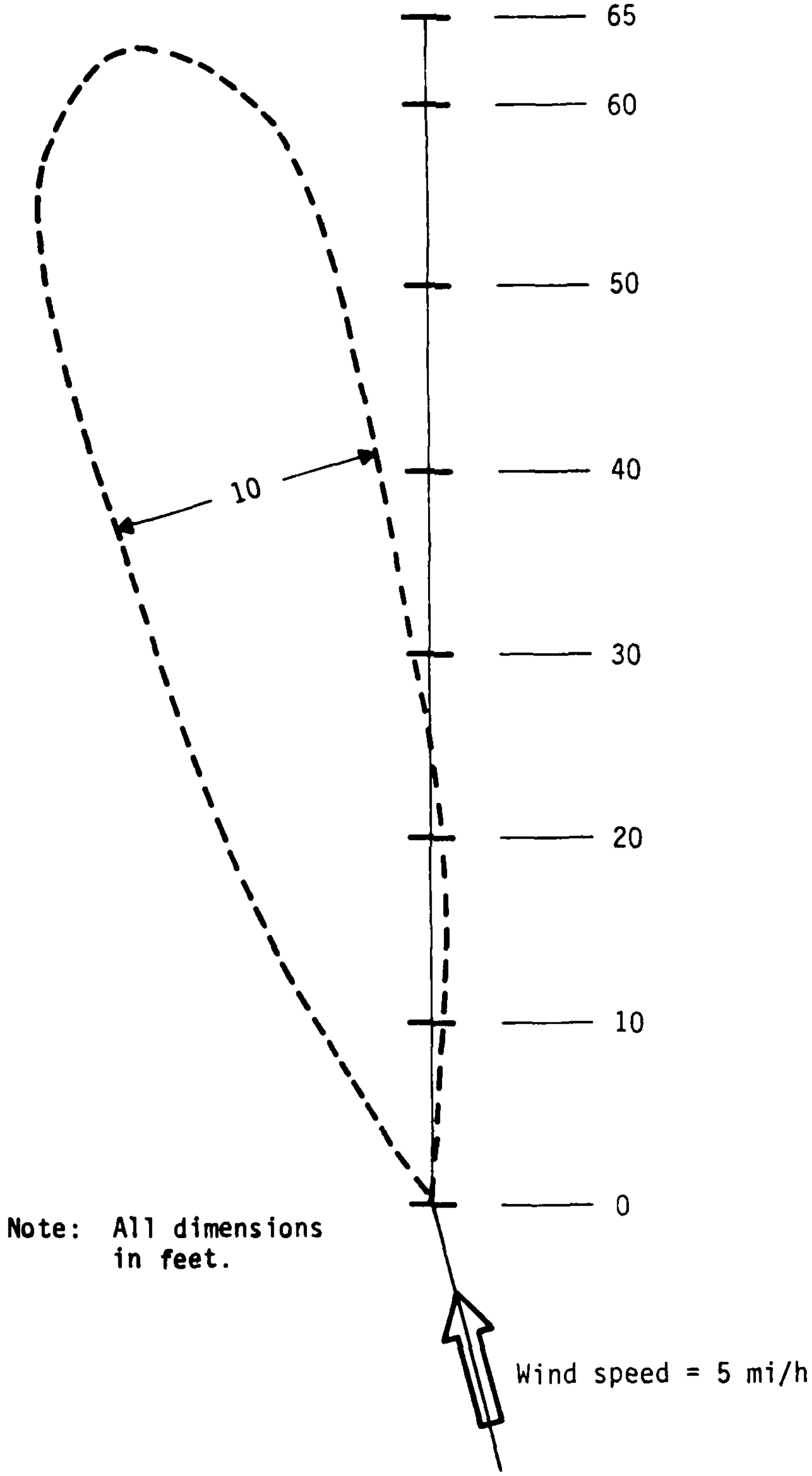

Figure 2. Agent Discharge Pattern.

For the developed system using a 7.92-millimeter (0.312-inch) plain-tip nozzle, an average discharge rate of 2.69 kg/s (5.94 lb/s) with an average throw range of 24.9 meters (82 feet) was observed. The discharge rate observed using Boralon-1-30V was higher than that observed for the modified water. The higher flow rate is because the Boralon-1-30V agent is composed of a gas dissolved in a liquid at room temperature. The resulting complex solution has slightly different properties than the model agent of hydroxypropyl methylcellulose-modified water.

C. FLOW CALCULATIONS

To assess the limits of the system and provide data for final system engineering, design and construction calculations were made of pressure drop as a function of flow rate for the nozzle diameters considered in this study. Additional calculations were carried out to determine pressure drop as a function of flow rate for a series of viscosities. The later calculations were determined to better assess the effects of ambient temperatures on the response of the extinguishing system. All calculations in this section were accomplished in English units, and the results are reported in English units.

1. Effects of Nozzle Diameter on Flow

To better understand the mechanics of the extinguishing system, the pressure drop was calculated as a function of flow rate for a series of nozzle diameters. The calculations were carried out following procedures described in Reference 3. The results of these calculations are shown in Figure 3. The results were obtained for a 10-cP fluid flowing through a 100-foot-long, 1-inch-diameter pipe, attached to an 8-inch nozzle of the stated diameter. The pressure drops through the pipe and nozzle are given by:

$$\Delta P \text{ lb/in}^2 = \frac{f \, \overline{V}^2 \, L \, \rho}{2 \, g_c \, D \, (144)} \qquad (1)$$

where

f is the friction factor
$\bar{V}$ is the average velocity
L is the pipe length
ρ is the fluid density (75.9 lb/ft^3)
g_c is Newton's Law conversion factor -- 32.174 ft-lb mass/ s^2 lbf
D is the diameter of the pipe or nozzle

The sudden constriction of the fluid is taken into account by Equation (2)

$$\Delta P \ (lb/in^2) = \frac{k_c \ \rho \ \bar{V}^2}{2 \ g_c \ (144)} \tag{2}$$

where k_c is a factor for turbulent flow around a sudden constriction. The total pressure drop was calculated as the sum of the pressure drops through the pipe, the nozzle, and around the constriction.

The above described calculations may be used to approximate flow characteristics for the Boralon-1-30V agent. The above calculations are for an ideal fluid; however, Boralon-1-30V is a complex fluid at room temperature and deviations from calculated values under in-service conditions should be expected. The results depicted in Figure 3, as well as the results of calculations contained in Table 2, support the choice of a 0.312-inch-diameter, nozzle for the system. The 0.312-inch nozzle gives the largest velocity component for the flow rates observed in the initial flow tests (98.8 ft/s for the 0.312-inch nozzle compared to 85.8 ft/s for the 0.375-inch nozzle). The velocity component is the determining factor in the throw range; therefore, the choice of the 0.312-inch nozzle represents the most efficient use of the agent, while providing a reliable opening through which the agent may be dispensed without clogging.

2. Effects of Agent Viscosity on Flow

Pressure drops were also calculated as a function of flow rate for several viscosities. The pressure drops were calculated for an ideal fluid

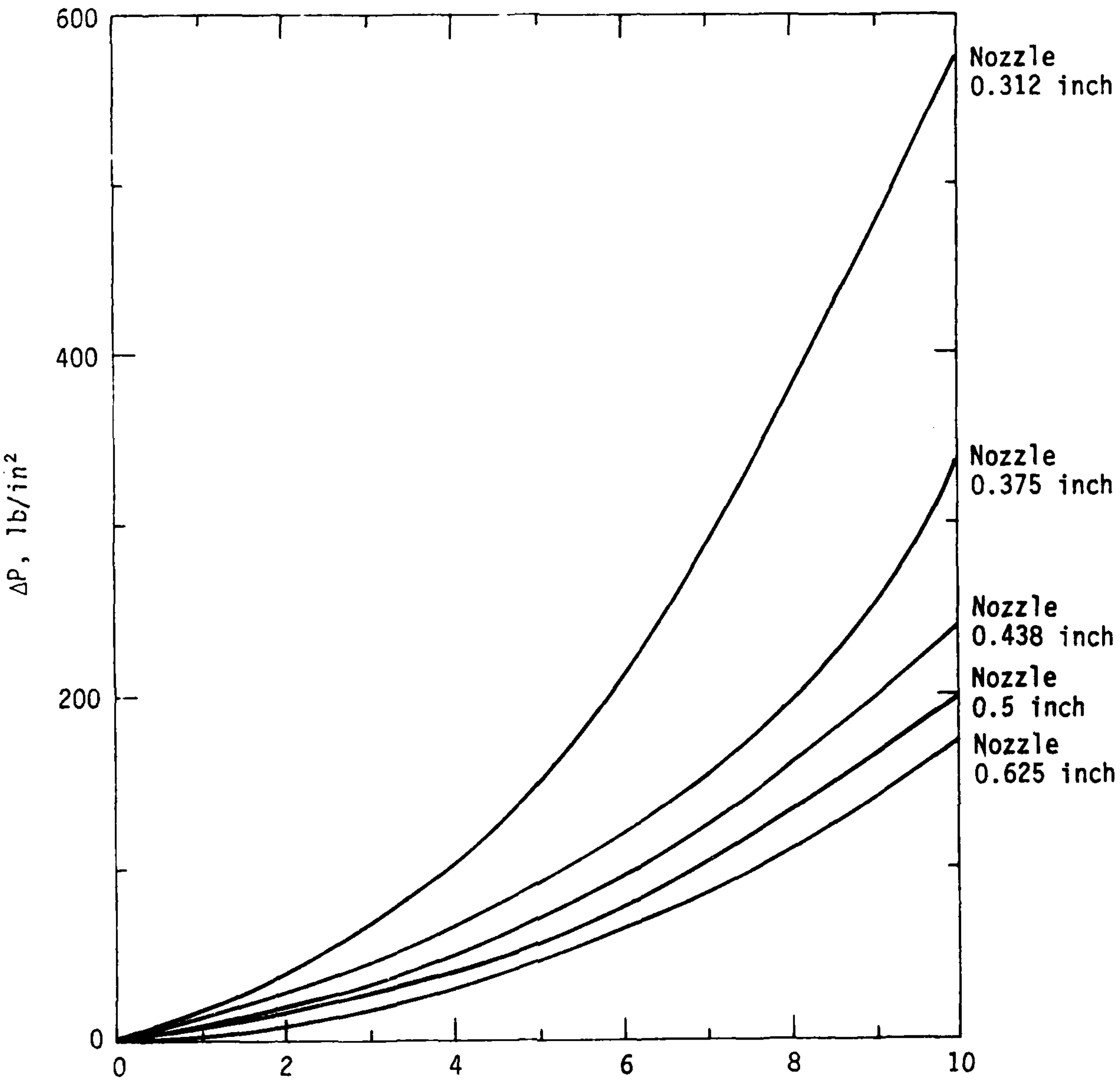

Figure 3. Pressure Drop Versus Flow Rate for Various Nozzle Diameters and a 13-cP Fluid.

flowing through a 100-foot-long, 1-inch-diameter pipe and then through a 0.312-inch-diameter, 8-inch-long nozzle. The flow through the nozzle was assumed to be laminar to simplify the calculations. The results of these calculations are shown in Figures 4-8. The results in Figure 4 show that for a pressure drop of 200 lb/in^2, a theoretical flow rate of 5.4 lb/s should be observed. This flow rate is slightly lower than the 5.9 lb/s flow rate observed for the Boralon-1-30V agent. The method and equations used in these calculations may be used to assess the performance of the delivery system as a function of ambient temperature. The effect of temperature on agent performance is detailed in Section V, but in general the viscosity of the agent increases as the temperature decreases, and this increase in viscosity would result in a decreased flow.

To obtain a viscosity limit for agent performance, a calculation was done to determine a maximum viscosity at which a 4 lb/s flow rate could be maintained by the extinguishing system. The result of this calculation was that a viscosity of 120 cP was the viscosity limit for the delivery system. From the results of this calculation, a temperature limit for use with little decrease in system performance may be determined. This point is discussed further in Section V.

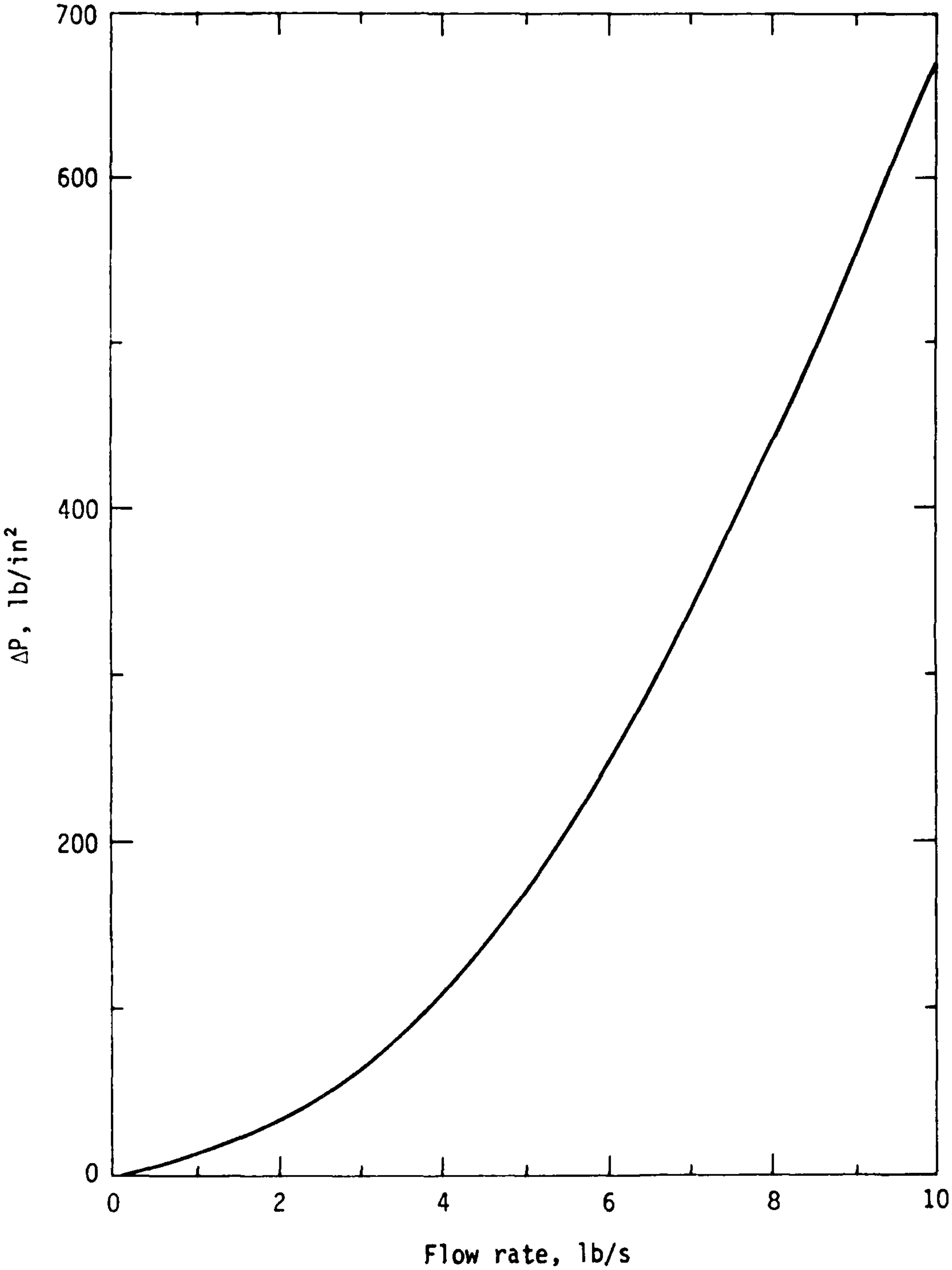

Figure 4. Pressure Drop Versus Flow Rate Calculated for a 10-cP Fluid Flowing Through the Developed System.

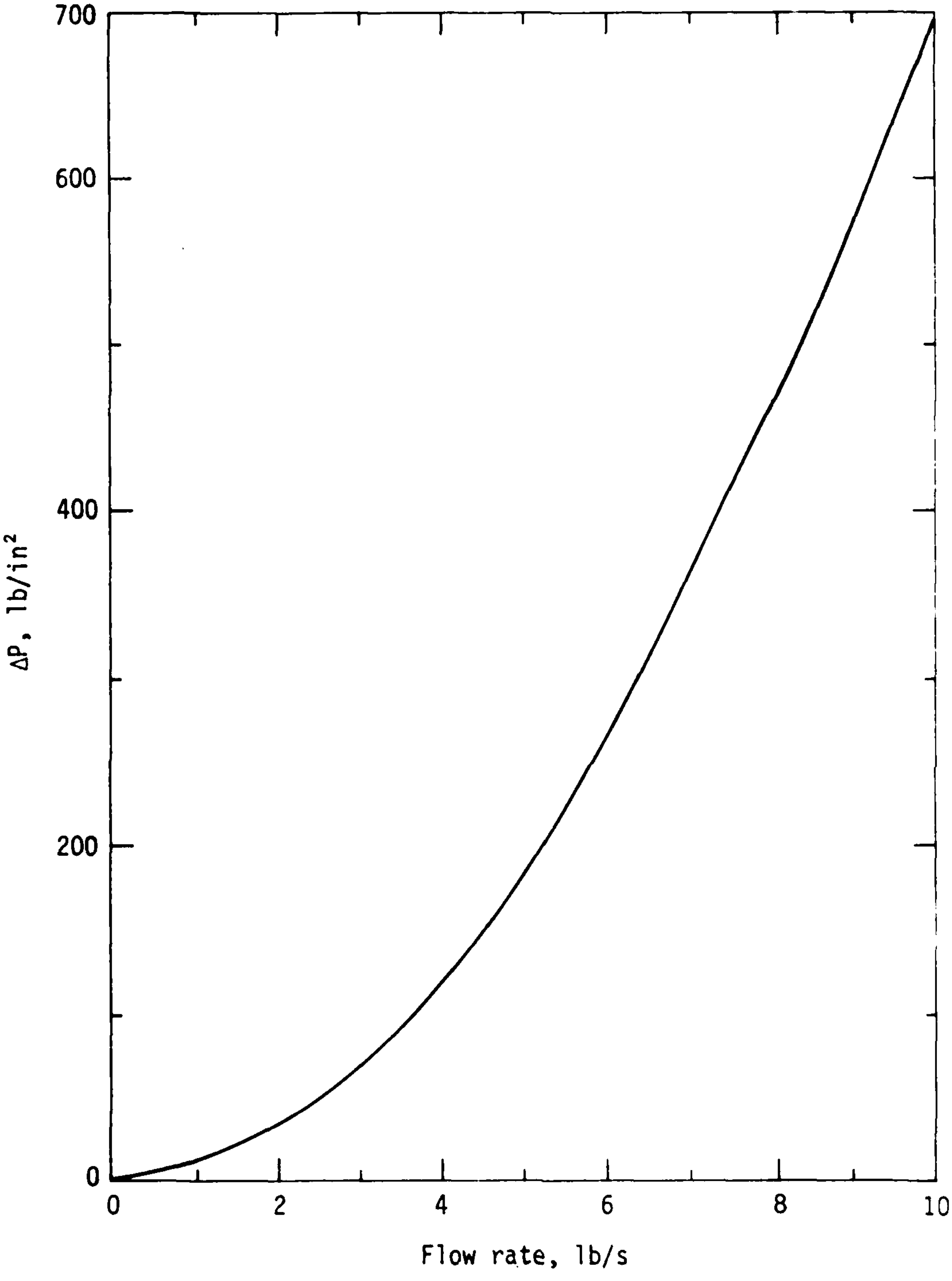

Figure 5. Pressure Drop Versus Flow Rate Calculated for a 20-cP Fluid Flowing Through the Developed System.

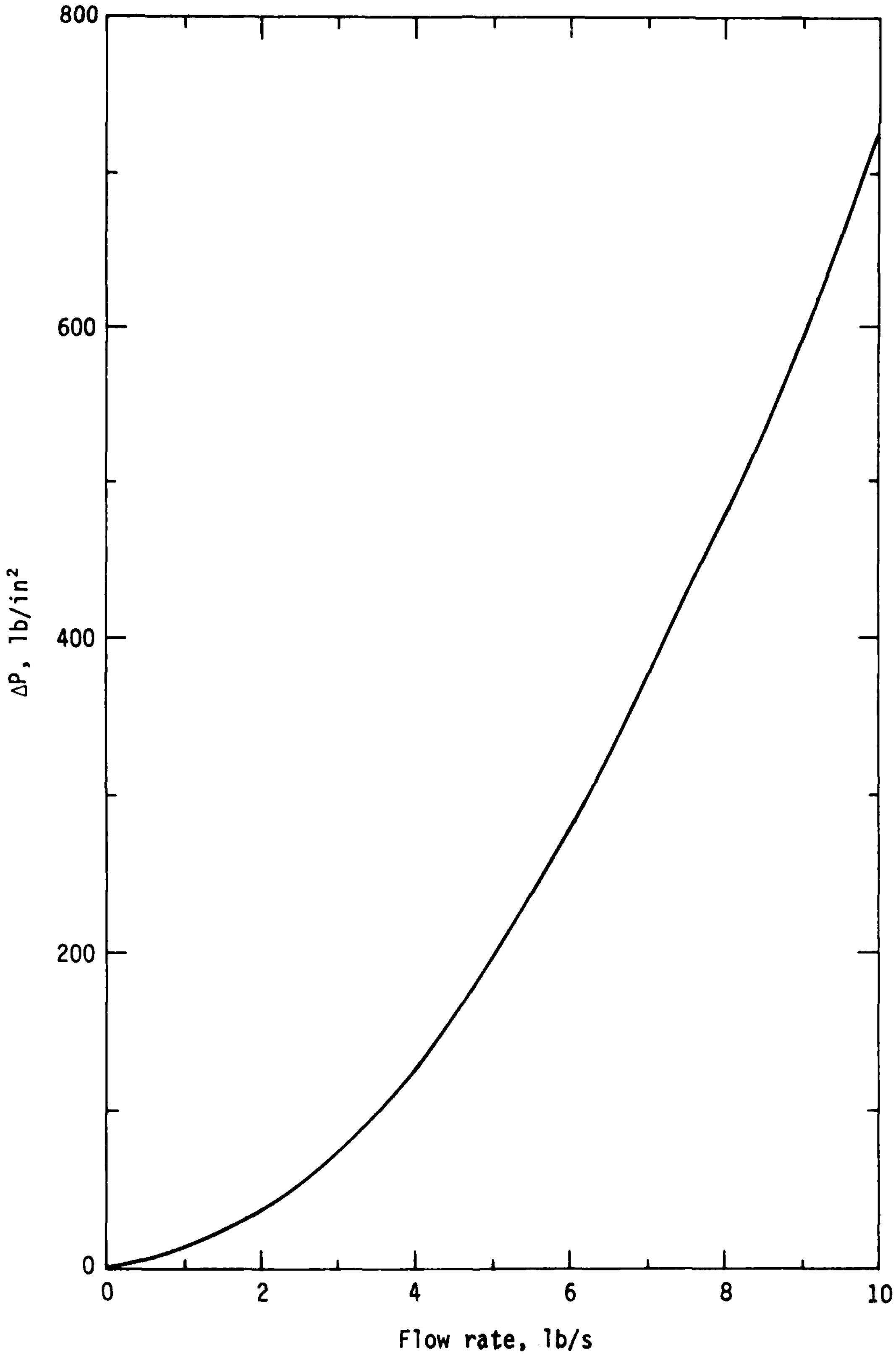

Figure 6. Pressure Drop Versus Flow Rate Calculated for a 30-cP Fluid Flowing Through the Developed System.

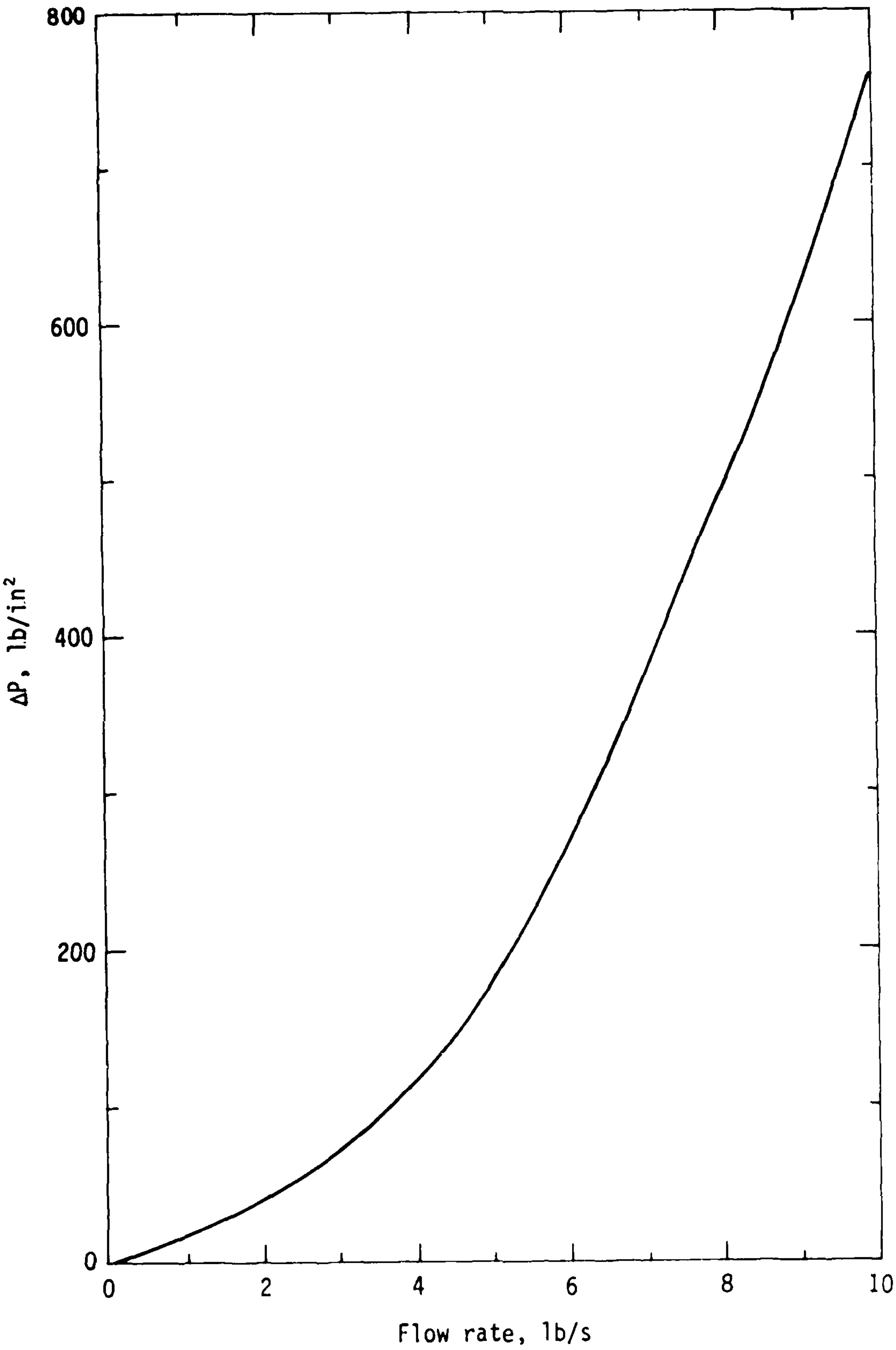

Figure 7. Pressure Drop Versus Flow Rate Calculated for a 40-cP Fluid Flowing Through the Developed System.

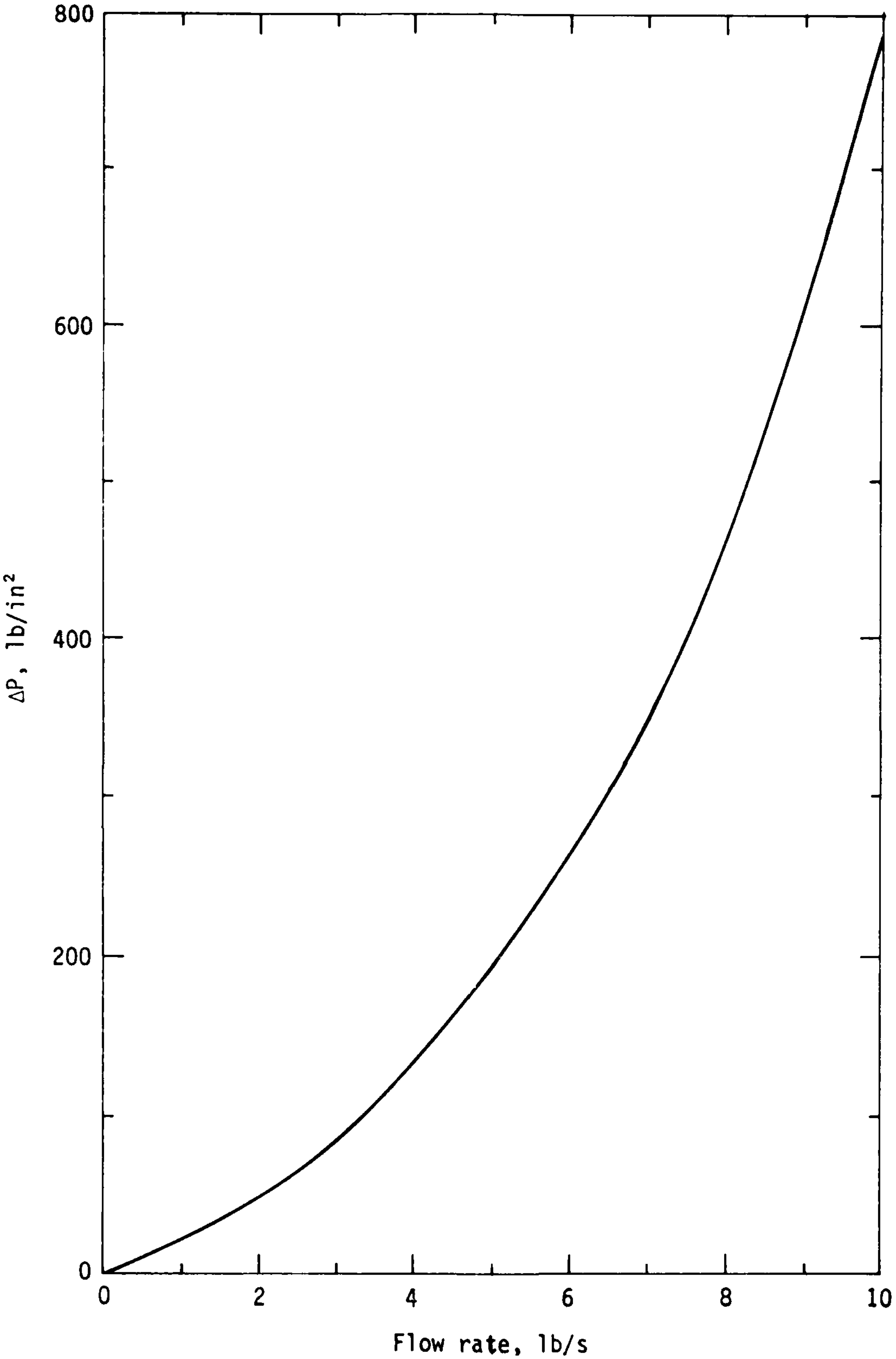

Figure 8. Pressure Drop Versus Flow Rate Calculated for a 50-cP Fluid Flowing Through the Developed System.

SECTION IV
DELIVERY SYSTEM RESPONSE TO IN-SERVICE CONDITIONS

Tests were conducted to assess the effects of in-service conditions on the extinguishing system. These tests included system aging tests and testing of agent compatibility with system components. In addition, an assessment was made of the effects of handling, transporting, and maintaining the system.

A. SYSTEM AGING TEST

To assess the effects of aging on the metal fire extinguishing system, a prototype delivery system was constructed, filled with Boralon-1-30V, weighed, and allowed to age for 124 days. During this time the system was placed on the bed of a truck on which an AFFF and halon system were also placed and used for other testing. The system was subjected to normal vibrations of improved and unimproved road surfaces during this time at speeds between 8.04 km/h and 88.5 km/h (5 and 55 mi/h). During the aging process periodic checks were made of connections to ascertain if any leaks had occurred in the system. During this period, no leaks were found in the system and the system showed no effects due to normal transporting and handling. At the end of the 124 days the system was reweighed and showed no weight loss. The system was then used to successfully extinguish a 90.6-kilogram (200-pound) magnesium fire, the details of which are discussed in Section VI.

B. AGENT/SYSTEM COMPONENT COMPATIBILITY TESTS

In the course of this effort, one of the concerns was the effects of the boralon agents on various materials of construction. Reference 1 contains a detailed analysis of the effects on nonmetalic materials of construction. To ensure the reliability of the system, it was recommended that the amount of plastic or elastomeric material in contact with the agent should be minimized or eliminated. In the proposed system, only two valves are in contact with the Boralon-1-30V agent. One of these valves, which is used for filling, would be in contact with the Boralon-1-30V agent; however, a change in filling procedure could eliminate this valve. The valve as specified would be of stainless steel construction with Teflon seats or packing material and since it is in contact only with the vapor component during storage it would not be expected to deteriorate during the life of the system. The other valve is a pressure-relief valve. This valve should be checked for leaks periodically; however, such valves are currently in use on Halon 1211 systems without any difficulties.

Neither component of the Boralon-1-30V is corrosive to metals if the quality of the materials used in the formulation of the Boralon-1-30V conforms to military specifications (References 4 and 5). Therefore, the Boralon-1-30V, as specified, is not expected to be corrosive to the materials of construction--steel, brass, and nickel. If attention is not paid to the amount of water in the system, then the hydrolysis of either the Halon 1211 or the TMB would have a certain amount of corrosivity to metal components. Significant corrosion of metal components in the agent delivery system is unlikely for two reasons. First, TMB would act as a drying agent toward hydrolysis of Halon 1211, that is, water would degrade the TMB preferentially to the Halon 1211 forming boric acid. Second, if a significant amount of boric acid did form, it is not expected to be any more corrosive than sodium chloride and is probably less corrosive since boric acid does not ionize to the extent that sodium chloride does.

The discharge hose, which is provided as an integral part of the system, represents a critical component of the system that would be in contact with the agent for varying lengths of time. To determine specification requirements for the discharge hose, the compatibility of three hose types with the boralon agents was assessed. The three hoses used in the testing were a chemically resistant hose, a standard fire extinguishing booster hose, and bromochloromethane-resistant hose (MIL-H-7536B).

To determine the compatibility of the hose material with the agent, ASTM test D543-67 was employed. Weight, dimension (length and thickness), and hardness changes were monitored for the three hose materials in contact with TMB, Boralon-2-10V, and Boralon-1-30V. Hardness was determined by using a Type A durometer. The hoses were cut into 1-inch lengths and each length was cut into thirds. One corner of each piece was scribed with an "x" for reference in order to compare before and after measurements. Three samples of each hose material were tested with each agent. The hose materials were allowed to sit for 62 days. Single measurements of weight, length, and thickness and multiple measurements of hardness (three locations) were performed on each sample before and after aging. A separate closed container was used for each sample tested. The results are given in Table 4.

The results show that the bromochloromethane-resistant hose is less susceptible to changes in hardness then the chemical-resistant hose or the booster hose. The bromochloromethane-resistant hose was more susceptible to swelling than the other two hoses tested, with the chemical-resistant hose being the least resistant to swelling. In all cases Boralon-1-30V showed the greatest tendency to harden the hose material while showing the least tendency to swell the hose material. The testing did not point toward incompatibility between any of the hose materials tested and the boralon agents. Based on the results of this study any chemical-resistant discharge hose with a sufficient pressure rating should be compatible with the developed system.

TABLE 4. PROPERTY CHANGES FOR HOSE MATERIALS IN CONTACT WITH BORALON AGENTS[a]

Hose[b]/Agent[c]	Hardness change[d]	Change, percent		
		Weight	Length	Thickness
1/B-0	5.44(279)	2.6(2)	1.2(6)	3.5(21)
1/B-1	16.67(185)	-1.3(4)	-1.0(4)	0.5(21)
1/B-2	6.66(185)	3.6(3)	0.9(4)	2.3(24)
2/B-0	4.56(119)	0.9(1)	0.6(7)	-0.8(9)
2/B-1	17.89(143)	-7.3(3)	-1.3(15)	-5.2(6)
2/B-2	7.56(94)	1.5(2)	-0.1(5)	-1.3(10)
3/B-0	2.00(118)	5.2(4)	1.2(3)	2.9(10)
3/B-1	5.78(108)	2.4(13)	0.7(3)	1.7(14)
3/B-2	2.56(89)	7.2(11)	1.4(3)	3.5(16)

[a]Average deviations of last significant digit are given in parentheses.

[b]The numbers of the hose materials correspond as follows:
1--Chemical-resistant hose material
2--Fire extinguisher booster hose material
3--Bromochloromethane-resistant hose material

[c]The agents are denoted as follows:
B-0--TMB
B-1--Boralon-1-30V
B-2--Boralon-2-10V

[d]A Type A durometer was used for hardness determinations.

SECTION V
SYSTEM RESPONSE TO AMBIENT ENVIRONMENT

The response of the metal fire extinguishing system to the ambient environment is critical to the development of the system. One of the problems associated with the use of TMB is the high viscosity associated with the agent at low temperature, which renders TMB useless at temperatures below freezing. Halon 1211, being a gas at room temperature, exhibits a large temperature dependence on vapor pressure. In addition, because of the reactivity of the TMB, the interaction of the two agents as a function of temperature (that is, would the halon cause the TMB to decompose at higher temperatures) must be assessed. To address the above points, a series of tests was conducted to evaluate the agents' response to the ambient environment. In addition, the room temperature density was determined for Boralon-1-30V and is reported in this section.

A. VISCOSITY

The viscosity of the Boralon-1-30V was determined as a function of temperature for temperatures of between -40 °C and approximately -3 °C. The viscosities were determined using a Brookfield Model-LVTD Viscometer with a number 1 spindle at 60 rpm. The results of these tests are contained in Table 5.

Trimethoxyboroxine has a pour point of approximately -30 °C (Reference 6) and a minimum use temperature of 0 °C (Reference 5) as a fire extinguishing agent. The low temperature viscosity of TMB is one reason for discontinued use by DOD. As the result of the addition of Halon 1211, the viscosity of the Boralon-1-30V agent becomes acceptable at temperatures down to 30 °C. Theoretical calculations (Section III) conducted for the extinguishing system with a 7.92-millimeter (0.312-inch) nozzle at a flow rate of approximately 1.81 kg/s (4 lb/s) determined a limiting viscosity of 120 cP. The results of this study, coupled with the results of theoretical calculations, indicate that a minimum effective-use temperature of -25 to 30 °C may be specified for the extinguishing system.

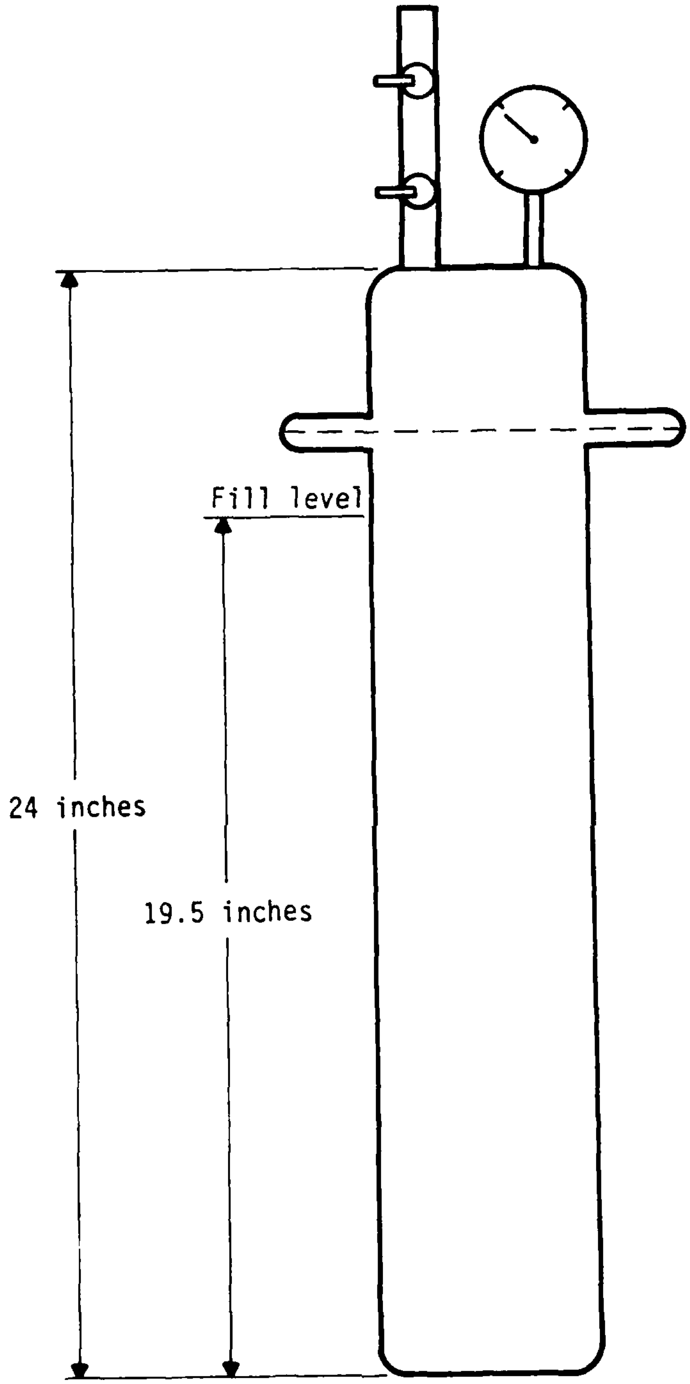

Figure 9. Falling-Sphere Viscometer.

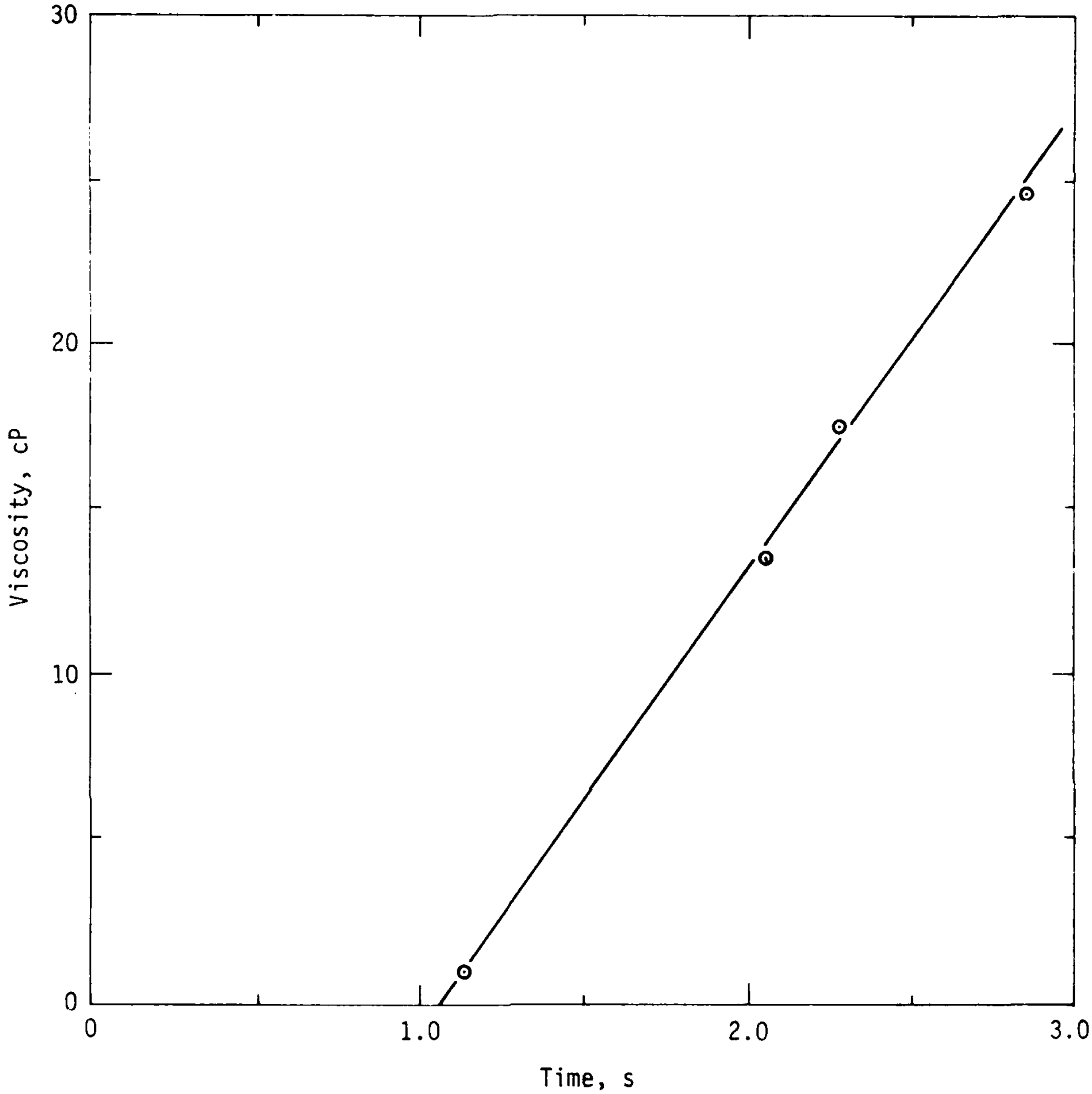

Figure 10. Falling-Sphere Viscometer Calibration Curve.

TABLE 6. BORALON AGENT VISCOSITY AS A FUNCTION OF HALON 1211 CONCENTRATION

Halon 1211, percent	Temperature, °C	Average Time, s[a]	Viscosity, cP
10	21.5	2.18(5)	15.7
20	21.5	1.87(4)	11.2
30	22.0	1.81(3)	10.4

[a]Averaged over 15 trials with the longest time and the shortest time discarded. Numbers in parentheses represent standard deviation in last figure.

B. VAPOR PRESSURE

The vapor pressures of Boralon-1 mixtures as a function of Halon 1211 concentration and temperature were determined to obtain information regarding agent handling and storage requirements. The vapor pressures were determined using an isoteniscope (Figure 11) similar to the one described in Reference 1 but constructed in such a way as to obtain vapor pressures for mixtures whose vapor pressure is above atmospheric. The vapor pressure measurements were conducted according to the procedure given in Reference 1. The results or the vapor pressure study as a function of temperature and Halon 1211 concentration are contained in Figure 12; the vapor pressures as a function of temperature obtained for Boralon-1-30V are given in Table 7.

The vapor pressure of Boralon-1-30V is less than the vapor pressure of Halon 1211 (Reference 7), which is an indication that the halon is in solution with the TMB. There is good agreement with the experimental vapor pressure, 147.9 kPa at 30 °C, and the vapor pressure of an ideal solution of 30 percent Halon 1211 and 70 percent TMB, 131.2 kPa at 30 °C. That the theoretical and experimentally determined vapor pressures are similar implies that the contribution of TMB to the vapor pressure is small; therefore, the spring-loaded pressure relief valve that is specifies for the system should be reliable since contact with TMB, which might form deposits

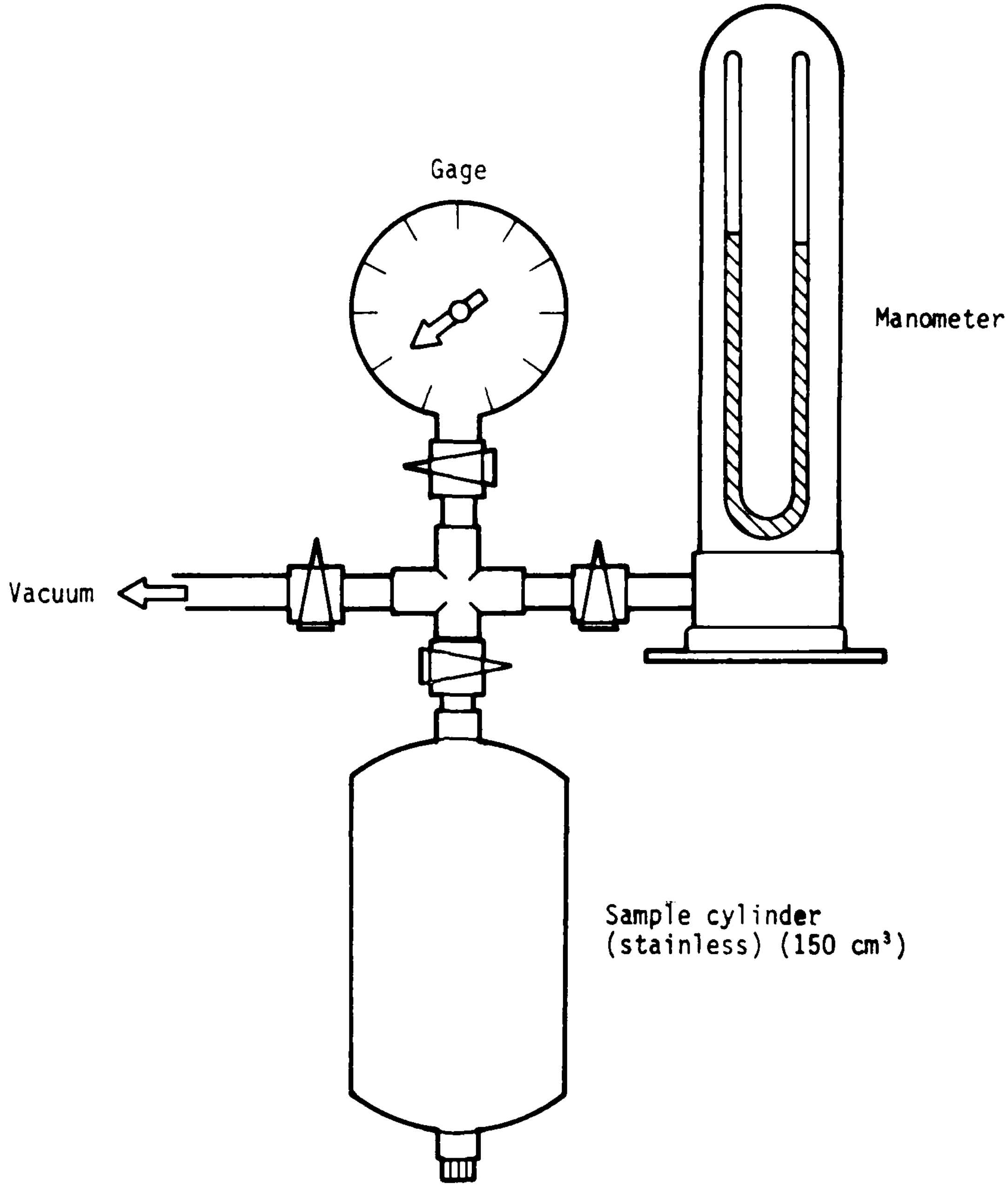

Figure 11. Isoteniscope Used for Vapor Pressure Measurements.

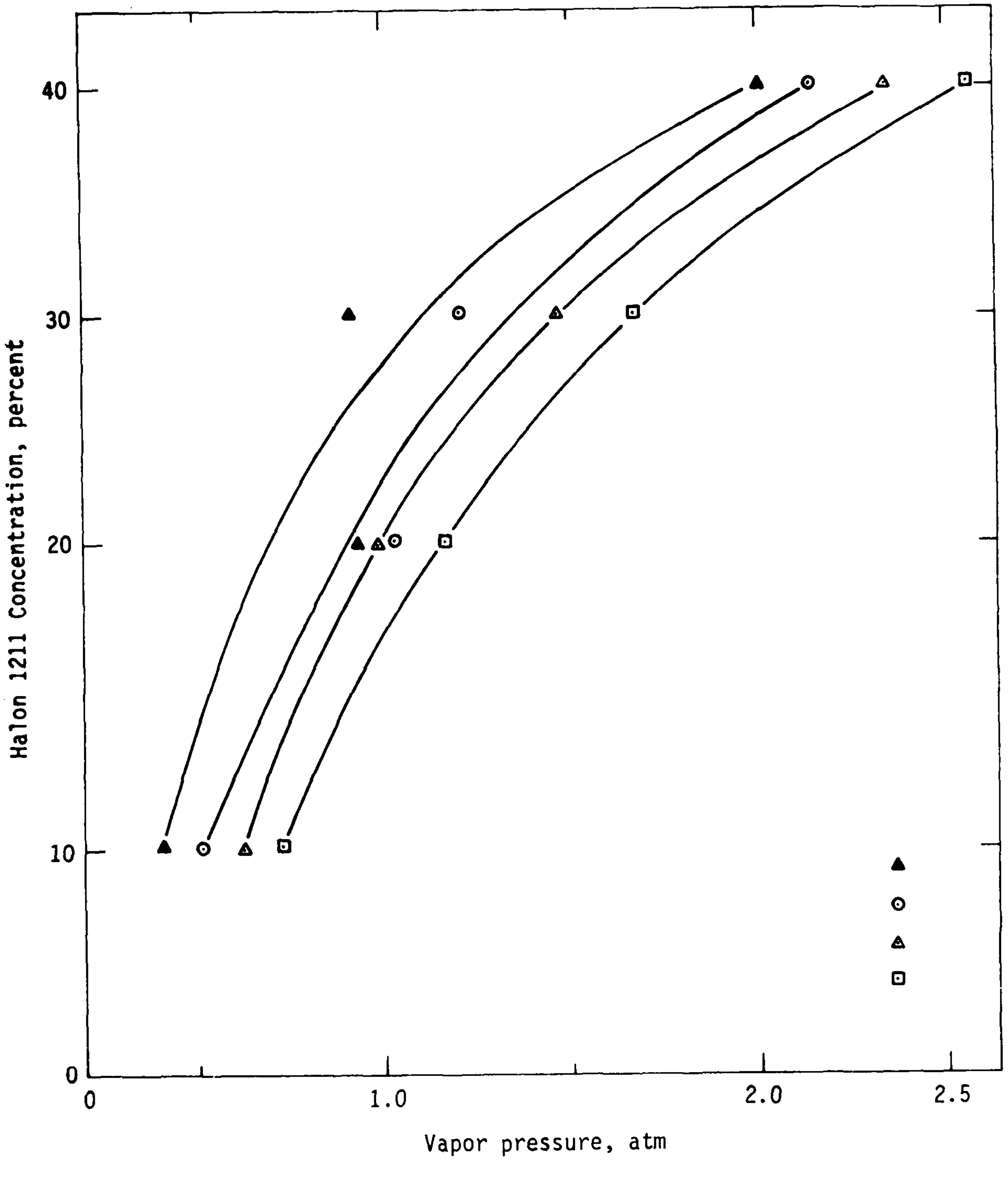

Figure 12. Halon 1211 Concentration Versus Vapor Pressure for Various Temperatures.

TABLE 7. VAPOR PRESSURE VERSUS TEMPERATURE FOR BORALON-1-30V

Temperature, °C	Vapor pressure, kPa
-40	18.64
-30	20.26
-20	23.71
-10	32.42
0	54.11
10	91.40
20	120.58
30	147.93
40	169.21

on the valve, would be limited. The results of the vapor pressure study presented here may be used in future system development work. In addition the results presented here may be used in the development of agent storage and transport containers and aid in decisions relating to agent handling.

C. AMBIENT EXTREME EFFECTS

1. Freeze/Thaw Cycle Testing

Freeze/thaw cycle experiments were conducted to determine effects of low-temperature storage on the agent. Observations were made to determine if the boralon agents would separate, crystallize, or decompose upon exposure to low-temperature extremes which may occur during agent storage and which might adversely effect agent performance.

In the freeze/thaw cycle experiments three glass pressure vessels were filled to an approximately 80-percent fill ratio with either TMB, Boralon-2-10V, or Boralon-1-30V and sealed with porcelain stoppers with rubber gaskets. The filled and sealed sample bottles were then placed in a dry-ice and acetone bath, the temperature of which was approximately -56 °C. The samples were allowed to remain in the dry-ice/acetone bath for varying periods of time and then removed and allowed to warm slowly to room temperature.

Observations were made to determine if any degradation, separation, or precipitation occurred in the solution upon freezing and if any adverse effects remained once the solutions returned to room temperature.

The three solutions were subjected to 10 cycles with the duration of the freeze lasting from between 4 hours and 6 days. During the study, it was observed. that upon freezing, TMB forms a precipitate which usually goes back into solution upon thawing. A precipitate was also observed in the Boralon-2-10V during one 5-day cycle. No precipitate was observed in the Boralon-1-30V agent upon freezing. No signs were observed of immiscibility of the liquids upon freezing nor any physical signs of degradation (e.g., change in color) in the solutions upon freezing.

The freeze/thaw study showed that no adverse physical effects result from exposure of Boralon-1-30V to extreme low temperatures during storage. The agent is useful; however, only at temperatures above approximately -30 °C.

2. Chemical Effects of Ambient Extremes

The effects of ambient extremes on the system were modeled by placing Boralon-1-30V in a stainless steel cylinder at an 80-percent fill ratio and exposing the cylinder to extremes in temperature of between -30 °C and 60 °C. The cylinder was subjected to nine temperature cycles. Each cycle consisted of placing the cylinder in a freezer at -30 °C for 21.5 hours, removing the cylinder and allowing it to warm to room temperature for 2.5 hours, and then placing the cylinder in an oven at 60 °C for 21.5 hours, removing it and allowing it to cool for 2.5 hours. The agent was then analyzed, using NMR and IR spectroscopy and the spectra obtained were compared to spectra of fresh Boralon-1-30V to ascertain if any chemical decomposition in the agent had occurred. The agent was also examined visually to determine if any discoloration or decomposition of the agent had occurred. In addition, the cylinder was cut into two pieces and the pieces were examined for deposits or signs of corrosion.

a. NMR

Carbon-13 nuclear magnetic resonance (NMR) spectra was determined on both fresh Boralon-1-30V (Figure 13a) as well as on Boralon-1-30V exposed to ambient extremes (Figure 13b). Both spectra were determined on a Varian FT-80 NMR. For the fresh Boralon-1-30V deuterated acetone was used as a lock solvent, while deuterated benzene was used as a lock solvent for the exposed Boralon-1-30V. The signals in both spectra were referenced to tetramethylsilane (TMS). The signal from TMB consisted of a single peak (with spinning side bands) at 51.23 p/m downfield from TMS. The signal for bromochlorodifluoromethane appears as a 1:2:1 triplet, the central peak of which is 109.37 p/m downfield from TMS. The left peak of this triplet appears as a shoulder of the right peak of the triplet arising from the deuterated benzene in Figure 13b. The 1:2:1 triplet for bromochlorodifluoromethane is due to the splitting of the carbon by the two attached fluorine atoms. Both spectra appear clean with no signs of chemical decomposition arising from the exposure of the agent to ambient extremes in temperature. There also appears to be no signs of chemical interaction between the TMB and the Halon 1211; such interaction would result in a shift in the NMR signal of the TMB (a spectrum for pure TMB is contained in Reference 1).

b. IR

IR spectra were collected for the fresh Boralon-1-30V (Figure 14a) and the Boralon-1-30V which had been exposed to ambient extremes (Figure 14b). The spectra were collected on a Nicolet Model 6000 Fourier Transform Infrared Spectrometer using a calcium fluoride pressure cell with a 0.1 cm (0.039 in.) path length. Because of the cell which had to be used in data collection the spectral information on wave numbers below 900 available. The spectral details in both figures arise from the presence of TMB (a reference spectrum for TMB may be found in Reference 8). Spectral information for the Halon 1211 is masked by the absorption caused by the sample cell. As in the case of NMR data, both of the spectra are clear and there appears to be no chemical decomposition of the agent arising from exposure to ambient extremes in temperature.

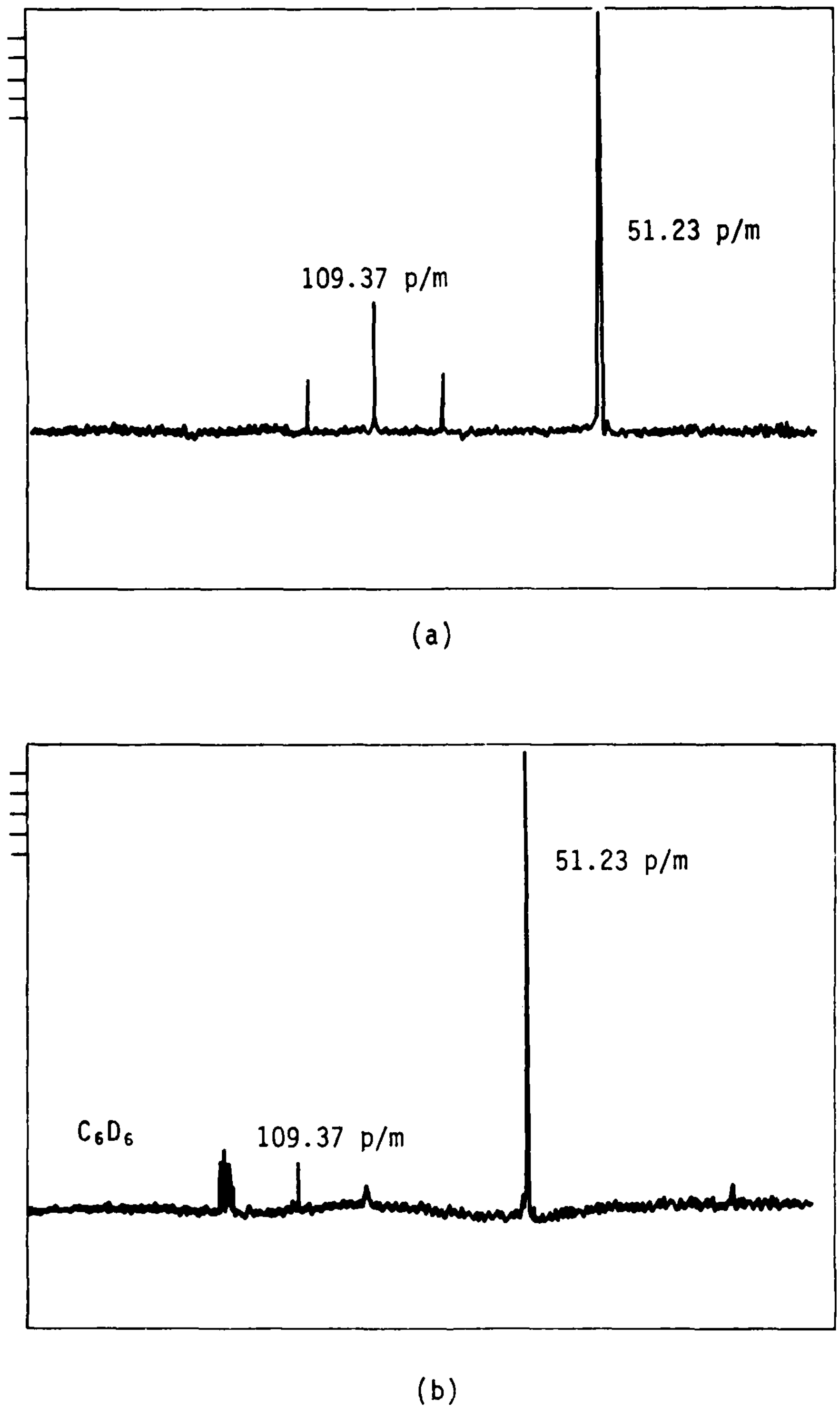

Figure 13. NMR Spectra of Fresh Boralon-1-30V (a) and of Boralon-1-30V Exposed to Ambient Extremes (b).

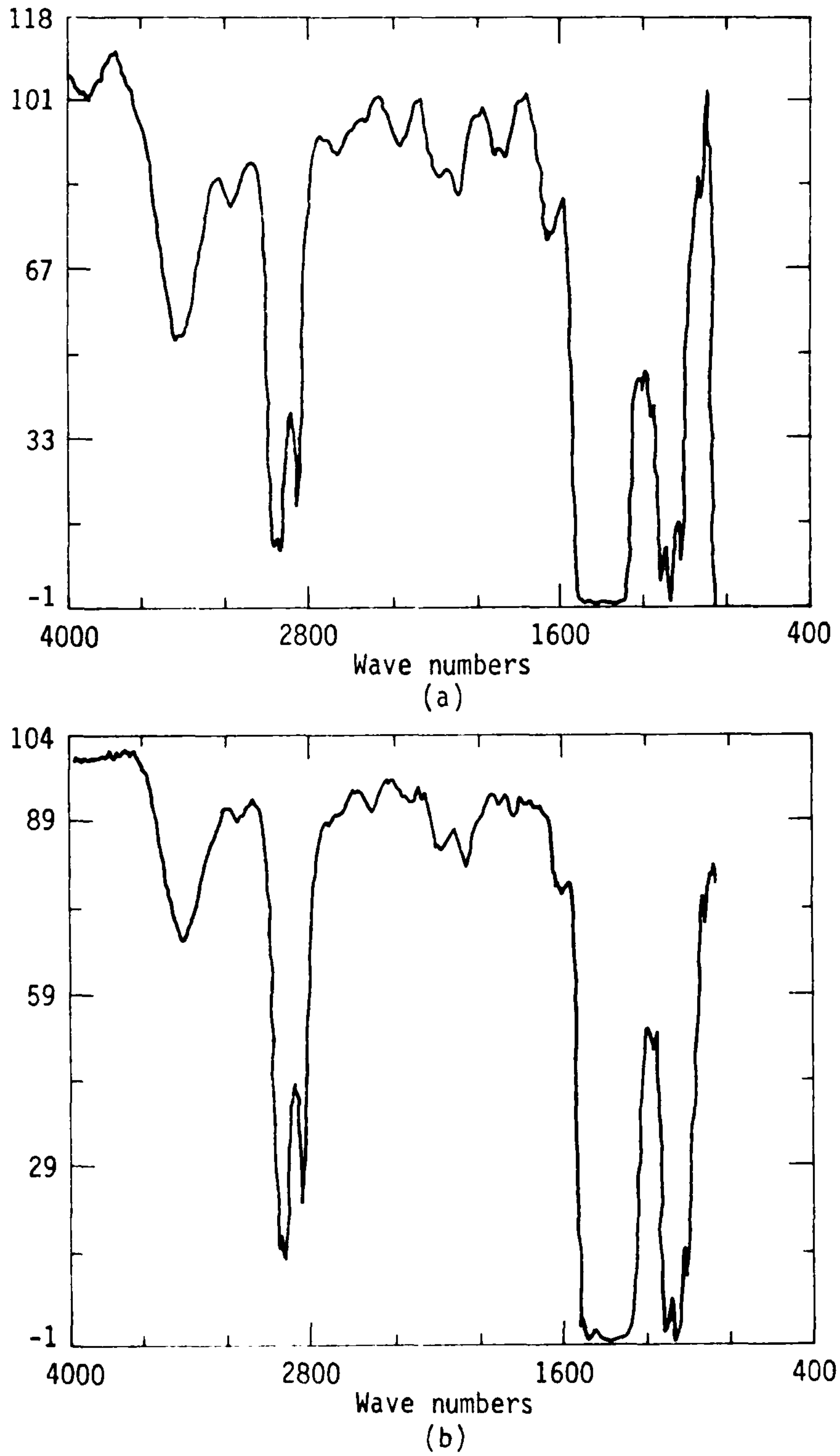

Figure 14. IR Spectra of Fresh Boralon-1-30V (a) and of Boralon-1-30V Exposed to Ambient Extremes (b).

c. Visual Examination

Following spectral data collection, the Boralon-1-30V which had been exposed to extremes in ambient temperature and the cylinder which had contained the agent were visually examined. No discoloration or precipitate was present in the agent; this indicated no significant amount of decomposition. Upon visual examination of the cylinder a small amount of boric acid residue was present in the cylinder; however, the amount present could be due to moisture introduced to the cylinder during sampling for the spectral studies. The sample cylinder was cut into halves and examined further for the presence of corrosion. No pitting or signs of corrosion were found even upon examination with 10X magnification.

C. DENSITY

The density of the Boralon-1-30V agent was measured to aid in further developmental work. The density was measured in a 25-mL volumetric flask which was calibrated with water a 22 °C. The density was measured by filling a dry preweighed volumetric flask with Boralon-1-30V which had been cooled to approximately -30 °C to prevent loss of the Halon 1211 during transfer. The flask was stoppered using a ground glass stopper which had been wrapped with Teflon tape to form a good seal. The flask was then allowed to warm to room temperature and mass and volume determined. Four determinations were done, the results of which are contained in Table 8. The density of the Boralon-1-30V was determined to be 1.409 + 0.012 g/mL. The determined density is in close agreement with the density of 1.400 g/mL determined by summing the densities of the individual components multiplied by their percent composition.

TABLE 8. RESULTS OF DENSITY DETERMINATION OF BORALON-1-30V

Test	Density, g/mL
1	1.395
2	1.425
3	1.409
4	1.406
Average	1.409 + 0.012

SECTION VI
FINAL TESTING

To validate the developed system, six large-scale metal fire tests were conducted which modeled four scenarios. The results of these tests may be used to draw conclusions as to the capabilities and limitations of the developed system. In addition, testing was accomplished to assess the agents compatibility with other agents which might be used to extinguish the hydrocarbon fuel fire.

A. LARGE-SCALE METAL FIRE TESTS

To validate the metal fire extinguishing system developed in this effort, six large-scale magnesium fire tests were conducted. The six tests modeled four scenarios: The first scenario modeled was that of a vertical, indirectly accessible magnesium metal fire. The second scenario modeled a vertical, indirectly accessible metal fire and a liquid-fuel fire. The third scenario modeled a wheel fire in which magnesium wheels, tires, and liquid fuel were involved. The fourth scenario modeled a vertical, indirectly accessible magnesium metal fire which also involved a complex wheel fire, which including a tire and liquid-fuel fire. The results of these tests are summarized in Table 9; more detailed descriptions of each test follow. The tests are not numbered chronologically, but rather in order of scenario progression. The control point referred to in these tests is the point at which the hydrocarbon fuel fire was under control (if a hydrocarbon fuel fire was present) and water or AFFF could be applied to the burning metal without a significant reaction being observed. In all cases the agent was applied in short bursts with intermittent cooling with water or AFFF, as recommended in Reference 1.

1. Test 1

Test 1 involved the placement of 90.6 kg (200 pounds) of magnesium metal in B-52 cowlings as described in Reference 1 and suspending the cowlings 2.43 meters (8 feet) in the air. The magnesium was then ignited by a liquid-fuel igniter using JP-4 and oxygen. Once ignited, the magnesium was allowed to burn until the magnesium in the left cowling was 30 percent

TABLE 9. RESULTS OF LARGE-SCALE METAL FIRE TESTS

Test	Scenario[a]	Fuels	mg, lb	Involvement, percent[b]	Control time, s	Boralon, lb[c]
1	1	Mg	200	60	190	118
2	2	Mg JP-4	200	90	120	295[d]
3	2	Mg JP-4	200	60	120	348
4	2	Mg JP-4	200	60	180	235
5	3	Mg JP-4 Tires	150	60	400	233
6	4	Mg JP-4 Tires Hydraulic fluid	150	60	120	335

[a]Scenario numbers correspond to the following:

1--Vertical, indirectly accessible metal fire.

2--Vertical, indirectly accessible metal fire and liquid-fuel fire.

3--Magnesium-wheel fire and liquid-fuel fire.

4--Vertical and indirectly accessible metal fire, liquid-fuel fire, and magnesium-wheel fire with landing gear.

[b]Percent of surface area of metal ignited prior to beginning extinguishment.

[c]Pounds of Boralon-1-30V required to extinguish metal fire.

[d]Hot spots extinguished with AFFF and water after supply of Boralon-1-30V exhausted.

involved and the magnesium in the right cowling was 90 percent involved. The metal fire was extinguished by applying agent from the prototype system which had been aging for the previous 124 days. The agent was applied in short bursts with intermittent cooling by the application of water. The metal fire was brought under control in 3 minutes and 10 seconds; once under control, a small amount of agent was applied to assure extinguishment of small hot spots. The fire was extinguished using 53.4 kg (118 pounds) of the agent.

2. Test 2

In Test 2, 90.6 kg (200 pounds) of magnesium were again placed in B-52 cowlings and suspended in the air where the magnesium was ignited. The ignited magnesium was allowed to burn until the magnesium in both cowlings was 70 percent involved. Once the magnesium fire was well-established, 51.5 liters (13.6 gallons) of JP-4 were added to pans placed on the ground beneath the cowlings, as described previously (Reference 1). Upon charging of the system with nitrogen, it was observed that the 1-inch ball valve for the nozzle was leaking agent, at which time the hose was drained and the ball valve was replaced. The extinguishment of the metal fire then resumed; however, the metal fire was now 90 percent involved and the draining of the discharge hose resulted in the loss of approximately 24.9 kg (55 pounds) of agent.

Boralon-1-30V was applied to the magnesium fire while AFFF was applied to the JP-4 fire and to the magnesium to cool the metal below the ignition temperature of the metal or the hydrocarbon fuel. The metal fire was brought under control in approximately 2 minutes; however, the entire charge of 133.6 kg (295 pounds) of the Boralon-1-30V agent which remained after draining the hose to replace the ball valve was used and there still remained some hot spots. The hot spots were ultimately extinguished by the application of AFFF and water.

3. Test 3

In Test 3, the same arrangement of magnesium were used in Test 2. The ignited magnesium was allowed to burn until the magnesium in both cowlings was approximately 60 percent involved, at which time 68.9 liters (18.2 gallons) of JP-4 were added to the fuel pans below the cowlings and ignited by the burning magnesium. Upon application of Boralon-1-30V control of the fire was obtained after approximately 2 minutes. The fire was completely extinguished by the application of 157.6 kg (348 pounds) of agent, which extinguished the metal fire, and AFFF, which again was used to extinguish the hydrocarbon fuel fire and to cool the metal to a point where it was below the ignition temperature of the JP-4.

4. Test 4

In Test 4, the 90.6 kg (200 pounds) of magnesium in the cowlings were ignited and allowed to burn until the magnesium was approximately 60 percent involved in both cowlings, at which point 56.8 liters (15 gallons) of JP-4 was added to the fuel pans beneath the cowlings and ignited by the burning magnesium. The resulting fire was brought under control within 3 minutes and extinguished through the application of 106.4 kg (235 pounds) of Boralon-1-30V (67 percent of the system charge) and AFFF.

5. Test 5

Because most fires in which magnesium is reportedly involved involve magnesium wheels and magnesium landing gear struts, a test configuration was developed to simulate a fire in which magnesium wheels, strut material, and tires were involved. In Test 5, two tires were placed on magnesium wheels suspended over steel pans using a pipe. To simulate a magnesium strut member, magnesium bar stock was placed over the wheels. The 68 kg (150 pounds) of magnesium were ignited to the point where 60 percent of the magnesium was burning, at which time 56.7 liters (15 gallons) of JP-4 were added to the steel pans and ignited by the burning magnesium. The resulting fire was brought under control in under 3.5 minutes and was ultimately extinguished using 105.5 kg (233 pounds) of Boralon-1-30V and AFFF. The Boralon-1-30V was used to extinguish the metal fire, while AFFF was used to extinguish the JP-4 fuel fire, the tire fire, and to cool the magnesium metal. The Boralon-1-30V agent had no effect on the tire fire.

6. Test 6

Test 6 demonstrated the extinguishment of a complex fire scenario which involved a number of fuel types. The right landing gear from an F102-A fighter aircraft, complete with wheel and tire, was placed in approximate operational position in a steel pan. Above the landing gear a B-52 cowling was suspended in which 54.4 kg (120 pounds) of magnesium metal was placed. An additional 13.6 kg (30 pounds) of magnesium metal was placed around the bottom of the landing gear in the steel pan. The resulting scenario consisted of a vertical, indirectly accessible magnesium metal fire in the cowlings, a horizontally configured but indirectly accessible magnesium metal fire in the steel pan, a tire fire, JP-4-fuel fire, hydraulic fluid from the landing gear, and magnesium-strut material from the landing gear. The magnesium present was ignited using a liquid fuel igniter consisting of JP-4 and oxygen. Once the magnesium metal was approximately 60 percent involved, 56.7 liters (15 gallons) of JP-4 were added to the steel pans and ignited by the other burning materials. During ignition one of the seals on the landing gear blew out, releasing hydraulic fluid, which ignited.

The resulting fire was brought under control in approximately 2 minutes by applying Boralon-1-30V to the metal fires and AFFF to the other fuel fires. Approximately 2.5 minutes into extinguishment, the cowling fell to the ground, having melted through the supports that were keeping the cowling suspended. The resulting configuration was completely extinguished using 151.8 kg (335 pounds) (96 percent of the total charge) of Boralon-1-30V and also AFFF. Extinguishment and cooling were attained to the point that when the main seal on the landing gear melted through 6 minutes into the extinguishment, the hydraulic fluid which was expelled did not ignite.

7. Conclusions

The tests described above have shown the system to be effective in the control and extinguishment of large complex metal fires. The developed agent, Boralon-1-30V, can be used in conjunction with other firefighting techniques to control and extinguish fires that involve a variety of fuels and ignition sources. In only one case was the amount of agent available insufficient to extinguish the metal fire. In this instance, the agent was wasted due to a leaky ball valve. No failures were observed in any of the other rupture discs or valves during this testing. It can, thus, be concluded that the developed system represents a reliable extinguishing system for large metal fires which may or may not be associated with other complex fire threats.

B. AGENT COMPATIBILITY

In the Phase I-IV report (Reference 1) the compatibility of Boralon-1-30V with other commonly used agents is discussed; in summary, the following information is presented in the Phase I-IV report regarding agent compatibility: Boralon agents are effective in the extinguishment of metal fires following the application of other metal fire extinguishing agents such as MET-L-X. Boralon-1-30V is recommended for use with AFFF for the control and extinguishment of metal fires in the presence of hydrocarbon-fuel fires. Boralon-1-30V may be used with Halon 1211; however, the hot metal that remains after extinguishment causes flashback of the hydrocarbon-fuel fire. If Boralon agents are used in combination with AFFF, care must be taken not to cross the agent application streams, which would result in the Boralon being diluted to the point that it can no longer effectively coat the metal surface.

PKP was the only commonly used agent whose compatibility with Boralon-1-30V was not addressed in Reference 1. To demonstrate compatibility of Boralon-1-30V with PKP, 4.53 kg (10 pounds) of magnesium metal were placed in a 0.608- by 1.22-meter (2- by 4-foot) steel pan with a 101.6-millimeter (4-inch) lip. The magnesium was ignited and allowed to burn until the magnesium was approximately 60 percent involved. Once ignited, 30.3 liters (8 gallons) of JP-4 was added to the pan and ignited by the burning magnesium. The resulting fire was extinguished by applying 5.68 liters (1.5 gallons) of Boralon-1-30V and 13.6 kg (30 pounds) of PKP. The Boralon-1-30V was applied from a 9.5-liter (2.5-gallon) converted water extinguisher which was filled with 9.5 liters (2.5 gallons) of the boralon agent and pressurized to 1034 kPa (150 lb/in^2). The PKP was applied using a standard 30-pound handheld portable unit for PKP. The Boralon-1-30V was applied in bursts with the PKP also being applied intermittently; at one point both agents were applied simultaneously. During extinguishment, the JP-4 fire flashed back several times; however, control and extinguishment were attained in 1 minute and 5 seconds. Following extinguishment, the hot metal remained in the JP-4 fuel and no reignition occurred.

This, and previous studies, lead to the conclusion that the developed agent is compatible with commonly used agents that might be applied to either the metal fire or the hydrocarbon-fuel fire.

SECTION VII
PHASE VI--SYSTEM SPECIFICATION

A. TECHNICAL REQUIREMENTS FOR PHASE VI

The current effort involved the validation testing of the extinguishing system for metal fires. During this testing, data on system performance and system reliability have been collected. Based on the data collected in Phase V, draft military specifications were developed in Phase VI for the agent and for the delivery system. These specifications include information relating to agent compatibility, delivery system performance, and system reliability.

B. AGENT SPECIFICATION DEVELOPMENT

The Draft Military Specification, **Fire Extinguishing Agent Modified Boron-Type For Metal Fires**, covers the requirements for a nonaqueous fire extinguishing agent composed of the liquid boron type fire extinguishing agent trimethoxyboroxine (TMB), and the halogenated hydrocarbon-type fire extinguishing agent bromochlorodifluoromethane (Halon 1211). The specified agent is suitable for use in controlling and extinguishing fires in metals such as magnesium and its alloys which are susceptible to ignition. The specification is written for an agent which is a mixture of TMB and Halon 1211. The agent as specified is 70 + 2 percent by volume TMB and 30 + 2 percent by volume Halon 1211. The raw materials specified are of such quality as to conform to the appropriate military specification (References 4 and 5).

To assure the quality of the agent supplied, requirements were placed on the percentages of the agent components, the viscosity at -25 °C, and the presence of suspended matter or sediment. The reasoning behind the various requirements is discussed below. Data are given to support a discussion of each requirement.

1. Assay

The percentages of trimethoxyboroxine and bromochlorodifluoromethane are determined by allowing the volatile component (bromochlorodifluoromethane) to evaporate and calculating the percentage by difference. This represents a simple method for the determination of the percentage of each component within the limits specified (+ 2 percent).

a. Procedure

Cool the sample in a closed container to approximately -15 °C, to aid in the sample handling by lowering the sample temperature below the boiling point of Halon 1211. Transfer 50 ± 1 mL of the sample to a clean, dry 100 mL graduated cylinder which has been cooled to approximately the same temperature as the sample. Immediately read the volume to the nearest 0.5 mL. Allow the graduated cylinder containing the agent to warm slowly, taking precautions to not allow the Halon 1211 to boil off too rapidly. Once the sample has reached room temperature, heat the sample slowly and agitate it to cause the remaining Halon 1211 to boil off. Do not heat the sample above 80 °C. After the Halon 1211 has boiled off, the graduated cylinder containing the sample is cooled to approximately -15 °C, and the final volume read to the nearest 0.5 mL. The procedure should be carried out in 8 hours to minimize any hydrolysis that might take place.

b. Calculations

(1) The percent of trimethoxyboroxine, $(CH_3O)_3B_3O_3$, is calculated as follows:

$$\text{Percent } (CH_3O)_3B_3O_3 = \frac{V_f}{V_i} \times 100 \qquad (3)$$

Where:

V_f = Final volume to the nearest 0.5 mL.
V_i = Initial volume to the nearest 0.5 mL.

(2) The percent of bromochlorodifluoromethane (CF ClBr) is calculated as follows:

$$\text{Percent } CF_2ClBr = \frac{V_i - V_f}{V_i} \times 100 \qquad (4)$$

c. Results and Discussion

Three samples of Boralon-1-30V were prepared and an assay was done according to the above procedure. The results of this study are contained in Table 10.

TABLE 10. RESULTS OF ASSAY PERFORMED ON BORALON-1-30V SAMPLES

Sample	V_i, mL	V_f, mL	TMB, percent	Halon 1211, percent
1	50.0	35.5	71.0	29.0
2	50.0	34.5	69.0	31.0
3	51.0	34.5	68.0	32.0

The assay for component percentage for TMB and Halon 1211 is within the specified limits of ± 2 percent for every sample tested. Based on the information collected as a result of previous studies (Reference 1), no negative effects are observed as the result of a ± 2 percent deviation in Halon 1211 content for Boralon-1-30V. The results of this study show that the procedure specified is accurate enough that deviations from the specified limits can be detected.

2. Conclusions

(1) The agent, as specified, shall be a mixture of TMB and Halon 1211 and shall be composed of 70 + 2 percent by volume TMB and 30 + 2 percent by volume Halon 1211.

(2) The limits of ± 2 percent on the percentage of each component of the agent represent realistic limits within which there are expected to be no negative effects on agent performance or effectiveness.

(3) The procedure specified for determining the percentage of each component is of sufficient accuracy as to assure a quality product.

2. Viscosity

The viscosity of the agent is determined at a temperature of -25 °C using a Brookfield-type LV viscometer or equivalent. There are three reasons for the specification of a low-temperature viscosity for the developed agent. First, because of the volatility of Halon 1211, an accurate viscosity can only be obtained at a temperature where both components are liquid and there is no significant loss of the more volatile component during temperature equilibration. Second, for a Brookfield viscometer, the accuracy of the viscosity measurement decreases as the viscosity decreases; therefore, a temperature determination is accurate and reproducible. Third, the Brookfield viscosity determination is accurate and reproducible. Third, the low-temperature viscosity characteristics define the Boralon-1-30V agent and assure a quality product. The viscosity is determined according to the procedure outlined below.

a. Procedure

An appropriate volume (as indicated in the instruction manual for the instrument) of the sample, which has been cooled to -10 °C, is placed in a 600 mL beaker which has been cooled in a low temperature bath at -25 °C. The solution is covered and allowed to equilibrate in the temperature bath for 30 minutes, at which time the temperature of the solution is measured. The viscosity is then measured, using the Number 1 spindle at 60 rpm following the directions given in the operating manual for the instrument used.

b. Results and Discussion

The viscosity of three solutions was measured using the above procedure except that the solutions were equilibrated in a -30 °C temperature bath and the viscosity measured as the solutions warmed. Except for Sample 2, whose viscosity was determined at -25 °C, the viscosity at -25 °C was then interpolated using the two data points closest to the desired temperature. The viscosity results are contained in Table 11.

TABLE 11. BROOKFIELD VISCOSITY RESULTS OBTAINED FOR BORALON-1-30V

Sample	-25 °C Viscosity, cP
1	25.3
2	32.0
3	30.6
average	29.3 ± 3.5

Based on the results contained in Table 11, a maximum value of 35 cP was chosen for the specified limit on the viscosity of the Boralon-1-30V agent at -25 °C. In addition, the measured viscosities are within a range which can accurately be measured, using a Brookfield viscometer with a Number 1 spindle at 60 r/m. The specified value represents a realistic maximum that can be used to assure a quality product.

c. Conclusions

The low-temperature viscosity limit of 35 cP at -25 °C represents a realistic limit while assuring a quality product.

d. Presence of Suspended Matter or Sediment

Boralon-1-30V hydrolyzes when it comes in contact with water. The result of this hydrolysis reaction is a white boric acid precipitate. Therefore, the presence of suspended matter or sediment indicates that the material had been mishandled or that components not in conformance with the appropriate military specifications were used to prepare the agent. The specification of no visible suspended matter or sediment aids in assuring that a quality product is delivered.

C. DELIVERY SYSTEM SPECIFICATION DEVELOPMENT

The Draft Military Specification, **Agent Delivery System For Use With Modified Boron-Type Fire Extinguishing Agent For Metal Fires**, covers the requirements for a (151.4-liter) 40-gallon-capacity agent delivery system for use with a modified boron-type fire extinguishing agent for metal fires. The agent is to be placed inside the delivery system described in the draft military specification and isolated from the ambient air and moisture through the use of appropriate valves and rupture discs. The development of the delivery system specification followed closely the military specification for the (226.5 kg) 500-pound capacity Halon 1211 fire extinguisher unit mounted on the Air Force P-13 Crash Rescue Vehicle, as described in Reference 9.

1. Performance Requirements

a. Agent Discharge Requirements

The specified performance limits are based on information collected during tests described previously for Phase V. Briefly, when the developed agent was discharged through a (7.94 mm) 0.312-inch plain-tip brass nozzle, an average throw range of (22.5 meters) 74 feet, an average discharge time of 63 seconds, and an average discharge rate of (2.67 kg/s) 5.9 lb/s were observed. The specified performance requirements of a minimum throw range of 60 feet (18 meters), a minimum discharge time of 40 seconds, and a minimum discharge rate of (1.81 kg/s) 4 lb/s represent realistic values for performance while allowing for a certain degree of manufacturing freedom. When designing the delivery system, it is important to consider that the developed agent is applied in short bursts and its effectiveness is due to the ability of the agent to coat the metal surface. Therefore, there is a tradeoff between discharge rate and discharge time.

b. Roadability Requirements

The roadability requirements are similar to those specified in Reference 9 and represent a realistic scenario against which the delivery system is tested. Although the system is tested for use when mounted on a land vehicle, the requirements of the test should be stringent enough to assure reliability of the delivery system for use aboard ships.

2. Fire Test

A fire test is included in the specification as the ultimate test of delivery system and agent compatibility. Fire tests conducted during system development consisted of magnesium metal fires consisting of up to 200 pounds (90.6 kg) of magnesium in a variety of configurations. The specified test involves a magnesium fire consisting of a minimum of 50 pounds (22.7 kg) of magnesium. The fire must be extinguished from a distance of at least (9.1 m) 30 feet. The results of the performance of the fire test may be used to assure that a quality product, which is ultimately compatible with the developed agent, is delivered.

3. Drawings

Level II engineering drawings, which form an ancillary part of the delivery system specification, were also prepared. These drawings, as specified in MIL-D-1000 (Reference 10), are to be used for prototype production or limited production. The drawings are contained in Appendix B, Figure B-2.

SECTION VIII

CONCLUSIONS AND RECOMMENDATIONS

As the result of research conducted during this effort, draft military specifications have been developed for an effective fire extinguishing agent for metal fires and for a delivery system from which to dispense that agent. The system validation testing conducted in Phase V and the specifications developed in Phase VI of this project permit the following conclusions and recommendations to be made.

A. CONCLUSIONS

1. The developed system represents a reliable extinguishing system for large metal fires which may or may not be associated with other complex fire threats.

2. The developed agent is compatible with commonly used agents that might be applied to either a metal fire or a hydrocarbon fuel fire.

3. The use of a 7.92 mm (0.312-inch) nozzle with the developed system results in reliable system performance.

4. No adverse effects to either the agent or the delivery system are caused by proper and routine handling, storage, transport, and maintenance of the system.

5. The agent specification developed as part of this effort assures that a quality product is delivered for DOD use in the extinguishment of metal fires.

6. The agent delivery system specification developed as part of this effort assures that a quality product that is capable of reliable use with the developed agent is delivered for DOD use in the extinguishment of metal fires.

7. The extinguishing system which consists of the specified delivery system properly filled with the specified agent represents a reliable system which can be used in the control and extinguishment of metal fires.

8. The developed specifications, as prepared, are ready for official processing by the proper agencies within the Department of Defense for acceptance as military specifications.

B. RECOMMENDATIONS

1. Because the agent and the delivery system are parts of an extinguishing system for metal fires, manufacture of the agent and the delivery system should be accomplished with the consideration of the final system, which integrates the two parts.

2. To assure a more reliable extinguishing system, a method of handling the manufactured agent, as delivered during filling procedures, will have to be addressed. Filling of the delivery system with agent should be carried out only by qualified personnel who are familiar with the properties of the agent and who have been trained in the filling of this particular extinguishing system.

3. The developed system is effective against even very large metal fire threats; however, because of the nature of the agent and the delivery system, once the rupture discs that separate the agent from the ambient air and moisture are ruptured the entire contents of the system must be used and the delivery system refilled. Because the threat of metal fires is not always large, it is recommended that a smaller handheld or wheeled delivery system be developed for use with the developed agent.

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10. Military Specification, MIL-D-1000, **Drawings, Engineering and Associated Lists,** 15 October 1975.

APPENDIX A

DRAFT MILITARY SPECIFICATION FOR THE FIRE EXTINGUISHING AGENT MODIFIED BORON-TYPE FOR METAL FIRES

DRAFT MILITARY SPECIFICATION
FIRE EXTINGUISHING AGENT
MODIFIED BORON-TYPE
FOR METAL FIRES

1. SCOPE

1.1 This specification covers the requirements for a nonaqueous fire extinguishing agent which is composed of the liquid boron-type fire extinguishing agent trimethoxyboroxine (TMB) and the halogenated hydrocarbon-type fire extinguishing agent bromochlorodifluoromethane (Halon 1211). The specified agent is suitable for use in controlling and extinguishing fires in metals susceptible to ignition, such as magnesium and its alloys.

2. APPLICABLE DOCUMENTS

2.1 Issues of documents. The following documents of the issue in effect on the date of invitation for bids form a part of this specification to the extent specified herein:

2.1.1 Specifications

Military.

MIL-B-38741	Bromochlorodifluoromethane, Technical
MIL-F-2261A	Fire Extinguishing Agent, Liquid, Boron Type, for Metal Fires

2.1.2 Standards

Military

MIL-STD-101	Color Code for Pipelines and for Compressed Gas Cylinders

MIL-STD-105 Sampling Procedures and Tables for Inspection by Attributes

MIL-STD-129 Marking for Shipment and Storage

(Copies of specifications and standards required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

49 CFR 100 - 199 Transportation

(Copies of specifications, standards, handbooks, drawings, and publications required by manufacturers in connection with specification functions should be obtained from the contracting activity or as directed by the contracting officer.)

3. REQUIREMENTS

3.1 Description. The modified boron-type extinguishing agent for metal fires, herein referred to as the "agent," shall be composed of trimethoxyboroxine and bromochlorodifluoromethane. The agent shall be 70 + 2 percent by volume trimethoxyboroxine and 30 + 2 percent by volume bromochlorodifluoromethane. The trimethoxyboroxine shall conform to MIL-F-2261A. The bromochlorodifluoromethane shall conform to MIL-B-38741. The resulting mixture shall conform to the requirements of Table A-1.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract, the contractor is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract, the contractor may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

TABLE A-1. REQUIREMENTS FOR MODIFIED BORON-TYPE EXTINGUISHING AGENT

Property	Requirement	Test Paragraph
Trimethoxyboroxine, percent by volume	70 + 2	4.6.1
Bromochlorodifluoromethane, percent by volume	30 + 2	4.6.1
Viscosity, centipoise maximum at -25 °C	35.0	4.6.2
Suspended Matter or Sediment	None visible	4.6.3

4.1.1 Component and material inspection. The contractor is responsible for ensuring that components and materials used are manufactured, examined, and tested in accordance with reference specifications and standards as applicable.

4.2 Classification of inspections. The inspection requirements specified herein are classified as follows:

a. Quality conformance inspection (see 4.4).

b. Inspection of packaging (see 4.5).

4.3 Sampling

4.3.1 Lot. A lot shall consist of all agent manufactured as one batch and offered for delivery at one time. A batch shall be that quantity of the agent manufactured at one time.

4.3.2 Sampling for inspection of filled containers. A random sample of filled containers shall be selected from each lot in accordance with MIL-STD-105, Level I, with an acceptance level (AQL) of 2.5 percent defective, when inspected as specified in 4.5.

4.3.3 Sampling for quality conformance inspection. From each lot of filled containers not less than two containers shall be taken at random for the tests described in 4.6.

4.4 Quality conformance inspection. The samples selected in accordance with 4.4.3 shall be subjected to the quality conformance inspection test described in 4.6. If the sample tested is found to be not in conformance with any of the quality conformance tests the lot represented by the sample shall be rejected.

4.5 Examination of filled containers. Each sample filled container shall be examined for defects of construction of the container and the closure, for evidence of leakage, and for unsatisfactory markings. Each filled container shall also be weighed to determine the amount of contents. Any container in the sample having one or more defects or less than required fill shall not be offered for delivery, and if the number of defective containers in any sample exceeds the acceptance number for the appropriate sampling plan of MIL-STD-105, this shall be cause for rejection of the lot represented by the sample.

4.6 Test methods

4.6.1 Assay. The percentage of trimethoxyboroxine and bromochlorodifluoromethane shall be determined by allowing the volatile component to evaporate and calculating the percentage by difference.

4.6.1.1 Procedure. The sample shall be cooled in a closed container to approximately -15 °C. Transfer 50 ± 1 mL of sample to a clean, dry 100-mL graduated cylinder which has also been cooled to approximately the same temperature. Immediately read the volume to the nearest 0.5 mL. Allow the graduated cylinder containing the agent to warm slowly, taking precautions to not allow the bromochlorodifluoromethane to boil off too rapidly. Once the sample has reached room temperature it may be necessary to heat the cylinder containing the sample slowly and agitate to cause the remaining bromochlorodifluoromethane to boil off. (Note: The sample shall not be heated above 80 °C.) After the bromochlorodifluoromethane has boiled off the graduated cylinder containing the sample shall again be cooled to approximately -15 °C and the final volume read to the nearest 0.5 mL. The entire procedure shall be accomplished in an 8-hour period.

Note: Bromochlorodifluoromethane should be allowed to evaporate under a hood.

4.6.1.2 Calculations

a. The percent of trimethoxyboroxine, (CH O) B O , shall be calculated as follows:

$$\%\ (CH_3O)_3B_3O_3 = \frac{V_f}{V_i} \times 100$$

Where:

a. V_f = Final volume to the nearest 0.5 mL.

b. V_i = Initial volume to the nearest 0.5 mL.

Trimethoxyboroxine percent less than that specified in Table I shall constitute failure of the test.

b. The percent of bromochlorodifluoromethane shall be calculated as follows:

$$\% \ CF2ClBr = \frac{V_i - V_f}{V_i} \times 100$$

Bromochlorodifluoromethane percent less than that specified in Table I shall constitute failure of this test.

4.6.2 Viscosity. The viscosity of the agent shall be determined at a temperature of -25 °C ± 0.1 °C using a Brookfield-type LV viscometer or equivalent. The viscosity shall be recorded in centipoise.

4.6.2.1 Test equipment. Brookfield-type LV viscometer or equivalent calibrated with standard reference fluids in the expected viscosity region. Constant temperature bath capable of maintaining a temperature of -25 °C. Thermometer or other thermometric device capable of measuring temperatures in the range of -40 °C to 0 °C and capable of being read to 0.1 °C. Standard laboratory glassware.

4.6.2.2 Procedure. An appropriate volume (as indicated in the instruction manual for the instrument) of the sample which has been cooled to 0 °C ± 3 °C, is placed in a 600-mL beaker which has been cooled in the low temperature bath at -25 °C. The solution is covered and allowed to equilibrate in the temperature bath for 30 minutes at which time the temperature of the solution is measured. The viscosity of the solution is then measured using the Number 1 spindle at 60 rpm following the directions given in the operating manual for the instrument used.

CAUTION: Perform the above procedure under a hood.

4.6.3 Suspended matter and sediment. Examine visually for any suspended matter or sediment. Observation of any suspended matter or sediment shall constitute failure of this test.

5. PREPARATION FOR DELIVERY

5.1 Packaging. The level of packing shall be Levels A and C. Unless otherwise specified, the agent shall be delivered in cylinders of (27.2- and 181.2-kg) 60- and 400-pound capacity conforming to Interstate Commerce Commission specification ICC 4B300 or ICC 4BA300. The contractor shall assure that containers are free from contamination and moisture and are suitable for shipment and storage.

5.2 Marking. In addition to any special marking required by the contract or order, containers shall be marked in accordance with MIL-STD-129. Filled cylinders shall be color-coded in accordance with MIL-STD-101. In addition each package shall be durably and legibly marked with the information shown in Figure A-1 in such a manner that the markings will not become damaged when the packages are opened.

6. NOTES

6.1 Intended use. The material covered by this specification is intended for the purpose of controlling and extinguishing fires in metals, such as magnesium and its alloys which are susceptible to ignition in ordinary atmospheres. It must be employed in pressurizable extinguishers of a design approved for the purpose and handled by personnel familiar with the agents' properties. It may be used in conjunction with other extinguishing methods such as water spray and foam where these are needed. No toxic effects are to be expected by its use either from the decomposition of the liquid in the presence of burning metals or from accidental contact of the skin with the material. Evacuation from tightly closed spaces is recommended after use of the agent on fires and dilution of the agent with water where accidental spillage has occurred.

6.2 Ordering data. Procurement documents should specify the following:

a. Title, number, and date of this specification.

b. Quantity of agent desired.

c. Type and size of containers required.

6.3 The material specified herein will be purchased by weight, the unit being an avoirdupois pound.

6.4 The percentage of trimethoxyboroxine and the percentage of bromochlorodifluoromethane may be determined as specified herein or by a method acceptable to the procuring agency.

FIRE EXTINGUISHING AGENT

MODIFIED BORON-TYPE

FOR METAL FIRES

MIL-F-

Stock No.____________________________

Manufacturers Identification
Designation

Name of Manufacturer

Date of Manufacture

Batch No.____________________________

CAUTION! REACTIVE LIQUID!
DO NOT OPEN UNTIL READY FOR USE-
DO NOT EXPOSE TO WATER OR HUMID
WEATHER AFTER OPENING - FLUSH
AWAY ALL SPILLED LIQUID WITH
COPIOUS AMOUNTS OF WATER
AVOID CONTACT WITH SKIN OR EYES
AVOID PROLONGED BREATHING OF VAPORS

Figure A-1. Marking for Agent Containers.

APPENDIX B

DRAFT MILITARY SPECIFICATION FOR THE AGENT DELIVERY SYSTEM FOR USE WITH MODIFIED BORON-TYPE FIRE EXTINGUISHING AGENT FOR METAL FIRES

DRAFT MILITARY SPECIFICATION
AGENT DELIVERY SYSTEM FOR USE WITH
MODIFIED BORON-TYPE FIRE EXTINGUISHING
AGENT FOR METAL FIRES

1. SCOPE

1.1 This specification covers the requirements for a 40-gallon capacity agent delivery system for use with a modified boron-type fire extinguishing agent for metal fires.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

2.1.1 Specifications

Military

MIL-P-116	Preservation-Packaging, Methods of
MIL-B-38741	Bromochlorodifluoromethane, Technical
MIL-F-2261A	Fire Extinguishing Agent, Liquid, Boron-Type, for Metal Fires
MIL-B-26195	Box, Wood, Cleated, Skidded, Load Bearing Base.
MIL-F-XXXX	Fire Extinguishing Agent, Modified Boron-Type, for Metal Fires

Federal

BB-N-411	Nitrogen, Technical

2.1.2 Standards

Military

MIL-STD-100	Engineering Drawing Practices
MIL-STD-129	Marking for Shipment and Storage
MIL-STD-130	Identification Marking of U.S. Military Property
MIL-STD-143	Standards and Specifications, Order of Precedence for the Selection of
MIL-STD-808	Finishes, Protective, and Codes, for Finishing Schemes for Ground and Ground Support Equipment
MIL-STD-831	Test Reports, Preparation of
MIL-STD-889	Dissimilar Metals
MIL-STD-1186	Cushioning, Anchoring, Bracing, Blocking and Waterproofing; with Appropriate Test Methods

2.1.3 Drawings

New Mexico Engineering Research Institute

2084-1772 Metal Fire Extinguishing System, 40-gallon Capacity

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publication. The following document forms a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on the date of invitation for bids or requests for proposal shall apply.

American Society of Mechanical Engineers

Boiler and Pressure Vessel Code
Section VIII Unfired Pressure Vessels

(Applications for copies should be addressed to the American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, New York 10017.)

3. REQUIREMENTS

3.1 Preproduction. This specification makes provisions for preproduction testing.

3.2 Description. The agent delivery system forms an integral part of a metal fire extinguishing system for use in controlling and extinguishing fires in metals susceptible to ignition, such as magnesium and its alloys. The metal fire extinguishing system is composed of two components: the agent and the agent delivery system. The agent is to be placed inside the delivery system described in the drawing which isolates the agent from the ambient air and moisture through the use of appropriate valves and rupture discs. The requirements of Drawing 2084-1772 apply as requirements of this specification with the exceptions and additions specified herein. The agent delivery system shall consist of the following major components:

Item Name	Requirement
Agent Tank	3.5.3
Nitrogen Propellant System	3.5.4
Discharge Hose	3.5.5
Nozzle Assembly	3.5.6

3.3. Selection of standards and specifications. Standards and specifications for necessary commodities and services not specified herein shall be selected in accordance with MIL-STD-143.

3.4 Agent requirements. Where specified the agent shall be composed of a mixture of trimethoxyboroxine and bromochlorodifluoromethane. The agent shall be 70 ± 2 percent by volume trimethoxyboroxine and 30 ± 2 percent by volume bromochlorodifluoromethane. The trimethoxyboroxine shall conform to MIL-F-2261A. The bromochlorodifluoromethane shall conform to MIL-B-38741. The resulting mixture shall conform to MIL-F-XXXX.

3.5 Agent delivery system requirements. The following requirements shall apply to the agent delivery system to the extent specified herein.

3.5.1 Materials. Materials shall be as specified herein. Materials not specifically covered by this or applicable specifications shall be suitable in every respect and of good quality. Wood shall not be used in construction.

3.5.1.1 Metals. Unless otherwise specified herein, parts and components of the agent delivery system which come in contact with the agent shall be fabricated of corrosion-resistant steel or brass.

3.5.1.1.1 Dissimilar metals. Unless protected against electrolytic corrosion, dissimilar metals shall not be used in intimate contact with each other. Dissimilar metals are defined in MIL-STD-889.

3.5.1.2 Non metals. The use of non metal materials in contact with the agent during storage shall be limited to the extent described and specified in the drawing. If possible the use of non metals in contact with the agent during storage should be eliminated.

3.5.2 Design and construction. The agent delivery system shall be so designed and constructed that parts will not work loose in service. It shall be inherently capable of withstanding the stresses, jars, vibrations, and other conditions incident to shipping, storage, and usage, and shall provide maximum ease and safety of operation.

3.5.2.1 Functional design. The agent delivery system shall be designed to operate efficiently when installed in either a pickup truck or a trailer designed to be pulled by a pickup truck.

3.5.2.2 Reliability. The reliability of the agent delivery system to satisfy its intended use will be demonstrated by successful completion of the tests specified herein.

3.5.2.3 Maintainability. The agent delivery system shall be designed and constructed to provide:

a. A minimum number of parts consistent with performances required herein.

b. Parts and components that are located or positioned for ease of inspection and recognition of excessive wear or potential failure.

c. Ease of adjusting, servicing, and replacing parts and components.

d. Use of readily available standard tools and equipment for maintenance.

e. Maintenance with a minimum number of tools.

3.5.3 Agent tank. The tank shall be constructed in accordance with Section VIII of the ASME Boiler and Pressure Vessel Code designed to operate at a working pressure of 200 lb/in^2 (1378 kPa). The welded seams on the tank shall not exhibit agent leakage rates exceeding (0.017 kg) 0.6 ounces per year each seam. Valves attached to the tank shall not exhibit agent leakage rates exceeding (0.28 kg) 10 ounces per year, each valve.

3.5.4 Nitrogen propellant system. A nitrogen gas cylinder having adequate capacity and pressure to provide performance requirements specified in 3.7 shall be furnished as an integral part of the system. The propellant gas cylinder shall be in accordance with DOT requirements and regulations. The fully charged gas cylinder shall be charged with nitrogen conforming to BB-N-411, Type I, Class 1, Grade B.

3.5.4.1 Pressure relief valve. The spring-loaded pressure relief valve shall operate to relieve the internal tank pressure at (1890 ± 70 kPa) 275 ± 10 lb/in^2 and shall close at a pressure not less than (1310 kPa) 190 lb/in^2. The relief valve shall incorporate features that will preclude tampering with the pressure relief setting.

3.5.4.2 Pressure regulators. The gas flow rate of the regulator and gas piping system shall be such as to provide performance requirements specified in 3.7. Dead end setting of the regulator shall be within 95 to 110 percent of the tank's design working pressure and be capable of handling the full regulator gas flow. The regulator shall be adjusted by the manufacturer and sealed in a manner to discourage manipulation in the field.

3.5.5 Discharge hose. The discharge hose shall be (30.4 meters) 100 feet long and (2.54 cm) 1 inch in diameter which is uncollapsable and chemically resistant. The burst pressure of the hose shall not be less than three times the working pressure of the tank. The discharge hose shall be attached to the delivery system in such a manner as to ensure its ease of rapid removal.

3.5.6 Nozzle assembly. The discharge hose shall be equipped with a nozzle incorporating an on-off control that will discharge agent in accordance with performance requirements specified in 3.7. The nozzle portion of the assembly shall be a plain tip straight-bore nozzle with a minimum diameter of 0.30 inches (0.762 cm). A 360 degree swivel connection shall be provided between the nozzle and the handline. The agent delivery system shall incorporate a means of restraining the discharge nozzle in a readily accessible stored position.

3.5.7 Rupture discs. Rupture discs shall be used to separate the agent from the nitrogen propellant system as well as from the discharge hose as shown in the drawing. The rupture disc shall be nickel, Type B, of the appropriate dimension. The rupture pressure shall be a minimum of 75 percent of the working pressure of the tank at 75 °F and shall not interfere with system performance at temperatures between -40 °F and 140 °F. The leak rate around each rupture disc and union shall not exceed (0.28 kg) 10 ounces per year.

3.5.8 Dimensions. The overall dimension shall be in accordance with the drawing.

3.5.9 Finishes and protective coatings. The delivery system shall be cleaned, treated, and painted in accordance with MIL-STD-808. Brass and corrosion resistant steel fittings may be painted provided that such painting is in compliance with these standards.

3.5.10 Part numbering of interchangable parts. All parts having the same manufacturer's part number shall be functionally and dimensionally interchangeble. The item identification and part numbering requirements of MIL-STD-100 shall govern the manufacturer's part numbers and changes thereto.

3.5.11 Markings

3.5.11.1 Identification of product. Equipment, assemblies, and parts shall be marked in accordance with MIL-STD-130.

3.5.11.2 Additional markings. In addition to the markings specified in 3.5.11.1, a plate, shown in Figure B-1, shall be attached to each end of the tank. The serial number of the tank and the gross weight of the tank with that serial number shall be stamped on these plates.

3.5.12 Workmanship. The agent delivery system, including all parts and accessories, shall be fabricated and finished in a thoroughly workmanlike manner. Particular attention shall be given to freedom from blemishes, defects, burrs, and sharp edges; marking of parts and assemblies; thoroughness of soldering, welding, brazing, riveting, and painting; alignment of parts; and tightness of assembly screws, bolts, et cetera.

3.6 System performance. Performance requirements of the metal fire extinguishing system shall be based on operation at sea level at temperatures of 75 ± 5 °F.

3.6.1 Agent discharge. The agent delivery system shall exhibit the following characteristics when discharging the agent at normal operating pressure through (30.4 m) 100 feet of (2.54 cm) 1-inch hose with nozzle installed.

a. Discharge time of not less than 40 seconds measured from opening of nozzle to the point when nitrogen pressure pulsations occur.

b. Effective discharge of not less than 95 percent of the agent capacity without pressure pulsations or interruptions to flow.

c. Throw range of (18 meters) 60 feet minimum as measured from the tip of the nozzle to the leading edge of the discharge pattern without assist from downwind conditions.

d. Discharge rate of not less than (1.81 kg/s) 4 lb/s under normal operating conditions.

3.6.2 Roadability. The fully charged agent delivery system shall not be damaged or lose pressure when installed in the body of a pickup truck and subjected to operation over improved and unimproved roads as follows:

a. Paved roads for a distance of (160 km) 100 miles at an average speed of (72 km/h) 45 mi/h.

b. Graded gravel roads for a distance of (160 km) 100 miles at an average speed of (40 km/h) 25 mi/h.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Classification of tests. The inspection and testing of the extinguisher unit shall be classified as follows:

a. Preproduction testing....................................See 4.4

b. Quality conformance tests..............................See 4.5

4.3 Test conditions

4.3.1 Preparation for test. All agent delivery systems submitted for test shall contain all specified components and shall be completely assembled and properly adjusted and serviced for immediate operation.

4.3.2. Test agent. Except for the hydrostatic pressure test and the leakage test, which shall be performed using dichlorodifluoromethane (CCL_2F_2), the test agent shall be that described in 3.4.

4.3.2.1 Agent filling. The agent delivery system shall be filled with not less than (121 liters) 32 total gallons and not more than (136 liters) 36 total gallons of the agent specified in 3.4. The agent shall be placed in the agent tank which shall be clean and free of moisture. Precautions shall be taken to ensure that the agent does not come in contact with moisture during the filling operation.

4.3.3 Test data. During the tests specified herein, at least the following data, as applicable, shall be recorded at time intervals dictated by the test objective:

a. Time started

b. Time completed

c. Ambient temperature

d. Ambient atmospheric pressure

e. Ambient wind conditions

f. Quantity of agent in the agent tank

g. Pressure in the agent tank

h. Pressure in the nitrogen bottle.

4.3.4 Test observations. Throughout all tests specified herein, the agent delivery system shall be closely observed for the following conditions which shall be considered cause for rejection:

a. Failure to conform to design and performance requirements specified herein.

b. Spillage or leakage of agent.

c. Undue loss of pressure in the agent tank and nitrogen bottle.

d. Erratic agent discharge as determined by flow rate, interruptions to flow, discharge range and pattern.

e. Misalignment of parts and components.

4.3.5 System recycling. Agent delivery systems submitted for test may be recycled by refilling the agent delivery system with agent per 3.6. The recycled system shall conform to 4.3.1.

4.4. Preproduction testing (see 6.2)

4.4.1 Test sample. One agent delivery system shall be subjected to the tests specified in 4.4.3.

4.4.2 Test report. After completion of the preproduction tests, a test report shall be prepared in accordance with MIL-STD-831. The report shall cover each test required under a separate section or paragraph which in turn shall list individual tests purposes or objectives; describe procedures followed in each individual test; and compare by means of a checklist and table (as applicable) test results with the respective performance or design requirement for which the test is intended to demonstrate compliance.

4.4.2.1 Reliability and maintainability information. The following information shall be included as an appendix to the test report:

a. All failures, servicing, adjustments, maintenance, and irregular functioning shall be identified by accumulated operating time; cycles, miles, or position in the test procedure, as appropriate. Test conditions at the time of the events identified shall be recorded.

b. Test operator and maintenance technician actions, test equipment and test facility failures, and other events that might serve as grounds for a request that an equipment failure not be counted as a reliability failure. Detailed descriptions of the events and the analysis to substantiate any such request shall be included and shall be clearly cross-referenced to each applicable failure.

c. A summary of the engineering analysis and of any tests conducted to determine assignable causes for any failure or irregular functioning.

d. A summary of the engineering analysis leading to any corrections made to design, construction, quality control, or other procedures, or leading to any corrections to be made or proposed to be made to production items. The summary shall also include an analysis of the predicted effectiveness of such corrections. Failures that have been corrected by design changes or by other means shall be counted as reliability failures until the corrections have been both analyzed and verified by test sufficiently to substantiate the effectiveness of the correction to the satisfaction of the procuring activity.

e. Clock time and man-hours required for each maintenance and servicing action taken during the tests. Only the time needed for actually preparing for and performing the tasks shall be measured and recorded. A brief description of experience and qualifications of the personnel taking such actions.

4.4.3 Preproduction tests. The preproduction tests shall consist of all tests specified under 4.6.

4.5 Quality conformance tests. The quality conformance tests shall consist of the following:

a. Individual tests ....See 4.5.1

b. Sampling plan and tests.................................See 4.5.2.

4.5.1 Individual tests. Each agent delivery system shall be subjected to the following tests as described under 4.6:

a. Examination of product.................................. See 4.6.1

b. Mechanical inspection................................... See 4.6.2

c. Hydrostatic pressure .... See 4.6.3

d. Leakage... See 4.6.4

e. Relief valve.. See 4.6.5.

4.5.2 Sampling plan and tests. One agent delivery system shall be selected at random from each fifty, or fraction thereof produced, and subjected to the following tests as described under 4.6:

a. Roadability... See 4.6.6.

b. Agent discharge... See 4.6.7.

4.5.2.1 Rejection and retest. When an item selected from a production run fails to meet the specification, items still on hand or later produced shall not be accepted until the extent and cause of failure have been determined and appropriately corrected. The contractor shall explain to the Government representative the cause of failure and the action taken to preclude recurrence. After correction, all tests shall be repeated.

4.5.2.2 Individual tests may continue. For production reasons, individual tests may be continued pending the investigation of a test failure. Final acceptance of the items on hand or produced later shall not be made until it is determined that all items meet all the requirements of the specification.

4.5.3 Defects in items already accepted. The investigation of a test failure could indicate that defects may exist in items already accepted. If so, the contractor shall fully advise the procuring activity of all defects likely to be found and methods of correcting them.

4.6 Test methods

4.6.1 Examination of product. The agent delivery system shall be inspected to determine compliance with requirements of this specification with respect to dimensions, materials, finishes, markings, workmanship, and installation of components.

4.6.2 Mechanical inspection. A critical inspection shall be made of the agent delivery system and all components including fastening devices, data plates, valves, gages, piping, hose, operating controls, et cetera, and data recorded as to their condition, defects in manufacture, damage in transit and damage through use prior to test.

4.6.3 Hydrostatic pressure. With pressure relief devices removed and openings plugged, the agent tank and all connected and associated components and accessories that operate under pressure shall be pressure tested in accordance with Section VIII of the ASME Boiler and Pressure Code for Unfired Pressure Vessels. In addition, each hose assembly shall be hydrostatically pressure tested at no less than two times the maximum working pressure for not less than 5 minutes. The initial and final pressures, and evidence of leakage or impending failures, shall be recorded. At the completion of this test, the test fluid shall be completely drained and the components thoroughly dried.

4.6.4 Leakage. With the agent tank charged with (22.6 kg) 50 pounds of dichlorodifluoromethane (CCl_2F_2), the agent delivery system shall be subjected to an ambient temperature of not less than 70 °F for a period of not less than 24 hours. At the end of the 24-hour period, a Halogen Leak Detector, such as the GE Type H-25, shall be used to determine the leakage rate at all seams, threaded connections around the rupture unions, and valves.

4.6.5 Relief valve. Prior to installation on the agent delivery system, the spring-loaded relief valve shall be subjected to a gradually increasing pressure of clean, dry, oil-free air or nitrogen at its inlet until it starts to discharge. The pressure then shall be reduced until the valve completely reseals. This procedure shall be repeated not less than two times. Following this test, the valve shall be checked for leakage by application of a soap film (film across the outlet and over all outside surfaces) with not less than the maximum working pressure of the component which the valve will be used to protect being applied at the valve inlet. Failure to open or reseal within the specific limits or an indication of leakage during the soap film test shall be recorded.

4.6.6 Roadability. With the agent delivery system secured in the bed of a pickup truck, the agent tank filled as specified in 4.3.2.1, and the nitrogen bottle fully charged with nitrogen and the agent tank pressurizing valve closed, the system shall be subjected to operation over improved and unimproved roads as follows. Upon completion of each run, the unit shall be inspected for looseness of the damage to components, agent leakage, and loss of pressure as a result of vibrations, jarring, and other conditions incident to the road test.

a. Paved roads for a distance of (160 km) 100 miles at an average speed of (72 km/h) 45 mi/h.

b. Graded gravel roads for a distance of (160 km) 100 miles at an average speed of (40 km/h) 25 mi/h.

4.6.7 Agent discharge. Upon successful completion of the roadability test, the agent tank shall be pressurized to (1378 kPa) 200 lb/in^2 from the nitrogen bottle, and agent shall be discharged from the handline nozzle without assist from downwind conditions. During this discharge, the nozzle shall be held horizontal with and (1.22 meters) 4 feet above ground level and a steady discharge rate shall be maintained until pressure pulsations or interruptions to flow occur. The discharge rate, range, pattern, and percentage of agent discharged prior to pressure pulsations or interruption to flow shall be observed for compliance with operational requirements. The percentage of agent discharged may be measured by weighing the agent tank when empty, when full, and again after test.

4.6.8 Fire test. A minimum of (22.6 kg) 50 pounds of magnesium metal shall be placed in a 12-ft^2 (1.22-m^2)/pan. The magnesium shall be ignited and allowed to burn to a point that at least 50 percent of the exposed metal surface is ignited. It shall then be demonstrated that the extinguishing system can extinguish the fire. It is suggested that a technique of intermittent application of agent followed by cooling with water be used in this test. The nozzle shall be held at a distance of no less than (9.1 meters) 30 feet from the pan during the agent application. The magnesium metal shall consist of pieces measuring no less than 3 by 3 inches by 1 inch (7.62 by 7.62 cm by 2.54 cm).

4.6.9 Determination of weight. The empty and full weights of the fully assembled extinguishing system shall be determined.

4.7 Inspection of preparation for delivery. Preservation, packaging, packing, and marking for shipment and storage shall be inspected to determine conformance to the requirements of Section 5.

5. PREPARATION FOR DELIVERY

5.1 Preservation and packaging. The agent delivery system shall be prepared according to Method III, MIL-P-116. The system shall be assembled and shall be adequately secured to prevent movement and damage in accordance with MIL-STD-1186. Exposed gages, controls, and similar items shall be wrapped with a waterproof barrier and taped with waterproof tape. All openings shall be closed with plugs, caps or waterproof barrier and tape.

5.2 Packing. Packing shall be Level A or C as specified (see 5.2.1). Should Level B be specified, Level A shall apply.

5.2.1 Level A. Each complete agent delivery system shall be packed within a container conforming to Type II, Style A, Class I plywood superstructure, MIL-B-26195. The agent delivery system shall be secured to the container base in accordance with MIL-STD-1186.

5.2.2 Level C. Level C shall be the same as Level A except the container shall be Type I and the container superstructure may be attached by nailing in lieu of lag bolts.

5.3 Markings. In addition to the marking specified in 3.5 and any special marking required (see 6.2), marking for shipment and storage shall be in accordance with MIL-STD-129.

6. NOTES

6.1 Intended use. The agent delivery system is intended for use with the modified boron-type fire extinguishing agent for metal fires specified in MIL-F-XXXX by qualified firefighting personnel for the control and extinguishment of fires involving metals susceptible to ignition, such as magnesium and its alloys.

6.2 Ordering data. Procurement documents should specify following:

a. Title, number, and date of specification

b. In the event it becomes necessary to change the drawings (see 3.2) to achieve the performance requirements of the specification, the contractor will immediately notify the contracting officer with recommendations for drawing changes to obtain the required performance. To the extent approved, such changes will be processed in accordance with the provisions of the changes clause of this contract

c. Location and conditions for preproduction testing

d. Level of preservation and packaging required (see 5.1)

e. Level of packing required (see 5.2)

f. Additional markings if required (see 5.3).

S/N______________________

Gross Weight______pounds

METAL FIRE EXTINGUISHING SYSTEM

In accordance with

MILITARY SPECIFICATION MIL-A-

This metal fire extinguishing system is for use by qualified firefighting personnel in the control and extinguishment of metal fires.

Agent performance may be affected if used below -25 °F.

Avoid prolonged exposure to moisture.

Once filled with agent this system is for one-time use only. Do not use if the system has been previously charged and agent dispensed.

This system shall only be refilled and recycled by qualified personnel.

Figure B-1. Marking for Metal Fire Extinguishing System.

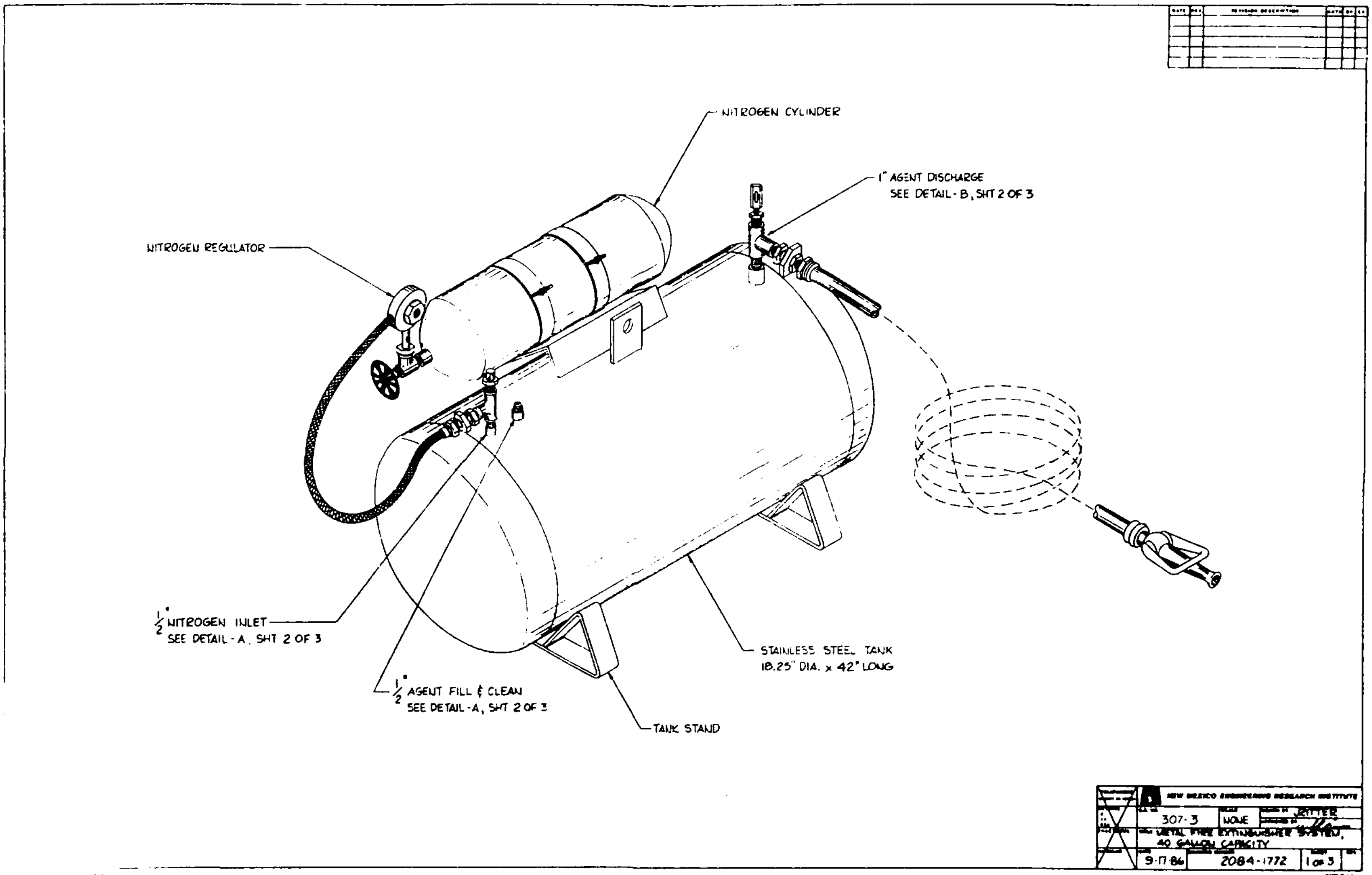
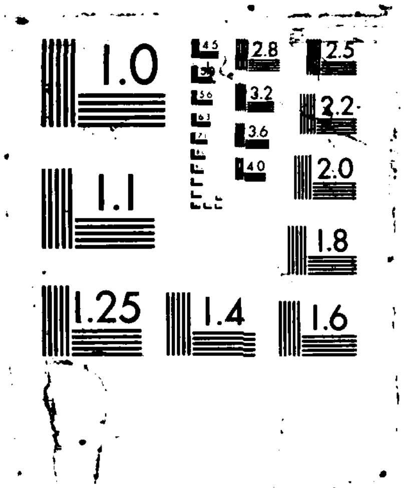
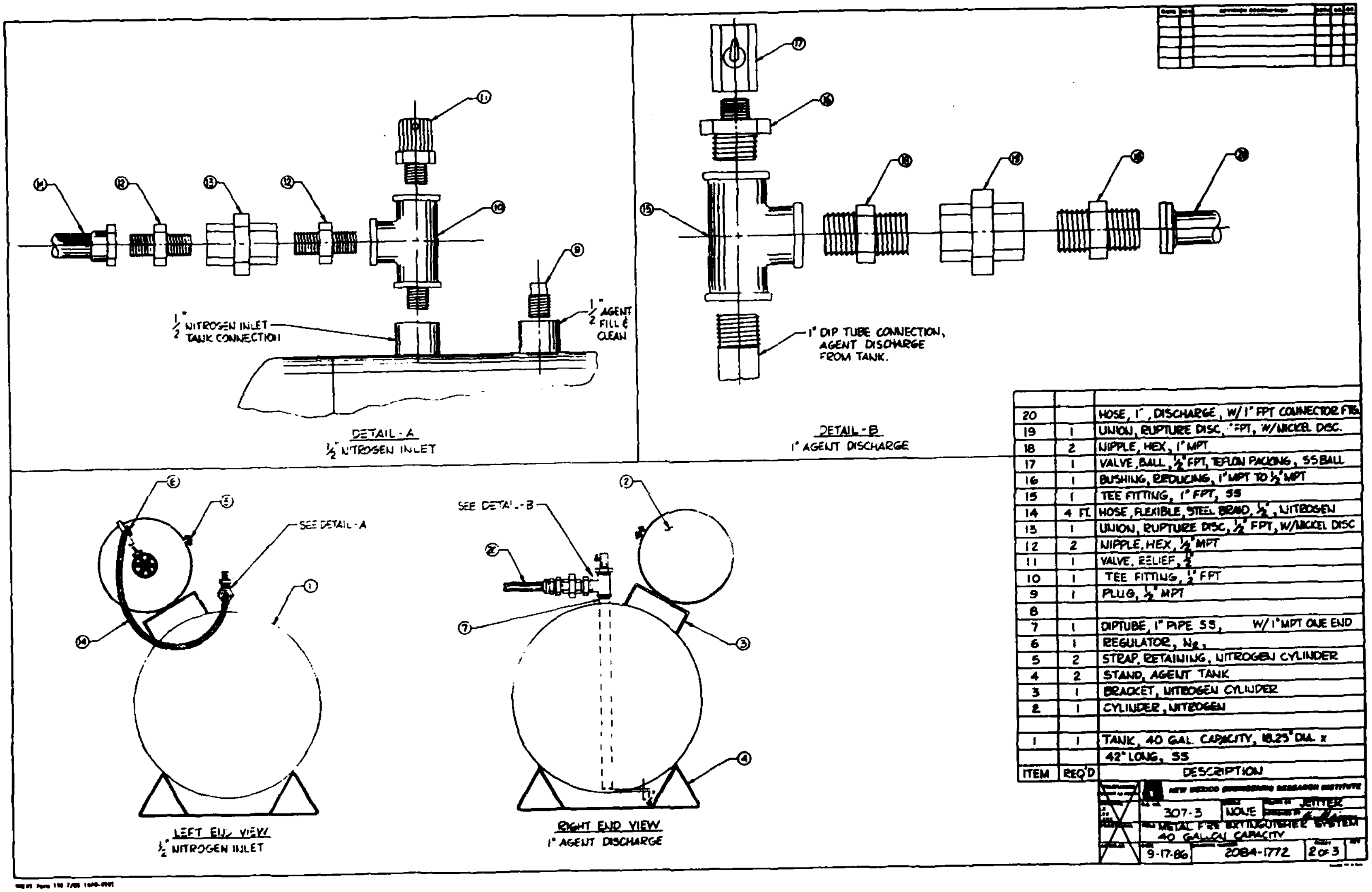


Figure B-2. Metal Fire Extinguishing System, 40-Gallon Capacity.

AD-A192 436 EXTINGUISHING AGENT FOR MAGNESIUM FIRE: PHASES 5 AND 6 2/2
(U) NEW MEXICO ENGINEERING RESEARCH INST ALBUQUERQUE
H D BEESON ET AL. JUL 87 NMERI-WA3-34(3.07)
UNCLASSIFIED AFESC/ESL-TR-86-65 F29601-84-C-0080 F/G 13/12 NL


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0



ITEM	REQ'D	DESCRIPTION
20		HOSE, 1", DISCHARGE, W/ 1" FPT CONNECTOR FTG
19	1	UNION, RUPTURE DISC, "FPT, W/NICKEL DISC.
18	2	NIPPLE, HEX, 1" MPT
17	1	VALVE, BALL, ½" FPT, TEFLON PACKING, SS BALL
16	1	BUSHING, REDUCING, 1" MPT TO ½" MPT
15	1	TEE FITTING, 1" FPT, SS
14	4 FT.	HOSE, FLEXIBLE, STEEL BRAID, ½", NITROGEN
13	1	UNION, RUPTURE DISC, ½" FPT, W/NICKEL DISC
12	2	NIPPLE, HEX, ½" MPT
11	1	VALVE, RELIEF, ½"
10	1	TEE FITTING, ½" FPT
9	1	PLUG, ½" MPT
8		
7	1	DIPTUBE, 1" PIPE SS, W/ 1" MPT ONE END
6	1	REGULATOR, N_2,
5	2	STRAP, RETAINING, NITROGEN CYLINDER
4	2	STAND, AGENT TANK
3	1	BRACKET, NITROGEN CYLINDER
2	1	CYLINDER, NITROGEN
1	1	TANK, 40 GAL. CAPACITY, 18.25" DIA. x 42" LONG, SS

Figure B-2. Metal Fire Extinguishing System, 40-Gallon Capacity (Continued).

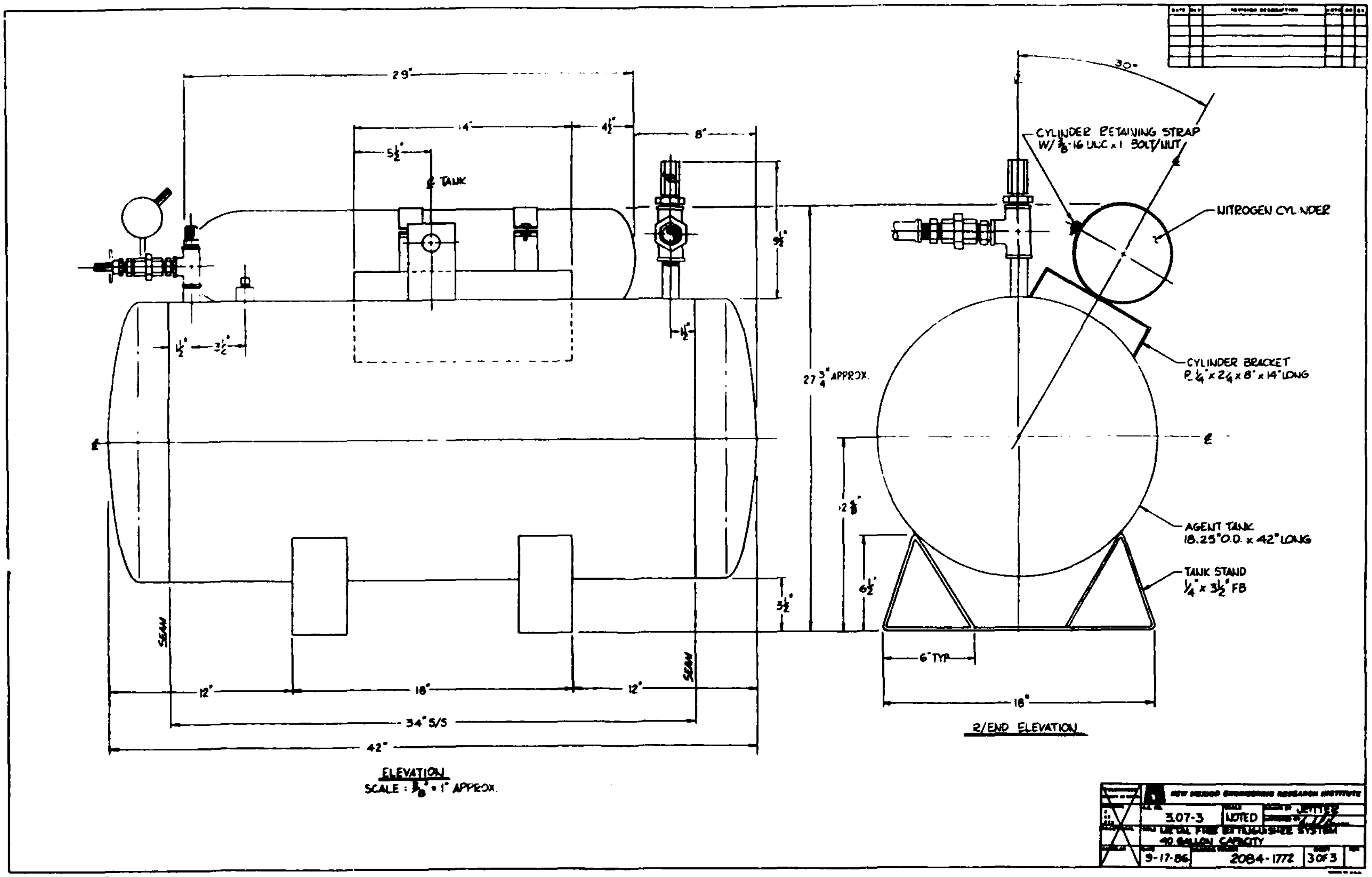


Figure B-2. Metal Fire Extinguishing System, 40-Gallon Capacity (Concluded).

END
DATE
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6-1988
DTIC