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A SOLID-PROPELLANT PRESSURIZER FOR FIRE-EXTINGUISHING SYSTEMS IN POLAR REGIONS

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ABSTRACT

A solid-propellant pressurizer with an automatic firing device for a 300-gallon sprinkler system has been developed. The unit is designed to operate from -65°F to room temperature. One 300-gallon sprinkler system can provide fire protection for two 20 x 48 ft buildings. The pressurizer employs the combustion gases of a double-base propellant to expel the extinguishant. The propellant is shaped into a hollow cylinder, 3-1/4 inches in diameter and 4-1/2 inches long. These cylinders, or grains, can be burned either singly or coaxially in groups of two or three. This feature, with the selection of suitable nozzles and other hardware, permits the use of different sizes of cartridges while retaining the advantages inherent in the use of a single propellant-grain design. The use of different sizes of cartridges is advantageous, since the volume of space to be pressurized varies widely as the operation of the sprinkler system proceeds.

The cartridges are fired at the proper time and in the proper sequence by a battery-powered firing system which employs two pressure switches and a stepping relay, and which is triggered by pressure changes in the sprinkler tank and loop. To initiate operation, a supervisory pressure of 10 to 15 psi is maintained in the sprinkler loop. When this pressure is reduced to 5 psi by the opening of one or more sprinkler heads, the first cartridge is fired. The high pressure (about 100 psi) resulting from the combustion of the first cartridge arms the firing system preparatory to firing the second cartridge. When enough fluid has been expelled through the open heads to reduce the pressure in the system to a predetermined level (about 35 psi), the second cartridge is fired. The process is then repeated automatically until all the cartridges are fired or until the line switch is opened manually. It appears that four cartridges will be sufficient for a 300-gallon system, although the use of a greater number would not require any basic changes in design.

PROBLEM STATUS

This is a final report on this problem. This problem was closed as of Jan. 1, 1958.

AUTHORIZATION

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A SOLID-PROPELLANT PRESSURIZER FOR FIRE-EXTINGUISHING SYSTEMS IN POLAR REGIONS

INTRODUCTION

Fire is a much more serious hazard in polar regions than it is in temperate climates. Not only is shelter necessary for survival, but the loss of a facility in the Arctic, such as an aircraft warning station, for example, may represent a loss much greater than the cost of replacement. Commercial fire-fighting equipment is generally not suitable for use at the extremely low temperatures encountered in arctic regions, so a need for specialized low-temperature fire-fighting equipment exists.

One possible method of pressurizing low-temperature fire extinguishers is by the use of solid propellants. A project was initiated and sponsored by the Bureau of Yards and Docks to develop solid-propellant cartridges for pressurization of fire-extinguishing systems at polar installations. The objective originally assigned to the U.S. Naval Research Laboratory was to develop solid-fuel cartridges to pressurize fire extinguishers of 2-1/2-gallon to 5-gallon sizes at polar temperatures (1). Satisfactory operation at polar temperatures was defined as requiring a new extinguisher to provide fire extinguishment as efficiently at -65°F as do presently available and accepted extinguishers at temperate climates. The work originally planned has been completed.

In January 1954, work on a second project for BuDocks was initiated. The objective of the new project was to determine the applicability of solid-fuel cartridges to the pressurization of a large sprinkler system at polar temperatures. Work on the sprinkler system was, from the beginning, divided into two separate projects. The sprinkler system itself was to be developed by the U.S. Naval Civil Engineering Laboratory (NCEL), at Port Hueneme, and the solid-fuel pressurizer with automatic firing system was to be developed by NRL. After the development of the pressurizer had advanced to a suitable stage, arrangements were made to test it in conjunction with the sprinkler system. These tests were made at NCEL, Oct. 29 to Nov. 6, 1957 (2). The development of the sprinkler pressurizer has now been completed and is covered in this report.

EXPERIMENTAL SPRINKLER SYSTEM REQUIREMENTS

At the time NRL started work on the project, the sprinkler system under consideration was a 250-gallon tank connected by standard 2-inch pipe to two sprinkler loops. The loops were made of smaller pipe (either 1 inch or 3/4 inch), and each, fitted with twelve sprinkler heads, was located in a separate 20 x 48 ft building. NRL was to develop a pressurizer to maintain proper operating pressure on the tank while one loop (one to twelve sprinkler heads) was operating. It was assumed that both loops would not operate simultaneously. Proper operating pressure was defined by BuDocks as a range of operating pressures satisfying two requirements: (a) with all twelve sprinkler heads of one loop open, the extinguishant must not be expelled in less than five minutes, and (b) tank pressure must at no time fall below the minimum value required for efficient sprinkling. This minimum tank pressure was considered to be about 30 to 35 psi, but the value was deliberately left indefinite because the final design of the sprinkler heads had not been selected. (The tank capacity for the system was eventually raised to 300 gallons.)

The original plan was to design a cartridge of slow-burning nitroguanidine-base propellant which would maintain an essentially constant pressure on a single operating sprinkler head. A firing system was then to be devised to initiate burning of the cartridges in such a way as to provide one burning cartridge for each head in operation. The size of propellant charge required for these cartridges was calculated, and burning tests of temperature-cycled charges of the calculated size were made. The tests indicated that it was feasible to use a nitroguanidine-base propellant charge of the required dimensions (about 2 inches diameter and 14 inches long). However, a study of the problem exposed some serious disadvantages inherent in the use of this propellant in the sprinkler-system pressurizer. The most important of these disadvantages are as follows.

1. The sprinkler system has a void of approximately 34 gallons which must be pressurized quickly to operating pressure while at the same time one or more sprinkler heads are operating. The conventional end-burning charge of nitroguanidine fuel cannot be used in the initial cartridge of the pressurizer, because the rate of gas production required necessitates a larger size charge of this fuel than has been successfully restricted. An unrestricted charge of the nitroguanidine fuel, burning on all surfaces, could be used in the initial cartridge and conventional end-burning charges used in succeeding cartridges. However, the unrestricted charge requires igniter material on all surfaces, and this material is considered to be too fragile to meet handling and transportation specifications.

2. A complicated system for igniting the charges is required. A fresh charge must be ignited each time a sprinkler head opens and also each time a charge completes burning.

3. Since a sprinkler loop has twelve heads, somewhat more than twelve cartridges would be required. It is desirable to use a smaller number of cartridges.

In view of these factors, the original plan of development was modified. The slow-burning nitroguanidine-base propellant was replaced by a double-base propellant (designated APZ) having a burning time of about 8 to 11 seconds. Also, a pressure switch attached to the tank was used to fire all cartridges except the first one. A second pressure switch was installed on the sprinkler loop to fire the first cartridge. In this way, tank pressure would be replenished when needed, regardless of the number of sprinkler heads operating. The total amount of propellant required to empty the sprinkler tank was determined by the gas production of the propellant, the volume of the sprinkler system, the volume of extinguishant, and the final, or minimum, tank pressure required to pressurize the sprinkler heads adequately. After these factors had been fixed, the number and sizes of cartridges required still had to be determined by the initial void in the system and the operating pressure limits. A small initial void and narrow operating-pressure limits would require a greater number of cartridges (but of smaller size) than would a larger initial void and wider operating-pressure limits. The original estimate was that three to five cartridges would be sufficient to pressurize the system adequately (3-8).

DESCRIPTION

Sprinkler System

The 300-gallon experimental sprinkler system, in its present state of development, is similar in many ways to the early 250-gallon system described above. The system consists essentially of a 325-gallon tank to which is connected by standard piping two sprinkler loops and the solid-propellant pressurizer. The loops are located in two separate 20 x 48 ft buildings, and the tank and pressurizer are outside and adjacent to one of the buildings. Each sprinkler loop consists of approximately 104 ft of pipe with fittings to which are attached twelve sprinkler heads. The optimum sizes of the loop pipe and sprinkler heads have not yet been selected, but the sizes of these components will not affect the operation of the pressurizer. One-inch and 3/4-inch pipe and 5/16-inch and 1/4-inch sprinkler heads are under consideration. Figure 1 is a photograph of the tank-pressurizer assembly. The tank is provided with a fire-alarm bell, a safety relief valve, and various other valves and fittings. The two-inch pipe line connecting the tank to the sprinkler loops has a flow switch to operate the alarm bell and a frangible disc to confine the supervisory gas pressure to the loop. In a standby position, 15 psi supervisory gas pressure is maintained in the loop to initiate operation of the system. For operation, the tank is loaded with 300 gallons of extinguishant which is expelled automatically by the pressurizer when a fire results in one or more sprinkler heads being opened.

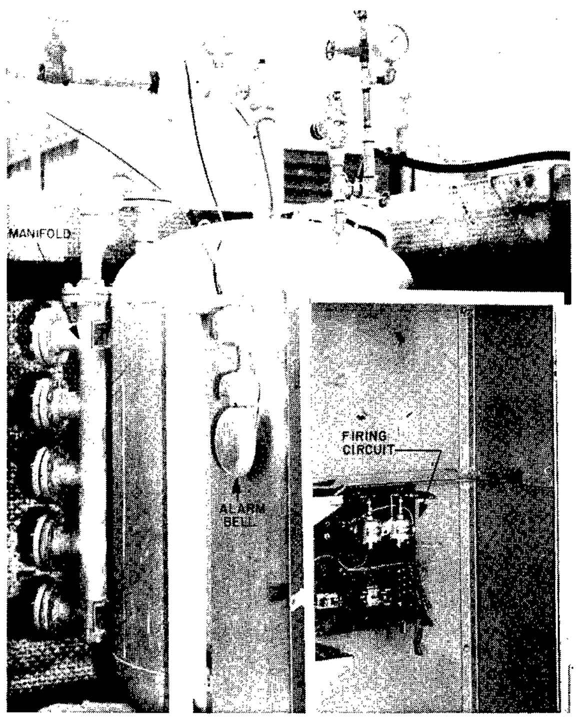


Fig. 1 - Sprinkler tank and pressurizer assembly

Pressurizer

The pressurizer consists of: (a) a fuel tube-manifold assembly for burning the solid propellant, and confining the combustion gases to the sprinkler system, (b) the solid propellant and igniters, and (c) an automatic firing system for igniting the propellant cartridges at the proper time and in the proper sequence. As a result of the tests at NCEL, two changes have been made in the design of the pressurizer. These changes are the incorporation of a new igniter and a new firing circuit. The following description will cover both the old and new systems.

Fuel Tube-Manifold Assembly – The manifold was designed to permit the attachment of as many as five cartridges to the sprinkler tank. Figure 1 shows the manifold (without cartridges) welded to the side of the tank. Figure 2 shows the assembled manifold and cartridges when detached from the sprinkler system. For test purposes, a nozzle was attached to the manifold outlet to provide a manifold pressure which would simulate the tank pressure of the sprinkler system. The propellant is shaped into hollow cylinders 3-1/4 inches in diameter and 4-1/2 inches long. These cylinders, or grains, can be burned either singly or coaxially in groups of two or three. The fuel tubes (cartridge cases) were made in three different lengths to accommodate, respectively, one, two, and three grains of the APZ propellant. Both the manifold and fuel tubes were constructed of standard 3-1/2-inch pipe with flanged connections. The bursting pressure of this pipe, calculated by using a fiber stress of 50,000 psi, is 5650 psi. This appears to provide an adequate factor of safety in view of the burning pressures attained. Figure 3 shows typical pressure-time curves for the APZ cartridges.

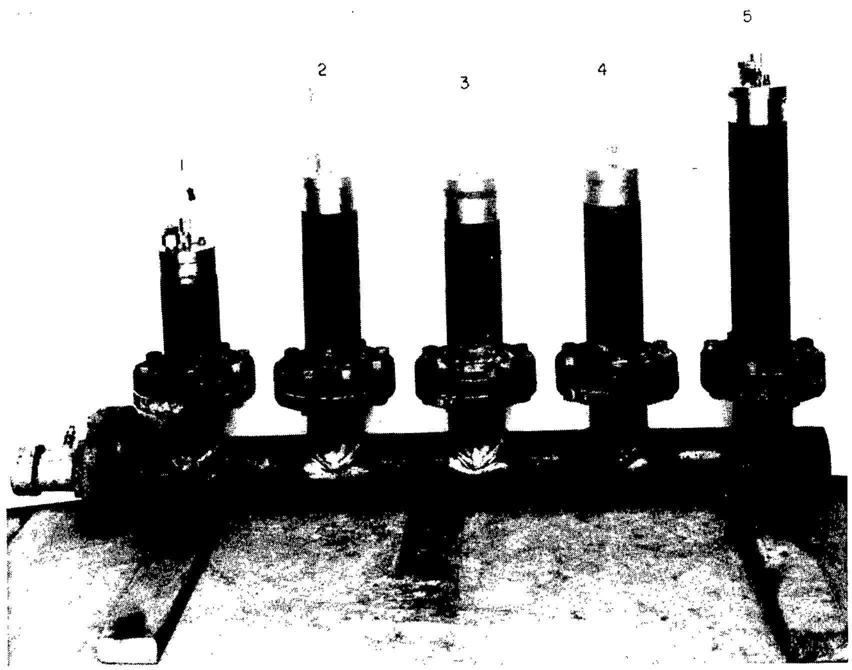


Fig. 2 - Pressure manifold and cartridges. The firing order of the cartridges is shown above the manifold.

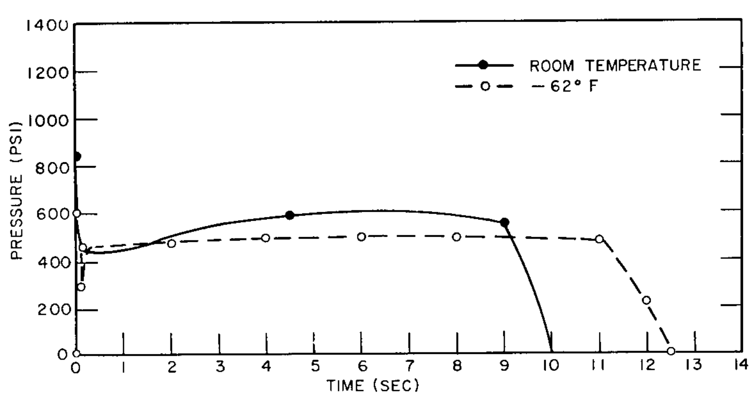


Fig. 3 - Pressure-time curves of an APZ cartridge using two 1-1/2-pound grains

Figure 4 is a drawing of an assembled and loaded two-grain cartridge. The propellant grains are spaced and their positions retained in the fuel tube by steel-ring spacers and a sheet of asbestos packing material (Garlock), which is used as a liner for the tube. The nozzle, located at the flange end, is provided with a frangible closure which ruptures at 700 to 800 psi. This disc insures that moisture does not enter the fuel tube through the nozzle and also that hot gases from one burning cartridge do not ignite another cartridge. The metal strainer located between the propellant and the nozzle insures that cinders from the igniter will not partially clog the nozzle. The fuel-tube head is fitted with igniter parts, a safety rupture disc, and a threaded fitting for connection to a pressure recorder. Figure 5 is a photograph of a disassembled one-grain fuel tube with its components (except for the Garlock liner and pressure-recorder fitting).

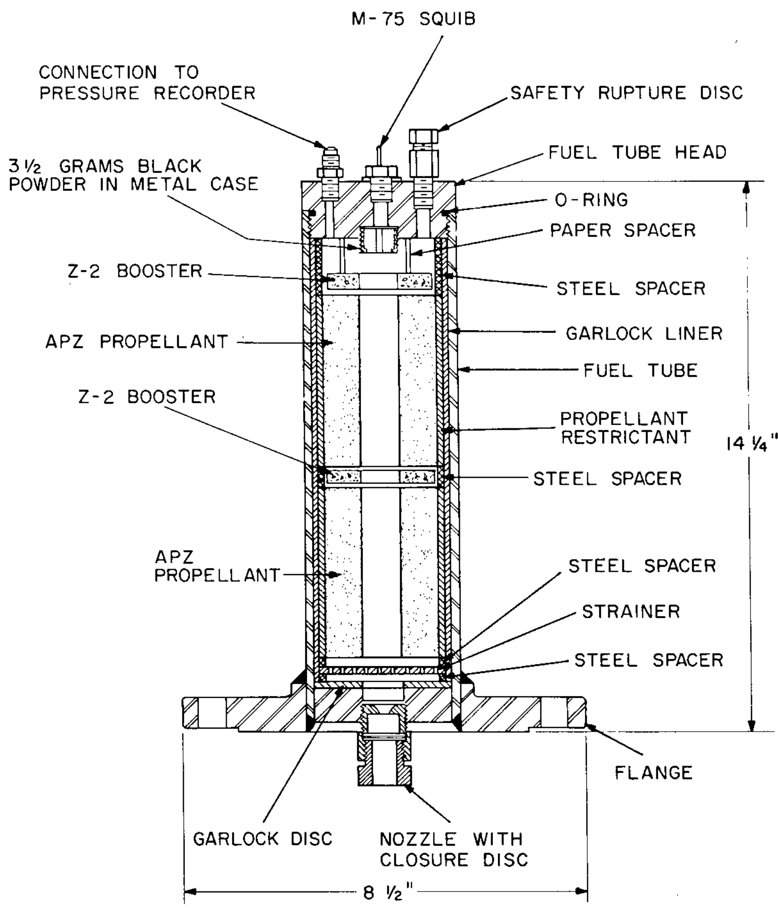


Fig. 4 - Two-grain APZ cartridge

Propellant – The solid propellant selected for use in the pressurizer is a double-base propellant, designated APZ, manufactured by the Allegany Ballistics Laboratory, Cumberland, Maryland. Major considerations leading to the selection of APZ for this application were its long-term storage ability and its burning characteristics, such as satisfactory performance over a wide temperature range (room temperature to -65°F) and at a relatively low burning pressure (500 psi).

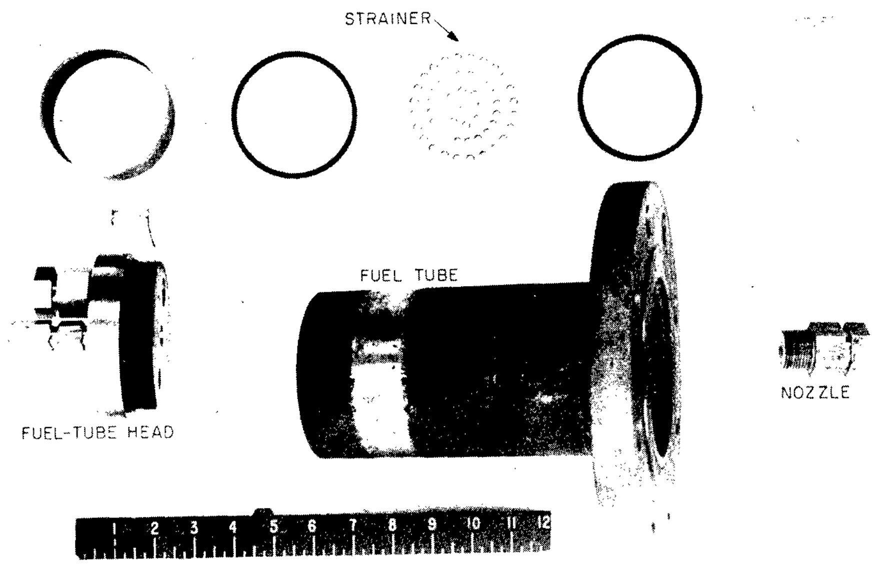


Fig. 5 - One-grain fuel tube

Since the gas space in the sprinkler system increases as the extinguishant is expelled, it is apparent that it would be advantageous to use various sizes of cartridges in the pressurizer. For this reason an APZ grain was designed to burn either singly or in groups of two or three. Thus a single-grain design permitted three cartridge sizes, provided that igniters, nozzles, and fuel tubes were suitably selected. The APZ grain is a singly perforated cylinder 4-1/2 inches long, 3 inches O.D. (without restrictant), and 1 inch I.D. It is restricted on the outer circumference and burns on both ends and on the inner surface. Burning time is approximately ten seconds, and grain weight (without restrictant) is 1-1/2 pounds. The ABL value for permanent gas production is 13.3 cu ft STP per pound of propellant. The grain with its igniter is shown in Fig. 6, and typical burning-pressure-vs-time curves for cartridges at both room temperature and -62°F are shown in Fig. 3.

<u>Igniter</u> – The first igniter developed for the APZ cartridges was a two-stage system consisting of an initiator and a booster. The initiator was a silk bag containing four grams of black powder and an electric match. The match wires were brought through the fuel-tube head by means of a Conax thermocouple gland (Fig. 5) which effectively sealed and insulated the two match wires. The booster was a cake of metal-oxidant-igniter material (Z-2) placed directly on the head end of each propellant grain. The powder-bag initiator along with the Z-2 booster and propellant grain is shown in Fig. 6.

As a result of the NCEL tests, the powder-bag initiator was replaced by a standard item, the M-75 pressure squib, produced by McCormick-Selph Associates of Hollister, California. The M-75 squib (Fig. 7) threads directly into the fuel-tube head. This squib contains a charge of only 1/2 gram of black powder, in contrast to the four grams contained by the bag initiator it replaced. Use of this smaller charge of black powder resulted in some ignition delay at low temperature, and consequently a booster charge of 3-1/2 grams of black powder was added to supplement the M-75. The new igniter (Fig. 4) consists of (a) the M-75 squib, (b) a 3-1/2-gram black-powder booster, and (c) a cake of Z-2 igniter mix on each propellent grain. The three different sizes of cartridges employ the same squib and black-powder booster. The one-grain cartridge uses a 55-gram cake of Z-2, the two-grain cartridge a 45-gram cake for each grain, and the three-grain cartridge a 35-gram cake for each grain. This igniter provides satisfactory ignition without excessive ignition pressures over the specified temperature range (room temperature to -65°F).

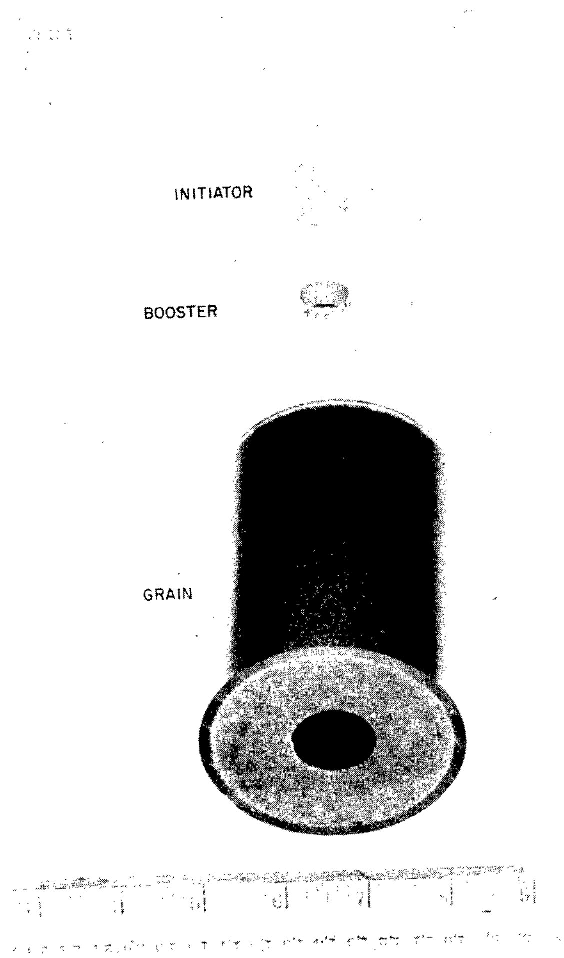
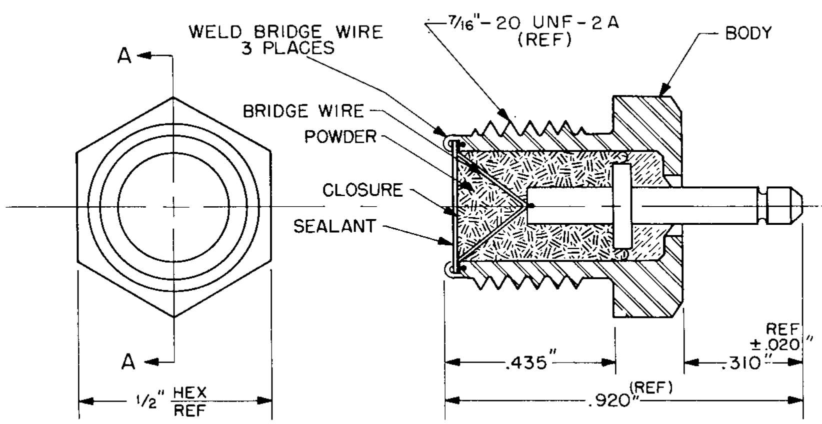


Fig. 6 - APZ grain with Z-2 booster and powder-bag initiator



1. PIN MATES WITH THOMAS & BETTS WIRE CONNECTOR #80-13885-4 OR USED AS SOLDER LUG
2. SQUIB RESISTANCE SHALL BE 1.00 ±0.2 OHM

Fig. 7 - M-75 pressure squib

Firing System – The cartridges are fired automatically and in the proper sequence when the pressure in the sprinkler system reaches predetermined values. Three different circuits were designed to fire the cartridges in this manner. The basic elements of each of the three circuits are two pressure switches and a stepping relay. In reality there are three pressure switches, but since two of them are mounted in a single housing, they are referred to as a double switch.

Circuit 1 was abandoned early because it required the stepping-relay coil to withstand energization for too long a time. It is common practice to design these coils for short-time, intermittent use. Circuit 2, designed with a second relay to protect the stepping-relay coil, was used in the NCEL tests. There was some trouble (described on pp. 10 & 11) with this circuit because the design of the igniter permitted its leads to short-circuit occasionally after ignition, and proper operation required that the igniter wires burn out or open the circuit at the proper time. Circuit 3 eliminates these undesirable features. The wiring diagram of circuit 2 is shown in Fig. 8 and that of circuit 3 in Fig. 9. A photograph of the assembled firing system employing circuit 2 can be seen in Fig. 1, and that employing circuit 3 is shown in Fig. 10. Figures 1 and 10 show the two pressure switches connected as if to be pressurized from a single source. In the complete sprinkler system, one switch is connected to the sprinkler loop and the other to the tank. The operation of circuits 1 and 2 are described in Ref. 8, and the following paragraph, along with Fig. 9, describes the operation of circuit 3.

To initiate operation of the system, about 15 psi supervisory gas pressure is maintained in the loop. To avoid the necessity of providing supervisory pressure for the tank void, the loop is separated from the tank by a frangible disc in the pipe line. When the supervisory pressure is reduced to 5 psi by opening a sprinkler head, pressure switch B closes and fires the first cartridge. The pressure produced by the first cartridge ruptures the frangible disc and closes the normally open pressure switch C, which arms the system by stepping the relay to the Charge 2 position. Charge 2 is then fired when enough fluid has been expelled to close the normally closed pressure switch C. The system then continues to arm

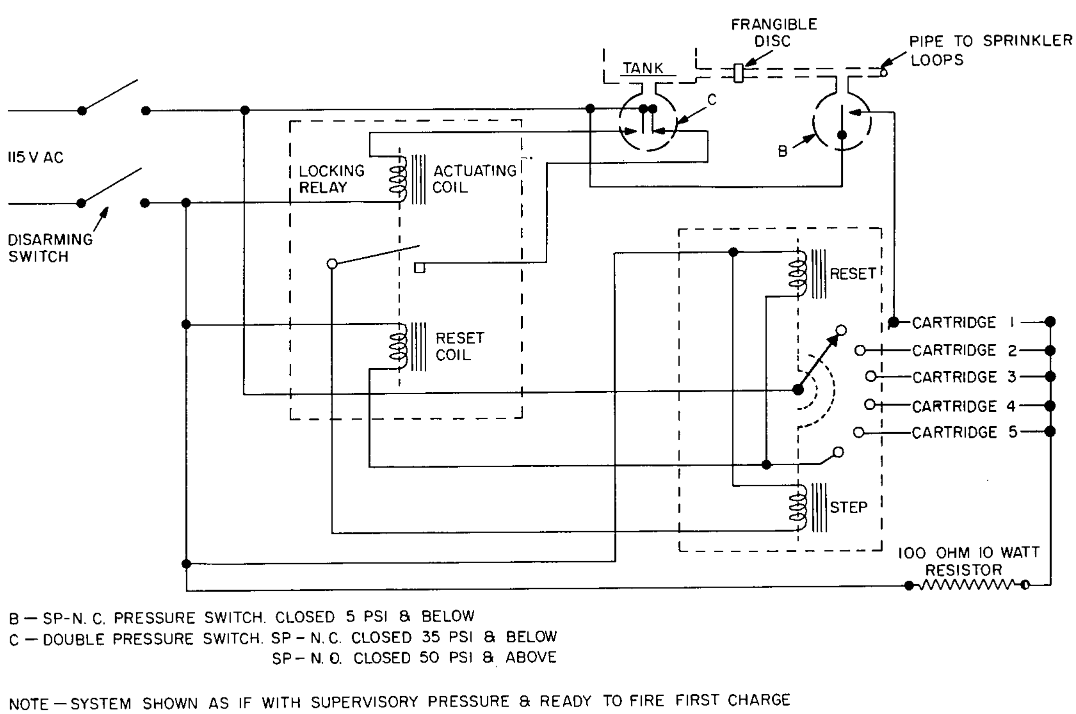
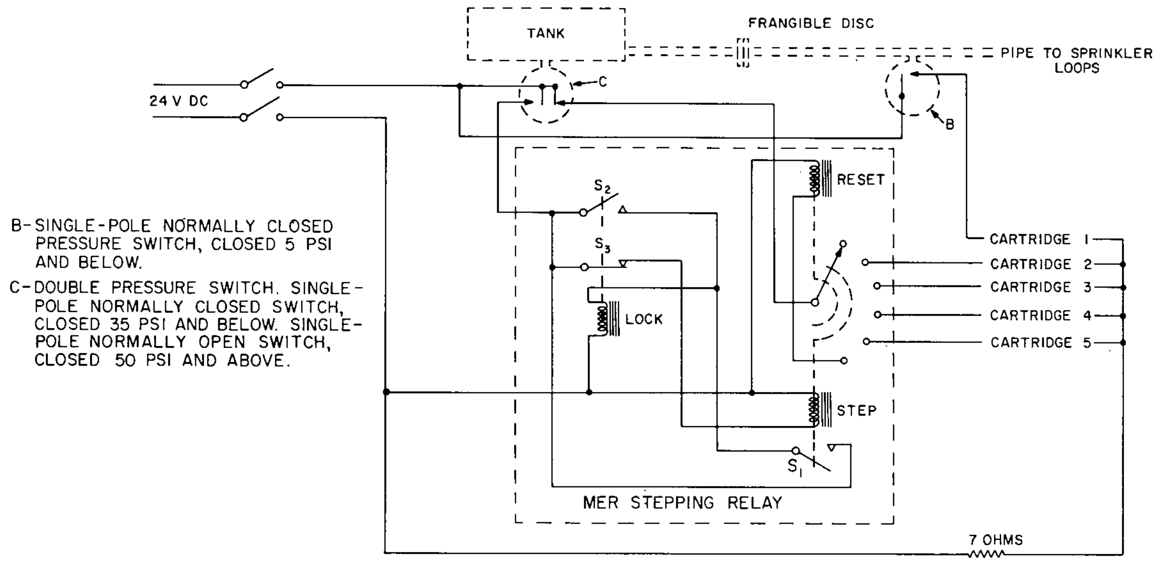


Fig. 8 - Wiring diagram of circuit 2



OPERATION OF MER STEPPING RELAY

SWITCH S_1 CLOSES AT END OF STEP-MAGNET STROKE AND ENERGIZES LOCKING COIL. LOCKING-COIL MAGNET THEN CLOSES SWITCH S_2 BEFORE OPENING SWITCH S_3. SWITCH S_3 OPENS AND DE-ENERGIZES STEP COIL TO OPEN S_1. LOCK COIL REMAINS ENERGIZED AND STEP COIL DE-ENERGIZED UNTIL END OF PULSE. WHEN PULSE IS ENDED BY PRESSURE SWITCH C, S_2 OPENS AND S_3 CLOSES. RELAY IS THEN READY FOR NEXT PULSE.

NOTE – SYSTEM SHOWN AS IF WITH SUPERVISORY PRESSURE AND READY TO FIRE FIRST CHARGE.

Fig. 9 - Wiring diagram of circuit 3

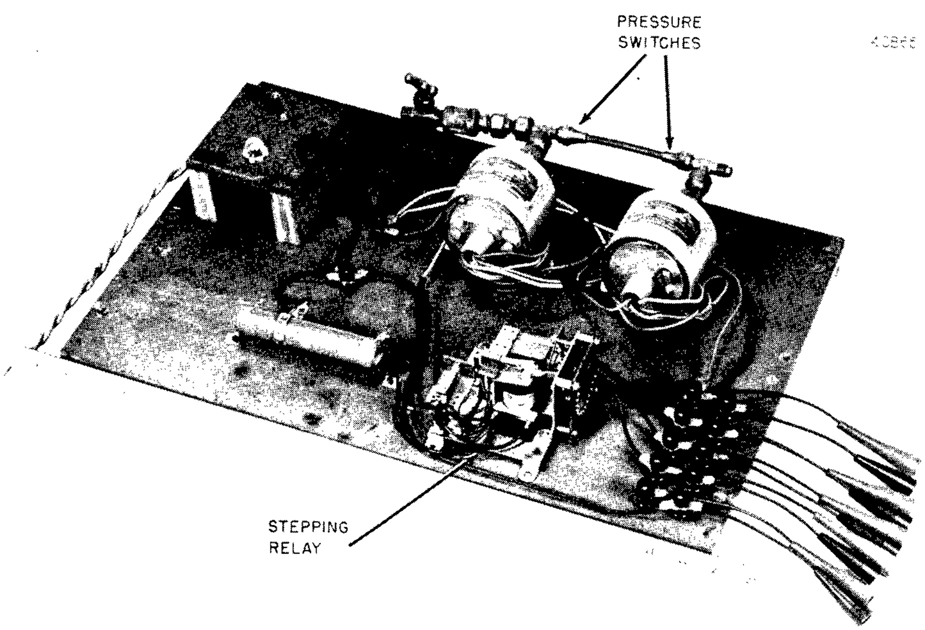


Fig. 10 - Firing system using circuit 3. The connection shown between the pressure switches is no longer used

on high pressure and fire a cartridge on low pressure until all the cartridges are fired or until the line switch is opened manually. The three switches in the stepping-relay circuit serve to switch the current from the stepping coil to a locking coil. This makes the circuit capable of withstanding continuous energization, although the safe energization time for the stepping coil is strictly limited.

Specifications – Detailed drawings of those portions of the system manufactured at NRL are given in Appendix A. Specifications for the fuel, igniter, and other components obtained from commercial sources may also be found in this appendix.

PERFORMANCE

The pressurizer was thoroughly tested, independently of the sprinkler system, at NRL. In these tests the APZ propellant and the igniters performed satisfactorily and reproducibly from room temperature to -65°F. Further, the hardware was found to be adequate and the firing system reliable. At this stage of development, the pressurizer was assembled with the sprinkler system and a series of tests was made at NCEL Oct. 29 to Nov. 6, 1957. The results of these tests are reported fully in Ref. 2, but they will be summarized in this report.

The purpose of the NCEL tests was (a) to determine the number and respective sizes of cartridges which would be required to maintain the proper operating pressure in the sprinkler system, and (b) to determine the operating characteristics of the combined pressurizer-sprinkler system over a range of conditions, the chief variable being the number of sprinkler heads open. The tests were not concerned with nozzle spray pattern or fire extinguishment. All the tests were made at room temperature using water as the fluid. Table 1 lists the tests and defines their operating variables. The series of numbers listed in the table under "firing sequence" is the number of APZ grains in each cartridge used in the test arranged in the order in which the cartridges were fired. The "firing pressure" is the pressure at which the firing system was set to ignite all cartridges except the first one of a particular test. It has not yet been determined what the firing pressure will finally be so two different values of this parameter were used in the tests. To illustrate typical results obtained in the NCEL tests, the pressure-time and temperature-time curves for one of the tests (No. 9 of Table 1) are shown in Fig. 11.

Tank pressures were recorded by a Brush Oscillograph Recorder. Gas temperatures were measured by an iron-constantan thermocouple located inside the tank near the center and about two inches from the top. Measurement of the time required to expel 300 gallons of water in different tests with various numbers of 1/4-inch sprinkler heads open made it possible to plot operating time as a function of the number of heads open. This curve is shown in Fig. 12. In some of the tests (not shown in Fig. 12) the number of heads open was increased as the run proceeded in order to simulate the effect of a fire. It is possible that the operating time can be increased by installation of a pressure regulator in the pipe line between the tank and the sprinkler loops.

In the NCEL tests, the sprinkler system, pressurizer hardware, propellant, and igniters performed satisfactorily. There were no mechanical failures of these components, and all propellant grains ignited and burned normally. However, the tests did expose some minor undesirable characteristics of the pressurizer. These characteristics, along with accomplished or suggested improvements, are discussed below.

Circuit Design

In the NCEL tests, circuit 2 (Fig. 8) was used with the powder-bag initiator (Fig. 6). It can be seen in Fig. 8 that when the stepping relay steps, it connects a cartridge directly across the line. Therefore, if the cartridge initiator does not burn out to open the circuit,

Table 1
Data on Test Firings

Test No.	Firing Sequence*	Firing Pressure (psi)	System Void (gal)	Size Sprinkler Heads (inches)	Number of Heads Open	Remarks
1	1	-	34	-	0	Results discarded due to Inaccurate measurement of void.
2	1	-	34	-	0	
3	1-1-2	20	34	1/2	1	
4	1-1-2-2	20	34	1/4	5	
5	1-1-2-2	20	34	1/4	†	Results discarded because only first cartridge burned. Open circuit in firing panel.
6	1-1-2-2	20	34	1/4	†	
7	1-1-2-2	29	34	1/4	9	
8	1-1-2-2	29	34	1/4	12	
9	1-1-2-2	29	34	1/4	6	
10	1-1-2-2	29	34	1/4	3	
11	1-1-4	29	34	1/4	†	Two 2-grain cartridges fired simultaneously.

*Firing Sequence refers to the number of propellant grains in each cartridge, arranged in the order of firing.

†One 1/4-inch sprinkler head open first 5 minutes of operation.
Two 1/4-inch sprinkler heads open second 5 minutes of operation.
Three 1/4-inch sprinkler heads open remainder of operating time.

current will continue to flow through the initiator wires and the resistor until the tank pressure drops sufficiently to step the relay to the next cartridge. If only one head is open, the relay may not step for several minutes. The powder-bag initiator (or electric match) ordinarily does burn out. However, in this case, it was found that the relatively long match wires inside the cartridge sometimes became entangled during ignition and completed the circuit. This resulted in burning out the resistor. Two changes were made to remedy this condition. First, the McCormick-Selph M-75 pressure squib, which does burn out reliably and which has no long leads to become entangled, was adopted. Secondly, circuit 3 (Fig. 9) was adopted. Examination of Fig. 9 will show that pressure switch C opens the circuit immediately after a cartridge is ignited; therefore with this circuit it is not necessary that the initiator burn out. Thus the powder-bag initiator would perform satisfactorily with circuit 3. Circuit 2 would be adequate if used with the M-75 pressure squib.

Initiator

Although the powder-bag initiator is entirely adequate for the purpose of igniting the propellant, its design is such that it would be difficult to assemble under many conditions which

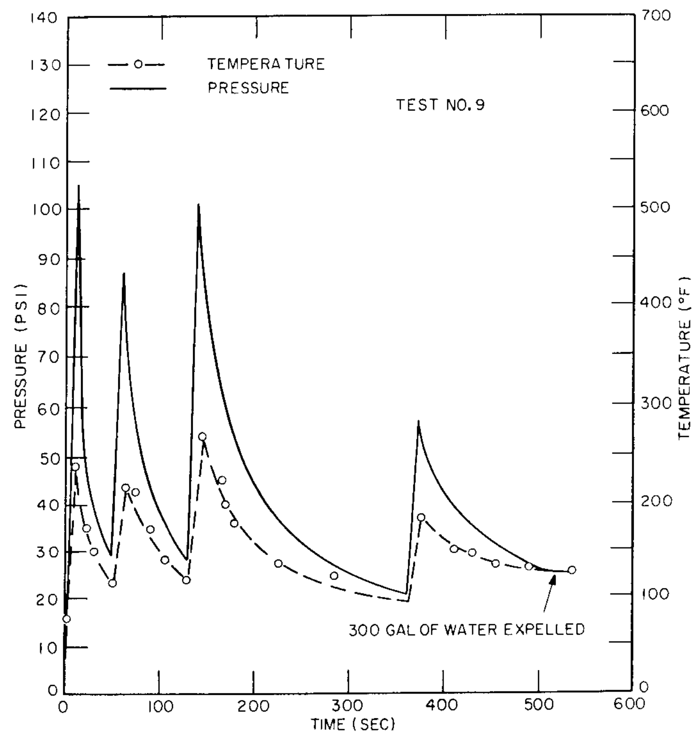


Figure 11 - Pressure-time and temperature-time curves for 1-1-2-2 firing sequence with six 1/4-inch sprinkler heads open

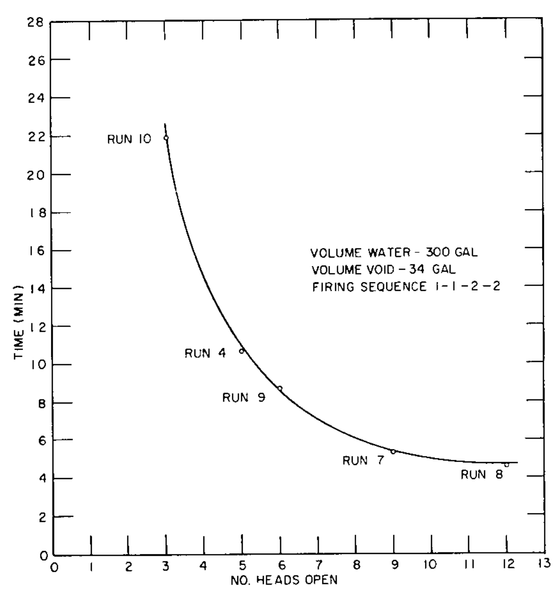


Fig. 12 - Operating time of 300-gallon sprinkler system as a function of the number of 1/4-inch sprinkler heads open

exist in the field. The adoption of the McCormick-Selph M-75 pressure squib with the black-powder booster has solved this problem. The assembly of this initiator requires only that it be screwed into the threaded hole in the fuel-tube head and connected to the circuit by means of a standard connector.

Wiring

One source of trouble in the NCEL tests was inadequate wiring. For example, a broken wire on one occasion and short circuits on others interfered with some of the tests. The use of weatherized components with wiring and connectors adequately protected from weather and mechanical damage should make the firing system entirely reliable. A weatherized stepping relay to operate on 24 v dc (Appendix A) has been procured.

Nozzle-Closure Discs

In the NCEL tests, it was found that the small nozzle-closure discs (copper foil and asbestos packing material discs fastened over the fuel-tube nozzles) were sometimes swept through the manifold, tank, and sprinkler loop and partially clogged a sprinkler head. This condition can easily be eliminated by the installation of a screen or filter at some convenient place in the manifold or pipe line.

Firings

Only a few firings of any particular combination of initiator, booster, and propellant have been made. However, the components of the firing train (M-75 squib, black powder, Z-2 igniter, and APZ propellant) have been individually proven. If a large number of firings should expose a defect (an ignition delay at low temperature is considered to be more probable than any other defect), it is felt that it could easily be corrected by an adjustment of the quantities of black powder and Z-2 used.

CONCLUSIONS

It appears that the pressurizer in its present form can be used to provide efficient and reliable pressurization for the sprinkler system throughout the specified temperature range (room temperature to -65°F). There are a number of possibilities for refinements in design, and some of them should be adopted. For example, a strainer should be installed at some convenient place in the system to prevent nozzle-closure discs from entering the sprinkler loop. Also, it may be desirable to eliminate the manifold and attach the cartridges directly to the tank. It is possible that the operating time can be increased by installation of a pressure regulator in the pipe line between the tank and the sprinkler loops.

If it becomes apparent that tank pressure must be controlled within a smaller range than the 20 to 100 psi used in the NCEL tests, there is considerable latitude in the present system for making such an adjustment. The lower limit of tank pressure is set by adjusting the pressure switch to fire the cartridges at that pressure. The upper limit is determined by the size of the cartridges (firing sequence) and the system void and would have to be determined by experiment. The limiting factor here is the size of the propellant grain.

Control of tank pressure within very narrow limits might require that the propellant be available in smaller increments (grains). The design of a smaller grain would not be difficult.

ACKNOWLEDGMENTS

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APPENDIX A

SPECIFICATIONS FOR COMPONENTS OF SPRINKLER SYSTEM PRESSURIZER

PROPELLANT

The propellant used in the pressurizer was manufactured by the Allegany Ballistics Laboratory, Cumberland, Maryland. The grain design is that of a singly perforated cylinder (Fig. A1). The propellant grain, restricted on its outer circumference by a cellulose acetate restrictant, burns on both ends and in the central hole. The grains are made by casting the double-base propellant in a cellulose acetate beaker and machining to size. Various sizes of beakers are available. The grains may be burned singly or in groups of two or three, provided that the nozzle is suitably sized. Nozzle cross-sectional area is directly proportional to propellant burning surface. The area of the port (central hole) is not large enough to permit burning more than three grains in a single cartridge. The grain dimensions and design calculations are as follows:

Propellant designation	APZ
Grain O.D.	3 in.
I.D.	1 in.
Length	4.5 in.
Cross section of powder	6.283 sq in.
Weight of propellant	1.521 pounds
Burning time (t_b)	8 sec
Initial burning surface	26.705 sq in.
Final burning surface	23.560 sq in.
Initial K	744
Initial pressure	at -15°F: 480 psi at 130°F: 560 psi
Final K	656
Final pressure	at -15°F: 430 psi at 130°F: 530 psi
Area of nozzle throat (1 grain)	0.0359 sq in.
Surface-to-port ratio (3 grains)	102
Permanent gas production	13.3 cu ft per pound
Cost	$5.50 per pound

K is defined as the ratio of the propellant burning surface to the cross-sectional area of the nozzle. The area of the nozzle throat given above should be multiplied by the number of grains being fired in a given cartridge.

INITIATOR

The initiator, the M-75 pressure squib, is a standard item produced by McCormick-Selph Associates of Hollister, California. This squib threads into the fuel-tube head and can be connected to the firing circuit by a standard wire connector or by soldering. The M-75 is shown in Fig. 7, and the more important design features are listed below:

Explosive load	500 mg FFFG black powder
Contact-pin-to-case resistance	1.00 ±0.15 ohm
Recommended ignition current	2.0 amps min for satisfactory ignition 0.8 amps max for zero ignition
Cost	\$1.36 each

BOOSTER

A two-stage booster consists of (a) 3-1/2 grams of FFFG black powder packed in a metal case screwed to the fuel-tube head, and (b) a cake of Z-2 igniter located on the head end of each propellant grain. A drawing of the black-powder stage of the booster is shown in Fig. A2, along with that of a fitting designed to aid in packing the powder in the metal case. The powder is moistened with the binder solution described below and tamped lightly into the case which has been previously placed over the fitting. The fitting is then removed, leaving the charge of powder with an axial hole. The charge of black powder is the same for the three different sizes of cartridges.

The Z-2 boosters are made in different sizes for the different sizes of cartridges. The one-grain cartridge employs a 55-gram cake of Z-2, the two-grain cartridge uses two 45-gram cakes, and the three-grain cartridge uses three 35-gram cakes. The Z-2, a mixture of 21 percent zirconium and 79 percent barium chromate, is obtained from the Catalyst Research Corp., Baltimore, Maryland. It is obtained as a powder and is made into a cake by mixing with a binder solution and casting in a paper cup. Binder solution is added to a weighed quantity of Z-2 to get the proper pouring consistency (about that of concrete). If the material is poured too thin, the cakes will crack upon drying. The paper cups are made so as to produce a doughnut-shaped cake (Fig. A3) which will fit into the fuel tube and rest on the end of a propellant grain. The cups are assembled with Scotch Tape and are not removed from the Z-2 cake after casting. If a loaded cartridge is to be subjected to much handling, the Z-2 cakes should be held firmly in place by paper spacers. Cost of the Z-2 igniter mix is approximately \$10.00 per pound.

The binder solution used with both the black powder and Z-2 is made by dissolving nitrocellulose with dibutyl phthalate in acetone in the following proportions:

Nitrocellulose	10 grams
Dibutyl phthalate	3 grams
Acetone	250 cc

PRESSURE SWITCHES

The two pressure switches used in the pressurizer, obtained from Barksdale Valves, Los Angeles, California, are shown in Fig. 10. In use, the model 420 switch is attached to the sprinkler loop and serves to fire the first cartridge, while the model 424 switch is attached to the tank and fires all cartridges except the first of a series. Model 424 is in reality two electrically independent switches housed in the same body.

The electrical connection (to both switches) is made to leads extending from the switch through a 1/2" - 14 NPT connection for conduit. The pressure connection is a 1/4" - 18 NPT internal thread. Operating characteristics and ordering data are listed below:

Switch model	420	424
Catalog number	420E-20L	424E-37L
Proof pressure (psi)	120	150
Adjustable range (psi)		
Decreasing		
minimum	0.5	1.0
maximum	78.0	92.0
Increasing		
minimum	2.6	9.0
maximum	80.0	100.0
Approx. actuation value (differential psi)	1.3 ± 0.8	5.0 ± 3.0
Cost (approximately)	$17.00	$29.00

STEPPING RELAY

The stepping relay used in the pressurizer is a modified Series MER (midget electrical reset) stepper manufactured by the Guardian Electric Manufacturing Company of Chicago, Illinois. Guardian's Standard Series MER stepper was modified by weatherizing the unit and providing an arrangement to permit continuous duty. Weatherizing the unit included (a) varnish baking the coils, (b) fungus proofing the entire unit, and (c) use of a low-temperature lubricant in manufacture. Provision for continuous duty was made by utilizing an additional relay interwired with the intermittent-duty stepper coil, so that a pulse applied to the stepper magnet coil passes through a normally closed switch on the auxiliary relay. The wiring diagram is shown in Fig. 9. The relay may be seen in Fig. 10.

At the end of the step-magnet operational stroke, a switch (operated by the stepper magnet) closes, thus energizing the auxiliary relay. The auxiliary relay, using a make-before-break transfer switch, completes a self-energizing hold circuit and cuts off the power to the step magnet. The auxiliary relay remains energized until the input pulse is terminated. At the end of the pulse the auxiliary relay drops out, and the units are ready for the next cycle of operation.

The cost of the modified series MER stepping relays is about $45.00 in quantities of less than ten. The operational characteristics of the relay are given below.

Speed of operation - Maximum, 20 steps per second within rated voltage of unit

Operating voltage - Unit can be constructed to operate at any specific voltage from 6 to 220 volts ac, 60 cycles, or from 6 to 220 volts dc

Voltage range - Will operate satisfactorily at 10-percent above or 15-percent below rated voltage

	Step Coil	Reset Coil	Lock Coil
Watts ac	18	7	
Maximum energization ac			
Period	5 min	5 min	continuous
Cycle	10 percent	10 percent	
Watts dc	17	5	
Maximum energization dc			
Period	5 min	5 min	continuous
Cycle	10 percent	10 percent	

GARLOCK PACKING

The Garlock packing used for gaskets and fuel-tube liners is an asbestos-rubber packing material designated Garlock No. 900. It can be obtained in various sizes and shapes from the Garlock Packing Company, Philadelphia, Pennsylvania.

PRESSURIZER COMPONENTS DESIGNED AND AND BUILT AT NRL

The remaining components of the pressurizer were constructed of standard materials at NRL and will be specified by the detailed drawings which follow. Specifically, these components are the manifold, fuel tubes, nozzles, and safety rupture discs, and are shown in Figs. A4, A5, A6, and A7.

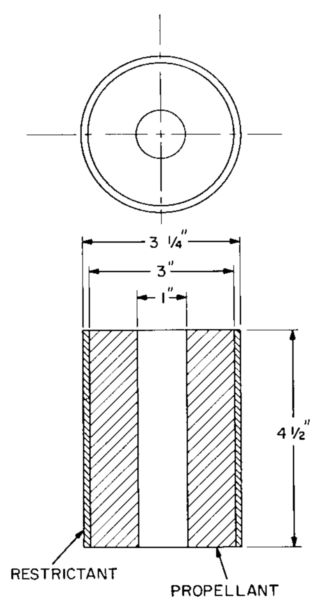


Fig. A1 - APZ propellant grain

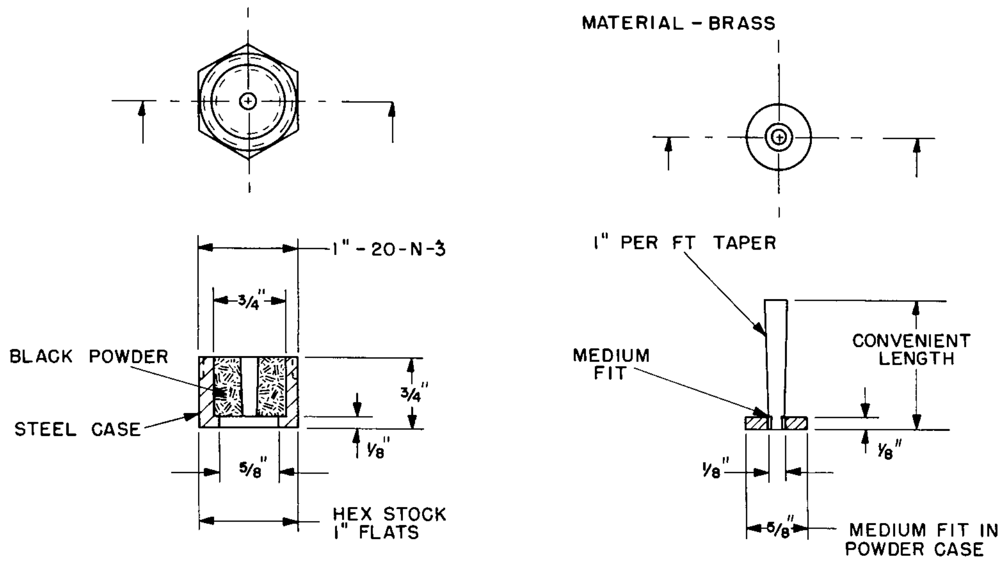


Fig. A2 - Black-powder booster with fitting for loading

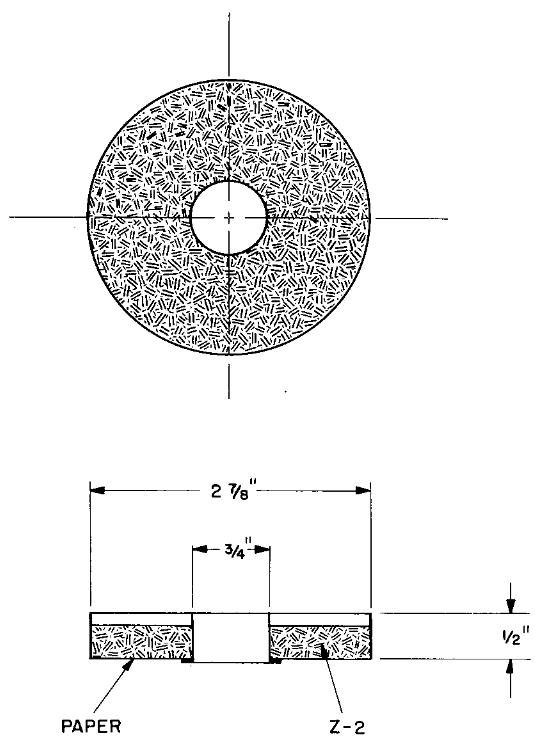


Fig. A3 - Z-2 booster

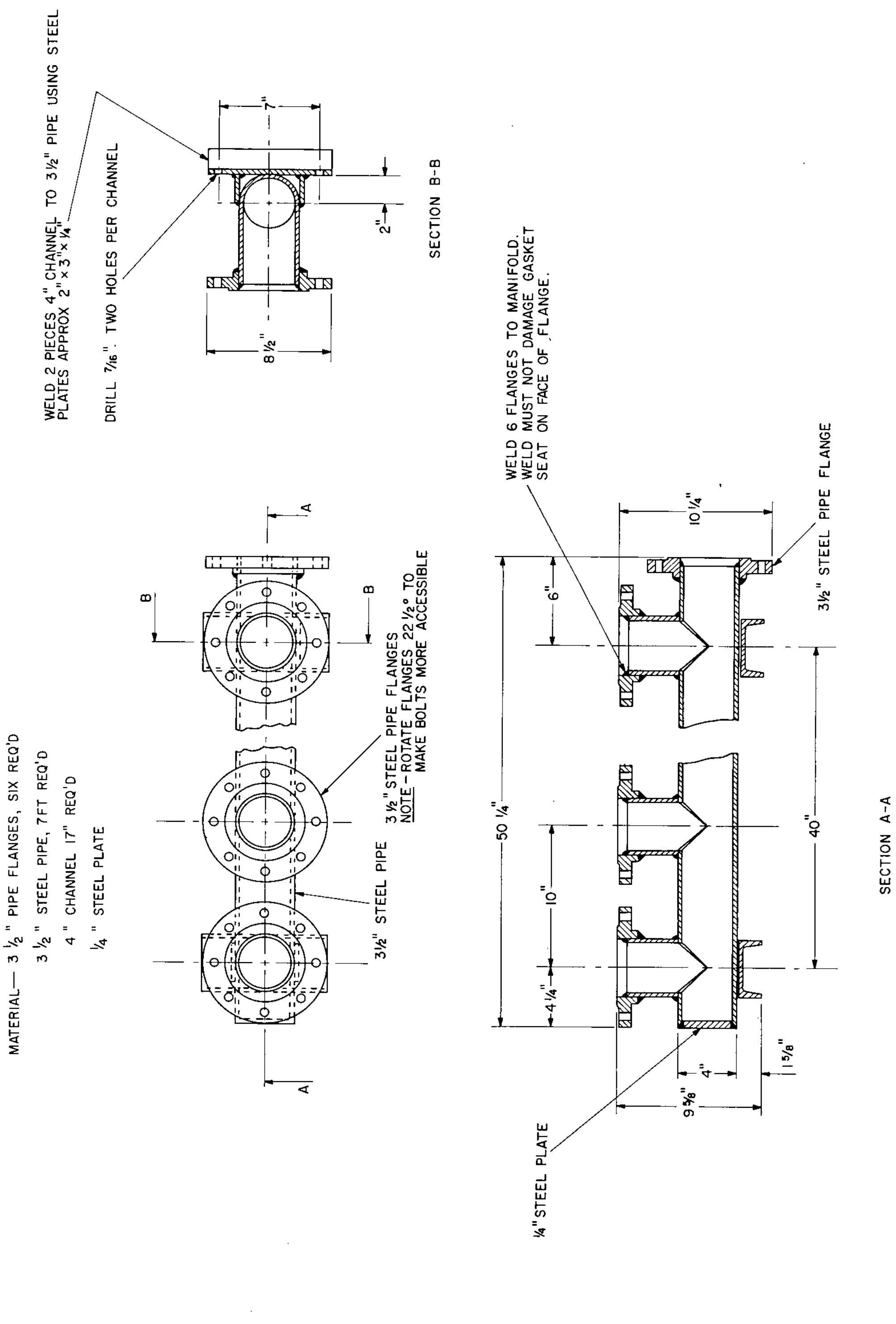


Fig. A4 - Manifold

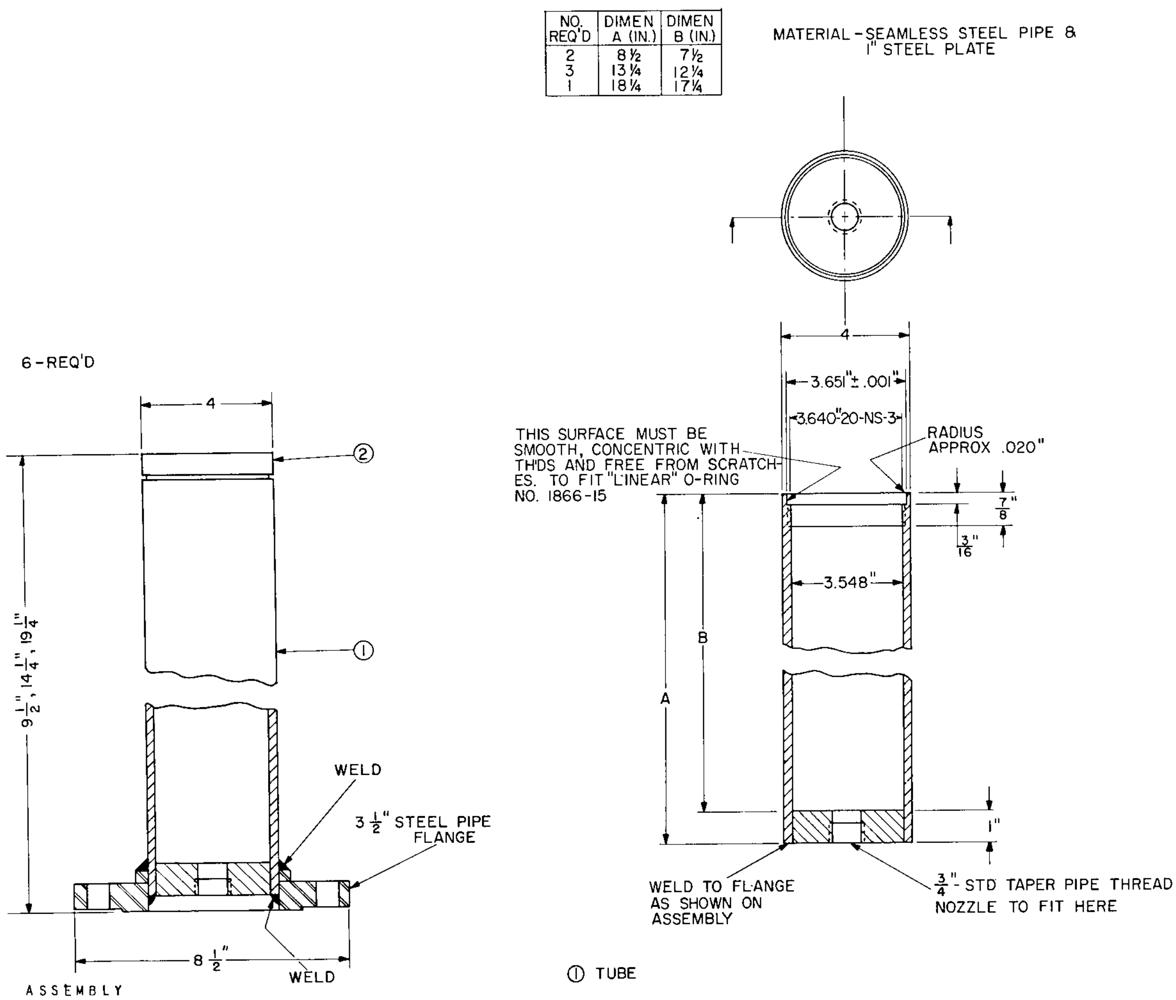
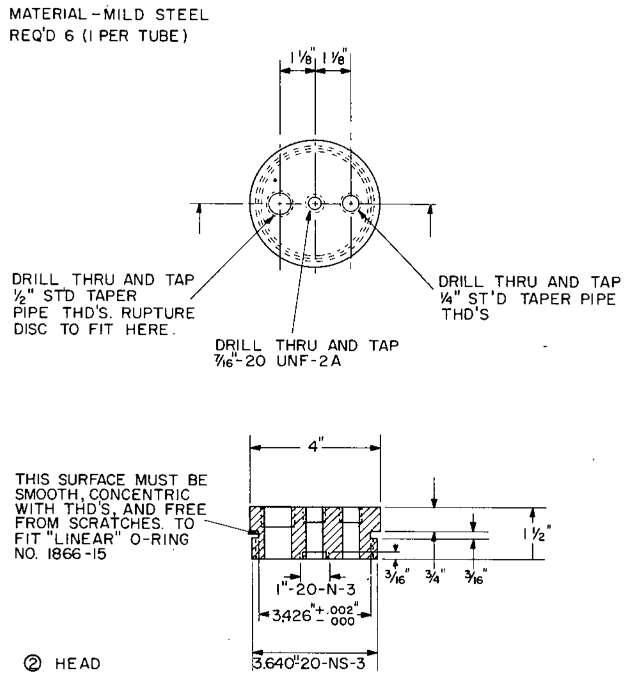
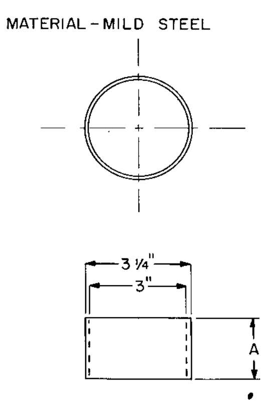


Fig. A5 - Fuel tube

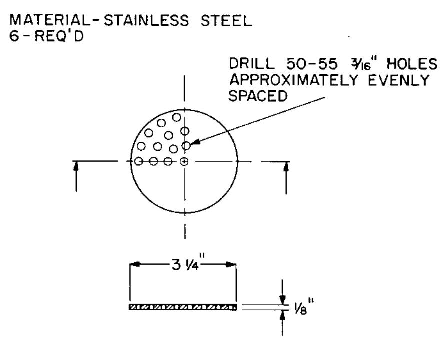


② HEAD

NO. REQ'D	DIMEN. A (IN.)
12	1/4
4	1/2
6	1 5/16



③ SPACER



④ STRAINER

Fig. A5 (continued) - Fuel tube

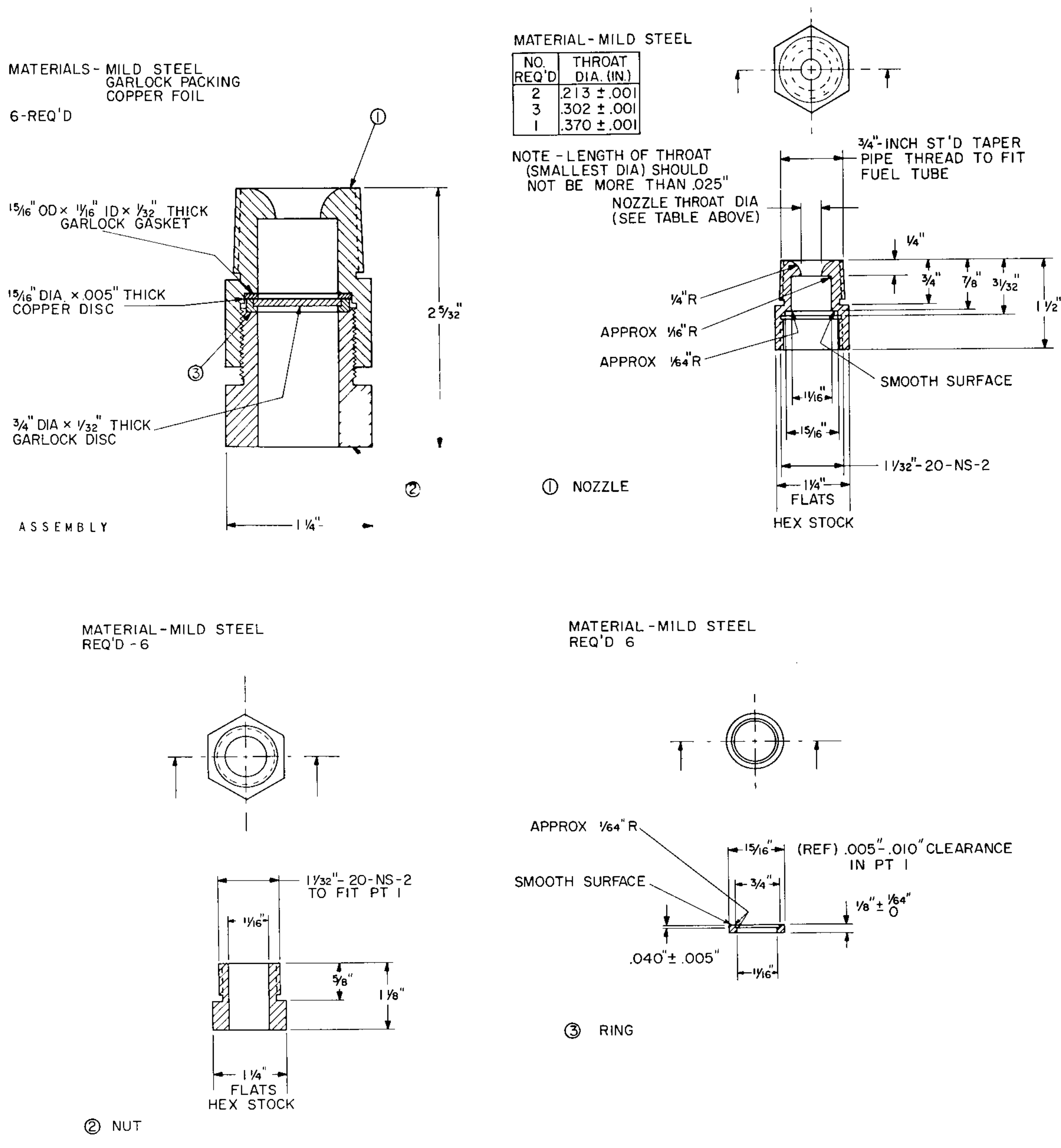


Fig. A6 - Nozzle

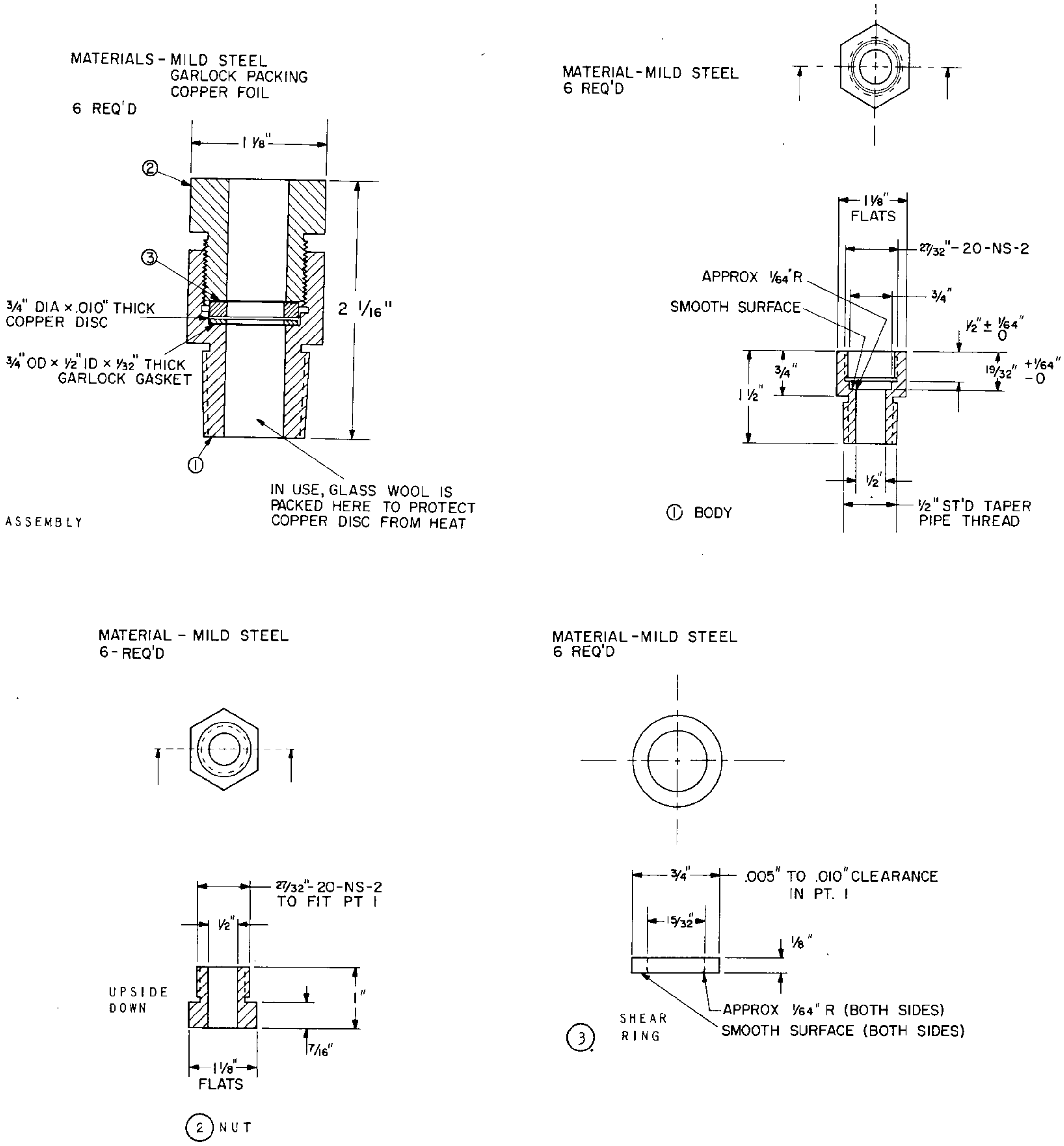


Fig. A7 - Safety rupture disc

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APPENDIX B

OPERATING INSTRUCTIONS

Once the sprinkler system starts, it will continue operation automatically until all the cartridges are burned and all the fluid is expelled, unless it is stopped manually. Opening the line switch at any time will prevent additional cartridges from being fired. Flow of fluid through the sprinkler heads can be stopped at will by venting the tank and closing the valve on the loop feed line (after opening the line switch). To place the sprinkler-system pressurizer back into operating condition after use, the following procedure is recommended. It is assumed that the tank is loaded with fluid and that all sprinkler heads are intact.

TO REARM THE PRESSURIZER

1. Open the line switch to disconnect the firing system from the power source.

2. Replace the frangible disc in the sprinkler pipe line.

3. Pressurize the loop with supervisory pressure (about 15 psi).

4. Make sure that the stepping relay is set on the first contact, as shown in Fig. 9. If an operation is allowed to proceed to completion, the reset coil of the relay automatically returns the relay to starting position. If an operation is stopped manually before completion (as described previously), the relay will have to be returned to starting position manually. This can be done by pressing the reset lever of the relay against the reset magnet. This should be checked after each run.

5. Remove spent cartridges from the manifold, reload as described below, and attach fresh cartridges on manifold.

6. Connect the wires of the firing system to the cartridges in the proper arrangement, as shown in Fig. 9.

7. Close the line switch; the system is then in operating position.

TO RELOAD THE CARTRIDGES

1. Unscrew the heads and discard the spent squib and black-powder booster case. Remove spacers and strainer from the cartridge case (fuel tube) and clean for reuse.

2. Clean the cartridge case of ash and unburned propellant restrictant.

3. Remove the nozzle, clean, replace closure disc, and thread tightly into case. The safety rupture disc will seldom need replacement if it is protected from the heat of combustion by a wad of glass wool.

4. Replace spacers, strainer, propellant grains, and Z-2 boosters in the cartridge case in the arrangement shown in Fig. 4 of the text.

5. Thread a fresh black-powder booster into the head and screw the head into the cartridge case. The O-ring seal between the head and the case requires occasional lubrication.

6. Bolt cartridges to manifold

7. Thread M-75 squibs into the cartridge case heads.

PRECAUTIONS

1. If loaded cartridges are to be handled or stored, a plug, or spent-squib case, should be fitted into the head and replaced by a live squib only when necessary. The live squib pin should be shorted to the squib case by a suitable shunt until the cartridge is placed in firing condition.

2. The usual precautions must be taken in handling the propellant and igniters. Black powder and Z-2 igniter are very easily fired.

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