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THE TEST AND EVALUATION OF FLOW FUSES FOR USE IN MANNED PRESSURE CHAMBERS

Clifford R. Holland

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Panama City, Florida

August 1973

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TEST AND EVALUATION OF FLOW FUSES FOR USE IN MANNED PRESSURE CHAMBERS

CLIFFORD R. HOLLAND

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ABSTRACT

Manned pressure chambers used in sea or shore diving operations are subject to catastrophic depressurization from external piping failures. Recently, a device designed to permit bidirectional fluid flow while protecting "flow out" lines has become available. This device, called a Flow Fuse, is essentially a flow sensitive check valve with the poppet spring-loaded open.

Offering promise of rapid reliable flow shut-off but lacking substantiating use or test data, fuses were procured and performance evaluated. A test piping system capable of simulating line ruptures and sudden large increasing leaks was constructed and each of four fuse sizes were tested (1/4", 1/2", 1" and 2" line sizes). Data on closure flows, differential pressures, and closure speeds were collected and analyzed. Tests indicated rapid closure (10 - 100 milliseconds) when flow attempted to exceed the trip point settings. There were no failures during more than 10,000 total actuations on the four fuses. All fuses have adjustable trip points, easy serviceability, and should provide excellent resistance to corrosive environments.

It is concluded that the Flow Fuse type device can provide an increase in safety for manned pressure chambers and that sufficient data has been collected to demonstrate adequacy of design and performance for certification of material adequacy.

ADMINISTRATIVE INFORMATION

The Flow Fuse tests were performed under Project Order PO-2-0019-1 in response to Naval Facilities Engineering Command letter of authorization FAC-032C dated 10 July 1972. The testing effort began in May 1972 (in anticipation of written authorization) and was completed in December 1972.

The author wishes to thank the Task Leader, Dr. E. L. Richards and Lieutenant George Green, USN, for their beneficial assistance in formulating the testing concepts and criteria.

Approved August 1973
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Manned pressure chambers used in sea or shore diving operations are subject to catastrophic depressurization from external piping failures. Recently, a device designed to permit bidirectional fluid flow while protecting "flow out" lines has become available. This device, called a Flow Fuse, is essentially a flow sensitive check valve with the poppet spring-loaded open.

Flow fuses were procured and evaluated using a test piping system to simulate line ruptures and sudden large increasing leaks; four fuse sizes were tested (1/4", 1/2", 1" and 2" line sizes). Data on closure flows, differential pressures, and closure speeds were analyzed. Rapid closure (10 - 100 milliseconds) occurred when flow attempted to exceed trip point settings. No failures occurred in 10,000 total actuations. All fuses have adjustable trip points, easy serviceability, and should provide excellent resistance to corrosive environments.

Conclusions: the Flow Fuse type device can increase safety for manned pressure chambers. Sufficient data has been collected to demonstrate adequacy of design and performance for certification of material adequacy.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Tests						
Evaluation						
Hyperbaric testing						
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Penumat[illegible] equipment						
Relief valves						
Performance tests						
IDENTIFIERS						
Pneumatic safety device						
Pressure chamber						
Flow fuse						
Manned pressure chamber						

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

When designing pressure chamber systems for human occupancy, particular care must be taken in the selection of materials and their thicknesses for the pressure retaining boundaries. Because of the nature of saturation diving, a rapid loss of a few pounds per square inch of pressure can result in serious physiological problems or even death to the chamber occupants. Obviously, then, pressure (depth) must be maintained reliably. If economics were not a factor, wall thicknesses for vessels and piping could be selected which would give very large margins of safety; but economics dictate as thin a wall as practicable. This tradeoff between safety and economics makes it highly desirable to have other means of preventing uncontrolled chamber decompression, with its resultant human injury or death, than just wall thickness. There are, fortunately, a number of methods for preventing rapid chamber gas loss (pressure drop) due to failure of external pipes, valves, or other pressure retaining components. These methods either limit flow to one direction (into chamber only), shut off flow completely once excessive flow is detected, or limit flow to some safe manageable level.

Check valves provide reliable protection for flow-in piping; and a fixed orifice[1] can be used to limit flow to a manageable level in low flow-rate gauge lines; but until recently, only expensive, complicated quick-closing remote valves have been available for bidirectional flow or flow-out piping. Now a device called a Flow Fuse[2] is being marketed which purports to protect flow-out lines reliably and economically.

Offering promise of rapid, reliable flow shut-off but lacking substantiating use or test data, fuses in four sizes (Figures 1, 2, 3, 4) were procured and performance evaluated.

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(1) Unpublished Letter Report, Test of Lee Jets, by Clifford R. Holland, Naval Coastal Systems Laboratory, Panama City, Florida, dated October 1972.

(2) Manufactured by Marotta Scientific Controls, Boonton, N. J.

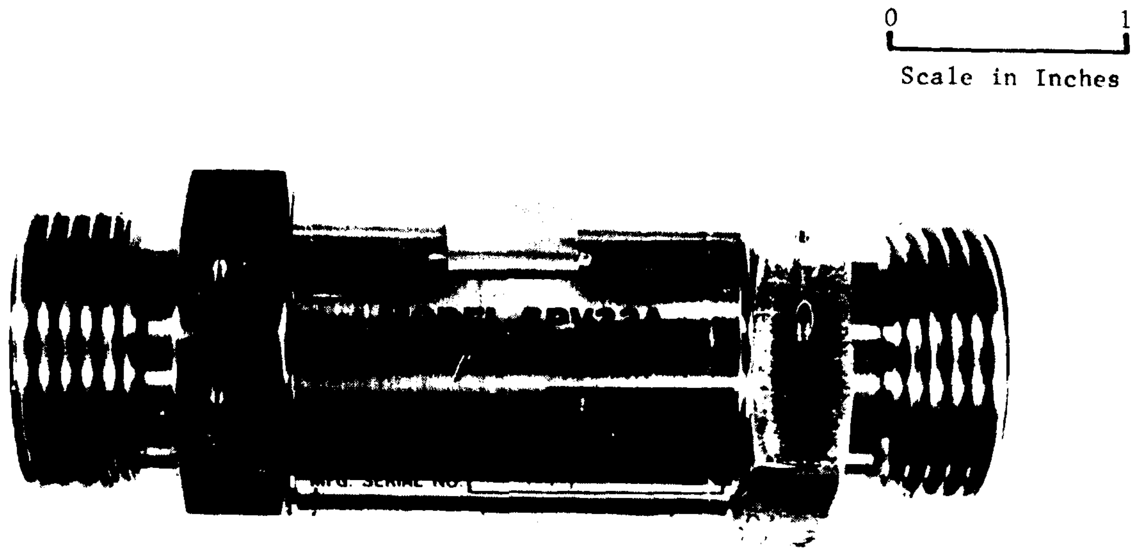

FIGURE 1. 1/4-INCH FLOW FUSE

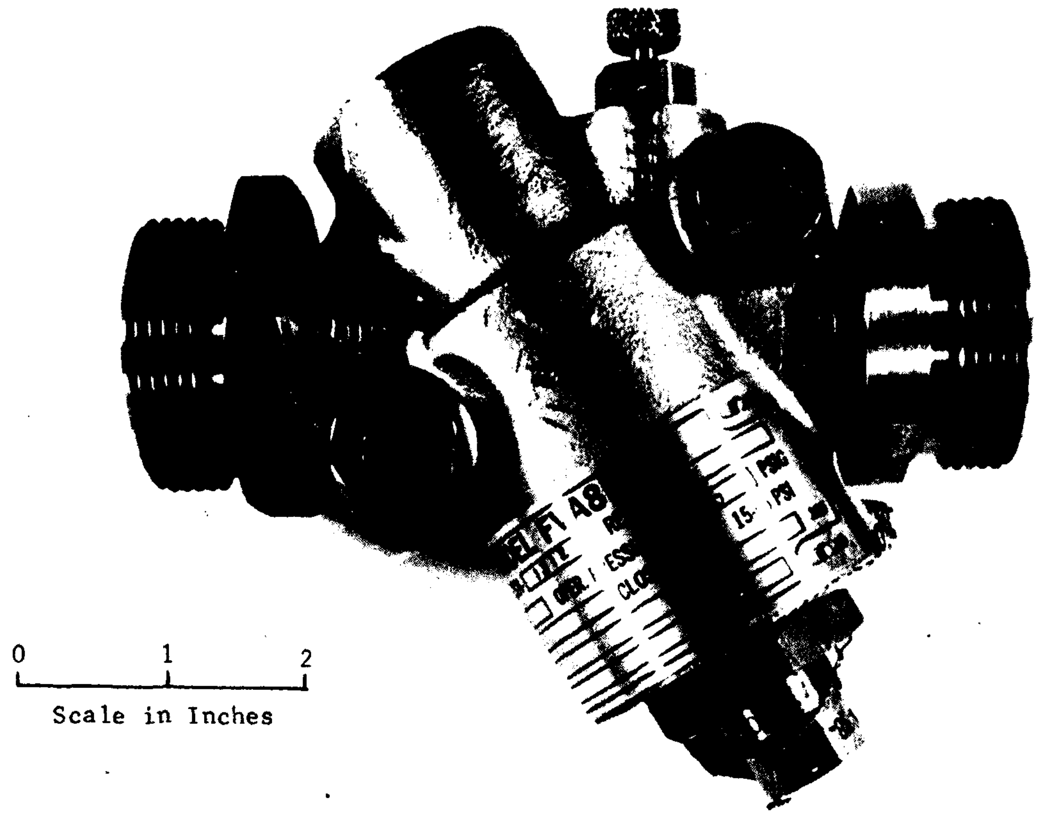

FIGURE 2. 1/2-INCH FLOW FUSE

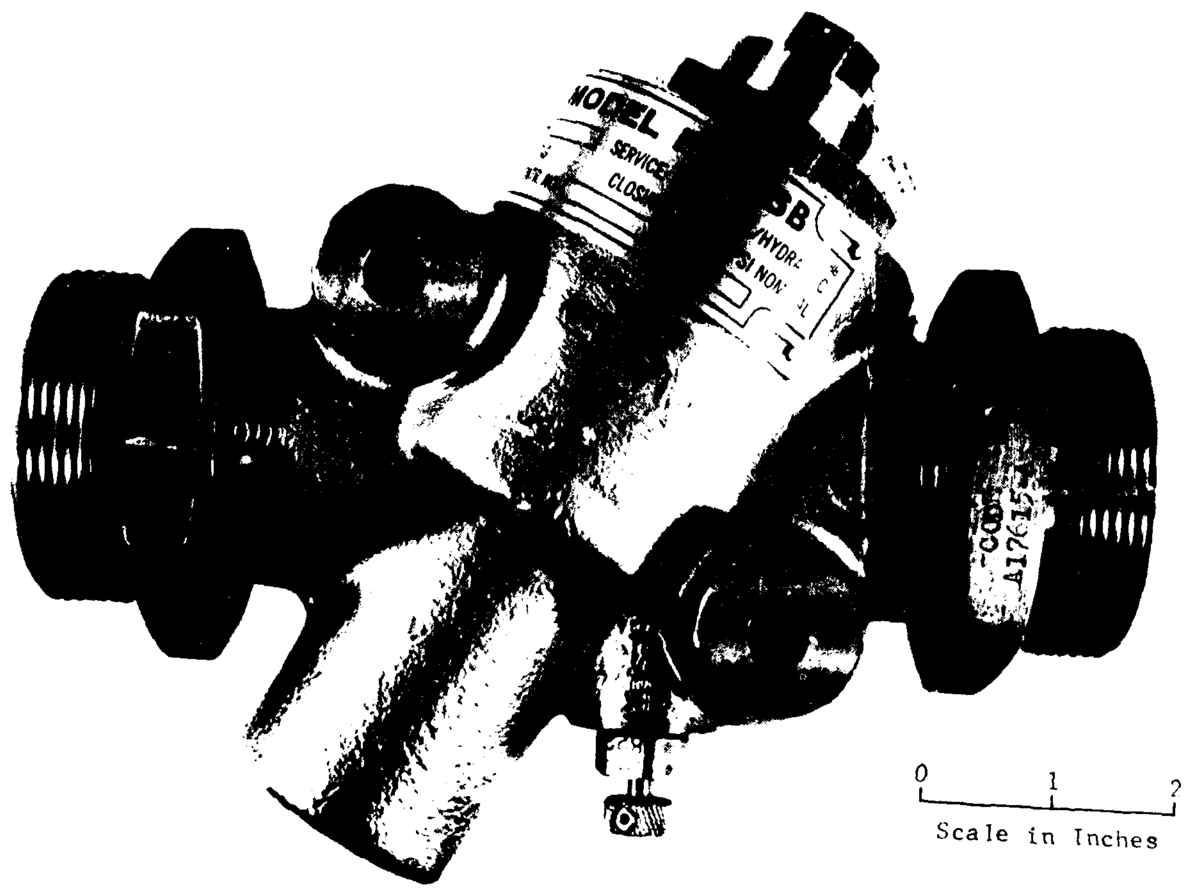

FIGURE 3. 1-INCH FLOW FUSE

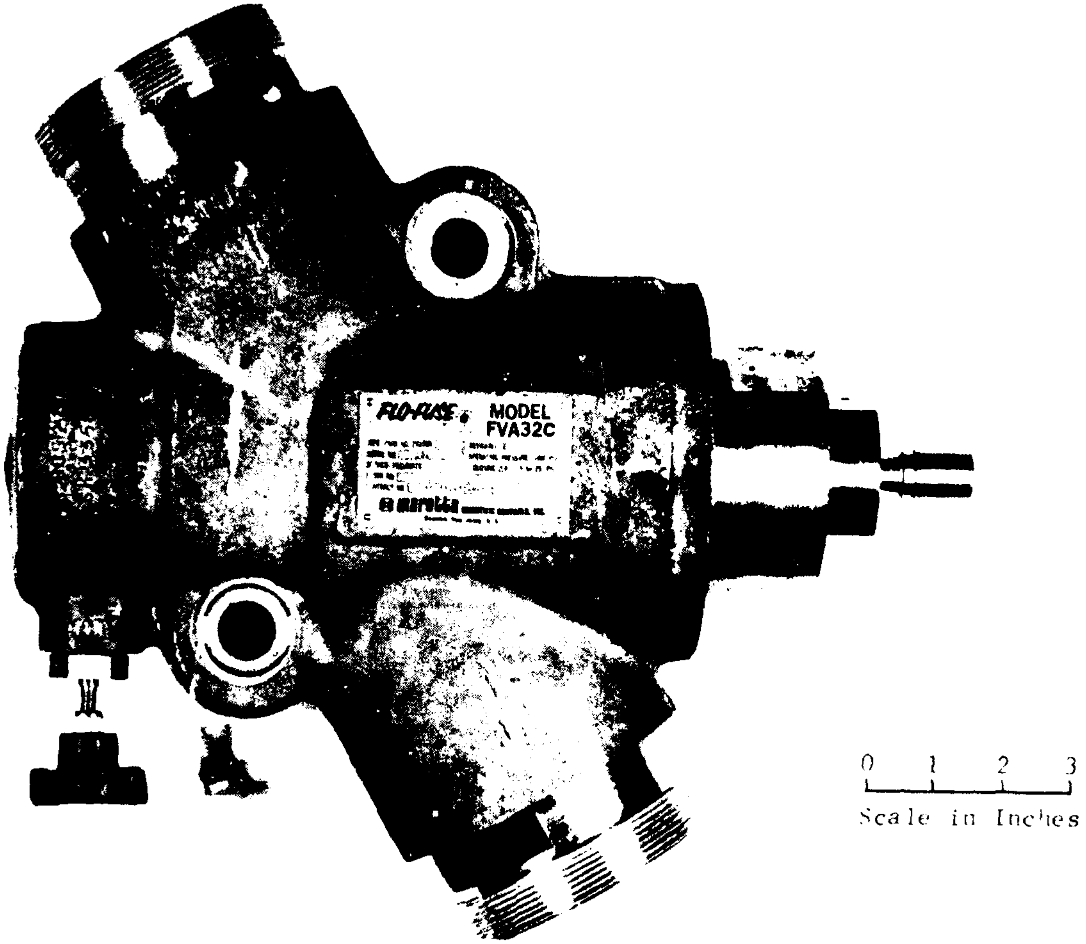

FIGURE 4. 2-INCH FLOW FUSE

FLOW FUSE OPERATION

The Flow Fuse is a check valve with its poppet spring loaded open. It is a free-flow element for pneumatic or hydraulic systems in one direction and a mass flow-sensitive check valve in the reverse direction. The mechanical operation is simple as the poppet is the only moving part. Under normal conditions, the poppet is spring loaded to the open position as shown in Figure 5A. During this condition and up to the flow trip point, the force differential created by flow across the poppet is equal to or less than the spring force. If the flow increases beyond the trip point, as would occur if a downstream pipe ruptured or developed a large leak, the pressure differential across the poppet, and therefore closing force, increases sufficiently to counteract the spring force and slam the valve shut (Figure 5B). The trip point is externally adjustable but operation of the fuse, once adjusted, requires no external sensing or actuating system. Reducing the pressure differential across the poppet by repressurizing the downstream line automatically reopens the spring-loaded poppet as shown in Figure 5C.

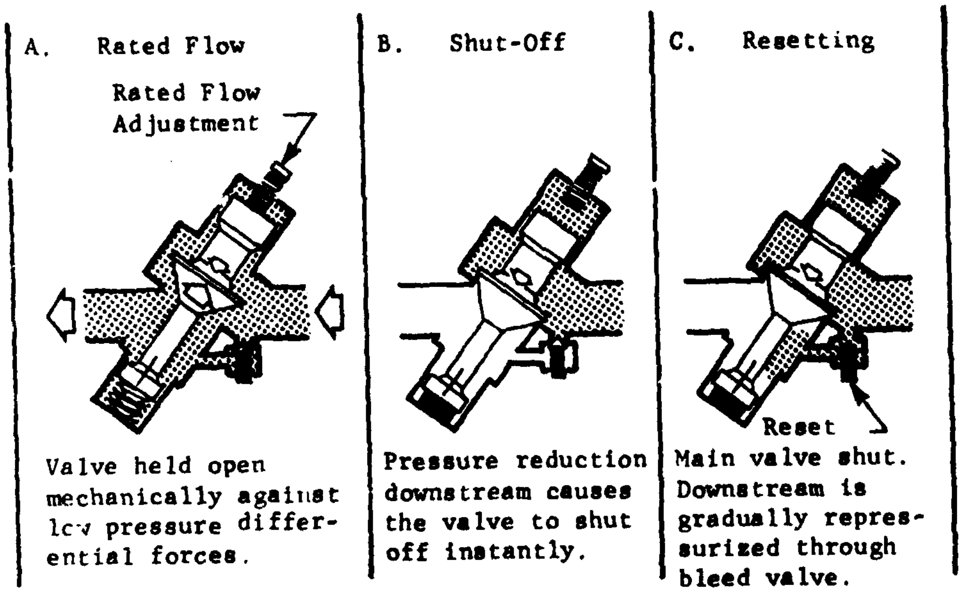

FIGURE 5. FLOW FUSE OPERATION

TESTS

PURPOSE

The tests were designed to determine two important factors: (1) what are the capabilities and limitations of Flow Fuses when used as primary pneumatic safety devices; and (2) can the fuses perform reliably and predictably enough to permit certification as to their safety and material adequacy.

Based on the principles of operation of the Flow Fuse, test setups were designed and fabricated to obtain the necessary data.

SETUP

Basically, the procedure involved the installation of each fuse into an instrumented piping system capable of simulating line ruptures and leaks. Conditions were then created and data collected to define the characteristic performance envelopes and cycling life.

Because of the size range of the fuses tested (1/4 inch to 2 inch), it was decided to use two different setups, the only important difference being the piping size and, therefore, flow capacity. A schematic diagram of the general test setup is shown in Figure 6. This diagram is best understood by considering the four functional subsystems composing it.

The left side of Figure 6 describes the gas supply subsystem. Its function is to supply gas at the flows demanded by downstream conditions while maintaining the upstream pressure set into the dome-loaded regulator. The center portion of Figure 6 shows the pressure sensing subsystem. Here, the upstream pressure and differential pressures across the fuse are sensed and electrical analog signals transmitted to the display and recording subsystem. The right side of the figure shows the flow adjusting and sensing subsystem. These elements are needed to simulate downstream leaks and line ruptures. Flow sensing elements are used to measure the flow responses with electrical analog signals transmitted to display and recording equipment. The display and recording subsystem (lower right in the figure) receives the analog signal voltages ages and converts them into visual displays and records them. An oscilloscope was used because of the shortness of signal duration and the need to analyze transitory phenomenon. A memory oscilloscope was selected so that signals could be temporarily stored and photographed for record purposes. The chart recorder was only used during life cycle tests. Details of the specific test setup used for each of the Flow Fuses and an example of data produced are discussed in Appendix A.

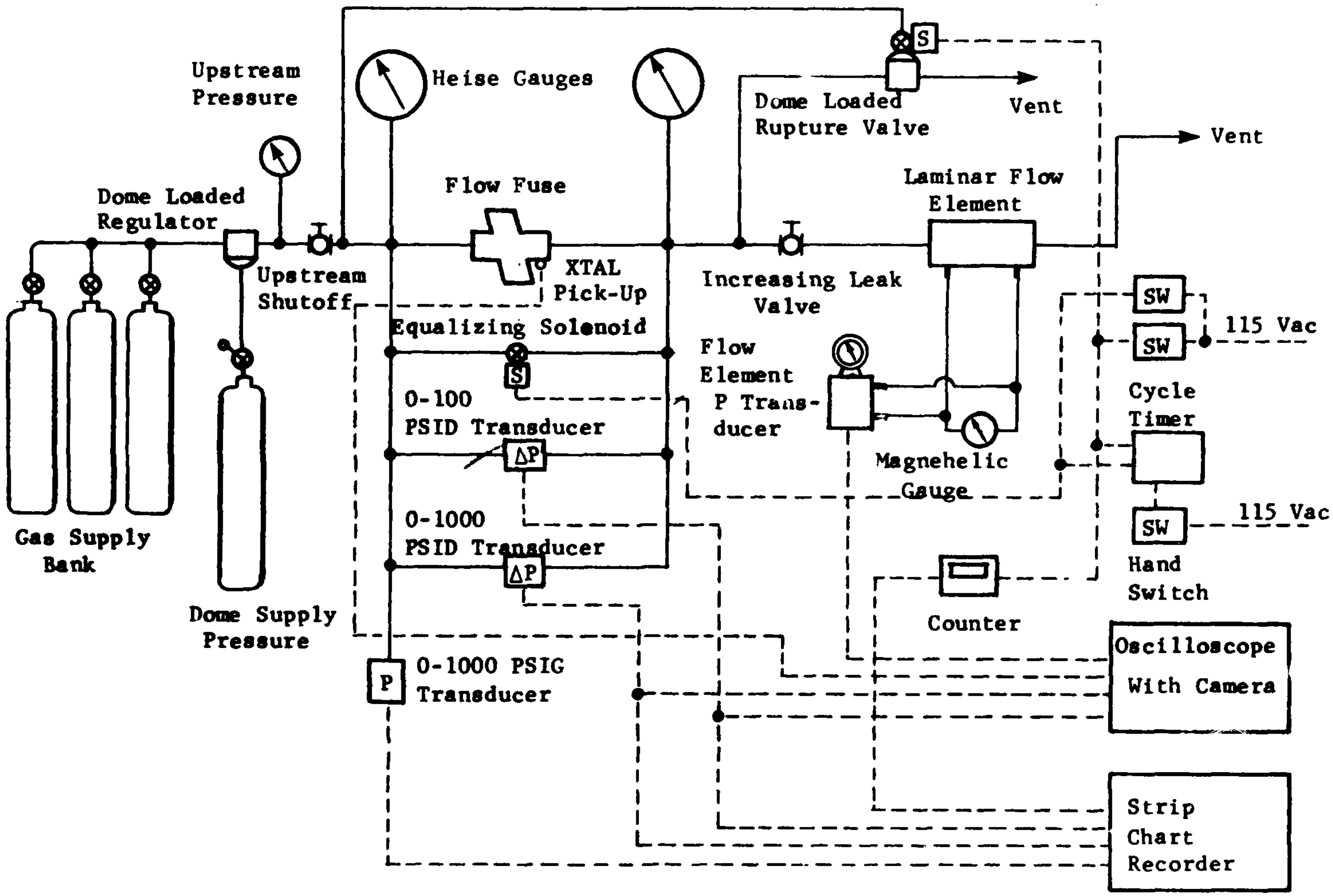

FIGURE 6. SYSTEM SCHEMATIC - FLOW FUSE TESTS

DATA

The collected data were divided into two groups. Group One data consist of measurements of each fuse's performance envelope and permits pneumatic system designers to match Flow Fuse capabilities to specific system safety requirements. Group One data produced information on closure response time, minimum closure pressure versus adjustable poppet setting, closure actuating flow versus poppet settings for a low (100 psig) and a high (700 psig) upstream pressure, and closure actuating flow versus upstream pressure (100 to 1000 psig) at a mid-range poppet setting.

Group Two data consist of measurements of each fuse's ability to survive 2000 actuations. Depending on the application, this cycle life test is equivalent to several years of in-service operations.

Summing both the cycle life tests and the performance envelope tests, each fuse received between 2500 and 3000 actuations during its evaluation.

TEST RESULTS

This section discusses the general test results which describe the Flow Fuse family of devices. For specific details on a particular Fuse, refer to the following appendices: Appendix B for 1/4-inch Fuse; Appendix C for 1/2-inch Fuse; Appendix D for 1-inch Fuse; Appendix E for 2-inch Fuse; and Appendix F for the trip-point matrices.

SPEED OF RESPONSE

Closure speeds were measured and found to be from 10 milliseconds to 100 milliseconds depending on test conditions and fuse size. In general, the fastest closures occurred at high pressure (1000 psig) and simulated downstream line rupture; while the slowest closures were at low pressure (100 psig) and a simulated leak which increased the flow until actuation occurred. For applications where rupture protection at pressures greater than 200 psig is required, the closure time can be expected to be between 10 and 50 milliseconds.

Closure speed in terms of gas loss is an important consideration. A simple estimating procedure can be applied to obtain a conservative answer. First, determine the gas flow at which the fuse must close. This will usually result from an analysis of the intended application by considering line size(s), working pressures, and maximum expected normal flow rate. It could also be found for a particular fuse size and poppet set-point by referring to the trip-point matrix in Appendix F. Once the closure flow is known, the fuse closure time must be selected; use 100 milliseconds for pressures between 100 and 200 psig, and 50 milliseconds for pressures greater than 200 psig. Using the approximating assumption that after rupture the flow increases linearly to the closure flow value and realizing that lost volume through the fuse equals the area under the flow versus time curve, it follows that the product of one half the closure flow times the closure time will yield the desired answer. Consider the following example: In a 1-inch pipe pressurized to 400 psig, the normal gas flow does not exceed 400 standard cubic feet per minute (scfm). Allowing a 20 percent overflow, the fuse can be set to interrupt the flow if conditions cause it to try to exceed 480 scfm. Table D5 of Appendix D shows that the fuse should be set about three turns open. Since the system is operating at more than 200 psig in this example, a 50-millisecond (0.83 x 10^{-3} minute) closure time will be used. To determine the amount of gas lost the formula of 1/2 x closure flow x closure time is used. Substituting then 1/2 x 480 x 0.83 x 10^{-3} = 0.2 scf which is an extremely small amount of lost gas. For example, a 50-ft^3 (water volume) pressure chamber at 400 psig contains about 1360 scf of gas. A loss of 0.2 scf amounts to 0.015 percent or a pressure drop of 0.06 psig! These exceptionally low values are due, of course, to the extremely rapid closure time of the fuse. Since this method yields conservative estimates, the actual gas loss will be less than that calculated.

RELIABILITY

Adding the actuations during the performance envelope testing and subsequent life cycle tests, results in a total of 2500 to 3000 actuations per fuse during the evaluation. For the four fuses this amounts to 10,000 to 12,000 closures. The exact number of cycles during performance testing were not recorded. Never during the testing did a fuse fail to close. It would appear that the large number of actuations were insufficient to indicate any less than 100 percent reliability. This is not a statistically accurate figure, however, because only one of each size fuse was tested and the fuses were not tested to failure.

WEAR EFFECTS

Wear due to repeated cycling appeared to be nonexistent. Each fuse was performance checked after every 500 cycles during the 2000-cycle life test. These checks were then compared for changes and trends that might occur because of wear. In no case were significant changes in performance recorded nor any trends toward degraded performance detected. The speed of closure did not vary for similar conditions throughout the testing sequence for any fuse.

A disassembly and visual inspection also failed to reveal any significant wear. The Flow Fuses tested were constructed of high durability, low corrosion susceptability materials and should be extremely long lasting for nitrogen, oxygen, and helium gases or their mixtures. Probably the greatest cause of wear will be any lack of cleanliness in the system. The soft seats used in the fuses can be easily damaged by pipe scale, welding slag, filings, etc. Consequently, the importance of system cleanliness cannot be overstressed.

FUSE DIFFERENCES

There are important differences between the fuses since each was designed to do a particular job. These differences pertain to size, pressures, adjustment range, media, and method of reset; not to speed of closure or reliability of actuation (Table 1).

TABLE 1

COMPARISON OF FUSE CHARACTERISTICS

Fuse	Weight (lb)	Operating Press (psig)	Proof Press (psig)	Burst Press (psig)	Temperature Range (°F)	Media	Capacity
1/4"	1.75	100-4500	6750	18,000	28 - 130	Air, helium oxygen, sea water	0.2-250 scfm at 4500 psig
1/2"	6.0	4500	6750	11,250	0 - 160	Air, nitrogen, oxygen	-
1"	12.0	3000	4500	7,500	0 - 160	Air	-
2"	73.0	6000	12,000	24,000	0 - 140	Inert gas	

SIZE

The first obvious difference is size and weight; the 1/4-inch fuse weighs 1.75 pounds and can be held in the palm of one hand while the 2-inch fuse at 73 pounds can be lifted by one man only with difficulty.

ADJUSTMENT RANGE

The four fuses, considered as a family, provide a wide range of adjustable closure flows. For the test program, the measurement range was 22 scfm to more than 2120 scfm. This last value has been extrapolated to 5624 scfm by data synthesis (see Appendix F).

The adjustment range differs between fuses, and is less for the 1/4-inch fuse wherein all settings take place in the first revolution of the adjustment screw. For the 1/2-inch fuse the tested range was 4 turns, and for the 1-inch and 2-inch fuses, 6 turns. It is probable that the adjustment range is somewhat greater for the 1/2-, 1-, and 2-inch fuses than that tested; this is indicated by the performance curves in the appendices. Reference to the closure flow versus turns-open curves shows that the peak flow achievable for these fuses has not been achieved and, therefore, more turns are available in the adjustment than tested. The adjustment ranges evaluated resulted from gas supply and flow measurement limitations imposed by the test setup.

It should also be understood that the 1/4-inch fuse is not designed for a wide range of adjustments; it must be disconnected from the connecting tubing to change the setting. The closure flow trip point adjustment can be changed in the other three fuses while installed in a system.

RESET METHODS

Resetting of the 1/2-, 1-, and 2-inch fuses after actuation is accomplished by opening a needle valve in the fuse body and allowing the upstream pressure to equalize around the seated poppet to the downstream side. When the differential pressure across the poppet becomes sufficiently low, the restoring force of the internal spring will reset the Flow Fuse. The 1/4-inch fuse does not have a needle valve; instead a small bleed port has been placed across the poppet so that a small but constant flow exists under all pressurized conditions. This fuse will automatically reset itself after repair of the downstream piping.

CONCLUSIONS

Based on the test results, it is concluded that 1/4-, 1/2-, 1-, and 2-inch Flow Fuses are reliable and effective pneumatic safety devices. The closure speeds are several orders of magnitude faster than needed to keep pressure loss in a manned hyperbaric chamber to a foot or two of depth. The volume of gas lost will be essentially that contained in the downstream piping system for line rupture. A Flow Fuse will not respond to leaks which cause a flow below the trip point setting. If the trip point flow is set for a few percent more flow than the normal maximum, such leaks will rarely be catastrophic.

It is concluded that service life measured as a function of cycles to wearout is very long. It also appears, but was not verified by tests, that the materials of construction should provide very long service life in terms of corrosion.

Maintenance requirements should be limited to inspection, cleaning, and occasional replacement of seat materials. Cleaning and seat replacement can be accomplished without removing the fuse from the piping system for all fuses except the 1/4-in. fuse. The system must be depressurized for this type maintenance, however. The seat in the 1/4-inch fuse does not require replacing. Cleaning may never be required where system contamination is prevented by specific procedures or equipments. Replacement of seats will be governed by the frequency of actuations. More than 2500 actuations were insufficient to require changing of seats on any of the test fuses. Again, for many applications this form of maintenance may never be required.

It is concluded that sufficient evidence of performance and reliability was obtained during this program to permit material certification of these Flow Fuse types for manned hyperbaric work.

RECOMMENDATIONS

It is recommended that Flow Fuses be used in gas systems wherein gas losses due to line rupture would be harmful or dangerous. The applications include hyperbaric chambers for diving, hospital treatment chambers, bulk storage of flammable gases or gas mixtures, and storage of rare gases.

It is recommended that appropriate allowances be made during installation for accessibility for reset, adjustment, and servicing. No other installation precautions appear necessary except to note the flow sensitive direction marked on the fuse body.

It is also recommended that, based upon the findings of this evaluation, that the family of Flow Fuses be given a Category 1 Materials classification as defined in NAVSHIPS Manual 0994-007-7010. This manual, also known as NAVFAC P-422 is entitled *Hyperbaric Facilities, General Requirements for Material Certification*.

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APPENDIX A

TEST SETUPS AND EXAMPLE DATA

TEST SETUP

The test setup is shown in Figure A1. The circled numbers appearing in this figure refer to item numbers for the equipment listing shown in Table A1. A comparison of Figure A1 and Table A1 will indicate the exact items of hardware used to collect data on the Flow Fuses.

The test setups were functionally and instrumentationally the same for all four fuses. The only significant difference between test setups was piping size and therefore flow capacity.

Figure A2 shows the piping sizes used in the test setup for evaluation of the 1/4-inch and 1/2-inch Flow Fuses. A photograph of this setup is shown as Figure A3.

The 1-inch and 2-inch fuses required considerably larger capacity piping for their evaluation. It was decided to create a new test setup using the large, high-pressure accumulators of the NCSL Diving Locker. Figure A4 shows the piping sizes used in this larger test setup. A photograph of this setup, in use, is shown as Figure A5.

EXAMPLE DATA

The data collected using the test setups was of the same type for all four fuses. The data on each fuse can be subdivided, however, into two categories: single cycle and life cycle. The single-cycle tests were designed to discover the time- or flow-dependent response of a fuse to a simulated piping failure at a controlled poppet setting and upstream driving pressure. Each actuation during the single-cycle tests provided, therefore, a single data point for one of the performance curves (see Appendices B, C, D, or E). By varying the poppet settings and measuring the resultant closure flow and closure time values for a fixed upstream driving pressure, performance curves of closure flow versus poppet setting and closure speed versus poppet setting were produced. Similarly, by varying upstream driving pressure and measuring the resultant closure flow and time values for a fixed poppet setting yielded performance curves for closure flow versus driving pressure and closure speed versus driving pressure.

(Text Continued on Page A-8)

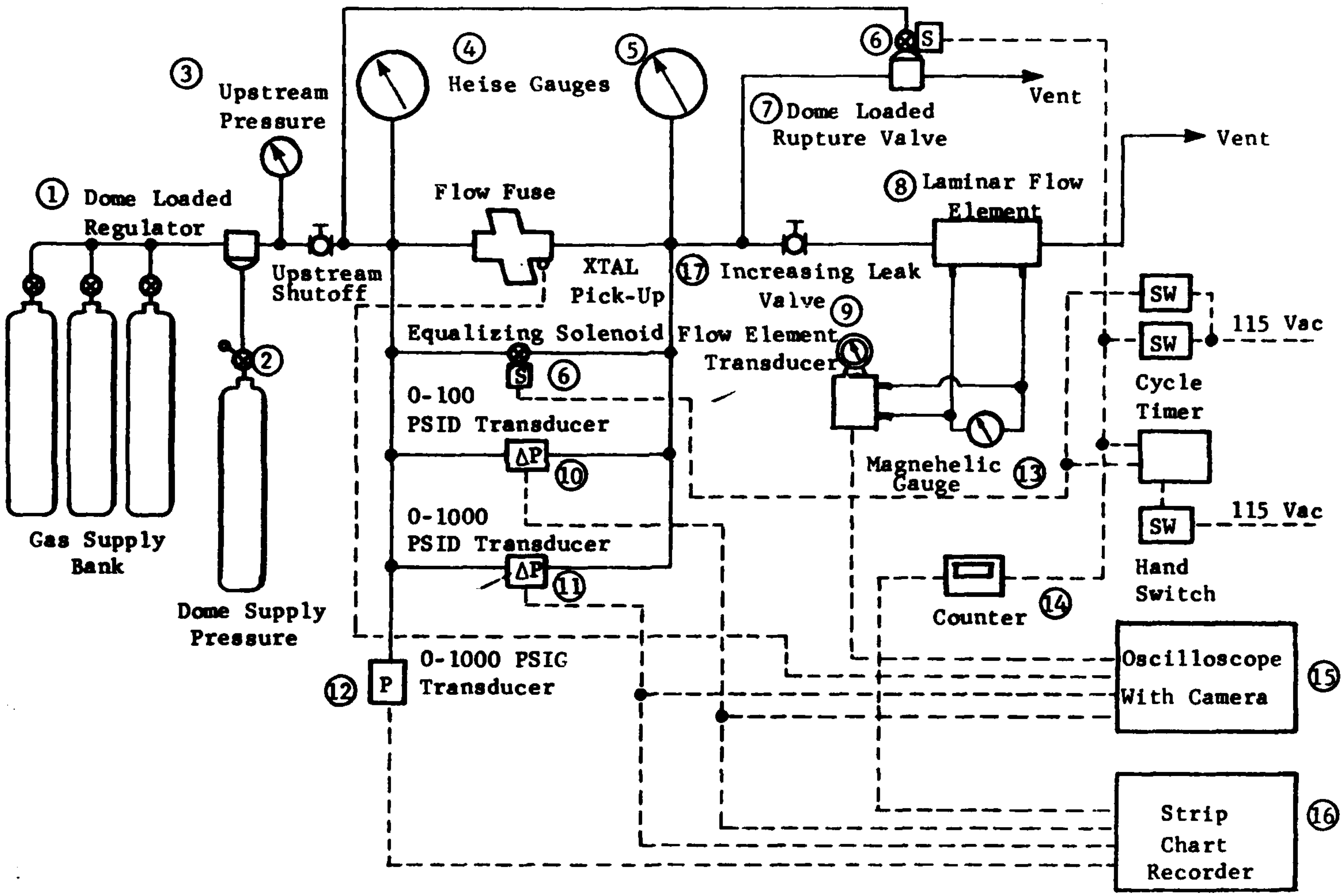

FIGURE A1. SYSTEM SCHEMATIC - FLOW FUSE TESTS

TABLE A1

TEST SETUP EQUIPMENT LISTING

1. Grove Regulator Model 94W (for 1/4-inch and 1/2-inch fuse tests); Model 301B (for 1-inch and 2-inch fuse tests).
2. Harris regulator.
3. Ashcroft 6-inch Test Gauge.
4. Heise 6-inch gauge Model CMM 2919.
5. Heise 8-inch gauge Model CMM 7157.
6. Circle Seal Corp. solenoid Model SV11S32P4P.
7. Anderson Greenwood Model 736-23.
8. Meriam Model 50MH10-4 (170 scfm max.); and Model 50MC2-8 (2000 scfm max.) as appropriate.
9. Rosemount Model 1151 DP.
10. BLH Model HMD 0-100 PSID.
11. BLH Model HHD 0 - 1500 psid.
12. Dynisco Model PT 310-1M 0 - 1000 psig.
13. Dwyer Instrument, Inc., Magnehelic gauges: 0 - 2" and 0 - 8" as appropriate.
14. General Controls 4-digit electromechanical counter.
15. Memory Oscilloscope, Tektronix Model 434 with C-30 camera (1/4" and 1/2" fuses); HP model 141A with Polaroid camera (1" and 2" fuses).
16. Clevite Brush Mark 260 six-channel recorder, Model 15636700.
17. Valves - Test piping quarter turns are Clayton Mark 1/2" (for 1/4" and 1/2" fuses) or 2" (for 1" and 2" fuses).
    Loading valve (Dome regulator - Dragon).
    Bottle manifold and instrumentation shut-off valves - Hoke.

Misc. Electronic Equipment - Power supply, Dual HP Model 6227B 0 - 25 vdc. Single channel, dual stage, differential amplifier NCSL design.

Rosemount ΔP transmitter output card NCSL design.
Cycle timer - NCSL design; 4-rpm electric motor with can actuated switches.

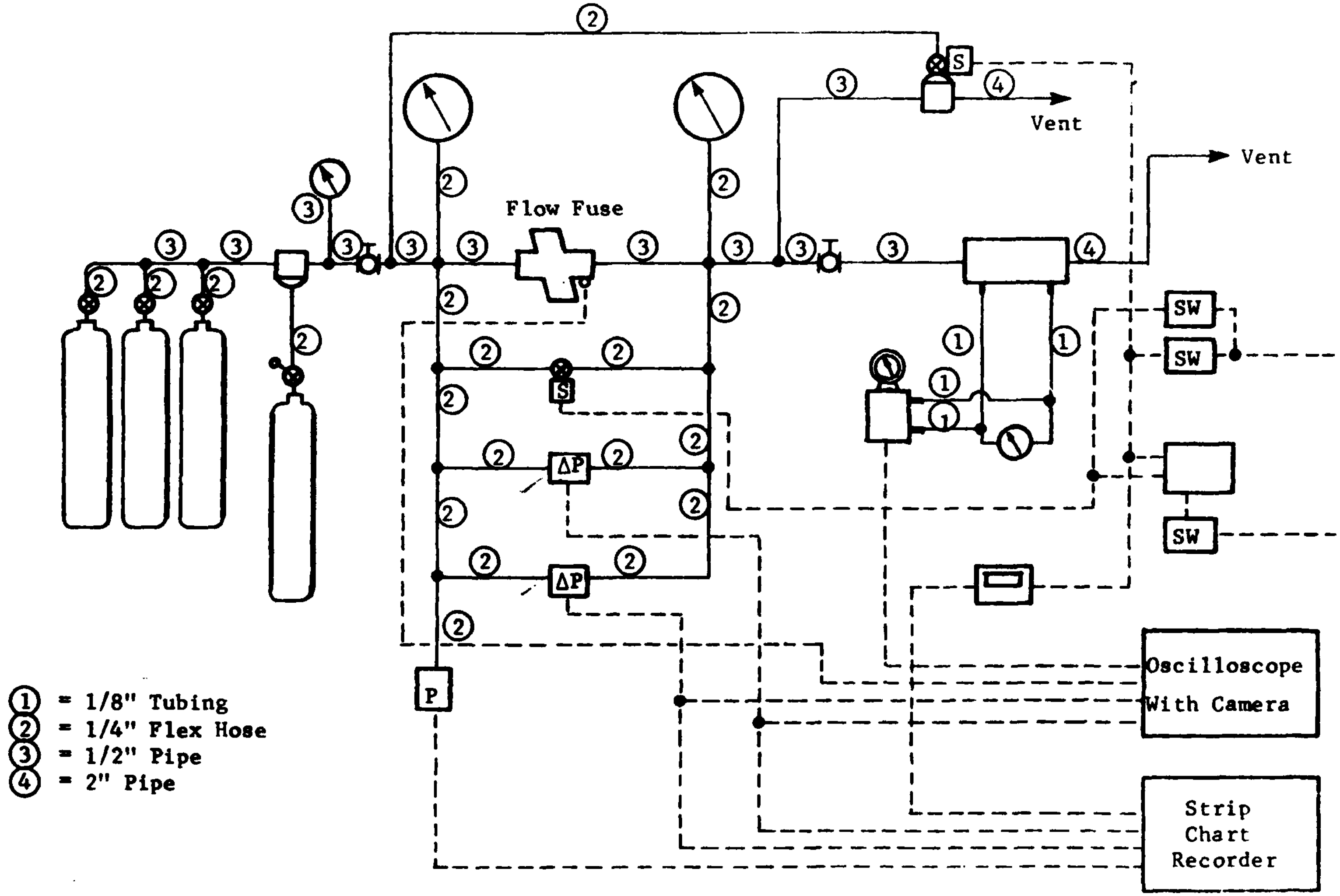

FIGURE A2. PIPING SCHEMATIC - FLOW FUSE TESTS - 1/4 & 1/2 INCH

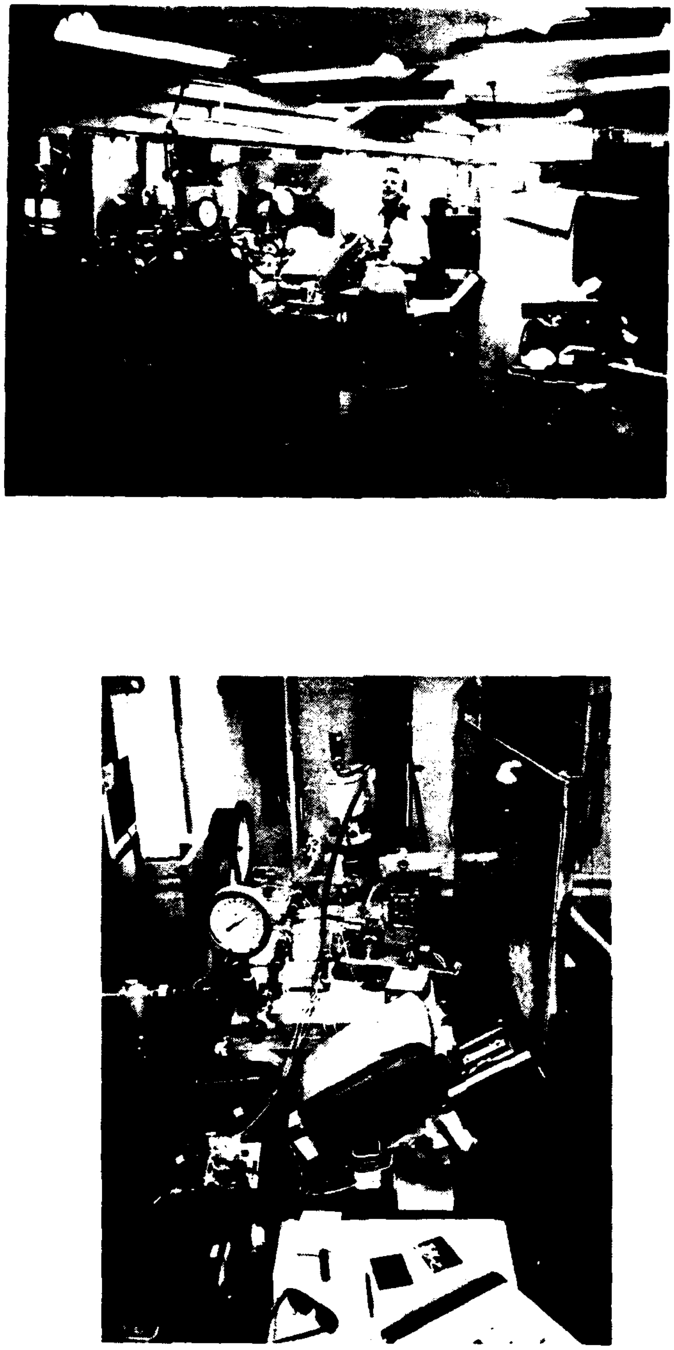

FIGURE A-3. PHOTOGRAPH OF TEST SET-UP, 1/4" AND 1/2" FUSES

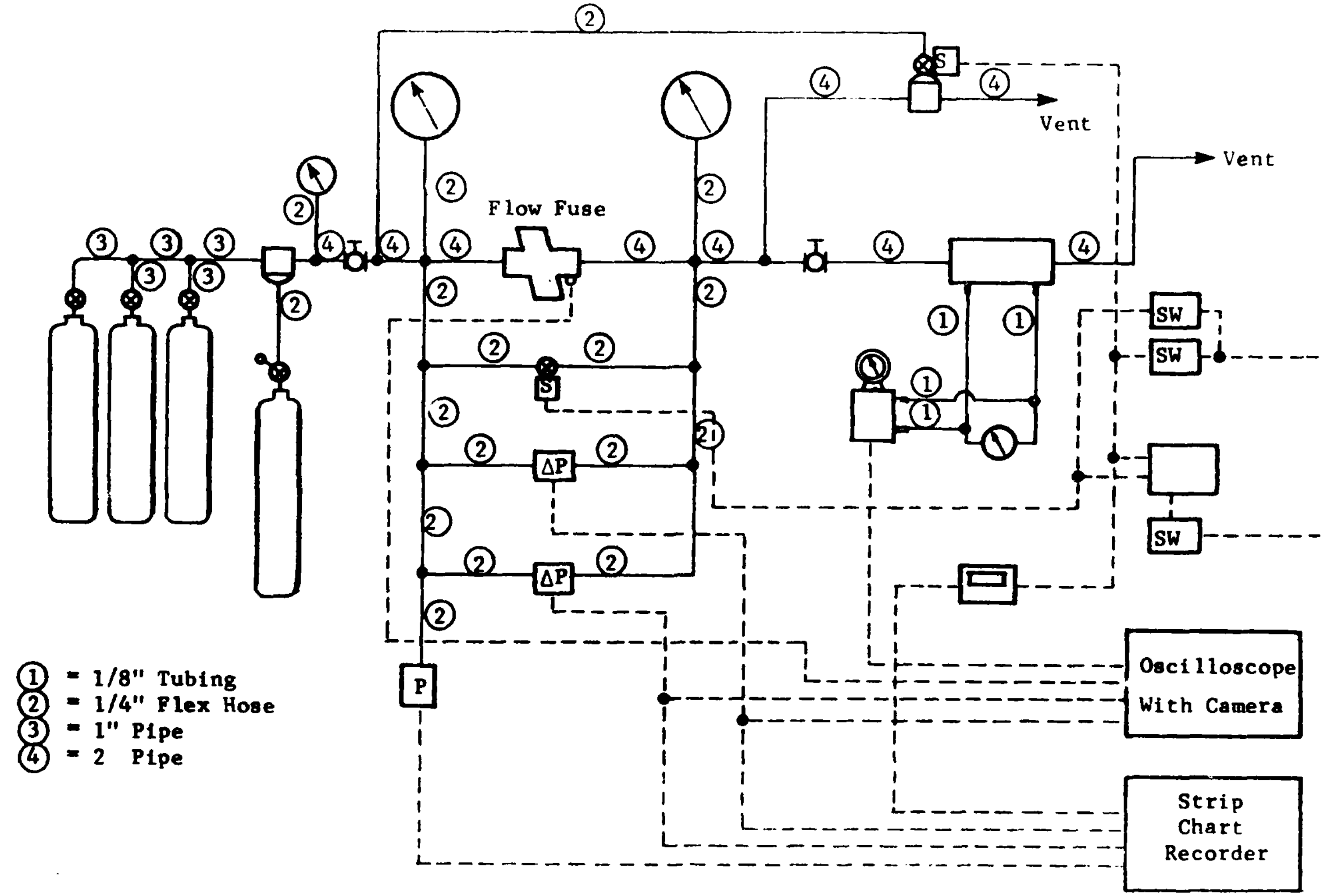

FIGURE A4. PIPING SCHEMATIC - FLOW FUSE TESTS - 1 & 2 INCH

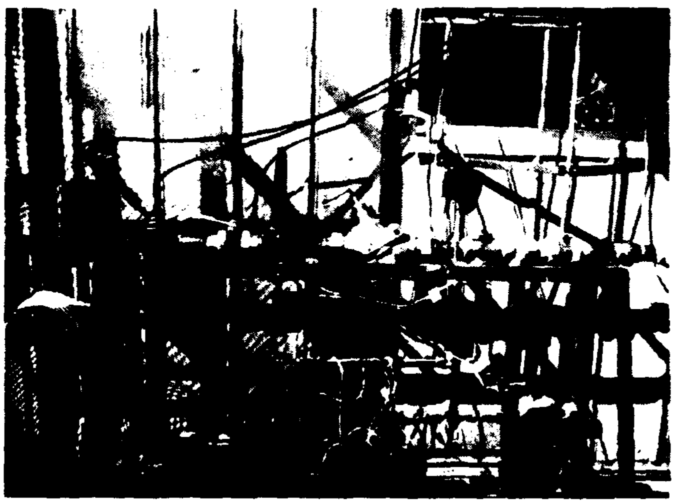

FIGURE A5. PHOTOGRAPH OF TEST SET-UP, 1 AND 2" FLOW FUSES

To obtain each performance curve data point, the desired conditions for poppet setting and upstream driving pressure were first set into the test setup. Full reset of the fuse was next checked by opening the bypass solenoid for approximately 10 seconds and then closing it. The memory oscilloscope was erased to give a clean screen and set for either external trigger or internal single sweep and the appropriate sweep rate. External trigger was used for simulated downstream pipe ruptures. The oscilloscope trigger signal was derived from the electrical solenoid signal which caused opening of the dome-loaded rupture valve (Figure A1). An internally triggered single sweep was used during simulations of increasing leaks. After the oscilloscope trace was initiated, the increasing leak valve (Figure A1) was opened at a rate which caused fuse closure before the oscilloscope trace completed its single sweep. In either case, line rupture or increasing leak, the voltage analogs of pressure and gas flow were traced onto the oscilloscope screen against a calibrated time sweep and held there by the memory circuits until a photograph could be made for more permanent data storage.

In addition to pressure and flow signals, a small piezoelectric crystal was used to "listen" to the movements of gas and mechanical parts inside the fuse. The crystal pickup was mounted on the fuse and as close to the poppet seat as practical. In this way, the sound of the poppet closing was often clearly detectable and provided an additional means of determining the point of fuse closure (differential pressure signature being the other means).

An example of a typical data point for a simulated line rupture is shown in Figure A6. The dual traces are triggered by the signal to the rupture valve. The upper trace is differential pressure versus time. The lower trace is the crystal "listening." First notice that after the signal is sent to the rupture valve (start of oscilloscope trace) there is a delay before anything happens of about 30 milliseconds. This time is being consumed in operating the solenoid on the dome-loaded rupture valve and in the valve opening time. Once the rupture valve opens, flow at the downstream end of the test piping begins as evidenced by the crystal detection of flow noise. This initial flow is the piping attempting to empty to atmosphere. After about 75 milliseconds from the rupture, the test piping has emptied enough for the pressure regulator to detect a need for pressure sustaining flow as indicated in Figure A6 by the increasing flow noise (lower trace). Because flow has been created through the Flow Fuse, a differential pressure drop is also detected (upper trace). This pressure drop increases as the upstream regulator continues increasing flow to maintain the upstream set pressure (700 psig in this case). At 100 milliseconds into the rupture, a "loud" but short duration noise is detected by the crystal; this is the poppet in the fuse slamming against the seat. Note also the change in the slope of the differential pressure

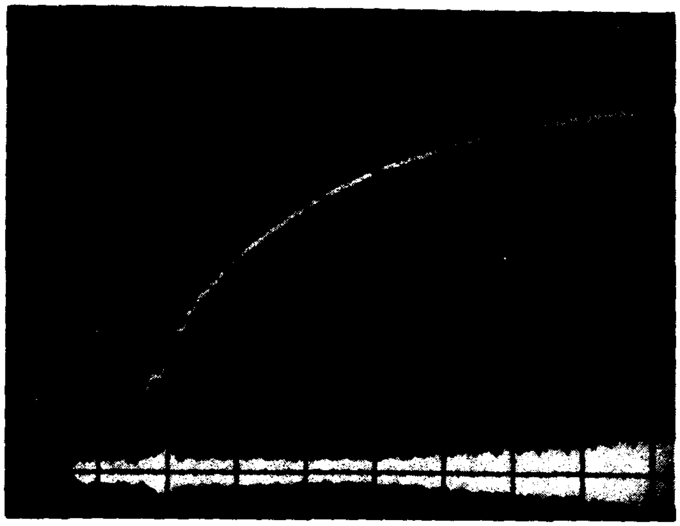

FIGURE A6. SIMULATED LINE RUPTURE - 1/4-INCH FUSE RESPONSE. UPPER TRACE 150 PSIG/DIV. LOWER TRACE CRYSTAL. HORIZONTAL 50 msec/ DIV. UPSTREAM PRESSURE 700 PSIG. FUSE 1/2-TURN OPEN

trace at this point. With the fuse now closed, flow through it has ceased except for the bleed port of this particular size fuse. This flow reduction is indicated by a corresponding drop in detected flow noise. The downstream piping continues to empty to the atmosphere as indicated by the differential pressure continuing to increase toward 700 psig (the difference between the regulator set pressure and atmospheric pressure). The flow noise shows a fairly constant flow as the downstream piping empties followed by an increase in flow. This effect is due to the combination of two factors. As the downstream piping empties, the flow attempts to reduce to zero but simultaneously, the flow through the bleed port is increasing as the differential pressure across it increases. The combination of these actions results in the somewhat stable flow noise followed by the increasing flow noise. The fluctuations noticeable in the differential pressure trace are most probably due to small flow and pressure transients caused by movements of the poppet and resulting pressure wave reflections.

Considerable detail of the sequence of test events can be deduced from the recorded data. By using such a "fine look" technique very precise times and fuse responses were measurable. Fo: Figure A6, the fuse closure time would be calculated from the instant a differential pressure increase began (flow through poppet begins) to the instant the poppet closes (as indicated by the noise spike). For this example, the closure time is 20 milliseconds.

Figure A7 shows the response of the 1/4-inch fuse to a piping repair. Only the 1/4-inch fuse has automatic reset capability so this example is not representative of data taken on all fuses as is Figure A6. Figure A7 does demonstrate, however, the ability of the instrumentation to "see" what goes on inside the test setup. The beginning of the trace signifies the closing of the rupture valve (line repaired). As the fuse bleed port begins to pressurize the repaired downstream piping, the differential pressure across the fuse decreases. As the differential driving pressure decreases so does the flow through the bleed port, as indicated by the decreasing flow noise. These decreases continue until the differential pressure created force equals the spring force attempting to reopen the poppet. At this point the poppet snaps open (see spike in noise trace) equalizing the last few pounds of pressure and rapidly reduces the flow to zero.

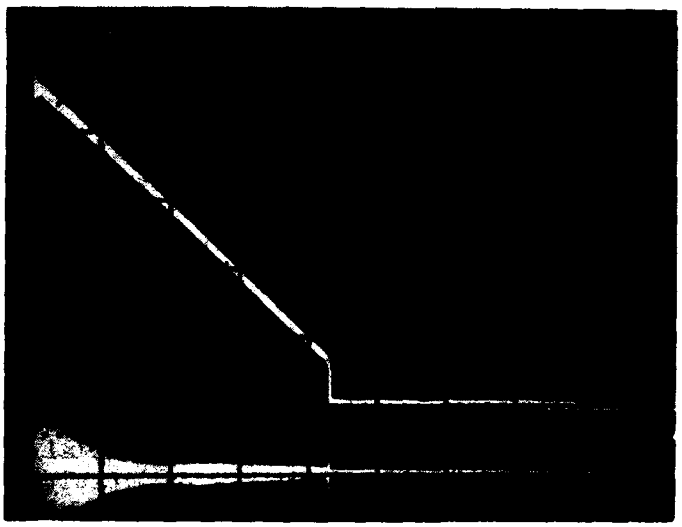

FIGURE A7. RESPONSE TO LINE REPAIR - 1/4-INCH FUSE. ALL VALUES SAME AS FIGURE A6 EXCEPT HORIZONTAL 5.0 SEC/DIV.

Figure A8 is typical of data collected on fuse response to an increasing leak. To create this condition the increasing leak valve of Figure A1 was used instead of the dome-loaded rupture valve. Figure A8 shows the increase in differential pressure across the fuse (upper trace) and flow noise generated (lower trace) as the leak valve is opened wider and wider. Once the spring force is exceeded by the

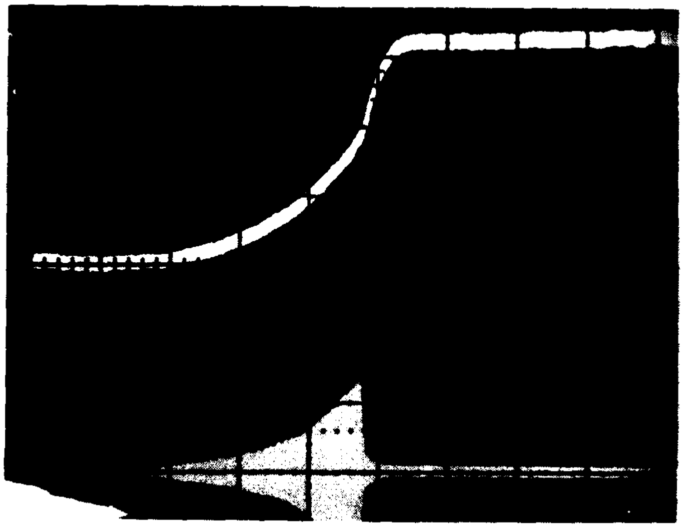

FIGURE A8. RESPONSE TO INCREASING LEAK - 1/4-INCH FUSE
UPPER TRACE 50 PSI/DIV. LOWER TRACE CRYSTAL
HORIZONTAL 0.5 SEC/DIV. UPSTREAM
PRESSURE 160 PSIG FUSE 1/2 TURN OPEN

flow created differential pressure, the fuse poppet closes completely as indicated by the slope change in the pressure trace and the simultaneous rapid reduction in flow noise. The lack of a noise spike from the poppet is probably due to either the gradual changes taking place as opposed to sudden changes for the rupture situation or by masking flow noise. Possibly, as the differential pressure gradually increases, the spring holding the poppet open would compress thus allowing the poppet to move toward the seat. By the time the spring was compressed enough to result in a more rapid buildup in differential pressure, as indicated by the constantly changing slope of the upper trace in Figure A8, the final closure required little movement and therefore produced no noise spike.

Figure A9 shows the flow response to the same conditions of increasing leak used for Figure A8. As the increasing leak valve is opened, the differential pressure increases due to flow as before (upper trace) and the flow coming out of the test setup to the atmosphere is indicated by the lower trace. The point of fuse closure was accurately established in Figure A8 by the indication in flow noise and the simultaneous change in slope of the differential pressure curve. This information applied to Figure A9 gives the point, in time, of fuse closure for the closure flow measurement. In Figure A9, this point is 2.25 seconds after trace initiation. Reading directly below this point, the flow at closure or closure flow is seen to be 38 standard cubic feet per minute (scfm). After the fuse closes, the downstream piping continues to empty resulting in a gradual decrease of flow until the downstream piping is completely emptied.

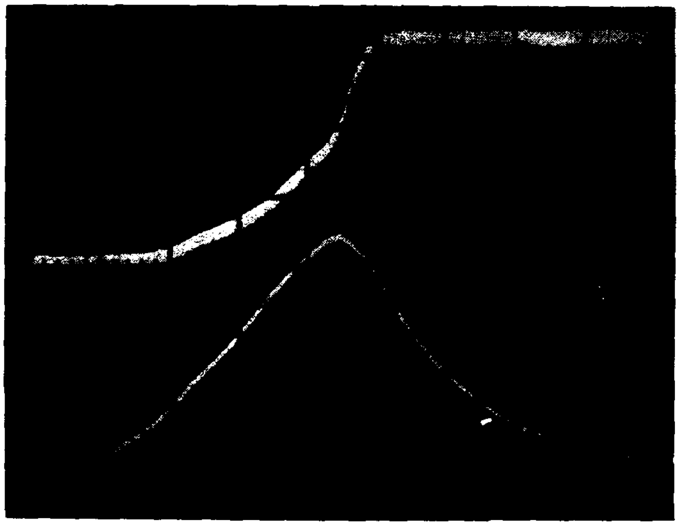

FIGURE A9. RESPONSE TO INCREASING LEAK - 1/4-INCH FUSE
UPPER TRACE 50 PSI/DIV. LOWER TRACE 11.2
SCFM/DIV. HORIZONTAL 0.5 SEC/DIV.
UPSTREAM PRESSURE 160 PSIG.
FUSE 1/2 TURN OPEN

In this manner, the single cycle performance data, Figures A6, A8, and A9, were collected on each of the fuses. The resulting performance envelope curves are shown in Appendices B, C, D, and E for the 1/4-, 1/2-, 1-, and 2-inch fuses, respectively.

The second category of collected data was the life-cycle test results. The life-cycle tests were designed to determine the ability of each fuse to survive a large number of closures without operational failures. No attempt was made to determine the ultimate number of actuations required to produce failure; instead, a number was selected (2000) which appeared much larger than would be required for most applications. Conditions were set up for upstream pressure (700 psig) and fuse poppet setting (number of turns open) and the cycle timer turned on (Figure A1).

The function of the cycle timer was to alternately open the rupture valve by dumping its dome pressure and then equalize pressure across the actuated fuse to cause reset. The operation of the rupture valve and equalizing solenoids were mutually exclusive; when one was open, then the other was closed. While the cycle timer was exercising the fuse, the strip chart recorder was recording, as a function of time, the upstream driving pressure, differential pressure across the fuse, and each instant the cycle timer began a new cycle. Counts were manually recorded on the chart paper beside the appropriate cycle timer pulse.

Figure A10 is an example of the type chart recordings obtained. The left most trace is the cycle timer count. The next trace is the differential pressure across the fuse and varies between 0 psig (equalized) and 700 psig (actuated). This trace tells whether or not the fuse actuated for each cycle of the timer. The next trace was not used because of a recorder amplifier problem. The fourth trace indicates upstream driving pressure which is 700 psig for this case. This trace is used to insure that the upstream regulator maintains a constant driving pressure for uniformity between cycles.

At the beginning of a life-cycle test, and at 500-cycle intervals, checks were made of the fuse's performance characteristics using the single-cycle testing technique mentioned earlier. In this manner, any trends could be detected that were significant. The results of the life-cycle tests are contained in Appendices B, C, D, and E.

The instrumentation system used proved extremely useful in making the desired evaluations and was a good deal more reliable than anticipated. The only failure experienced was in the memory oscilloscope. Fortunately, an acceptable substitute was located and testing continued without undue delay.

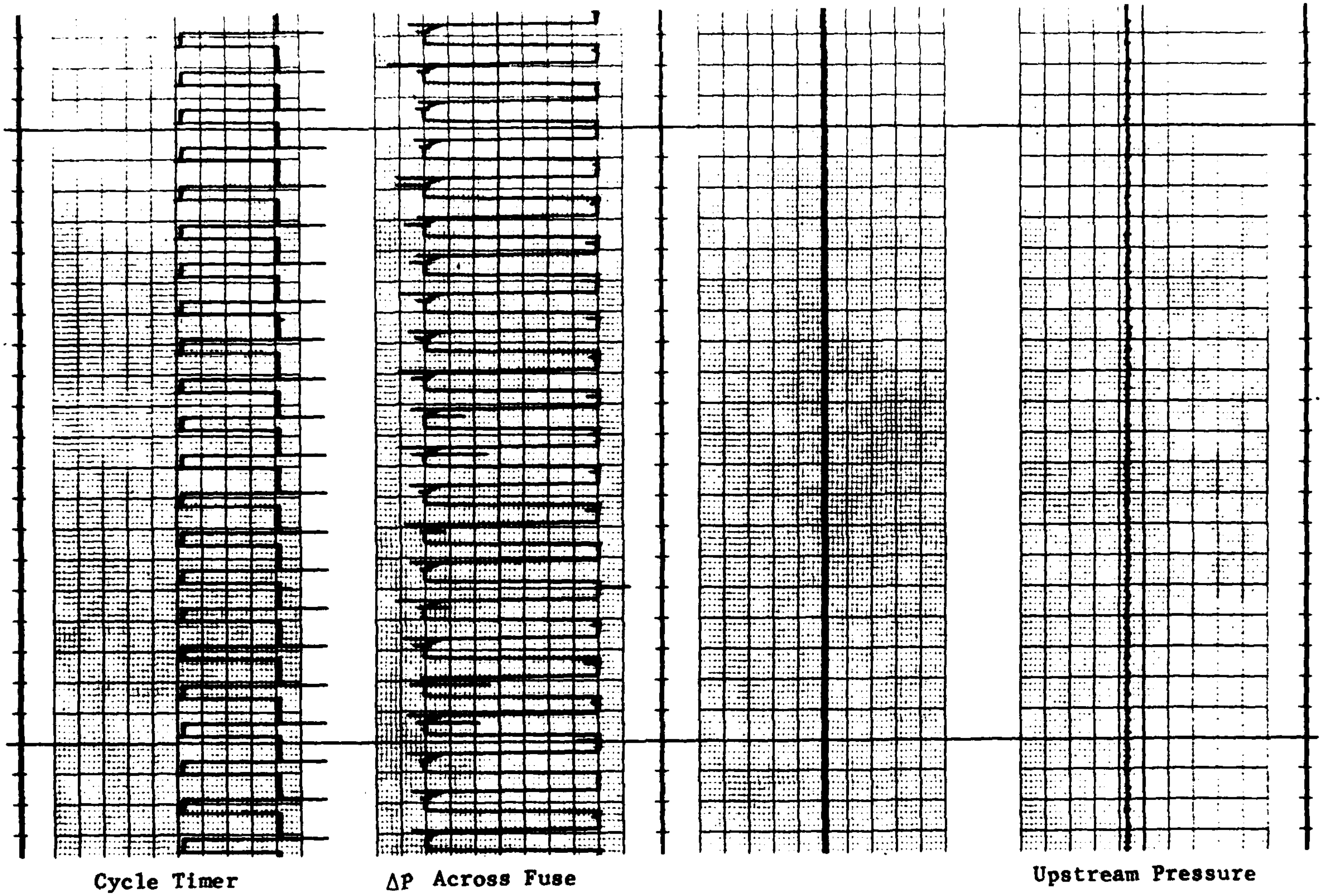

FIGURE A10. STRIP CHART RECORDING - 1/4 INCH FUSE
1/2 TURN OPEN

APPENDIX B

TEST RESULTS FOR 1/4-INCH FLOW FUSE

MECHANICAL CHARACTERISTICS

The 1/4-inch Flow Fuse tested was Marotta Valve Corporation Model SPV33A, part number 280623-4, and serial number 177. The specified service (operating) conditions are listed in Table B1. Materials in contact with line fluids are monel, nylon, teflon, and synthetic rubber per MIL-R-6855. Body material is monel "R."

A photograph of the 1/4-inch fuse is shown in Figure B1.

TABLE B1

FUSE SPV33A SERVICE CONDITIONS

Parameter	Permissible Range
Operating Pressure	100 - 4500 psig
Proof Pressure	6750 psig
Burst Pressure	18,000 psig
Operating Temperature	+28°F to +130°F
Operating Media	Air, helium, oxygen, seawater
Weight	1.75 lb (nominal)
Capacity	0.2 to 250 scfm at 4500 psig

TEST METHOD

The test setup and examples of collected data are described in detail in Appendix A.

(Text Continued on Page B-3)

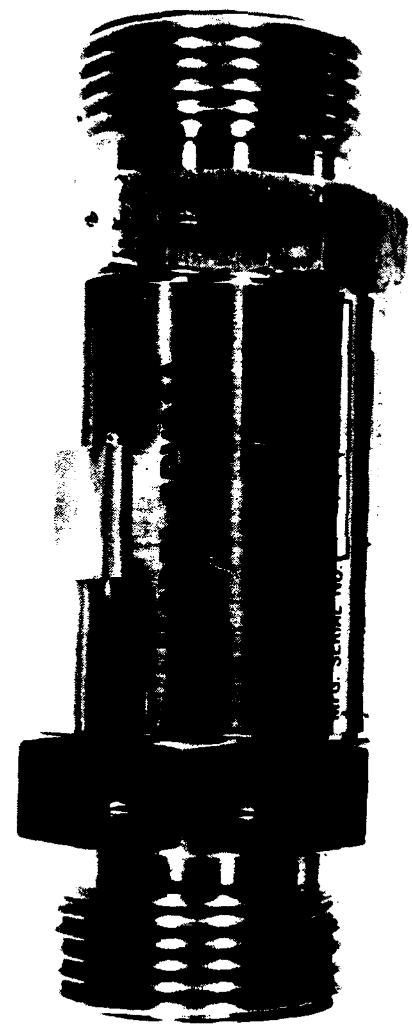

FIGURE B1. 1/4 INCH FLOW FUSE

TEST RESULTS

This appendix is devoted to the detailed results of the evaluation of the 1/4-inch fuse. The performance results of the single-cycle tests are presented as a series of tables and plots, while the results of the life-cycle tests are presented in tabular form. For a detailed discussion of the methods used to collect the data, refer to Appendix A.

RESPONSE TIME

The response time of fuse closure is somewhat affected by the upstream driving pressure and poppet setting (number of turns open). Table B2 indicates the response time (closure time) of the 1/4-inch fuse to upstream driving pressure using nitrogen gas. Notice that as the driving pressure increases, the closure time decreases for a constant poppet setting. This is to be expected because the fuse is mass-flow sensitive and greater upstream pressure causes greater mass flow per unit time.

TABLE B2

EFFECT OF UPSTREAM PRESSURE ON CLOSURE SPEED OF 1/4-INCH FLOW FUSE

Response Time (msec)	Upstream Pressure (psig)	Poppet Setting (turns)
90	200	1/2
34	400	1/2
21	700	1/2
12	1010	1/2

Table B3 indicates that closure speed is slightly affected by poppet setting for this fuse. Even though data were taken for poppet settings out to 3-1/2 turns open, it was later discovered that only the first full turn produces any change in distance between poppet and seat. This limited range of adjustability is due to the poppet contacting a stop (shoulder) after being opened one full turn from the closed position.

TABLE B3

EFFECT OF POPPET SETTING ON CLOSURE SPEED
OF 1/4-INCH FLOW FUSE

Response Time (msec)	Upstream Pressure (psig)	Poppet Setting (Turns)
20	705	1/4
20	710	1/2
22	700	1
22	710	2
22	700	3-1/2

The gas used for these tests of the 1/4-inch fuse was dry, oil-free nitrogen. Because nitrogen has an atomic mass of 28 and air an atomic mass of 28.8, the results for these tests are also applicable when using air as the flowing medium. The use of other gases having different atomic mass will produce response times that are considerably different; response to helium is discussed later in this appendix.

POPPET SETTING EFFECTS

Figure B2 plots the values of gas flow at time of fuse closure versus the poppet setting for a simulated leak. The upstream driving pressure was low (165 psig) for these tests to determine the ability of the fuse to reliably actuate at low pressures. In addition, the lower limits of closure-actuating flow were ascertained. Refer to Appendix A for a complete discussion of the test procedure for collecting these data.

Figure B3 plots the results for the same situation except at a higher upstream pressure. Notice that the two curves (Figures B2 and B3) peak at about one turn open. Beyond this setting, closure flow does not change because all the adjustability is in the first turn. The variation in flow that is illustrated is due to measurement error in both the data collection and in reading the photo-recorded results.

(Text Continued on Page B-6)

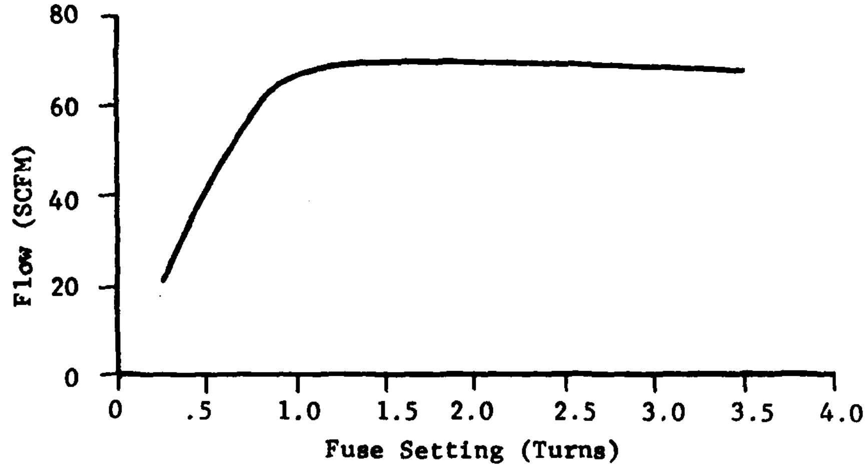

FIGURE B2. CLOSURE FLOW VS. POPPET SETTING FOR LOW UPSTREAM PRESSURE (165 PSIG) - 1/4 INCH FUSE

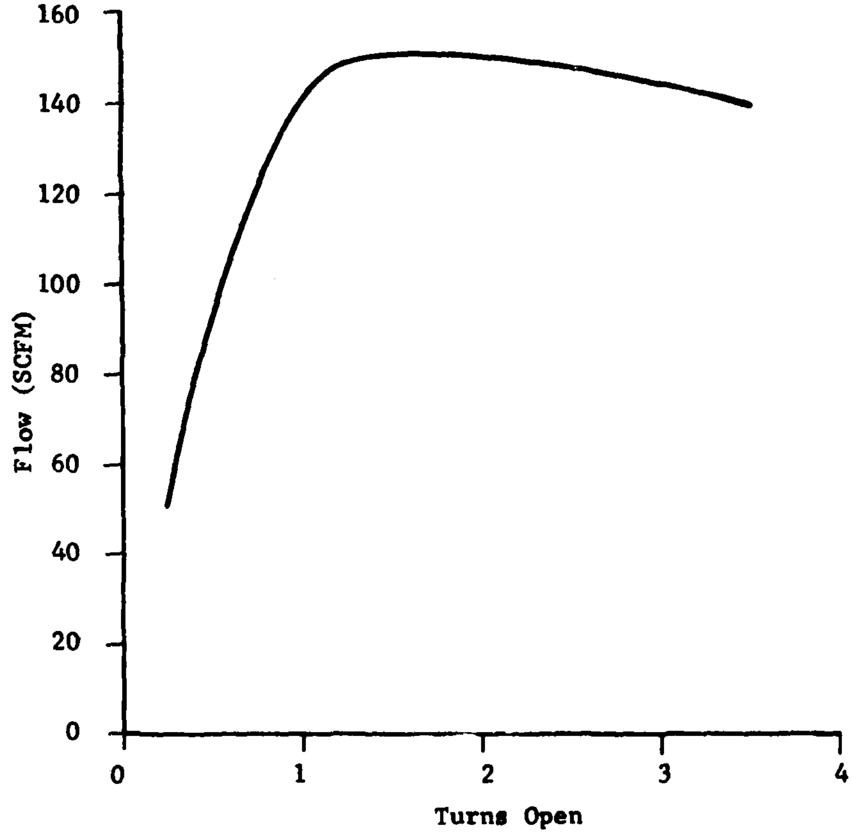

FIGURE B3. CLOSURE FLOW VS. POPPET SETTING FOR HIGHER UPSTREAM PRESSURE (700 PSIG) - 1/4 INCH FUSE

PRESSURE DEPENDENCE

Figure B4 illustrates the effects on closure flow of different upstream driving pressures. These results are for an increasing leak using a mid-range poppet setting (1/2-turn open). The dotted curve corresponds to the closure flow results and is quite linear above 300 psig. The solid curve corresponds to the differential pressure existing across the fuse at the instant of closure. It should be noted that this curve (solid line) should be a constant value regardless of driving pressure since the same force (ΔP times area) is required each time to actuate the fuse. The demonstrated decrease in closure ΔP is probably due to the faster response at higher driving pressures (see Table B2).

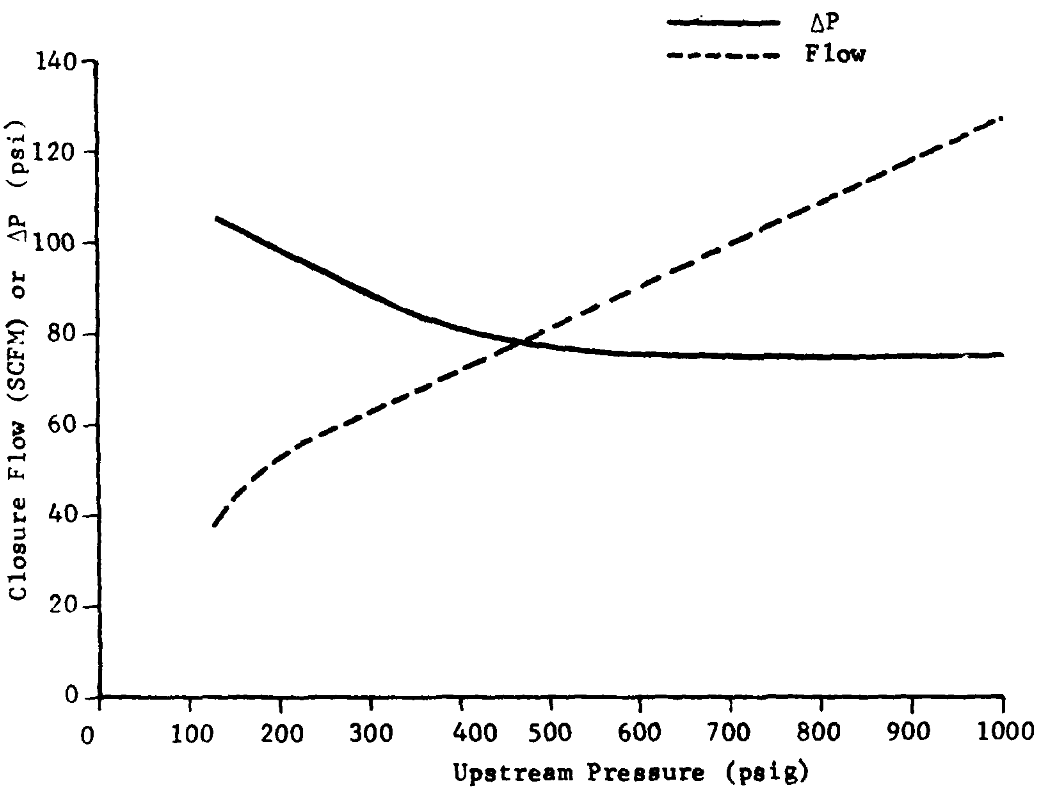

FIGURE B4. CLOSURE FLOW VERSUS UPSTREAM PRESSURE FOR FIXED POPPET SETTING (1/2 TURN OPEN) - 1/4-INCH FUSE

EXTENSION OF SINGLE CYCLE RESULTS

From the data shown in Figures B2, B3, and B4, it has been possible to synthesize a matrix which specifies approximate poppet settings as a function of desired closure flow (flow at which the fuse should actuate) and system working pressure. The method used to create the matrix and how to apply it is described in Appendix F. For convenience, the set-point matrix for the 1/4-inch fuse is reproduced here as Table B4.

TABLE B4

SET-POINT MATRIX - 1/4-INCH FUSE
(NITROGEN OR AIR SYSTEMS ONLY)

Turns Open	Pressure (psig) 100	200	300	400	500	600	700	800	900	1000
	Closure Flow (scfm)									
1/4	25	35	43	48	54	59	64	70	76	83
1/2	37	52	64	72	80	88	96	104	114	124
3/4	54	76	94	105	117	129	140	153	167	182
1	62	86	107	120	134	147	160	175	190	208

LIFE-CYCLE TESTS

These tests were designed to determine the ability of the fuse to operate within its performance envelope after repeated actuations, and to a limited extent, the operating life expectancy of the fuse. A description of the method used in collecting the life-cycle data is contained in Appendix A. The life-cycle tests were made immediately following the single-cycle performance envelope tests. The poppet setting was 1/2-turn open and the upstream pressure was kept constant at 700 psig. Because the single-cycle tests require a few hundred cycles (300 - 400), the fuse was well "broken in" prior to commencement of the life-cycle tests. By scheduling the tests in this order, effects or trends due to "wear in" should have been avoided.

The life-cycle tests involved 2000 total actuations (cycles) and began with base-line data being collected on the fuse. The fuse was next subjected to 500 nonstop cycles and then rechecked for operation. This procedure continued until 2000 cycles were completed. The results are shown in Table B5. Notice the consistency of closure speed (time column) and closure flow over the 2000 actuations. No trends toward degraded operation are detectable and it seems most reasonable to assume that the "cycles to failure" capability of this fuse is considerably greater than 2000. Automatic reset, a feature of only the 1/4-inch fuse, is also very consistent although an increasing reset time trend may be developing.

TABLE B5

LIFE-CYCLE TEST RESULTS - 1/4-INCH FUSE

Cycles Completed	Rupture Closure ΔP	Rupture Time (msec)	Increasing Leak Closure ΔP	Increasing Leak Closure Flow	Reset Time (sec)
0	60 psid	20	80 psid	4.2" (91 scfm)	21.5
500	70	20	70	4.1" (89 scfm)	21.5
1000	70	20	75	3.8" (83 scfm)	22.5
1500	85	20	80	4.2" (91 scfm)	22.5
2000	65	20	75	4.1" (89 scfm)	23.0

GAS DENSITY TESTS

Immediately after completion of the life-cycle tests, a test was made to determine the differences in performance resulting from use of a much less dense gas. The normal test gas of nitrogen (atomic mass 28) was changed to helium (atomic mass 4) and a series of single-cycle tests performed. Table B6 compares the performance results using nitrogen and helium. It can be seen that the 1/4-inch fuse actuates twice as fast and resets about 2-1/2 times as fast using helium. The closure differential pressure for an increasing leak is about the same for both gases; a reasonable result considering that the same force is necessary to overcome the spring and close the poppet regardless of the gas used.

Closure flow, for some reason, was extremely difficult to measure with helium. In the first attempt (see Table B6), the laminar flow element used was of insufficient capacity to make an accurate measurement. In the second attempt, a much greater capacity flow element was used (2000 scfm) but in making the measurement it was discovered that the leak valve opening rate had a pronounced effect on the helium closure

TABLE B6

COMPARISON OF NITROGEN AND HELIUM GAS AT 700 PSIG

	Nitrogen	Helium
Closure ΔP (Rupture)	70 psid	120 psid
Closure time (Rupture)	20 msec	10 msec
Closure ΔP (Leak)	76 psid	80 psid
Closure Flow (Leak)	4.1" (89 scfm)	>8"(>170 scfm)
Reset Time	22 sec	8.8 sec

flow value (Figure B5). This effect had previously been observed for nitrogen where too quick an opening rate produced transitory flow instead of steady-state flow at time of fuse actuation. This produced a lower than actual closure-flow reading. By experiment, the opening rate for nitrogen which produced accurate results was determined to be 1.5 seconds or longer. From Figure B5 it would appear that 16 to 18 seconds or longer are required to produce steady-state flow at time of fuse closure. Because of gas supply limitations and excessive expansion cooling, such long leak valve opening rates were prohibitive. It can be stated, however, that the closure flow for helium will be considerably more than the closure flow for nitrogen, all other conditions being equal.

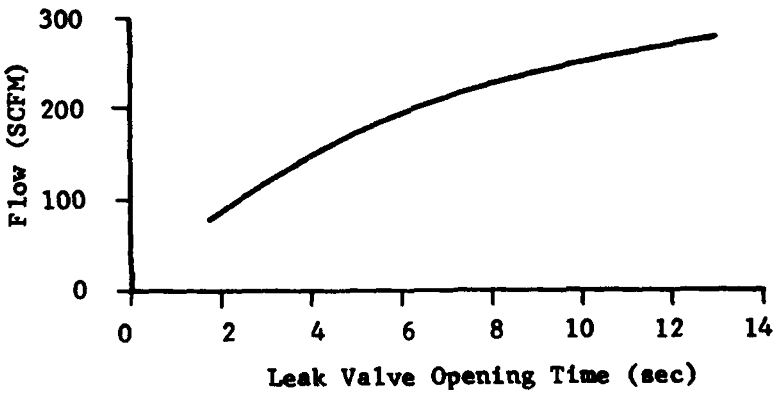

FIGURE B5. CLOSURE FLOW VERSUS LEAK VALVE OPENING RATE - 1/4-INCH FUSE, 1/2 TURN OPEN, HELIUM GAS

VISUAL INSPECTION

Upon completion of all gas tests, the 1/4-inch fuse was completely disassembled (an easy task) and visually inspected for signs of wear using a magnifying glass. No signs of scuffing, scratching, or nicking were evident. Except for a light coating of rust colored powder on the internal surfaces, the fuse looked as though it had hardly been used even though more than 2500 cycles had been completed. The rust dust was easily removed from the surfaces thus returning the fuse to like-new appearance. The source of the rust dust was probably the uncleaned piping of the test setup.

APPENDIX C

TEST RESULTS FOR 1/2-INCH FLOW FUSE

MECHANICAL CHARACTERISTICS

The 1/2-inch Flow Fuse tested was Marotta Valve Corporation Model FVA8B, part number 232324-1312, and serial number 699. The specified service (operating) conditions are listed in Table C1. Materials in contact with line fluids are: corrosion resistant steel alloys 303 and 316, nylon, and Kel-F. Body material is alloy 303 or 316 depending on part number ordered.

TABLE C1

FUSE FVA8B SERVICE CONDITIONS

Parameter	Permissible Range
Operating Pressure	to 4500 psig
Proof Pressure	6750 psig
Burst Pressure	11,250 psig
Operating Temperature	0°F to +160°F
Operating Media	Air, nitrogen, oxygen
Weight	6.0 lb
Capacity	No data given

A photograph of the 1/2-inch fuse tested appears as Figure C1.

TEST METHOD

The test setup and examples of collected data are described in detail in Appendix A.

(Text Continued on Page C-3)

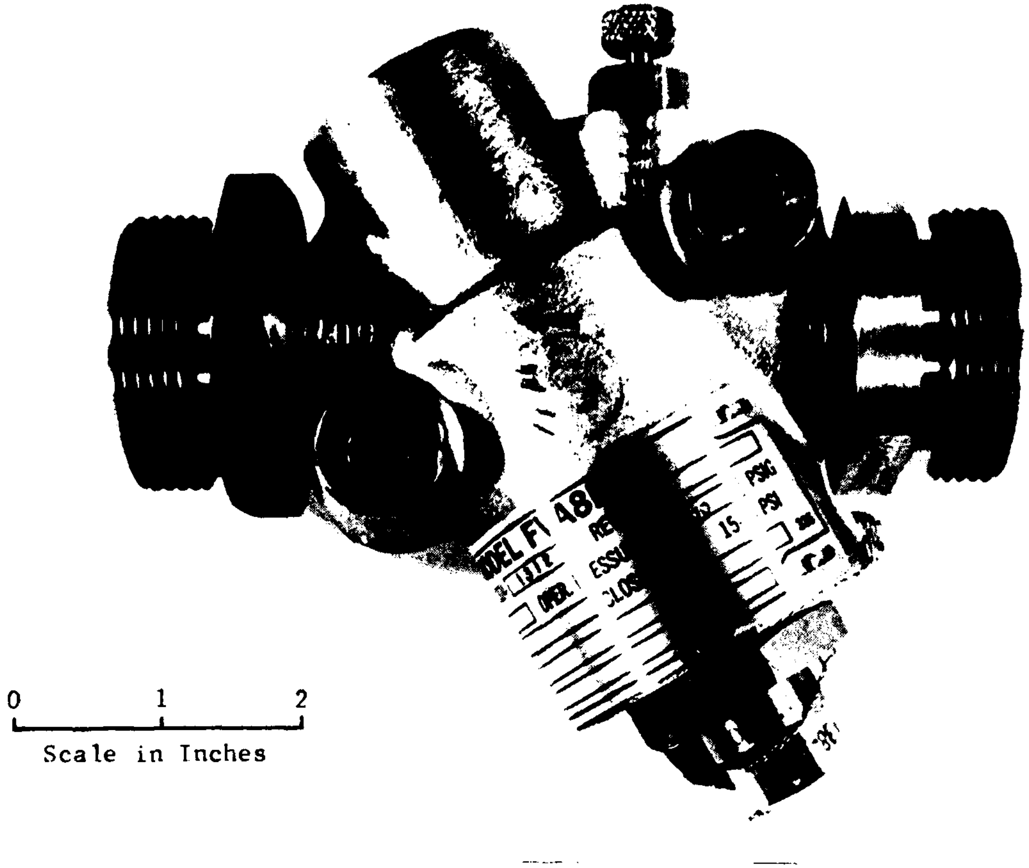

FIGURE C1. 1/2 INCH FLOW FUSE

TEST RESULTS

This appendix is devoted to the detailed results of the evaluation of the 1/2-inch fuse. The performance results of the single-cycle tests are presented as a series of tables and graphs, while the results of the life-cycle tests are presented in tabular form. For a detailed discussion of the methods used to collect the data, refer to Appendix A.

MINIMUM CLOSURE PRESSURE

The first test was to determine the minimum closure pressure that would reliably close the fuse versus a range of poppet settings. Since after closure, the downstream side of the test system drops to atmospheric pressure (0 psig), the minimum closure pressure is also the required closure differential pressure for various poppet settings. The results of this test are shown in Figure C2.

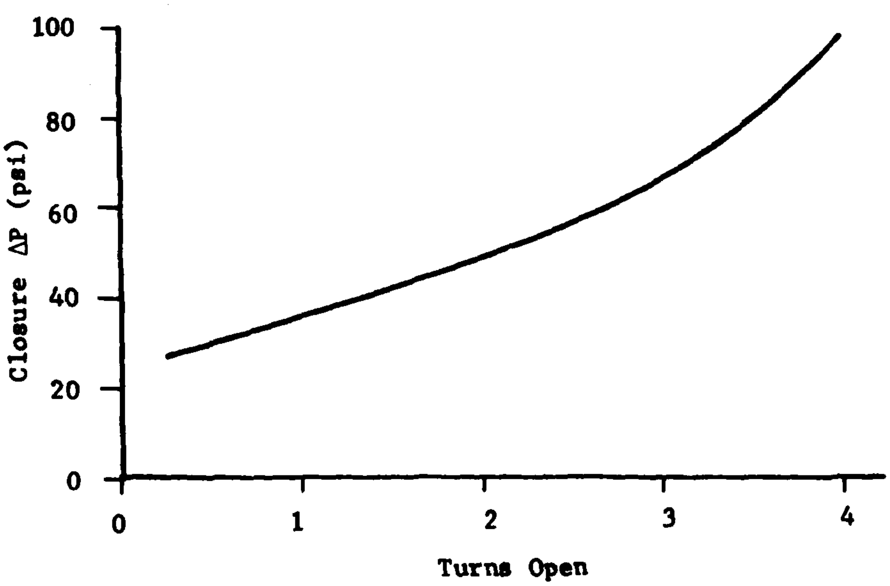

FIGURE C2. MINIMUM CLOSURE PRESSURE VERSUS POPPET SETTINGS - 1/2-INCH FLOW FUSE

The data of Figure C2 are for a simulated downstream pipe rupture. Pressure upstream was adjusted for a value which would actuate the Flow Fuse and hold it closed tightly enough that a downstream pipe repair did not result in a fuse reset in less than 2 minutes after the repair. The closure differential pressure (ΔP) values shown in Figure C2 are indicative, then, of the mass flow required to achieve reliable closure at various poppet settings. The gas for this test was dry, oil free nitrogen.

RESPONSE TIME

The response time of fuse closure is, on a percentage basis, considerably affected by the upstream driving pressure and poppet setting. This response time sensitivity does not, in fact, appear important since all the measured closure times are orders of magnitude faster than required for most applications. Table C2 indicates the response (closure) time of the 1/2-inch fuse to upstream driving pressure using nitrogen gas. Notice that as the driving pressure increases, the closure time decreases for a constant poppet setting. This is expected because the fuse is mass-flow sensitive and a greater upstream pressure means greater mass flow per unit time.

TABLE C2

EFFECT OF UPSTREAM PRESSURE ON CLOSURE SPEED OF 1/2-INCH FLOW FUSE

Response Time (msec)	Upstream Pressure (psig)	Poppet Setting (turns)
30	200	1
20	400	1
10	700	1
10	1003	1

Table C3 indicates that closure speed is even more greatly affected by poppet setting for this fuse.

TABLE C3

EFFECT OF POPPET SETTING ON CLOSURE SPEED OF 1/2-INCH FLOW FUSE

Response Time (msec)	Upstream Pressure (psig)	Poppet Setting (turns)
5	710	1/4
7	710	1/2
10	710	1
17	700	2
30	700	3

The gas used for the tests of the 1/2-inch fuse was dry, oil free nitrogen. Because nitrogen has an atomic mass of 28 and air an atomic mass of 28.8, the results for these tests are applicable when using air. The use of other gases having different atomic mass will produce response times that are considerably different; response of the fuse to helium is discussed later in this appendix.

POPPET SETTING EFFECTS

Figure C3 plots the values of gas flow at time of fuse closure versus the poppet setting for a simulated leak. The upstream driving pressure was low (100 psig) for these tests to determine the ability of the fuse to actuate reliably at low pressures. In addition, the lower limits of closure-actuating flow were ascertained. Nitrogen gas was used. Appendix A contains a complete discussion of the test procedure used in collecting these data.

Figure C4 plots the results for the same situation except at a higher upstream pressure. Both Figures C3 and C4 are for an increasing leak in the downstream piping.

PRESSURE DEPENDENCE

Figure C5 illustrates the effects on closure flow of different upstream driving pressures. These results are for an increasing leak

(Text Continued on Page C-7)

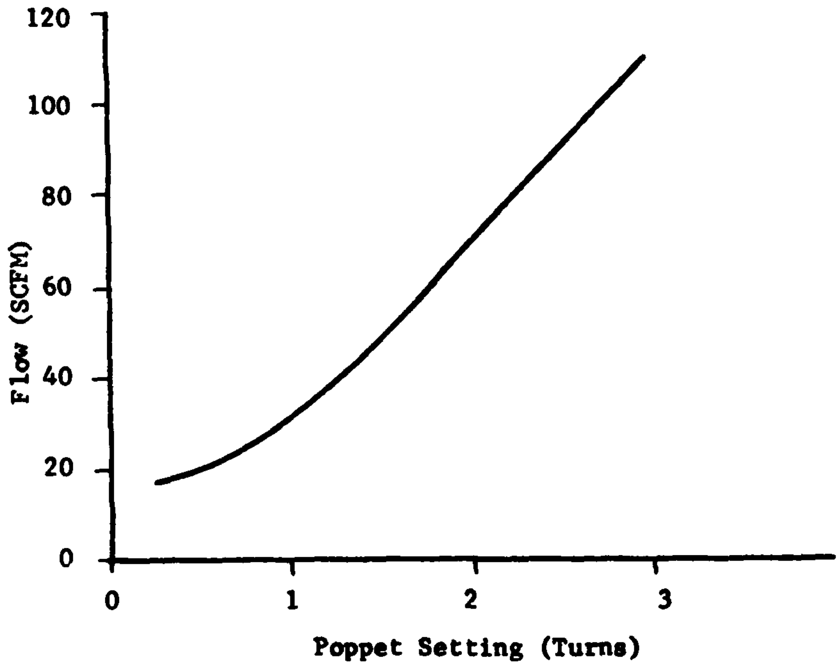

FIGURE C3. CLOSURE FLOW VS. POPPET SETTING FOR LOW UPSTREAM PRESSURE (100 PSIG) - 1/2 INCH FUSE

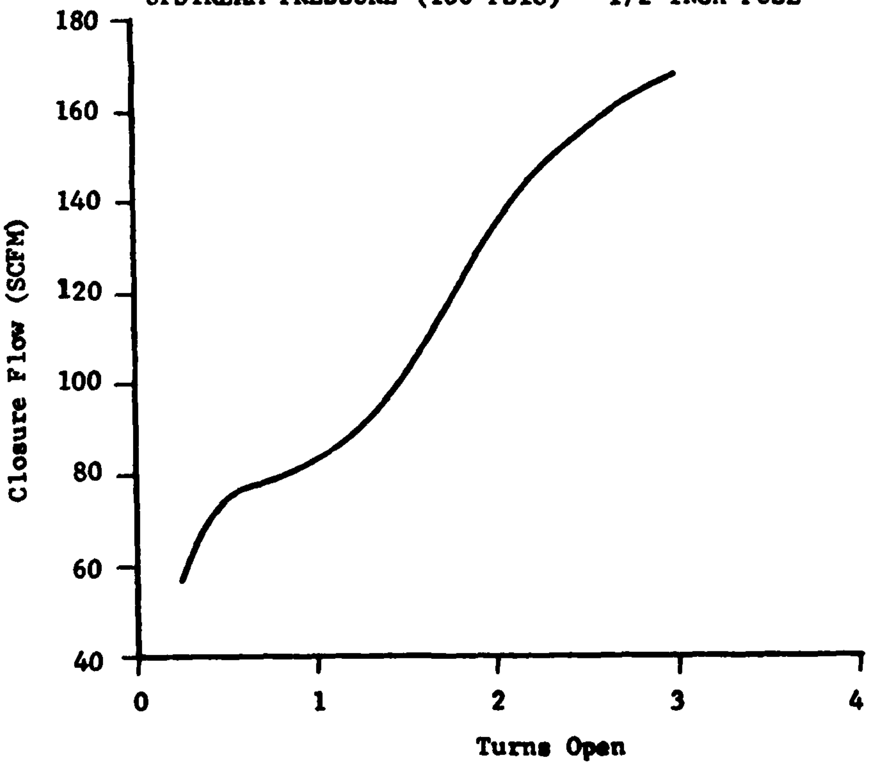

FIGURE C4. CLOSURE FLOW VS. POPPET SETTING FOR HIGH UPSTREAM PRESSURE (700 PSIG) - 1/2 INCH FUSE using nitrogen and a mid-range poppet setting (1-turn open). The solid curve corresponds to the closure flow results and is seen to be quite linear above about 400 psig. The broken curve corresponds to the differential pressure existing across the fuse at the instant of closure for the increasing leak case. It can be noted that this curve (broken line) fairly well demonstrates the constant value of fuse closure force (ΔP times area) that would be expected from the understanding of how a fuse functions.

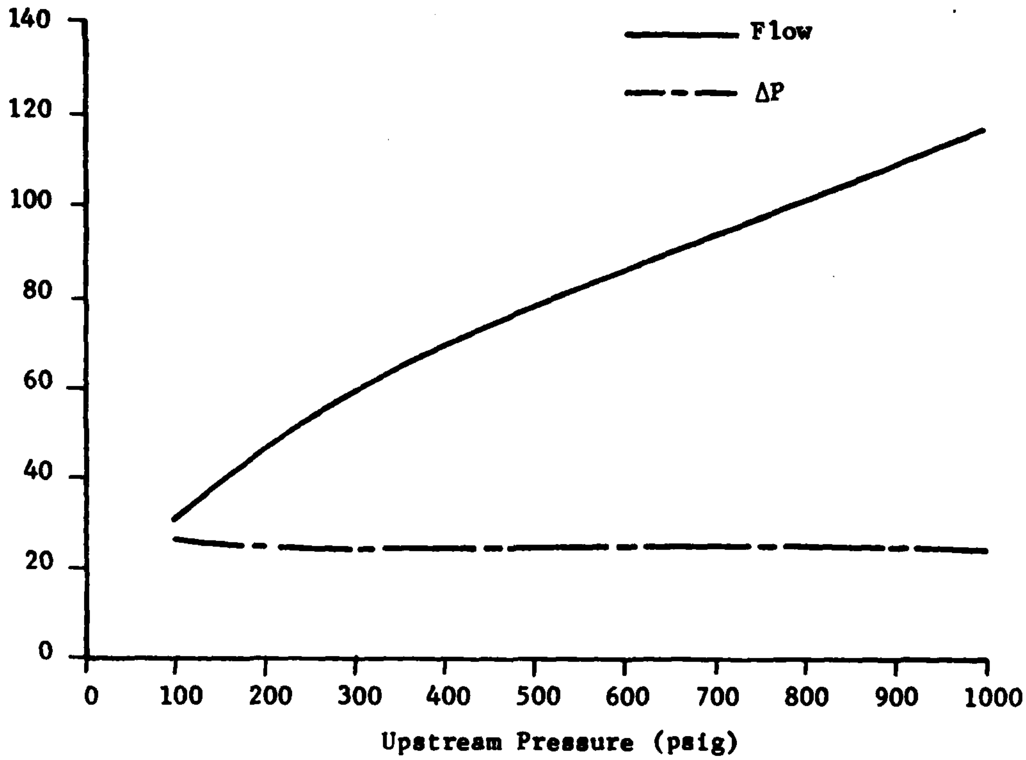

FIGURE C5. CLOSURE FLOW VERSUS UPSTREAM PRESSURE FOR FIXED POPPET SETTING (1-TURN OPEN) - 1/2-INCH FUSE

EXTENSION OF SINGLE CYCLE RESULTS

From the data shown in Figures C3, C4, and C5, it has been possible to synthesize a matrix which specifies approximate poppet settings as a function of desired closure flow (flow at which the fuse should actuate) and system working pressure. The method used to create the matrix and how to apply it is described in Appendix F of this report. For convenience, the set-point matrix for the 1/2-inch fuse is reproduced here as Table C4.

TABLE C4

SET-POINT MATRIX - 1/2-INCH FUSE
(NITROGEN OR AIR SYSTEMS ONLY)

	Pressure (psig)									
	100	200	300	400	500	600	700	800	900	1000
Turns Open	Closure Flow (scfm)									
1/4	21	31	40	47	52	57	62	67	73	78
1/2	27	40	52	60	67	73	80	87	94	100
3/4	29	43	55	64	72	79	86	93	100	107
1	32	49	62	72	80	88	97	104	113	121
1-1/4	37	57	72	85	94	103	113	122	132	141
1-1/2	45	68	87	102	113	124	136	146	158	169
1-3/4	53	80	103	120	133	146	160	173	187	199
2	61	92	118	138	153	168	184	199	215	229
2-1/4	67	102	130	152	169	185	203	220	237	254
2-1/2	73	111	141	165	184	201	220	238	257	275
2-3/4	78	118	151	177	196	215	236	255	275	294
3	83	126	161	188	209	229	251	271	293	313

LIFE-CYCLE TESTS

These tests were designed to determine the ability of the fuse to operate within its performance envelope after repeated actuations and, to a limited extent, the operating life expectancy of the fuse. A description of the method used in collecting the life-cycle data is contained in Appendix A. The life-cycle tests were made immediately following the single-cycle performance envelope tests. In these tests nitrogen gas was used, the poppet setting was 1-turn open, and the upstream pressure was kept constant at 700 psig. Because the single-cycle tests require a few hundred cycles (300 - 400), the fuse was well "broken in" prior to commencement of the life-cycle tests. By scheduling the tests in this order, effects or trends due to "wear in" should have been completely avoided.

The life-cycle tests involved 2000 total actuations (cycles) and began with base-line data being collected on the fuse. The fuse was next subjected to 500 nonstop cycles and then rechecked for operation. This procedure continued until 2000 cycles were completed. The results are shown in Table C5. Notice the consistency of closure speed (time column) and closure flow over the 2000 actuations. There was no evidence of wear or degradation of performance during the more than 2000 actuations.

TABLE C5

LIFE CYCLE TEST RESULTS - 1/2-INCH FUSE

Cycles	Rupture		Increasing Leak	
Completed	Closure ΔP	Time (msec)	Closure ΔP	Closure Flow
0	50 psi	20	20	4.2" (91.5 scfm)
500	50	20	25	3.6" (79 scfm)
1000	50	20	25	4.2" (91.5 scfm)
1500	50	20	25	4.2" (91.5 scfm)
2000	50	22	30	4.5" (98 scfm)

GAS DENSITY EFFECTS

Immediately after completion of the life-cycle tests, a test was made to determine the differences in performance resulting from use of a much less dense gas. The normal test gas of nitrogen (atomic mass 28) was changed to helium (atomic mass 4) and a series of single-cycle tests performed. Table C6 compares the performance results using nitrogen and helium. It can be seen that the 1/2-inch fuse actuates faster using helium. The closure differential pressure for an increasing leak is the same for both gases; a reasonable result considering that the same force is necessary to overcome the spring and close the poppet regardless of the gas used. Closure flow for helium is considerably higher than for nitrogen, which it should be since the fuse is mass-flow sensitive and the density of helium is very low (thus more of it is required per unit time to achieve actuation).

TABLE C6

COMPARISON OF NITROGEN AND HELIUM GAS AT 700 PSIG

	Nitrogen	Helium
Closure ΔP (Rupture)	50 psid	160 psid
Closure Time (Rupture)	20 msec	16 msec
Closure ΔP (Leak)	25 psid	25 psid
Closure Flow (Leak)	90.3 scfm	225 scfm

VISUAL INSPECTION

Upon completion of the tests, the 1/2-inch fuse was completely disassembled (an easy task) and visually inspected for signs of wear using a magnifying glass. No signs of scuffing, scoring, or nicking were evident. Except for a light coating of rust colored powder on the internal surface, the fuse looked as though it had hardly been used even though more than 2500 cycles had been completed. The rust dust was easily cleaned from the surfaces thus returning the fuse to like-new appearance. The source of the rust dust was probably the uncleaned piping of the test setup.

APPENDIX D

TEST RESULTS FOR 1-INCH FLOW FUSE

MECHANICAL CHARACTERISTICS

The 1-inch Flow Fuse tested was Marotta Valve Corporation Model FVA16B, part number 229294-1, serial number 244. The specified service (operating) conditions are listed in Table D1. Materials in contact with line fluids are corrosion resistant steel alloy 303, type 1 nylon, naval brass, synthetic rubber per MIL-P-5516, and polyurethane. Body material is alloy 303.

A photograph of the 1-inch fuse appears as Figure D-1.

TABLE D1

FUSE FVA16B SERVICE CONDITIONS

Parameter	Permissible Range
Operating Pressure	3000 psig
Proof Pressure	4500 psig
Burst Pressure	7500 psig
Operating Temperature	0°F to +160°F
Operating Media	Air
Weight	12 lb
Capacity	No data given

TEST METHOD

The test setup and examples of collected data are described in detail in Appendix A.

(Text Continued on Page D-3)

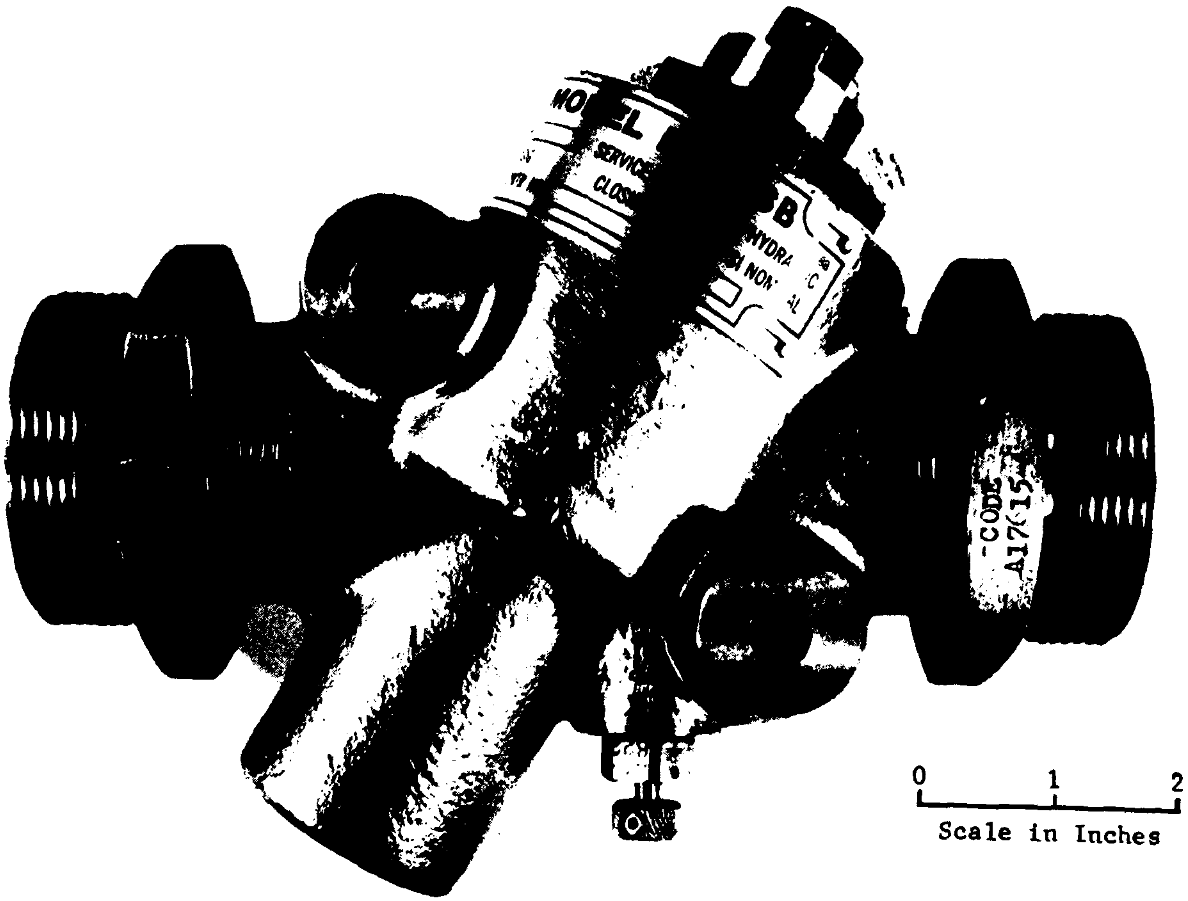

FIGURE D1. 1 INCH FUSE

TEST RESULTS

This appendix describes the results of the evaluation of the 1-inch fuse. The performance results of the single-cycle tests are presented as a series of tables and graphs, while the results of the life-cycle tests are presented in tabular form. For a detailed discussion of the methods used to collect the data, refer to Appendix A.

MINIMUM CLOSURE PRESSURE

The first tests were directed toward determination of the minimum closure pressure that would reliably close the fuse versus a range of poppet settings. Since after closure, the downstream side of the test system drops to atmospheric pressure (0 psig), the minimum closure pressure is also the required closure differential pressure for various poppet settings. The results of this test are shown in Figure D2.

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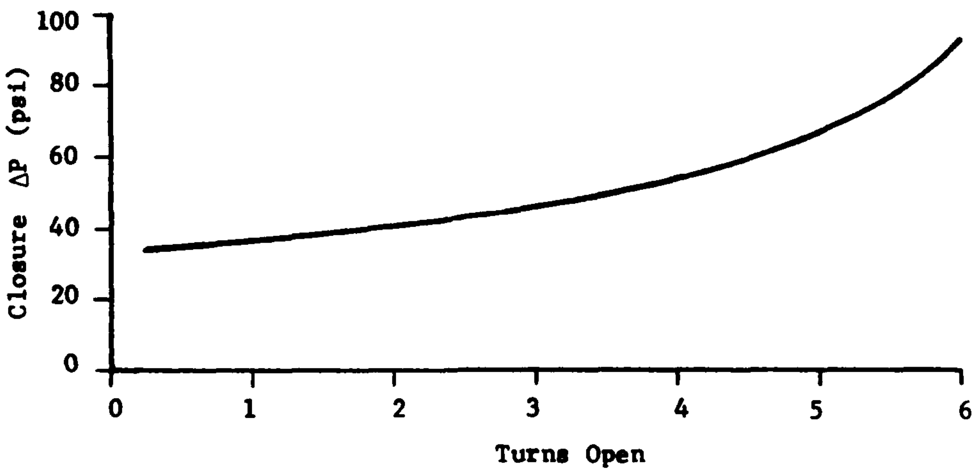

FIGURE D2. MINIMUM CLOSURE PRESSURE VERSUS POPPET SETTINGS - 1-INCH FLOW FUSE

The data of Figure D2 are for a simulated downstream pipe rupture. Pressure upstream was adjusted for a value which would actuate the Flow Fuse and hold it closed tightly enough that a downstream pipe repair did not result in a fuse reset in less than 2 minutes. The closure differential pressure (ΔP) values shown in Figure D2 are indicative, then, of the mass flow required to achieve reliable closure at various poppet settings. The gas for this test was compressed air.

RESPONSE TIME

The response time of fuse closure is, on a percentage basis, considerably affected by the upstream driving pressure and poppet setting. This response time sensitivity does not, in fact, appear important since all the measured closure times are several orders of magnitude faster than required for most applications. Table D2 indicates the response (closure) time of the 1-inch fuse to upstream driving pressure using compressed air. Notice that as the driving pressure increases, the closure time decreases for a constant poppet setting. This is expected since the fuse is mass-flow sensitive and greater upstream pressure means greater mass flow per unit time.

TABLE D2

EFFECT OF UPSTREAM PRESSURE ON CLOSURE SPEED
OF 1-INCH FLOW FUSE

Response Time (msec)	Upstream Pressure (psig)	Poppet Setting (Turns)
57	100	1-1/2
38	200	1-1/2
21	400	1-1/2
15	700	1-1/2
8	1000	1-1/2

Tables D3 and D4 indicate that closure speed is also affected by poppet setting for this fuse. The two tables show the effects at a low and high (relative to the testing range) upstream pressure. It can be seen that while the values change for a different upstream pressure, the trends are similar (longer closure times for larger poppet settings).

TABLE D3

EFFECT OF POPPET SETTING ON CLOSURE SPEED OF 1-INCH FLOW FUSE AT LOW PRESSURE

Response Time (msec)	Upstream Pressure (psig)	Poppet Setting (Turns)
45	100	1/4
54	100	1/2
59	100	1
63	100	2
72	100	3
90	100	4
110	100	5
140	100	6

TABLE D4

EFFECT OF POPPET SETTING ON CLOSURE SPEED OF 1-INCH FLOW FUSE AT HIGHER PRESSURE

Response Time (msec)	Upstream Pressure (psig)	Poppet Setting (Turns)
8	700	1/4
8	700	1/2
9	700	1
11	700	2
12	700	3
30	700	4
43	700	5
55	700	6

The gas used for these tests of the 1-inch fuse was compressed air. It must be remembered that the use of other gases having different densities will produce response times that are considerably different; this is discussed later in this appendix.

POPPET SETTING EFFECTS

Figure D3 plots the values of gas flow at time of fuse closure versus the poppet setting for a simulated leak. The upstream driving pressure was low (100 psig) for these tests to determine the ability of the fuse to reliably actuate at low pressures. In adiditon, the lower limits of closure actuating flow were ascertained. The gas used was again compressed air. Appendix A contains a complete discussion of the test procedure used in collecting this data.

Figure D4 plots the results for the same situation except at a higher upstream pressure. Both Figures D3 and D4 are for an increasing leak in the downstream piping.

PRESSURE DEPENDENCE

Figure D5 illustrates the effects on closure flow of different upstream driving pressures. These results are for an increasing leak using compressed air and a mid-range poppet setting (1-1/2 turns open). The solid curve corresponds to the closure flow results and is seen to be reasonably linear above about 400 psig. The dotted line corresponds to the differential pressure existing across the fuse at the instant of closure for the increasing leak case. The dotted curve fairly well demonstrates the constant value of fuse closure force (ΔP times area) that would be expected from the understanding of how a fuse functions.

EXTENSION OF SINGLE-CYCLE RESULTS

From the data shown in Figures D3, D4, and D5, it has been possible to synthesize a matrix which specifies approximate poppet settings as a function of desired closure flow (flow at which the fuse should actuate) and system working pressure. The method used to create the matrix and how to apply it is described in Appendix F. For convenience, the setpoint matrix for the 1-inch fuse is reproduced here as Table D5.

LIFE CYCLE TESTS

The life-cycle tests were designed to determine the ability of a fuse to operate within its performance envelope after repeated actuations and to a limited extent, the operating life expectancy of the

(Text Continued on Page D-8)

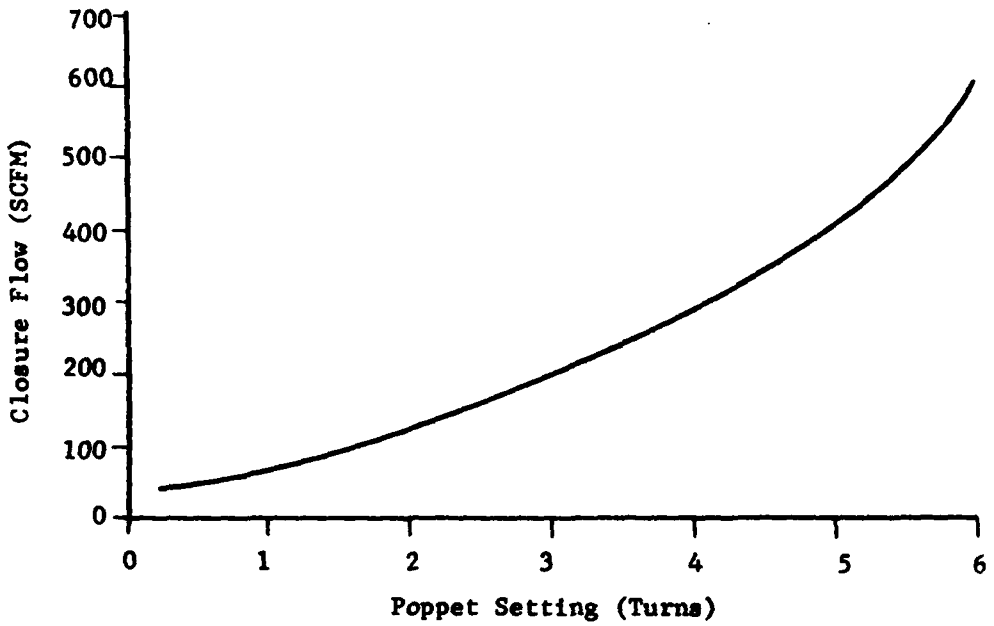

FIGURE D3. CLOSURE FLOW VS. POPPET SETTING FOR LOW UPSTREAM PRESSURE (100 PSIG) - 1 INCH FUSE

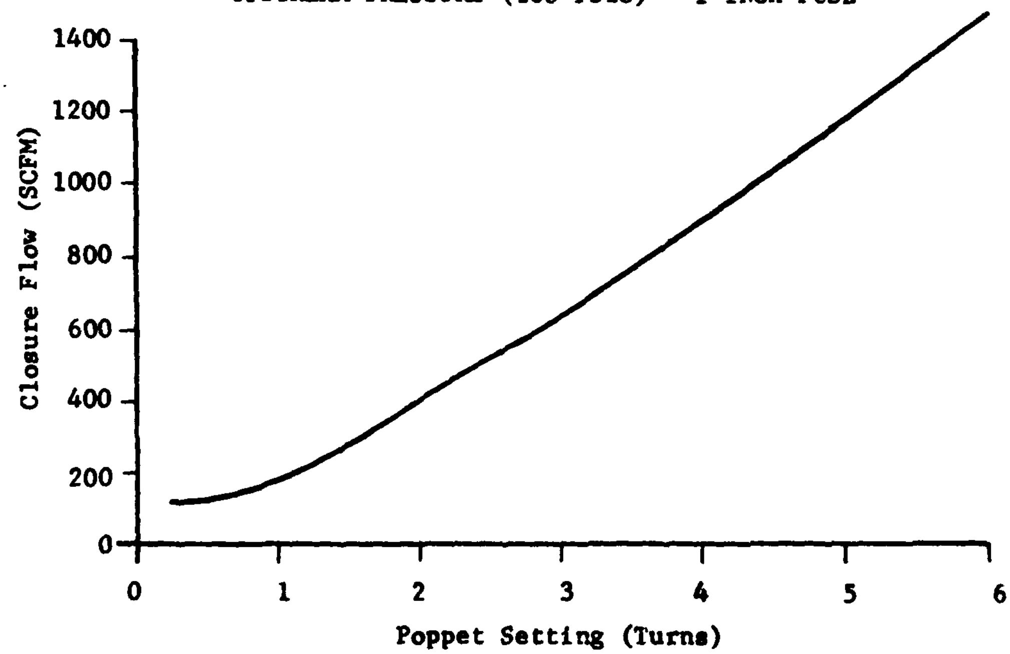

FIGURE D4. CLOSURE FLOW VS. POPPET SETTING FOR HIGHER UPSTREAM PRESSURE (700 PSIG) - 1 INCH FUSE

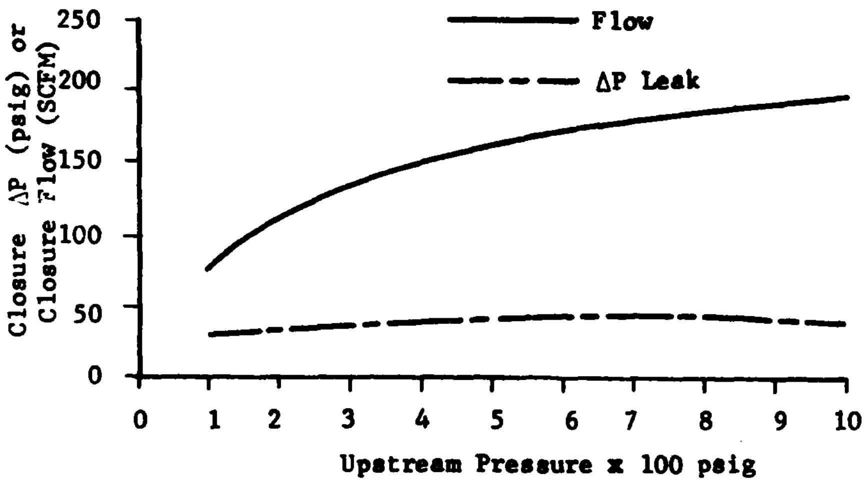

FIGURE D5. CLOSURE FLOW VERSUS UPSTREAM PRESSURE FOR FIXED POPPET SETTING (1-1/2 TURNS OPEN) 1-INCH FUSE

fuse. A description of the method used in collecting the life-cycle data is contained in Appendix A. The life-cycle tests were made following the single-cycle performance envelope tests. The gas used was compressed air, the poppet setting was 1-1/2 turns open, and the upstream pressure was kept constant at 700 psig. Because the single-cycle tests require a few hundred (typically 300 - 400) cycles, the fuse was well "broken in" prior to commencement of the life-cycle tests. By scheduling the tests in this order, effects or trends due to "wear in" should have been completely avoided.

The life-cycle tests involved 2000 total actuations (cycles) and began with base-line data being collected on the fuse. The fuse was next subjected to 500 nonstop cycles and then rechecked for operation. This procedure continued until all 2000 cycles were completed. The

(Text Continued on Page D-10)

TABLE D5

SET-POINT MATRIX - 1-INCH FUSE
(AIR OR NITROGEN SYSTEMS ONLY)

	Pressure (psig)									
	100	200	300	400	500	600	700	800	900	1000
Turns Open	Closure Flow (scfm)									
1/4	42	61	73	83	89	94	99	103	106	108
1/2	53	77	92	104	112	119	125	131	134	137
3/4	60	87	104	118	127	135	141	147	152	154
1	62	90	107	121	131	139	145	152	156	159
1-1/4	82	119	142	160	172	183	191	201	206	210
1-1/2	107	155	185	209	224	239	249	261	269	274
1-3/4	132	191	228	257	277	294	307	322	331	338
2	152	221	263	297	320	340	355	372	383	390
2-1/4	179	259	309	350	376	400	417	437	450	458
2-1/2	200	290	346	391	420	447	467	489	503	513
2-3/4	221	320	381	431	463	493	514	539	555	565
3	243	351	419	473	509	542	565	592	610	621
3-1/4	264	382	455	515	553	589	614	644	663	675
3-1/2	285	412	492	556	598	636	664	696	716	729
3-3/4	308	446	532	601	646	688	717	752	764	788
4	331	479	571	646	694	739	771	808	832	847
4-1/4	361	522	623	704	757	806	840	881	907	923
4-1/2	389	563	672	760	817	870	907	951	978	997
4-3/4	423	612	730	826	887	945	985	1033	1063	1083
5	458	663	792	895	962	1024	1068	1120	1152	1173
5-1/4	498	720	859	971	1044	1111	1159	1215	1250	1274
5-1/2	537	778	928	1049	1128	1200	1252	1312	1350	1375
5-3/4	580	839	1001	1131	1216	1295	1350	1416	1457	1484
6	622	900	1074	1214	1305	1389	1449	1519	1563	1592

results are shown in Table D6. Notice the consistency of closure speed (time column) and closure flow over the 2000 actuations. No trends toward degraded operation are detectable and it seems most reasonable to assume that the "cycles to failure" capability of this fuse is considerably greater than 2000.

TABLE D6

LIFE-CYCLE TEST RESULTS - 1-INCH FUSE

Cycles	Rupture		Increasing Leak	
Completed	Closure ΔP	Time (msec)	Closure ΔP	Closure Flow
0	65 psig	12	40 psig	.65" (180 scfm)
500	50	20	40	.67" (185 scfm)
1000	60	11	35	.64" (176 scfm)
1500	70	12	35	.61" (168 scfm)
2000	70	11	35	.61" (168 scfm)

GAS DENSITY TESTS

Immediately after completion of the life-cycle tests, a test was made to determine the differences in performance resulting from use of a much less dense gas. The normal test gas of compressed air (atomic mass 28.8) was changed to helium (atomic mass 4) and a series of single-cycle tests performed. Tables D7 and D8 compare the performance results using air and helium. It can be seen that the 1-inch fuse actuates faster using helium. The closure differential pressure for an increasing leak is about the same for both gases; a reasonable result considering that the same force is necessary to overcome the spring and close the poppet regardless of the gas used. Closure flow for helium is considerably higher than for compressed air, which it should be since the fuse is mass-flow sensitive and the density of the helium is very low (thus more of it is required per unit time to achieve actuation).

VISUAL INSPECTION

Upon completion of all gas tests, the 1-inch fuse was removed from the test setup and disassembled (an easy task) for inspection. A visual

TABLE D7

COMPARISON OF AIR AND HELIUM GAS AT 400 PSIG

	Air	Helium
Closure ΔP (Rupture)	50 psig	110 psig
Closure Time (Rupture)	19 msec	8 msec
Closure ΔP (Leak)	40 psig	40 psig
Closure Flow (Leak)	150.4 scfm	1.21" (336 scfm)

TABLE D8

COMPARISON OF AIR AND HELIUM GAS AT 700 PSIG

	Air	Helium
Closure ΔP (Rupture	50 psig	160 psig
Closure Time (Rupture)	12 msec	6 msec
Closure ΔP (Leak)	45 psig	45 psig
Closure Flow (Leak)	180 scfm	1.62" (449 scfm)

inspection under a magnifying glass revealed little wear after almost 2500 cycles. The guide end of the poppet showed some wear but the remainder of the poppet looked like new. The soft seat was scratched in two places but not all the way across. The seat showed no detectable wear other than the scratches. This fuse was the cleanest of all on disassembly showing very little rust dust accumulation. All visual signs considered, the fuse showed little wear considering the 2500 cycles, and then the wear was inconsequential according to the cycle test data.

APPENDIX E

TEST RESULTS FOR 2-INCH FLOW FUSE

MECHANICAL CHARACTERISTICS

The 2-inch Flow Fuse tested was Marotta Valve Corporation Model FVA32C, part number 281008, and serial number 101. The specified service (operating) conditions are listed in Table E1. Materials in contact with line fluids are: corrosion resistant steel alloys 17-4PH and 316, and nylon. Body material is alloy 316.

A photograph of the 2-inch fuse appears as Figure E1.

TABLE E1

FUSE FVA32C SERVICE CONDITIONS

Parameter	Permissible Range
Operating Pressure	6000 psig
Proof Pressure	12,000 psig
Burst Pressure	24,000 psig
Operating Temperature	0°F to +140°F
Operating Media	Inert gas
Weight	73 lb
Capacity	No data given

TEST METHOD

The test setup and examples of collected data are described in detail in Appendix A.

TEST RESULTS

This appendix is devoted to the detailed results of the evaluation of the 2-inch fuse. The performance results of the single-cycle tests

(Text Continued on Page E-3)

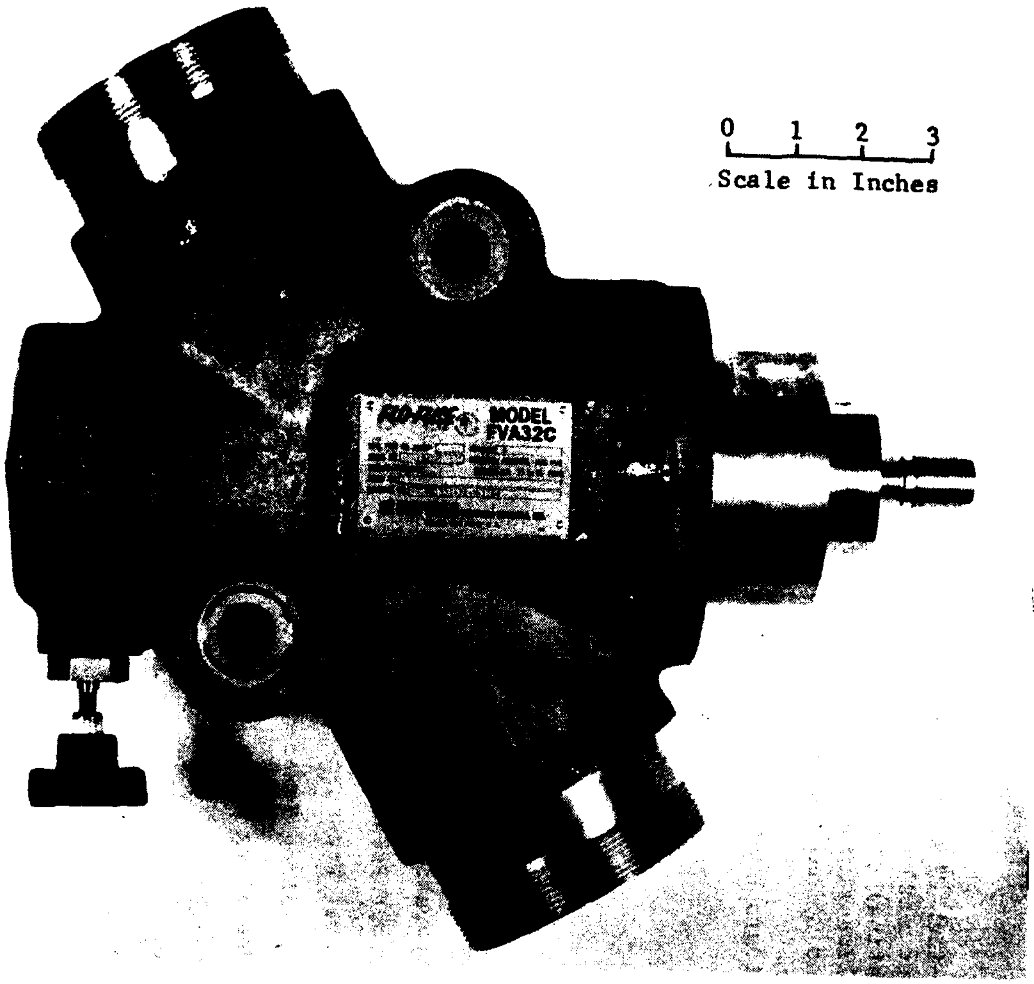

FIGURE E1. 2 INCH FUSE

are presented as a series of tables and graphs, while the results of the life-cycle tests are presented in tabular form. For a detailed discussion of the methods used to collect the data, refer to Appendix A.

MINIMUM CLOSURE PRESSURE

The first tests were directed toward determination of the minimum closure pressure that would reliably close the fuse versus a range of poppet settings. Since after closure, the downstream side of the test system drops to atmospheric pressure (0 psig), the minimum closure pressure is also the required closure differential pressure for various poppet settings. The results of this test are shown in Figure E2.

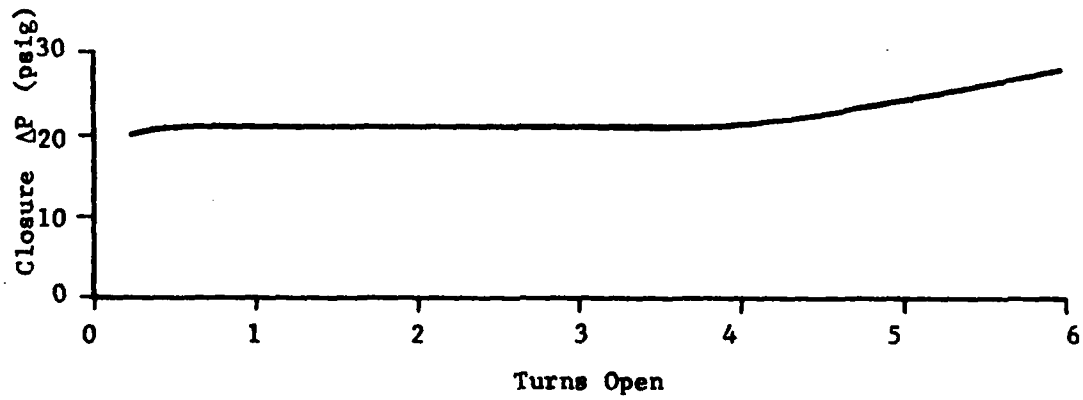

FIGURE E2. MINIMUM CLOSURE PRESSURE VERSUS POPPET SETTINGS - 2-INCH FLOW FUSE

The data of Figure E2 are for a simulated downstream pipe rupture. Pressure upstream was adjusted for a value which would actuate the Flow Fuse and hold it closed tightly enough that a downstream pipe repair did not result in a fuse reset in less than 2 minutes. The closure differential pressure (ΔP) values shown in Figure E2 are indicative, then, of the mass flow required to achieve reliable closure at various poppet settings. Compressed air was used in this test.

RESPONSE TIME

The response time of fuse closure is, on a percentage basis, considerably affected by the upstream driving pressure and poppet setting. The response time sensitivity does not appear important because all the measured closure times are several orders of magnitude faster than required for most applications. Table E2 indicates the response (closure) time of the 2-inch fuse to upstream driving pressure using compressed air. Notice that as the driving pressure increases, the closure time decreases for a constant poppet setting. This is to be expected because the fuse is mass-flow sensitive and greater upstream pressure causes greater mass flow per unit time.

TABLE E2

EFFECT OF UPSTREAM PRESSURE ON CLOSURE SPEED OF 2-INCH FLOW FUSE

Response Time (msec)	Upstream Pressure (psig)	Poppet Setting (turns)
38	100	1-1/2
30	200	1-1/2
24	400	1-1/2
20	700	1-1/2
19	980	1-1/2

Tables E3 and E4 show the effect of poppet settings on closure speed at two different upstream pressures. It can be seen that while the values change for a different upstream pressure, the trends are similar (longer closure times for larger poppet settings).

The gas used for tests of the 2-inch fuse was compressed air. It must be remembered that the use of other gases having different densities will produce response times that are considerably different; response of other fuses to helium are discussed in Appendices B, C, and D.

POPPET SETTING EFFECTS

Figure E3 plots the values of gas flow at time of fuse closure versus the poppet setting for a simulated leak. The upstream driving pressure was low (100 psig) for these tests to determine the ability of the fuse to reliably actuate at low pressures. In addition, the lower

TABLE E3

EFFECT OF POPPET SETTING ON CLOSURE SPEED OF
2-INCH FLOW FUSE AT LOW PRESSURE

Response Time (msec)	Upstream Pressure (psig)	Poppet Setting (turns)
26	100	1/4
30	100	1/2
32	100	1
40	100	1-1/2
45	100	2
55	100	2-1/2
70	100	3
75	100	3-1/2
80	100	4
90	100	5
95	100	6

TABLE E4

EFFECT OF POPPET SETTING ON CLOSURE SPEED OF 2-INCH
FLOW FUSE AT HIGH PRESSURE

Response Time (msec)	Upstream Pressure (psig)	Poppet Setting (turns)
15	700	1/4
15	700	1/2
18	700	1
18	700	1-1/2
21	700	2
40	700	2-1/2
55	700	3
68	700	3-1/2

limits of closure actuating flow were ascertained. Appendix A contains a complete discussion of the test procedure used in collecting this data.

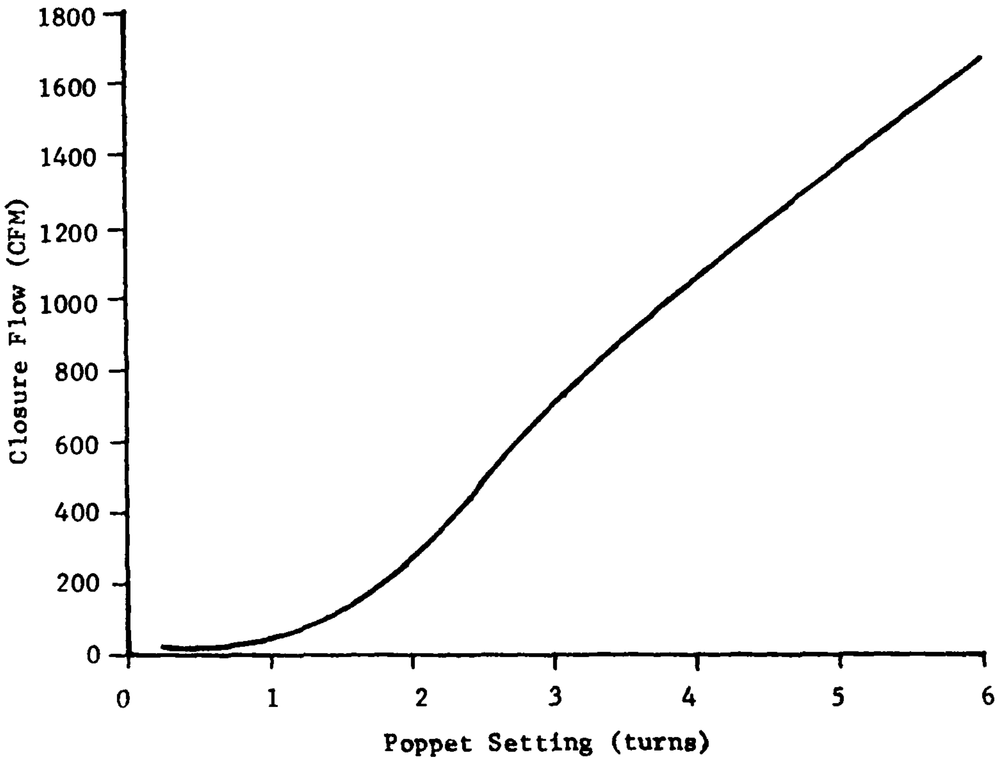

FIGURE E3. CLOSURE FLOW VERSUS POPPET SETTING FOR LOW UPSTREAM PRESSURE (100 PSIG) - 2-INCH FUSE

Figure E-4 plots the results for the same situation except at a higher upstream pressure. Both Figures E3 and E4 are for an increasing leak in the downstream piping.

PRESSURE DEPENDENCE

Figure E5 illustrates the effects on closure flow of different upstream driving pressures. These results are for an increasing leak using compressed air and a mid-range poppet setting (1-1/2 turns open).

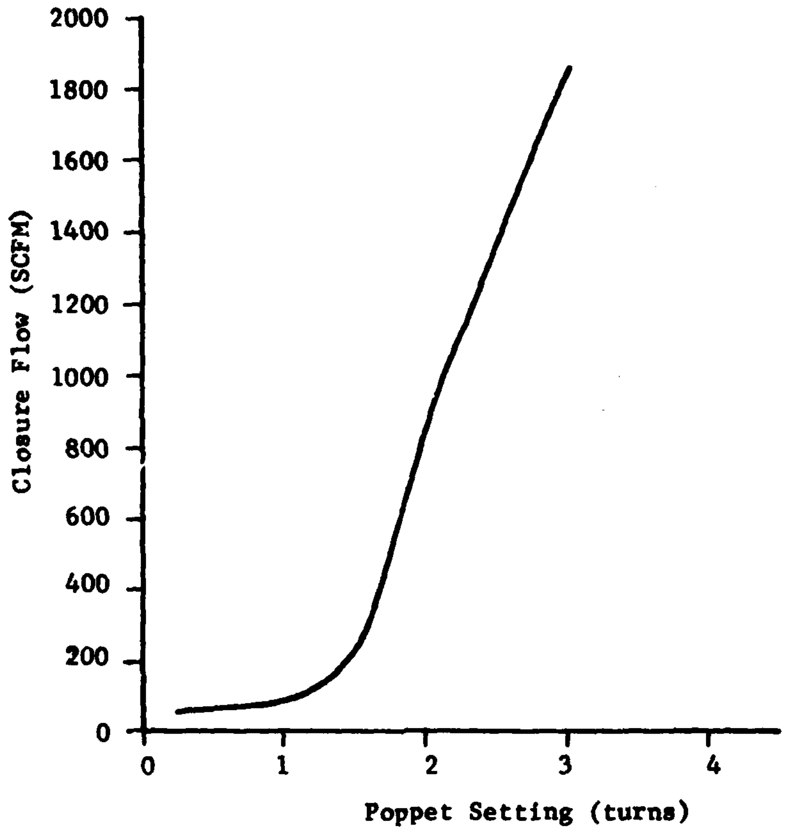

FIGURE E4. CLOSURE FLOW VERSUS POPPET SETTING FOR HIGHER UPSTREAM PRESSURE (700 PSIG) - 2-INCH FUSE

The solid curve corresponds to the closure flow results and while the relationship to a "best fit" linear curve is not illustrated, it can be shown that the deviations from linear are not large. The dotted curve corresponds to the differential pressure existing across the fuse at the instant of closure for the increasing leak case. The dotted curve demonstrates the constant value of fuse closure force (ΔP times area) that would be expected from the understanding of how a fuse functions.

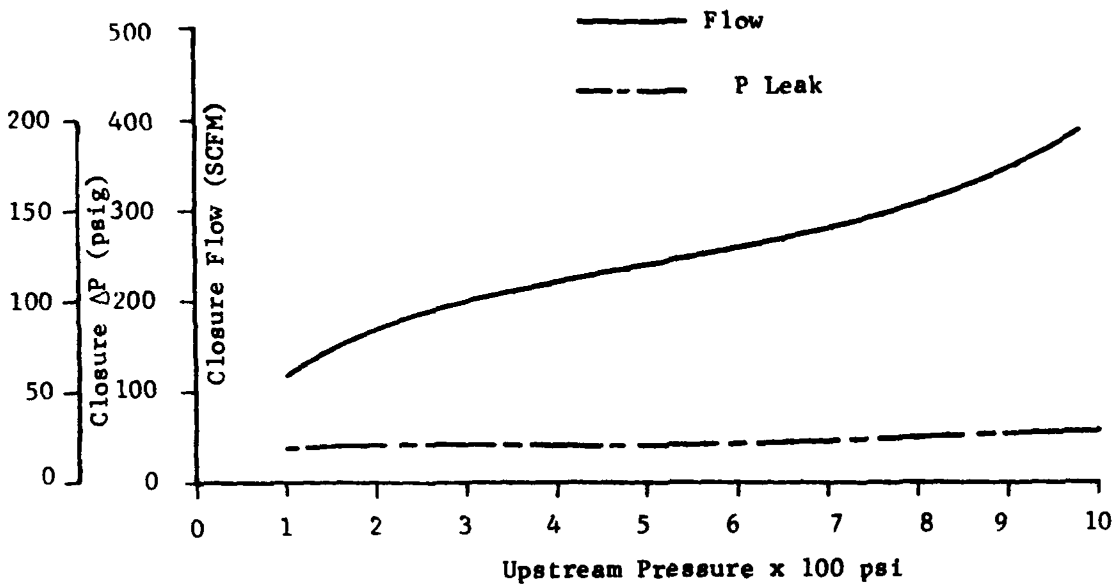

FIGURE E5. CLOSURE FLOW VERSUS UPSTREAM PRESSURE FOR FIXED POPPET SETTING (1-1/2 TURNS OPEN) - 2-INCH FUSE

EXTENSION OF SINGLE CYCLE RESULTS

From the data shown in Figures E3, E4, and E5, it was possible to synthesize a matrix which specifies approximate poppet settings as a function of desired closure flow (flow at which the fuse should actuate) and system working pressure. The method used to create the matrix and how to apply it is described in Appendix F. For convenience the set-point matrix for the 2-inch fuse is reproduced here as Table E5.

LIFE-CYCLE TESTS

These tests were designed to determine the ability of the fuse to operate within its performance envelope after repeated actuations and, to a limited extent, the operating life expectancy of the fuse. A description of the method used in collecting the life-cycle data is contained in Appendix A. The life-cycle tests were made immediately

(Text Continued on Page E-10)

TABLE E5

SET-POINT MATRIX - 2-INCH FUSE
(AIR OR NITROGEN SYSTEMS ONLY)

Turns Open	Pressure (psig) 100	200	300	400	500	600	700	800	900	1000
	Closure Flow (scfm)									
1/4	26	38	45	50	54	58	63	68	76	87
1/2	29	42	50	56	60	65	70	76	85	97
3/4	30	44	53	59	64	69	74	80	89	102
1	33	48	56	63	68	74	79	87	96	110
1-1/4	56	82	97	109	118	127	137	149	165	190
1-1/2	106	155	184	206	222	240	258	282	313	359
1-3/4	207	302	358	402	434	469	504	549	610	699
2	313	457	542	608	656	709	762	831	923	1058
2-1/4	422	617	733	821	886	958	1030	1123	1248	1429
2-1/2	535	782	928	1041	1123	1214	1305	1422	1581	1811
2-3/4	643	940	1116	1251	1350	1459	1569	1710	1901	2177
3	757	1106	1313	1472	1588	1717	1846	2012	2236	2561
3-1/4	802	1171	1395	1556	1684	1821	1957	2133	2374	2711
3-1/2	860	1256	1497	1669	1806	1953	2079	2288	2546	2908
3-3/4	929	1355	1615	1801	1950	2108	2265	2470	2748	3138
4	995	1453	1731	1930	2089	2259	2428	2647	2945	3363
4-1/4	1073	1567	1867	2082	2254	2436	2619	2855	3177	3627
4-1/2	1160	1693	2018	2250	2435	2633	2830	3085	3433	3920
4-3/4	1248	1822	2171	2421	2621	2833	3045	3320	3694	4218
5	1331	1943	2316	2582	2795	3022	3248	3541	3940	4499
5-1/4	1414	2065	2461	2744	2970	3210	3451	3762	4186	4780
5-1/2	1498	2186	2606	2905	3145	3399	3654	3983	4433	5062
5-3/4	1581	2308	2750	3067	3319	3588	3857	4205	4679	5343
6	1664	2429	2895	3228	3494	3777	4060	4426	4975	5624

following the single-cycle performance envelope tests. The poppet setting was 1-1/2 turns open and the upstream pressure was kept constant at 700 psig. Because the single-cycle tests require a few hundred cycles (300 - 400), the fuse was well "broken in" prior to commencement of the life-cycle tests. By scheduling the tests in this order, effects or trends due to "wear in" should have been avoided.

The life-cycle tests involved 2000 total actuations (cycles) and began with base-line data being collected on the fuse. The fuse was next subjected to 500 nonstop cycles and then rechecked for operation. This procedure continued until 2000 cycles were completed. The results are shown in Table E6. Notice the consistency of closure speed (time column) and closure flow over the 2000 actuations. No trends toward degraded operation are detectable and it seems most reasonable to ass e that the "cycles to failure" capability of this fuse is considerably greater than 2000.

TABLE E6

LIFE-CYCLE TEST RESULTS - 2-INCH FUSE

Cycles Completed	Rupture: Closure ΔP	Rupture: Time (msec)	Increasing Leak: Closure ΔP	Increasing Leak: Closure Flow
0	80 psig	20	20 psig	1.0" (274 scfm)
500	90 psig	20	20 psig	0.75" (208 scfm)
1000	120 psig	20	25 psig	1.03" (286 scfm)
1500	90 psig	20	25 psig	1.05" (292 scfm)
2000	110 psig	20	25 psig	1.10" (305 scfm)

GAS DENSITY TESTS

Because of the large flow rates involved and the lack of an adequate supply of helium (both flow and volume), no attempt was made to compare the performance results using the lighter gas.

VISUAL INSPECTION

Upon completion of all compressed air testing, the 2-inch fuse was completely disassembled (an easy task) and visually inspected for signs of wear using a magnifying glass. No signs of scuffing, scoring, or nicking were evident. Except for a light coating of rust dust on the internal surfaces, the fuse looked as though it had hardly been used even though more than 2500 cycles had been completed. The rust colored powder was easily removed from the surfaces thus returning the fuse to like-new appearance. The source of the rust dust was probably the uncleaned steel piping of the test setup.

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APPENDIX F

SYNTHESIS OF SET POINT MATRICES

PURPOSE OF SYNTHESIS

During the analysis of the collected data, it was clear that sufficient information had been gathered to determine the performance characteristics of each fuse to external stimuli. While these data yielded the fuse response to specific conditions of pressure and poppet setting, they did not plainly indicate the reverse; i.e., what settings were needed to give desired response for any pressure within the test range. From an inspection of the data, it was believed that a data synthesis could be performed to create a matrix giving approximate poppet settings as a result of specifying line pressure and trip point flow. This appendix describes the assumptions and methods used to derive the desired set point matrices.

It should be carefully noted that the poppet settings derived in this appendix are approximate only and that actual in-use settings will vary some between different fuses. Though not substantiated by tests, it is believed that the differences in response between fuses of the same model are not significant when compared to the primary purpose of the fuse: cut-off of excessive flow.

The matrices should be used then as a guide in selecting the proper size Flow Fuse and in determining the approximate setting that will be required for flow cut-off.

ASSUMPTIONS

Two assumptions were used to develop the matrices: (1) the shape of the flow versus poppet setting curves is not significantly altered over a wide range of pressures; and (2) the shape of the flow versus pressure curves is not significantly altered over a wide range of poppet settings (turns open).

If the first assumption is reasonably true, then the closure flow versus poppet setting curve for any pressure can be obtained by multiplying a unitized (normalized) curve by an appropriate scale factor. To test the validity of this assumption, the data for closure flow versus poppet setting (turns open) for 100 psig and 700 psig were normalized and graphed for each fuse (Figure F1). While the normalized

(Text Continued on Page F-3)

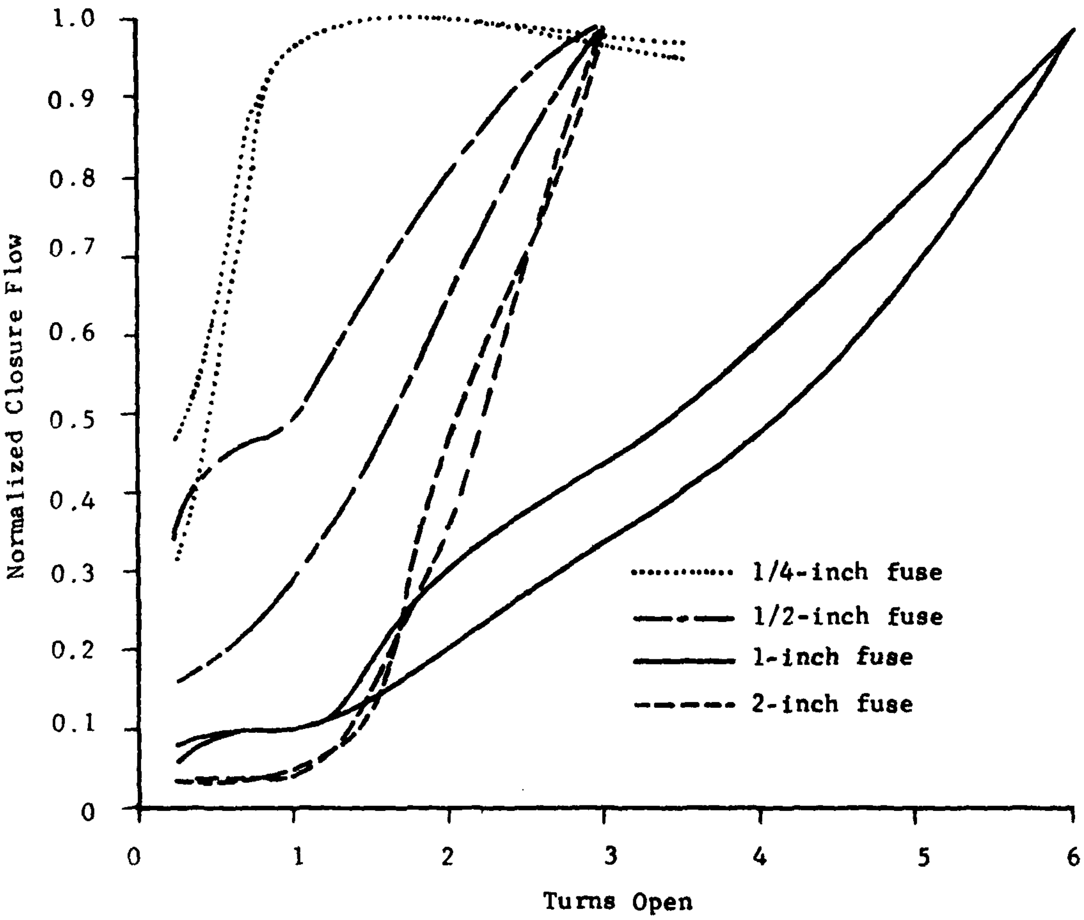

FIGURE F1. COMPARISON OF NORMALIZED DATA FOR FOUR FLOW FUSES data do not plot on top of each other, there is very good agreement for the 1/4-inch and 2-inch fuses, and reasonable agreement for the 1/2-inch fuse. The large difference shown for the 1/2-inch fuse is likely due to measurement error in the points chosen for normalization. It was determined by trial that a 10 percent or less change in the value used to normalize each of the curves for the 1/2-inch fuse was sufficient to eliminate the separation, provided the change was applied in the proper direction. It is believed, however, that there is sufficient agreement in Figure F1 to support assumption one.

An average of each "set" of curves in Figure F1 is shown in Figure F2 and are the "characteristic" curves used in calculating the matrix entries. Notice that the curve for the 2-inch fuse has been normalized to 6 turns instead of the previous 3 turns. This extended curve is not an averaged curve beyond the 3 turns point because data at the larger settings for such a large fuse could be measured only at the 100-psig test value. It is, of course, desirable to use this extended curve so that all the collected data could be used in developing the 2-inch fuse set-point matrix.

Calculation of the scale factors to apply to the "characteristic" curves at each pressure required the use of the second assumption. Collected data on closure flow versus driving pressure was normalized for each fuse and is shown in Figure F3. Based upon the fairly well demonstrated result that pressure did not change the shape of the flow versus poppet setting curves (Figure F1), it was assumed (assumption two) that poppet setting did not change the shape of the flow versus pressure curves. The validity of the second assumption is supported by the curves of Figure F3 where the normalized curves plot very close over much of the 100 psig to 1000 psig test range for three different poppet settings and three different fuse sizes. The fourth curve (1-inch fuse) has a similar shape but appears offset. As before, the most probable reason for this exception is measurement error in the data points used for normalization.

The scale factors were measured from the curves of Figure F3 using the following procedure. The known, but normalized, data point of 100 psig was assumed equal to unity and multipliers were calculated, based on curve measurements, to produce the remaining curve values at increments of 100 psig. This resulted in a table of intermediate multipliers. The same procedure was again used with the normalized 700 psig point as the unity value. This resulted in a second table of intermediate multipliers. The next step involved multiplying the measured closure flow data for 100 psig (the same values used to normalize the curves of Figure F1) by appropriate entries of the first table of intermediate multipliers to produce an intermediate table of scale factors based on 100 psig data (Table F1). The same procedure was applied to the 700 psig data to produce a second intermediate table of scale factors based on 700 psig data (Table F2).

(Text Continued on Page F-6)

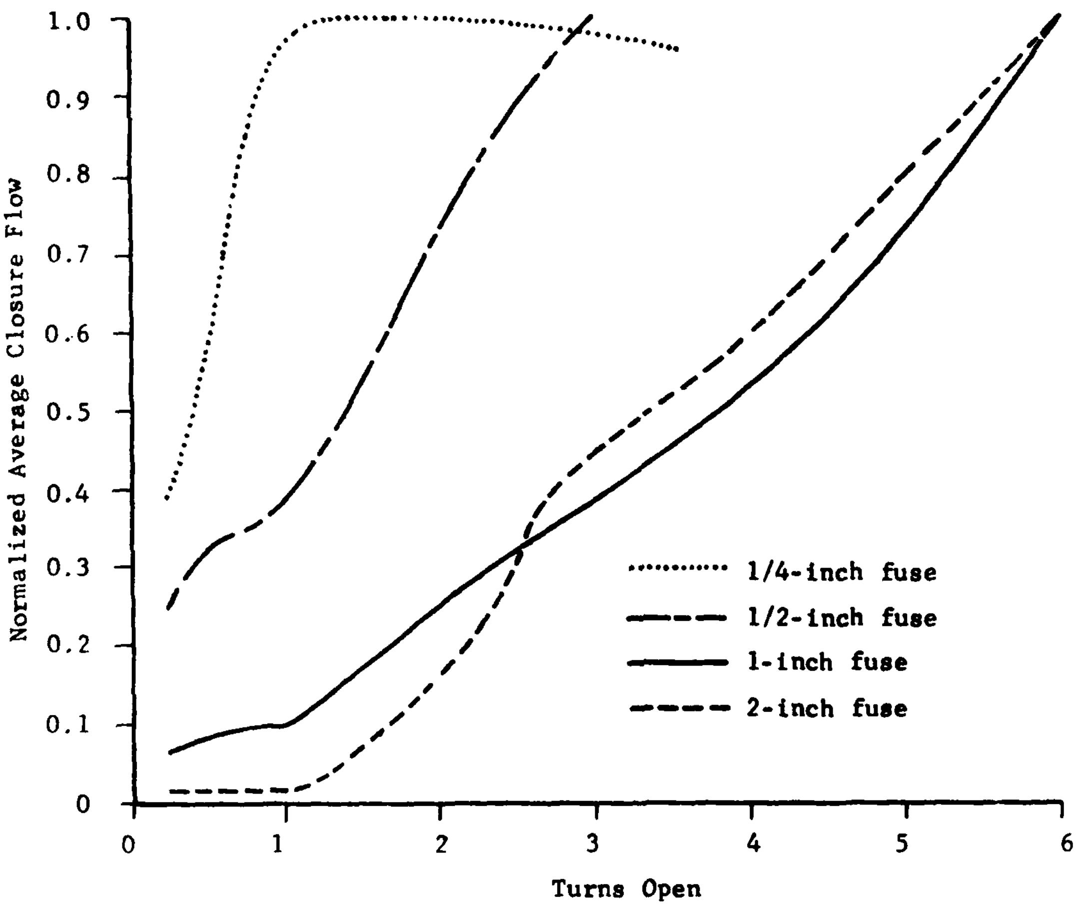

FIGURE F2. NORMALIZED DATA AVERAGE FOR FOUR FLOW FUSES

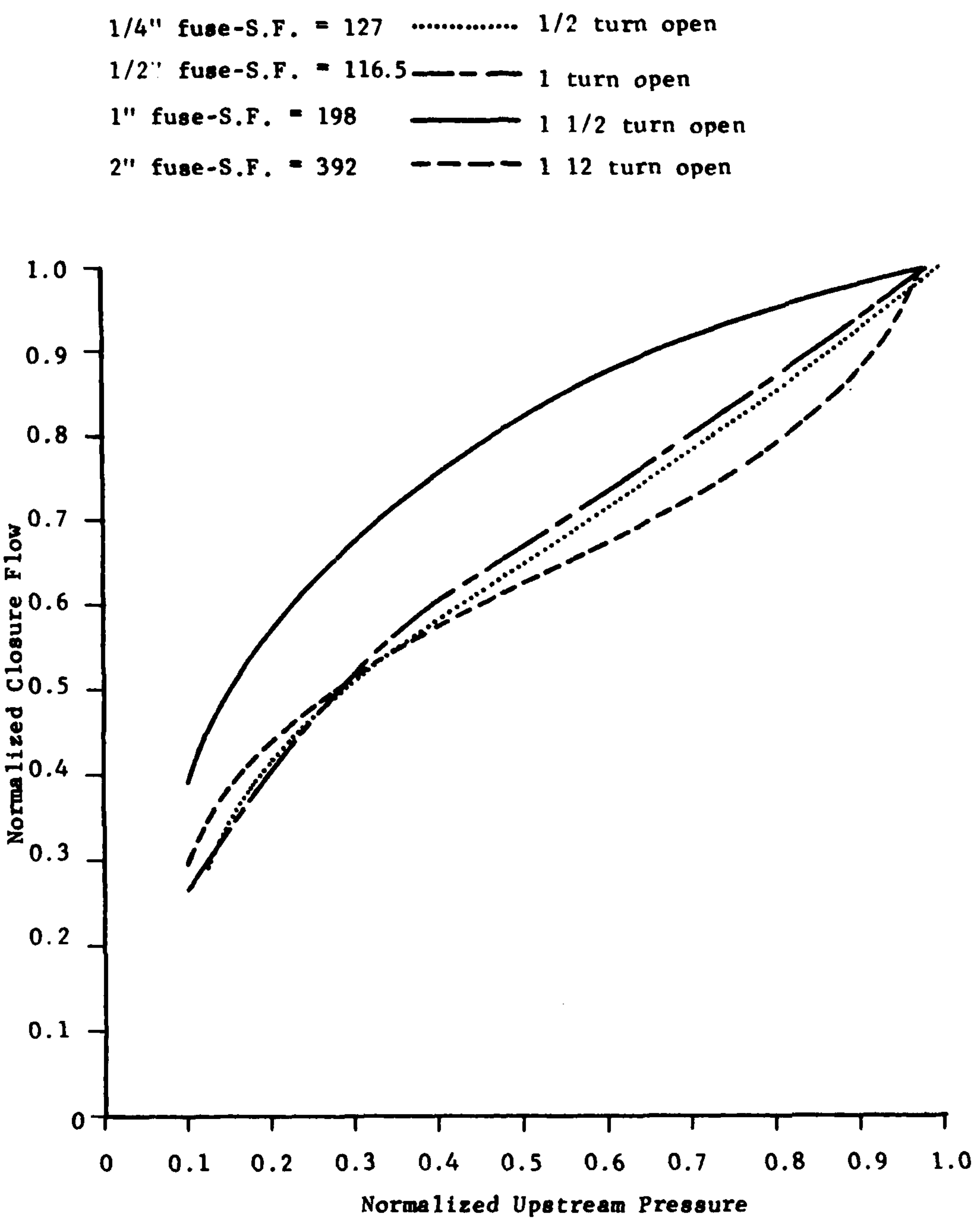

FIGURE F3. COMPARISON OF NORMALIZED PRESSURE DATA FOR FOUR FLOW FUSES

TABLE F1

INTERMEDIATE SCALE FACTORS BASED ON 100-PSIG DATA

Fuse	Upstream Pressure (psig) 100	200	300	400	500	600	700	800	900	1000
	Calculated Closure Flow Based on 100 psig									
1/4"	70	97	120	136	151	166	180	197	214	233
1/2"	110	166	213	249	277	303	332	359	387	415
1"	611	886	1057	1191	1283	1363	1424	1491	1534	1564
2" (to 3 turns)	748	1092	1301	1451	1571	1698	1825	1990	2214	2528
2" (to 6 turns)	1664	2429	2895	3228	3494	3777	4060	4426	4925	5624

TABLE F2

INTERMEDIATE SCALE FACTORS BASED ON 700-PSIG DATA

Fuse	Upstream Pressure (psig) 100	200	300	400	500	600	700	800	900	1000
	Calculated Closure Flow Based on 700 psig									
1/4"	58	80	100	112	125	137	149	162	177	194
1/2"	56	85	108	127	140	154	169	183	198	211
1"	633	913	1090	1237	1326	1414	1473	1547	1591	1620
2" (to 3 turns)	765	1120	1325	1493	1605	1735	1866	2034	2258	2594

It can be seen that the respective entries in Tables F1 and F2 are similar but not identical because the measured values used in producing Figure F1 are not the same. In an attempt to reduce the difference in the most likely direction, the respective entries of Tables F1 and F2 were averaged and the results appear as Table F3. Each curve of

TABLE F3

AVERAGE SCALE FACTORS

Fuse	100	200	300	400	500	600	700	800	900	1000
	Pressure (psig)									
	Calculated Average Flow (scfm)									
1/4"	64	89	110	124	138	152	165	180	196	214
1/2"	83	126	161	188	209	229	251	271	293	313
1"	622	900	1074	1214	1305	1389	1449	1519	1563	1592
2" (to 3 turns)	757	1106	1313	1472	1588	1717	1846	2012	2236	2561
2" (to 6 turns	1664	2429	2895	3228	3494	3777	4060	4426	4925	5624

Figure F1 when muptiplied by any one of the 10 appropriate entries of Table F3 yields a characteristic curve which relates closure flow to poppet setting at a pressure which corresponds to the scale factor multiplier (Table F3). All 10 possible curves for each fuse form a family of characteristic curves relating closure flow, poppet settings, and system operating pressure. The family of curves for each fuse is presented in matrix form in Tables F4 to F7 inclusive for easier readibility.

MATRIX USE

To use the matrices, it is necessary to know the working pressure of the line to be protected and the desired trip point (closure) flow in scfm. The desired closure flow must be expressed in scfm while actual flow within the pressurized piping system will usually be expressed in actual cubic feet per minute (acfm). Actual flow measurements can be converted to standard flow values using the following formula:

$$\text{scfm} = \frac{\text{acfm} \times \text{system pressure (psia)}}{14.7}$$

Note that system pressure is expressed in absolute and not gauge. Using the line size (fuse size), the appropriate matrix can be selected and

TABLE F4

CLOSURE FLOW (SCFM) VERSUS PRESSURE AND POPPET SETTING FOR 1/4-INCH FLOW FUSE

Turns Open	Pressure (psig) 100	200	300	400	500	600	700	800	900	1000
	Closure Flow (scfm)									
1/4	25	35	43	48	54	59	64	70	76	83
1/2	37	52	64	72	80	88	96	104	114	124
3/4	54	76	94	105	117	129	140	153	167	182
1	62	86	107	120	134	147	160	175	190	208

TABLE F5

CLOSURE FLOW (SCFM) VERSUS PRESSURE AND POPPET SETTING FOR 1/2-INCH FLOW FUSE

Turns Open	Pressure (psig) 100	200	300	400	500	600	700	800	900	1000
	Closure Flow (scfm)									
1/4	21	31	40	47	52	57	62	67	73	78
1/2	27	40	52	60	67	73	80	87	94	100
3/4	29	43	55	64	72	79	86	93	100	107
1	32	49	62	72	80	88	97	104	113	121
1-1/4	37	57	72	85	94	103	113	122	132	141
1-1/2	45	68	87	102	113	124	136	146	158	169
1-3/4	53	80	103	120	133	146	160	173	187	199
2	61	92	118	138	153	168	184	199	215	229
2-1/4	67	102	130	152	169	185	203	220	237	254
2-1/2	73	111	141	165	184	201	220	238	257	275
2-3/4	78	118	151	177	196	215	236	255	275	294
3	83	126	161	188	209	229	251	271	293	313

TABLE F6

CLOSURE FLOW (SCFM) VERSUS PRESSURE AND POPPET SETTING
FOR 1-INCH FLOW FUSE

	Pressure (psig)									
	100	200	300	400	500	600	700	800	900	1000
Turns Open	Closure Flow (scfm)									
1/4	42	61	73	83	89	94	99	103	106	108
1/2	53	77	92	104	112	119	125	131	134	137
3/4	60	87	104	118	127	135	141	147	152	154
1	62	90	107	121	131	139	145	152	156	159
1-1/4	82	119	142	160	172	183	191	201	206	210
1-1/2	107	155	185	209	224	239	249	261	269	274
1-3/4	132	191	228	257	277	294	307	322	331	338
2	152	221	263	297	320	340	355	372	383	390
2-1/4	179	259	309	350	376	400	417	437	450	458
2-1/2	200	290	346	391	420	447	467	489	503	513
2-3/4	221	320	381	431	463	493	514	539	555	565
3	243	351	419	473	509	542	565	592	610	621
3-1/4	264	382	455	515	553	589	614	644	663	675
3-1/2	285	412	492	556	598	636	664	696	716	729
3-3/4	308	446	532	601	646	688	717	752	774	788
4	331	479	571	646	694	739	771	808	832	847
4-1/4	361	522	623	704	757	806	840	881	907	923
4-1/2	389	563	672	760	817	870	907	951	978	997
4-3/4	423	612	730	826	887	945	985	1033	1063	1083
5	458	663	792	895	962	1024	1068	1120	1152	1173
5-1/4	498	720	859	971	1044	1111	1159	1215	1250	1274
5-1/2	537	778	928	1049	1128	1200	1252	1312	1350	1375
5-3/4	580	839	1001	1131	1216	1295	1350	1416	1457	1484
6	622	900	1074	1214	1305	1389	1449	1519	1563	1592

TABLE F7

CLOSURE FLOW (SCFM) VERSUS PRESSURE AND POPPET SETTING
FOR 2-INCH FLOW FUSE

	Pressure (psig)									
	100	200	300	400	500	600	700	800	900	1000
Turns Open	Closure Flow (scfm)									
1/4	26	38	45	50	54	58	63	68	76	87
1/2	29	42	50	56	60	65	70	76	85	97
3/4	30	44	53	59	64	69	74	80	89	102
1	33	48	56	63	68	74	79	87	96	110
1-1/4	56	82	97	109	118	127	137	149	165	190
1-1/2	106	155	184	206	222	240	258	282	313	359
1-3/4	207	302	358	402	434	469	504	549	610	699
2	313	457	542	608	656	709	762	831	923	1058
2-1/4	422	617	733	821	886	958	1030	1123	1248	1429
2-1/2	535	782	928	1041	1123	1214	1305	1422	1581	1811
2-3/4	643	940	1116	1251	1350	1459	1569	1710	1901	2177
3	757	1106	1313	1472	1588	1717	1846	2012	2236	2561
3-1/4	802	1171	1395	1556	1684	1821	1957	2133	2374	2711
3-1/2	860	1256	1497	1669	1806	1953	2079	2288	2546	2908
3-3/4	929	1355	1615	1801	1950	2108	2265	2470	2748	3138
4	995	1453	1731	1930	2089	2259	2428	2647	2945	3363
4-1/4	1073	1567	1867	2082	2254	2436	2619	2855	3177	3627
4-1/2	1160	1693	2018	2250	2435	2633	2830	3085	3433	3920
4-3/4	1248	1822	2171	2421	2621	2833	3045	3320	3694	4218
5	1331	1943	2316	2582	2795	3022	3248	3541	3940	4499
5-1/4	1414	2065	2461	2744	2970	3210	3451	3762	4186	4780
5-1/2	1498	2186	2606	2905	3145	3399	3654	3983	4433	5062
5-3/4	1581	2308	2750	3067	3319	3588	3857	4205	4679	5343
6	1664	2429	2895	3228	3494	3777	4060	4426	4975	5624

the value of closure flow (in scfm) nearest the desired trip point setting found under the column for the line working pressure (to nearest 100 psig). Moving from that value to the left find the approximate poppet setting to achieve the desired trip point.

An example will help to clarify the procedure. Assume that a 1-inch pipe operating at 300 psig and having a normal maximum actual flow of 30 acfm is to be protected. Since flow is not in scfm, a conversion is necessary:

$$\text{scfm} = \frac{30 \times 314.7}{14.7} = 642 \ .$$

Selecting the matrix for the 1-inch fuse (because a 1-inch pipe is to be protected) and starting at the 300 psig column, proceed down the column until the value 642 scfm is found. On Table F6, 642 scfm lies between 623 and 672. Moving to the left, the bracketing table entries correspond to poppet settings of 4-1/4 and 4-1/2 turns open. To ensure that maximum normal flow does not trip the fuse, the higher setting of 4-1/2 turns would be selected and set into the fuse.

The matrices were calculated only for pressure increments of 100 psig and poppet setting increments of 1/4 turn. Interpolation is acceptable but values for smaller increments probably are not needed because poppet adjustment accuracy is not any better than $\pm$ 1/8 turn.

These matrices are valid only for nitrogen or air as the system medium. If other gases or gas mixtures are used, appropriate conversions, beyond the scope of this report, must be applied.