

870 FILE COPY

4

CONTRACTOR REPORT BRL-CR-610

BRL

AD-A207 947

CONCEPTUAL VALVE DESIGN
FOR THE DRIVER TUBE
OF THE LARGE-BLAST, THERMAL SIMULATOR

T. R. REED
EG&G IDAHO, INC. (INEL)

MAY 1989

DTIC
ELECTE
MAY 22 1989
S E D

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

89 5 22 055

DESTRUCTION NOTICE

Destroy this report when it is no longer needed. DO NOT return it to the originator.

Additional copies of this report may be obtained from the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161.

The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The use of trade names or manufacturers' names in this report does not constitute indorsement of any commercial product.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

ADA207947

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

| | | | |
|---|---|---|---|
| 1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED | | 1b. RESTRICTIVE MARKINGS NONE | |
| 2a. SECURITY CLASSIFICATION AUTHORITY N/A | | 3. DISTRIBUTION / AVAILABILITY OF REPORT APPROVED FOR PUBLIC RELEASE DISTRIBUTION UNLIMITED | |
| 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE N/A | | | |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S) BRL-CR-610 | | 5. MONITORING ORGANIZATION REPORT NUMBER(S) | |
| 6a. NAME OF PERFORMING ORGANIZATION IDAHO NATIONAL ENGINEERING LAB (EG&G IDAHO INC.) | | 6b. OFFICE SYMBOL (if applicable) | 7a. NAME OF MONITORING ORGANIZATION U.S. ARMY BALLISTIC RESEARCH LABORATORY |
| 6c. ADDRESS (City, State, and ZIP Code) IDAHO FALLS, IDAHO 83415 | | 7b. ADDRESS (City, State, and ZIP Code) ABERDEEN PROVING GROUND, MD 21005-5066 | |
| 8a. NAME OF FUNDING / SPONSORING ORGANIZATION U.S. Army BRL | 8b. OFFICE SYMBOL (if applicable) SLC BR-TB-B | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER BRL-P0-75-87 | |
| 8c. ADDRESS (City, State, and ZIP Code) ABERDEEN PROVING GROUND, MD 21005-5066 | | 10. SOURCE OF FUNDING NUMBERS | |
| | | PROGRAM ELEMENT NO. 62120 | PROJECT NO. AH25 |
| | | TASK NO. | WORK UNIT ACCESSION NO. |
| 11. TITLE (Include Security Classification) CONCEPTUAL VALVE DESIGN FOR THE DRIVER TUBE OF THE LARGE BLAST/THERMAL SIMULATOR | | | |
| 12. PERSONAL AUTHOR(S) T. R. REED | | | |
| 13a. TYPE OF REPORT Final | 13b. TIME COVERED FROM 9/87 TO 4/88 | 14. DATE OF REPORT (Year, Month, Day) 28 March 1989 | 15. PAGE COUNT 29 |
| 16. SUPPLEMENTARY NOTATION | | | |
| 17. COSATI CODES | | 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) | |
| FIELD | GROUP | SUB-GROUP | |
| 20 | 04 | | Rapid Opening/Closing Valves, Blast Wave Simulation Fast Acting Valves, Valve Closing Time Variable Area Shock Tubes, Large Blast/Thermal Simulator |
| 19. ABSTRACT (Continue on reverse if necessary and identify by block number) The results of a conceptual design study of fast acting throat valves for metering the flow out of the driver tubes of the proposed U.S. LB/TS are reported. The short response times specified make it necessary to adopt a multi-element valve design for development of this wave shaping technique. (JES) | | | |
| 20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS | | 21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED | |
| 22a. NAME OF RESPONSIBLE INDIVIDUAL Mr. Klaus O. OPALKA | | 22b. TELEPHONE (Include Area Code) (301) 278-6036 | 22c. OFFICE SYMBOL SLC BR-TB-B |

TABLE OF CONTENTS

| | Page |
|------------------------------------|------|
| LIST OF ILLUSTRATIONS | v |
| INTRODUCTION | 1 |
| VALVE REQUIREMENTS | 8 |
| MAJOR DESIGN DIFFICULTIES | 10 |
| VALVE DESCRIPTION | 13 |
| Single Element Design | 13 |
| Double Sliding Sleeve Design | 13 |
| Multi-Element Design | 14 |
| DESIGN EVALUATION | 14 |
| Single Element Design | 14 |
| Multi-Element Design | 16 |
| CONCLUSION | 17 |
| DISTRIBUTION LIST | 19 |

| | |
|---------------------|-------------------------------------|
| Accession For | |
| NTIS Service | <input checked="" type="checkbox"/> |
| DTIC TAB | <input type="checkbox"/> |
| Unannounced | <input type="checkbox"/> |
| Justification | |
| By _____ | |
| Distribution/ _____ | |
| Availability Codes | |
| Dist | Avail and/or Special |
| A-1 | |

QUALITY
INSPECTED
2

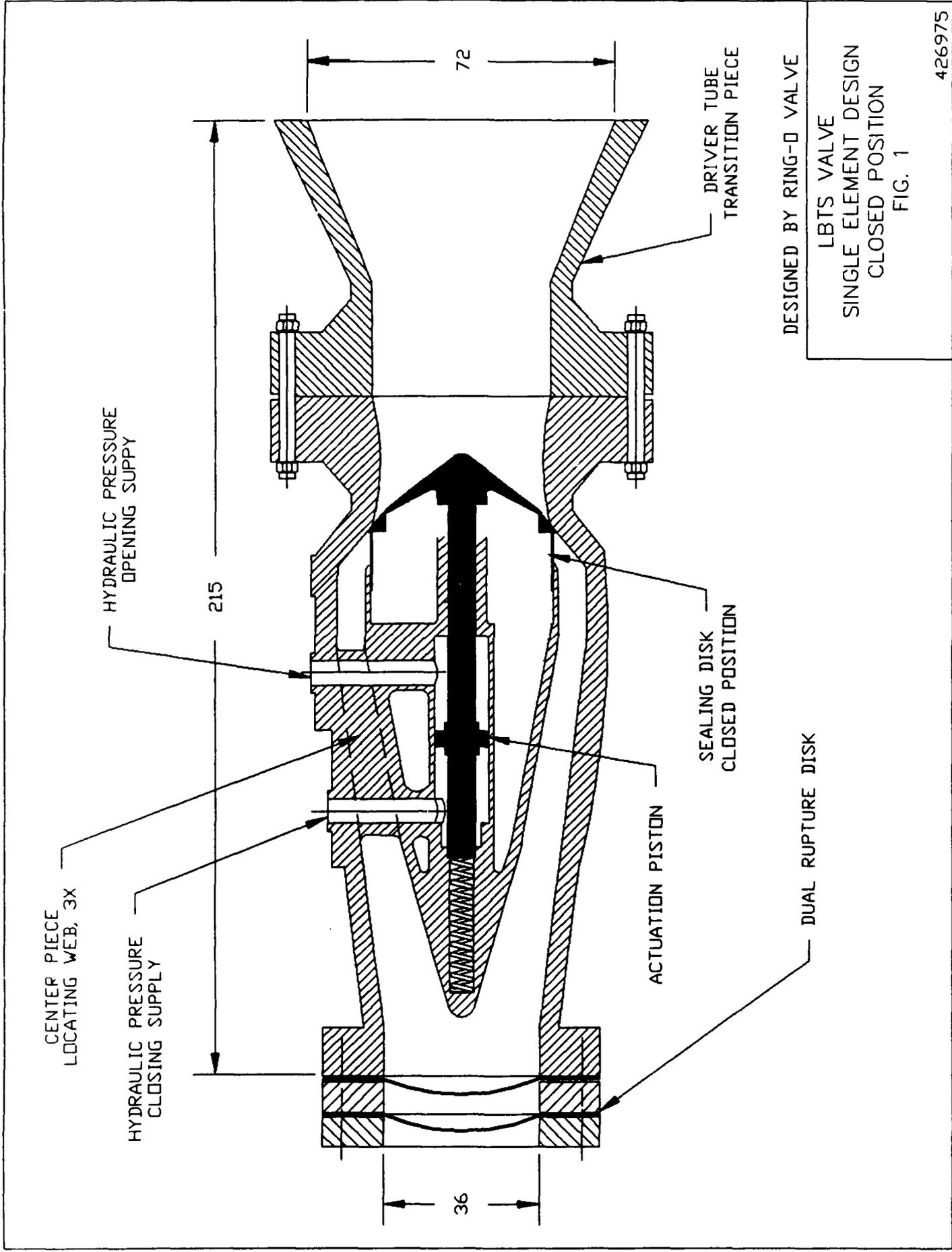
LIST OF ILLUSTRATIONS

| | Page |
|--|------|
| Figure 1. Single Element Design - Closed Position | 2 |
| Figure 2. Single Element Design - Open Position | 3 |
| Figure 3. Double Sliding Sleeve Design - Start Position | 4 |
| Figure 4. Double Sliding Sleeve Design - Intermediate Position | 5 |
| Figure 5. Multi-Element Design - Overall Arrangement | 6 |
| Figure 6. Multi-Element Design - Element Details | 7 |
| Figure 7. Valve Opening/Closing Schedule | 9 |
| Figure 8. Position Dependent Hydraulic Dampers | 12 |

INTRODUCTION

A key component required in the development of the Large Blast Thermal Simulator is the high speed driver tube valves. Although successful blast simulation facilities have been built without using driver tube valves, the simulation envelope, simulation accuracy, test turn around, and per test costs can be considerably improved by incorporating valves in the facility design. EG&G Idaho Mechanical Engineering has completed investigation and evaluation of different valve designs which could be used in this application. It is planned to develop a half scale model based on the preferred design which will be tested and evaluated by the Ballistics Research Laboratory, Aberdeen Maryland.

Although highly desirable, no existing valves could be found which would meet the operating requirements necessary for blast simulation, thus such a valve design needs to be developed. The initial phase of this development was the procurement of four separate conceptual designs from valve specialty companies. A fifth design concept was pursued independently by EG&G Idaho to be used as a comparative design. From these efforts, three basic designs emerged, 1) single element, 2) double sliding sleeve and 3) multi-element. Two of the vendor concepts were of the multi-element type, one chose the double sliding sleeve concept, while the remaining vendor developed a single element design. EG&G's baseline design was a double sliding sleeve type. Figures 1 through 6 of this report illustrate each of these designs. In the case where there are two similar designs, only one is shown.



DESIGNED BY RING-D VALVE
 LBTS VALVE
 SINGLE ELEMENT DESIGN
 CLOSED POSITION
 FIG. 1

426975

CENTER PIECE
LOCATING WEB, 3X

HYDRAULIC PRESSURE
CLOSING SUPPLY

HYDRAULIC PRESSURE
OPENING SUPPLY

215

72

FLOW

SEALING DISK
OPEN POSITION

ACTUATION PISTON

DRIVER TUBE
TRANSITION PIECE

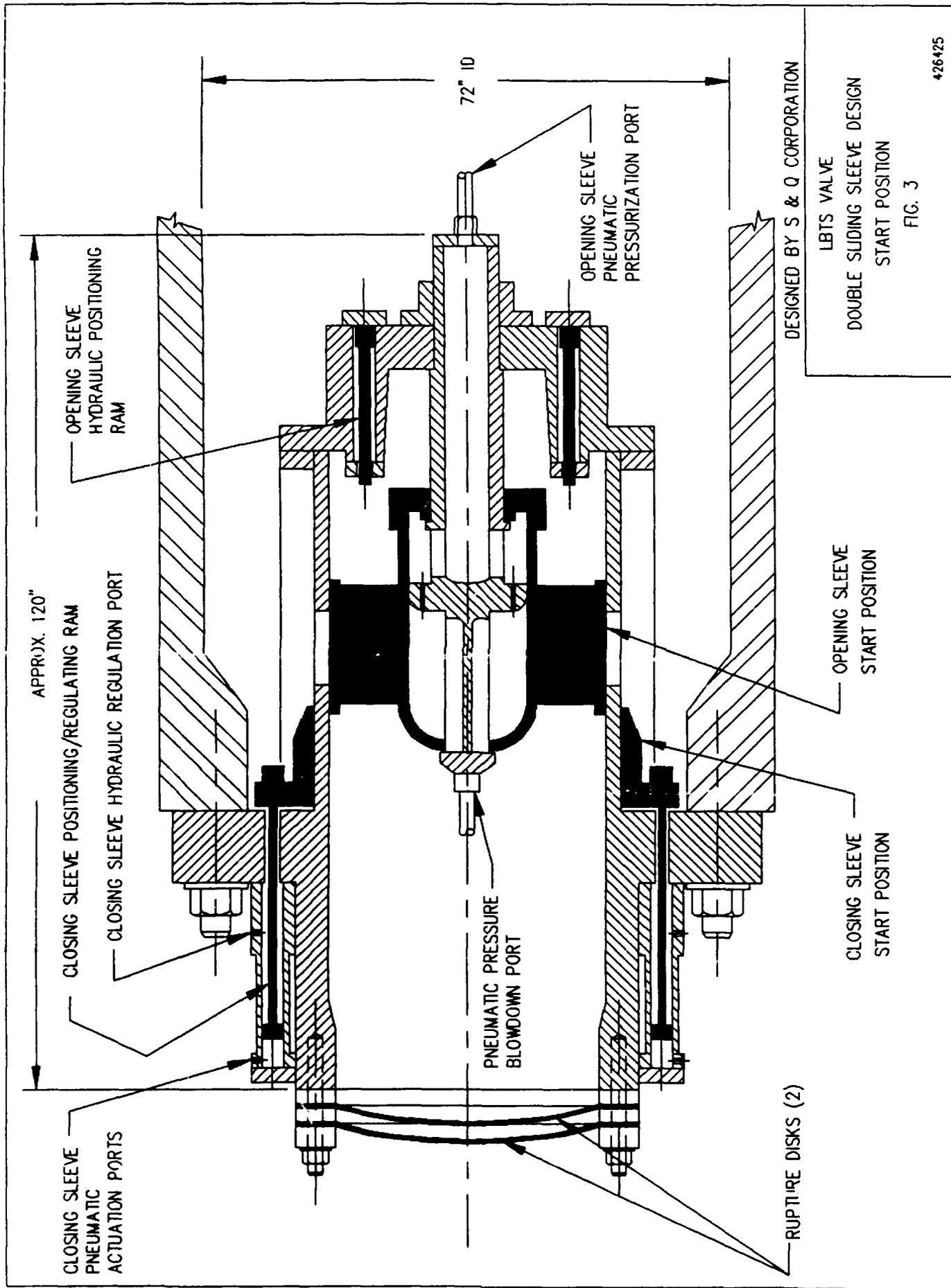
36

DESIGNED BY RING-O VALVE

LBTS VALVE
SINGLE ELEMENT DESIGN
OPEN POSITION

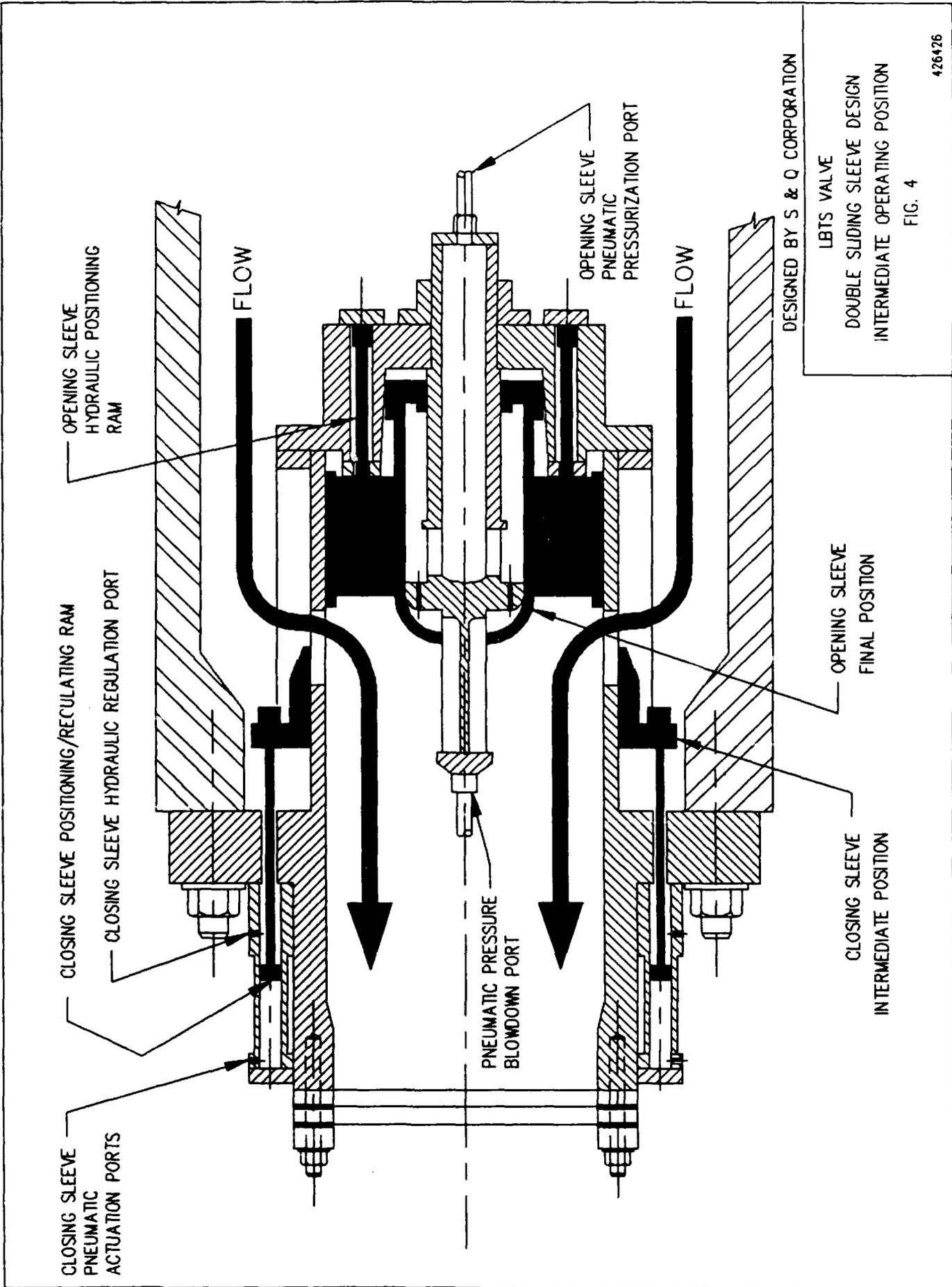
FIG. 2

426424



DESIGNED BY S & Q CORPORATION
 LBTS VALVE
 DOUBLE SLIDING SLEEVE DESIGN
 START POSITION
 FIG. 3

426425



CLOSING SLEEVE
PNEUMATIC
ACTUATION PORTS

CLOSING SLEEVE POSITIONING/REGULATING RAM

CLOSING SLEEVE HYDRAULIC REGULATION PORT

OPENING SLEEVE
HYDRAULIC POSITIONING
RAM

FLOW

PNEUMATIC PRESSURE
BLOWDOWN PORT

OPENING SLEEVE
PNEUMATIC
PRESSURIZATION PORT

FLOW

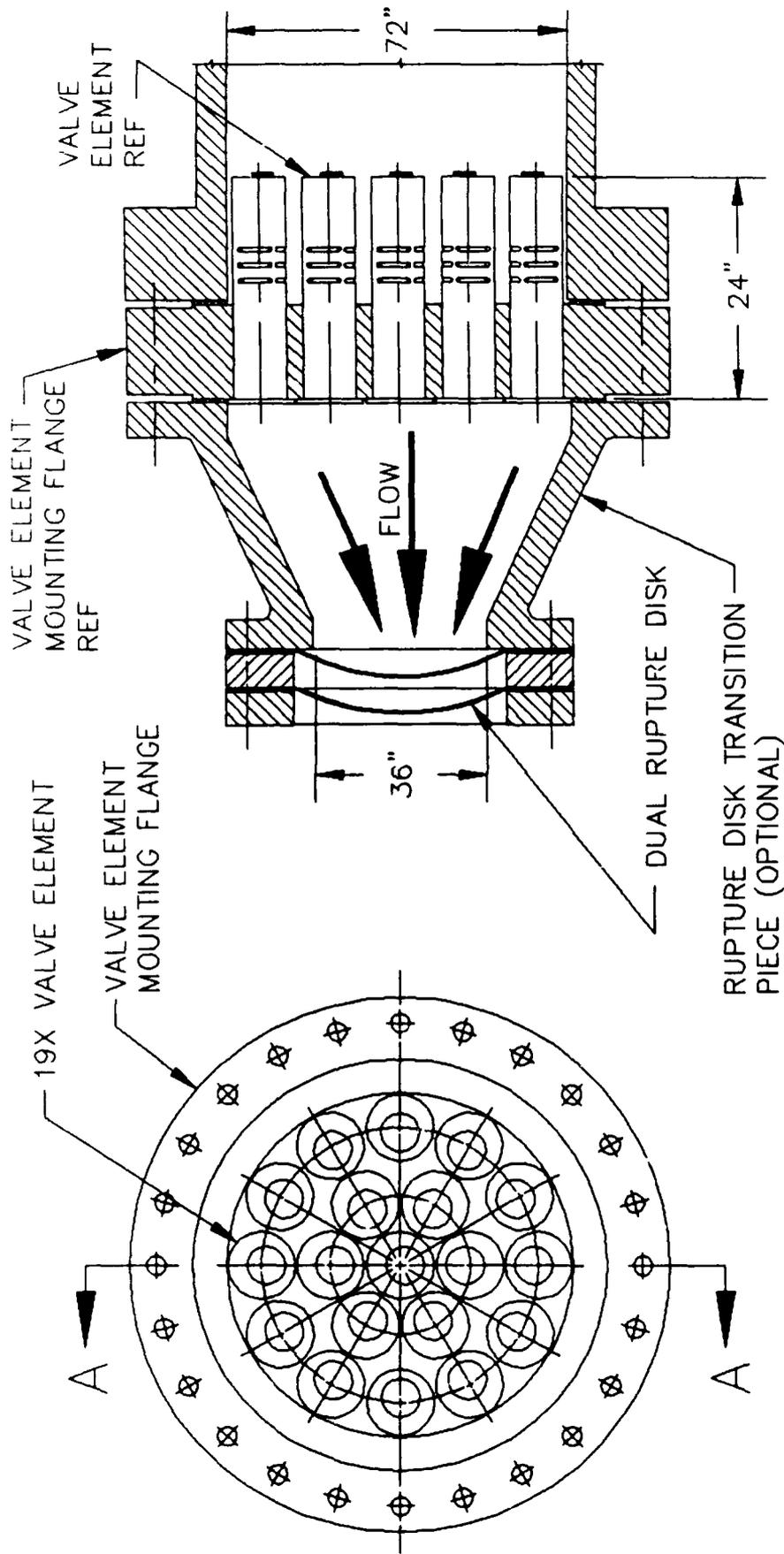
CLOSING SLEEVE
INTERMEDIATE POSITION

OPENING SLEEVE
FINAL POSITION

DESIGNED BY S & Q CORPORATION

LBTS VALVE
DOUBLE SLIDING SLEEVE DESIGN
INTERMEDIATE OPERATING POSITION

FIG. 4



SECTION A-A

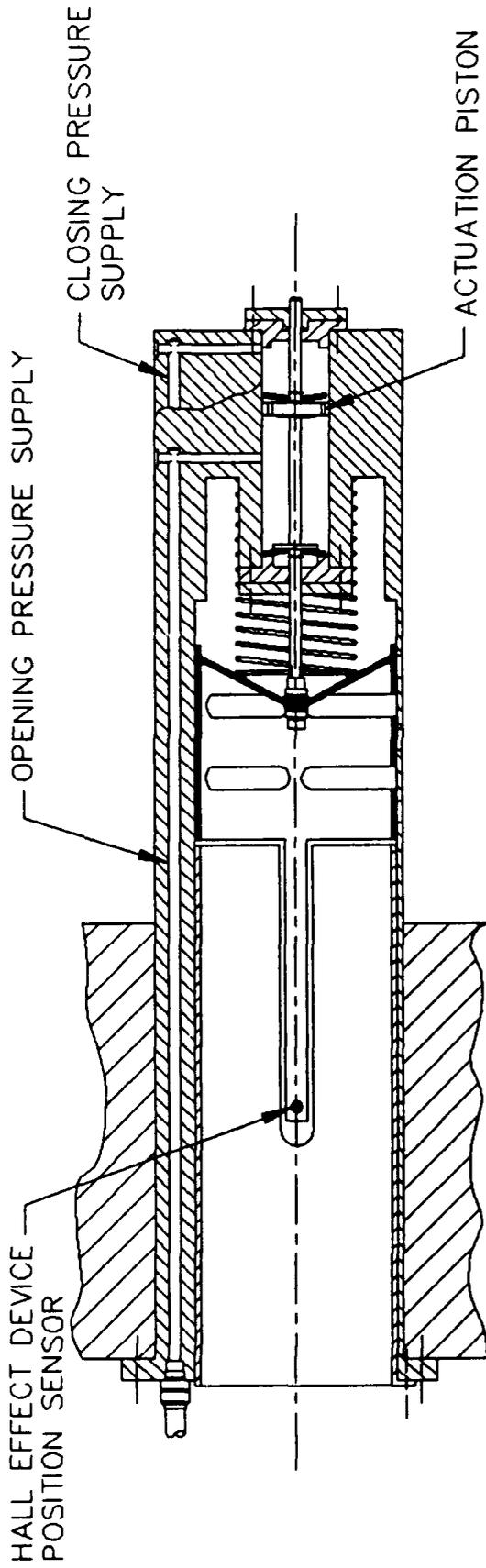
END VIEW

DUAL RUPTURE DISKS AND RUPTURE DISK TRANSITION PIECE REMOVED FOR CLARITY

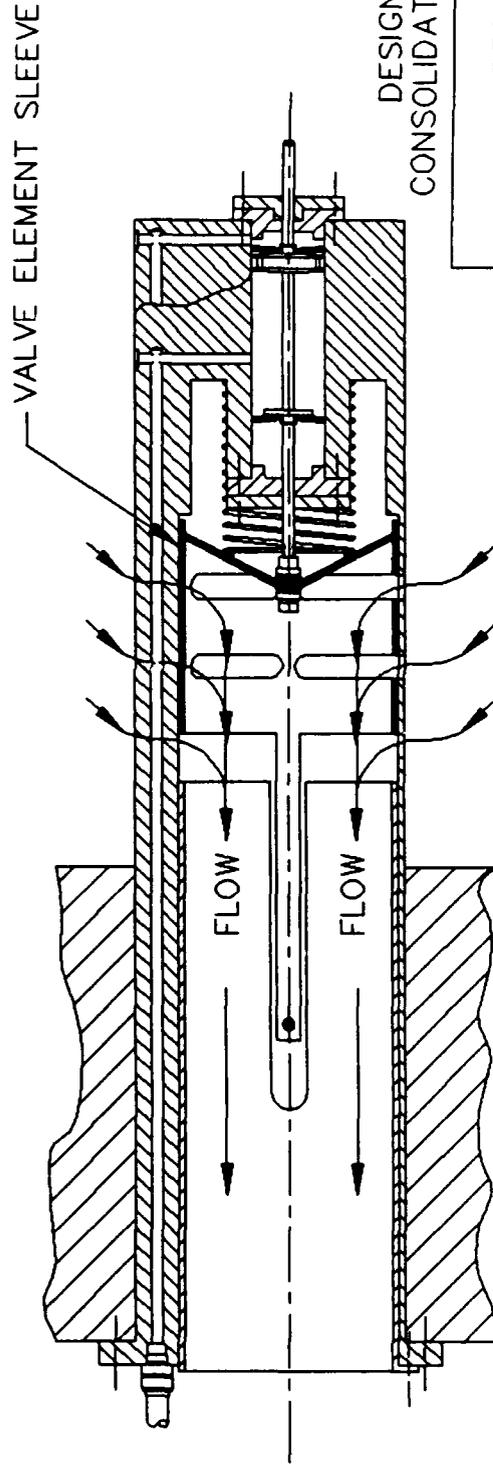
DESIGNED BY CONSOLIDATED CONTROLS

LBTS VALVE
 MULTI-ELEMENT DESIGN
 OVERALL ARRANGEMENT
 FIG. 5

426427



CROSS SECTION OF VALVE ELEMENT
VALVE IN CLOSED POSITION



CROSS SECTION OF VALVE ELEMENT
VALVE IN OPEN POSITION

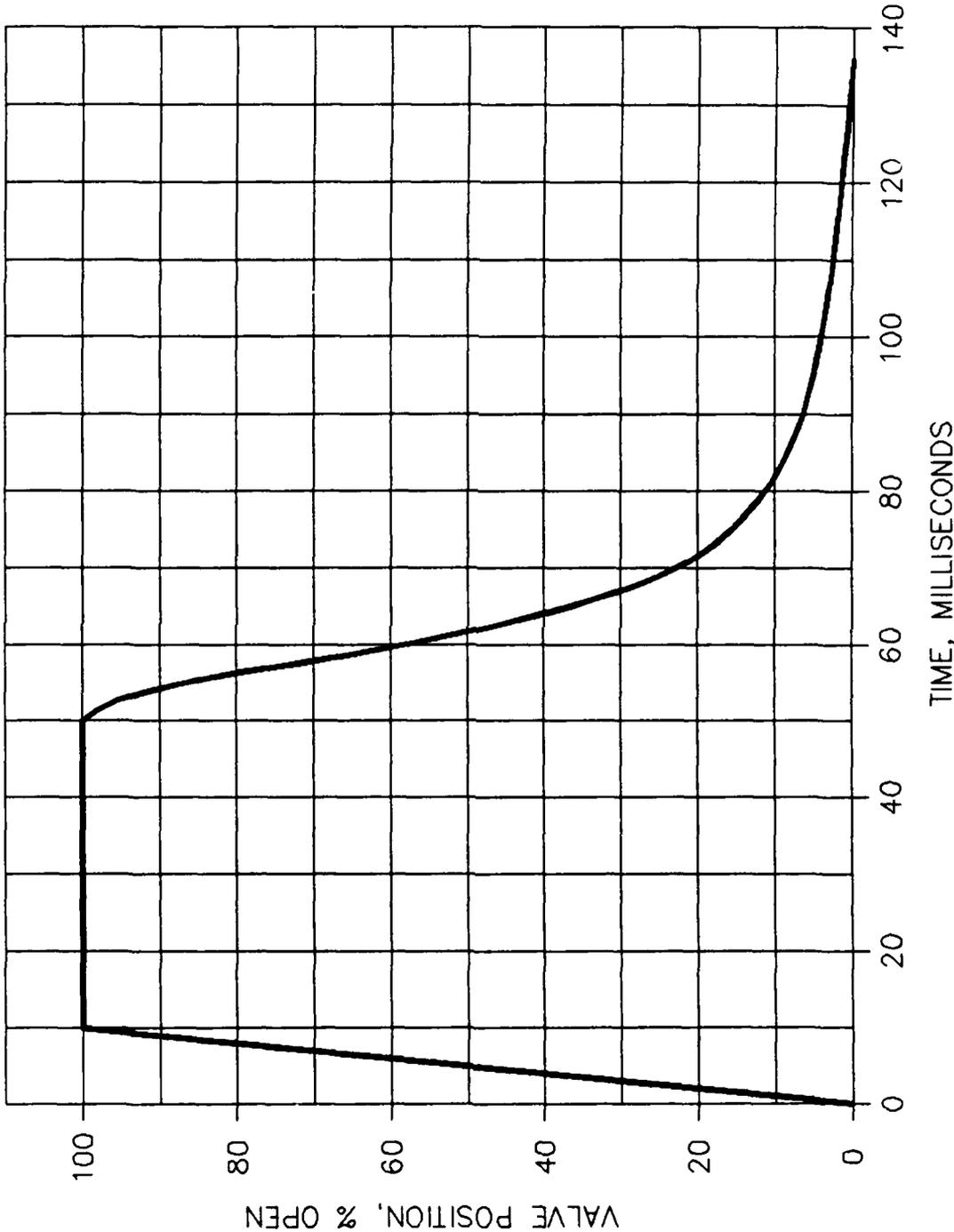
DESIGNED BY
CONSOLIDATED CONTROLS

LBTS VALVE
MULTI-ELEMENT DESIGN
ELEMENT DETAILS
FIG. 6

VALVE REQUIREMENTS

In the conceptual design of these valves the following general design requirements were used:

- 1) Flow Media: Nitrogen
- 2) Inlet Pressure: 35-2250 psig
- 3) Outlet Pressure: 0-1000 psig
- 4) Media temperature: 700 F max
- 5) Ambient conditions: -40 to 130 F at 0 to 100% relative humidity
- 6) Opening time: 10 ms max
- 7) Dwell time (time valve is fully open): 0 to 200 ms
- 8) Closing time: Valve must have variable open area verses time schedules which can be modified to produce the desired blast simulation. A typical closing schedule is shown in figure 7.
- 9) Upstream connection: Full scale - 72 in. ID driver tube
Half scale - 36 in. ID driver tube
- 10) Downstream connection: Full scale - 36 in rupture disks
Half scale - 18 in rupture disks
- 11) Flow coefficient: Full scale valve must flow the equivalent of a 36 inch pipe of similar length. Half scale valve must flow the equivalent of an 18 inch pipe of similar length.



VALVE OPENING/CLOSING SCHEDULE
 35 PSI-1KT BLAST WAVE
 FIGURE 7

MAJOR DESIGN DIFFICULTIES

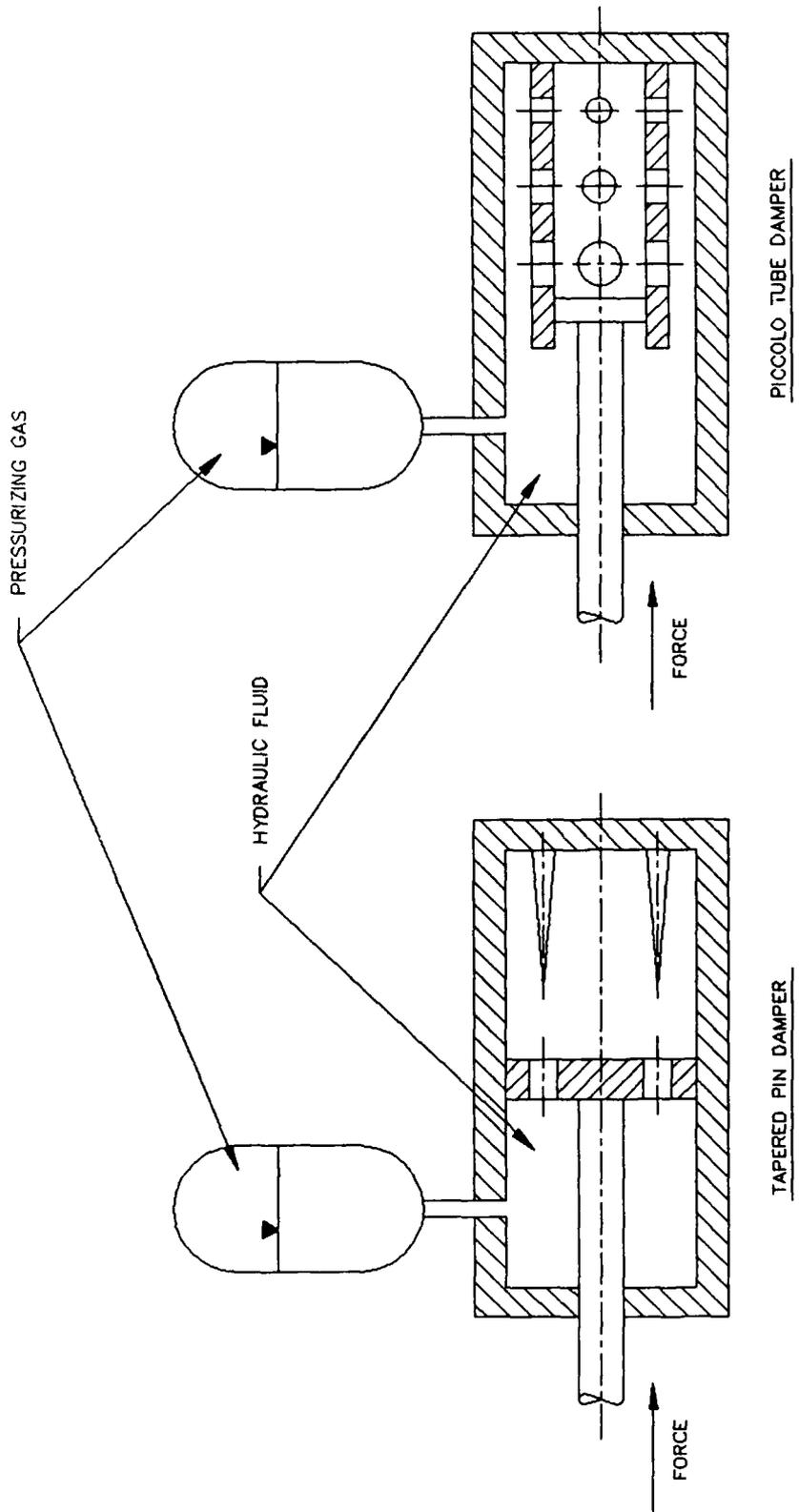
The primary difficulties in the design of a valve to meet the above requirements is 1) achieving the 10 ms opening times, 2) achieving 0 dwell time and 3) producing a closing schedule which is adjustable as well as capable of the fast cycle times. The fact the the valve is large, as well as subject to high pressure and temperature certainly complicates the design, but these items themselves are certainly within the capability of existing technology.

Achieving a 10 ms opening time in a valve of this size can be accomplished by several methods, including hydraulic actuation, gas actuation, propellant driven actuators and kinetic energy transfer devices. All of these methods require that a relatively large amount of energy be deposited in short period of time. Of these different methods, gas actuation was judged by EG&G Idaho to be the technology of choice. Dynamic simulation of a gas actuator was performed and verified that 10 ms opening times were possible in a valve of this size. However, in a single element valve design, opening times faster than 10 ms become difficult to achieve. Using helium as a driver gas, incorporating self venting actuator designs and utilizing exotic materials, opening times of 5 ms are possible. Of course if smaller valves are used, 10 ms opening times become easier to achieve. It is interesting to note that one of the major limitations of valve opening speed is the ability to transport the actuator gas into and out of the actuator volume. To attain high valve speeds the actuator control valves and supply/vent lines need to be large in comparison to the actuator size. Indeed, in most cases actuator flow restriction is the limit on valve speed rather than the mass of the moving element or the actuating pressure. However, in general, quick opening times are a balance of actuator pressure, actuator flow area, moving element mass and actuator piston area.

The requirement of a 0 dwell time is a significant complication in the design of single element large valves. This means that as the valve comes to 100% open it must immediately be driven in the opposite direction. If this were not a concern, the valve moving element could be accelerated throughout its

travel so as to minimize the opening time and, after opening being completed, be snubbed to a stop. However, to achieve 0 dwell, a single element valve must be decelerated prior to reaching 100% open. In effect the valve element must be accelerated for half of its travel, and then decelerated for the remaining half. This requires higher acceleration forces than would be necessary merely to open the valve quickly.

Perhaps the most challenging requirement is the necessity of a variable closing schedule. This requires that the valve element is in a specific position with respect to time. Complicating the matter is the fact the time duration for the closing is very short. In some instances the valve is 90% closed in about 80 ms. This would require that an active control system have to have a response time of less than 10 ms to adequately control the closing schedule. A complete control loop which would operate at these speeds would require custom fabrication and development. A simpler approach to this problem is to use open loop control in which the time delay for the control equipment can be accounted for. This approach requires highly repeatable control system components. Mechanically the most simple approach to this problem is to use damping equipment which is position sensitive, such as tapered pin or piccolo tube dampers. These devices, illustrated in figure 8, allow the hydraulic resistance to be related to damper position. However, these items have reduced flexibility. To alter the damping profile in the tapered pin type would require change out of the tapered pin. To some degree the damping profile on the piccolo tube type can be altered by connecting valves to the holes on the piccolo tube and adjusting these valves for the different conditions. This eliminates the need for equipment change out but still produces damping profiles within a limited envelope. Whatever control scheme is used, recording the actual closing schedule delivered would be useful in tuning the system and troubleshooting problems.



POSITION DEPENDENT HYDRAULIC DAMPERS

FIGURE 8

VALVE DESCRIPTION

Single Element Design

This concept was developed by Ring-O Valve S.p.A. and is illustrated in figure 1 and 2. This valve is an axial flow design using a single moving assembly. The sealing disk moves to the left to expose an annular flow area. Disk actuation is provided by hydraulic fluid which is routed to the piston actuator through each of three drilled locating webs. The hydraulic fluid pressure is attained in two gas charged accumulators. Sealing disk travel is approximately 9 inches. Closing schedule control is achieved by controlling the hydraulic fluid flow rate through an array of on/off cartridge valves. Control of the cartridge valves is via a computer which receives position input from a transducer in the valve.

Double Sliding Sleeve Design

This concept was developed by S & Q Corporation, and was also investigated independently by EG&G Idaho as a baseline design. An illustration of the S & Q design is found in figure 3 and 4. This valve uses two separate sleeves, one of which operates on the outside of a ported cylinder, while the other operates on the inside. During a blast sequence, the inner closing sleeve uncovers the flow port, while the outer sleeve is used to close the port. Each of the sleeves are pneumatically actuated, the opening sleeve being also pneumatically snubbed. The controlled closing schedule is provided by limiting the flow of hydraulic fluid from the closing sleeve actuating rams. Positioning rams are used to reset the inner opening sleeve to the armed position. The outer sleeve is likewise set to the start position using the positioning/regulating rams. Two separate sleeves are used to allow each sleeve some approach distance to 'get up to speed' prior to uncovering/covering the port. This also allows the opening sleeve to be accelerated throughout the port opening, and decelerated after the port is fully open. This results in fast opening times at reduced actuating forces while maintaining the capability for 0 dwell time.

Multi-Element Designs

Eaton Consolidated Controls and The Digital Valve Company independently developed a multi-element type design. The Eaton concept is illustrated in figures 5 and 6. These concepts incorporate 19 to 36 identical valve elements which have an total equivalent flow area of the single element valve. These elements are pneumatically operated to either an open or closed position at a fixed rate. No closing schedule regulation for an individual element is provided. The capability to achieve a closing schedule is provided by sequentially closing valve pairs to produce a stepped closing curve which approximates the required closing schedule. Other than the center valve element, the valves are closed in pairs, each pair being diametrically opposite so as to produce coaxial loading on the driver tube. The one off nature of these valve elements results in a stepped closing schedule which approximates the ideal closing profile. Control for this sequential closing will be provided by a digital computer which will time the closing of each valve. Position sensors are used on each element to monitor system performance.

DESIGN EVALUATIONS

Single Element Design

This design is the most basic, and at first look appears to have promise. The primary advantages of this concept is its mechanical simplicity. However, on closer inspection several problems can be seen with this approach:

- 1) When using a actuator piston diameter of 12.6 inches, and a moving element weight of 1500 lbs, approximately 10,000 gpm hydraulic fluid at 5000 psig would be required to open the valve in 20 ms. To open the valve in 10 ms would require 20,000 psig pressure at 10,000 gpm. Another approach would be to double the diameter of the cylinder which would give a 10 ms opening time at a flow rate of

40,000 gpm at 5000 psig. From this it can be seen that this design requires the use of high pressure hydraulics at very high flow rates particularly when fast opening times are desired. Small hydraulic actuated valves can be made to operate very fast, however as the valve is scaled up, the actuating forces to maintain the same opening time increase with the square of the valve diameter.

- 2) The force required to accelerate the hydraulic fluid in the line is considerable. Assuming the 20 ms opening time stated in the base case above, and also assuming that three 25 foot lines of 10 inch ID are to be used for each valve, then an additional 1500 psi would be required to accelerate the hydraulic fluid. If smaller line sizes are chosen the required accelerating pressure rises dramatically. Conversely, larger hydraulic lines are thought to be impractical. This item then tends to further increase the necessary hydraulic pressure requirements.
- 3) Using hydraulic actuation will require large lines and high pressures. Leakage at these high pressures is likely, and with the large volumes of oil involved, can result in very costly and time consuming maintenance.
- 4) This valve design is vulnerable to control system malfunction. For example, should the hydraulic valves which slow the piston fail to open, the valve disk can slam into the seat at speeds in excess of 75 ft/s. This can result in serious valve damage, necessitating valve replacement. A passive damping unit which could adsorb the maximum kinetic energy of moving elements and hydraulic fluid could be incorporated but would complicate the design and interfere with the requirement for controlled closing.
- 5) As previously stated this valve will have a hydraulic flow rate of at least 10,000 gpm. Since the programmable closing schedule is provided in this design by sequentially closing pilot operated on/off hydraulic valves, a large number of specialty high pressure high flow rate valves would be required.

- 6) In comparison with the multi-element concept, maintenance and repair of the valve would be difficult and time consuming.
- 7) Due to the single element nature of this valve, scale up problems from a smaller prototype could be expected. Also, development of the hydraulic control system is viewed as a potential problem area. Therefore this concept is seen to entail considerable risk in development.

Double Sliding Sleeve Valve The use of two moving elements rather than one offer some distinct advantages. This allows each sleeve to utilize acceleration and deceleration approach zones which result in high sleeve velocities as they open/close the ports. Over travel distances with the use of passive snubbing allow the sleeves be brought to rest in a reliable manner. With two sleeves a 0 dwell time is easily met by the proper timing of the closing and opening sleeves. Additionally, the closing sleeve can be at some velocity before opening the port which allows for greater flexibility in the possible closing schedules.

The major difficulty seen with this design is the hydraulic regulation of the closing sleeve. In order to meet a variety of closing schedules the hydraulic resistance in the regulating system needs to be sleeve position dependent. A single hydraulic resistance will not produce the variety of closing schedules required. Several passive snubbing systems are available that are position sensitive, such as the tapered pin and piccolo tube dampers previously discussed, but their lack of flexibility is judged to be a serious handicap. A closed loop control system would be very flexible, but difficult to engineer due to the response times required. In addition, similar to the single element design, significant risk is seen in the scale up development of this valve.

Multi-Element Design

By using a multitude of smaller elements many of the problems with the single element and double sliding sleeve valves can be minimized. Due to their

smaller size the individual elements can be made operate acceptably fast while keeping the kinetic energy of the elements low. Likewise, attaining a 0 dwell time is easier with a smaller element. The multi-element concept has other advantages which include:

- 1) Because the valve elements are small a single valve element can be fabricated and tested at a relatively modest cost. This would assure that the the desired valve speed and leakage could be attained, and would greatly reduce scale up problems.
- 2) Timing of the opening and closing schedule is easily changed and very flexible.
- 3) Failure of a single element would not seriously compromise test results.
- 4) Maintenance or replacement of a valve element is relatively easy since each element could be handled by hand or small handling equipment.

The major criticism of this proposal is that a stepped closing schedule is produced rather than a smooth transition. Although this appears to be a problem, computational models of the LBTS indicate that this stepped curve will not significantly compromise the blast simulation. Although not a serious limitation, this valve design requires a larger physical envelope to accommodate the reduced flow efficiency of the smaller elements.

CONCLUSION

The development of a LBTS valve which meets the design requirements is within the capability of existing technology. Although several viable approaches are available, the concept that appears to have the most promise is the multi-element design. This design will allow for early prototype testing which will highlight possible design problems. Thus the risk to the

overall program is considerably reduced with this concept. Also, the multi-element concept is thought to have the most technical merit. It is therefore recommended that the multi-element design be pursued for further development.

DISTRIBUTION LIST

| <u>No. of</u> <u>Copies</u> | <u>Organization</u> | <u>No. of</u> <u>Copies</u> | <u>Organization</u> |
|--------------------------------|--|--------------------------------|--|
| 12 | Administrator Defense Technical Info Center ATTN: DTIC-DDA Cameron Station Alexandria, VA 22304-6145 | 1 | Director National Security Agency ATTN: R15 (E. F. Butala) Ft. George G. Meade, MD 20755 |
| 1 | HQDA (SARD-TR) Washington, DC 20310-0001 | 6 | Director Defense Nuclear Agency ATTN: CSTI (Tech Lib) DDIR DFSP (Ullrich) NANS OPNA SPSD (Goering/Rohr) TDTR (Kennedy/Hrinishin) Washington, DC 20305 |
| 1 | Director of Defense Research & Engineering ATTN: DD/TWP Washington, DC 20301 | | |
| 1 | Assistant Secretary of Defense (Atomic Energy) ATTN: Document Control Washington, DC 20301 | 2 | Commander Field Command, DNA ATTN: FCPR FCTMOF Kirtland AFB, NM 87115 |
| 1 | Chairman Joint Chiefs of Staff ATTN: J-5 (R&D Div) Washington, DC 20301 | 1 | Commander Field Command, DNA Livermore Branch ATTN: FCPRL P.O. Box 808 Livermore, CA 94550 |
| 2 | Deputy Chief of Staff for Operations and Plans ATTN: Technical Library Director of Chemical and Nuclear Operations Department of the Army Washington, DC 20310 | 10 | Central Intelligence Agency DIR/DB/Standard ATTN: GE-47 HQ Washington, DC 20505 |
| 1 | Director Defense Advanced Research Projects Agency ATTN: Tech Lib 1400 Wilson Boulevard Arlington, VA 22209 | 1 | Commander US Army Materiel Command ATTN: AMCDRA-ST 5001 Eisenhower Avenue Alexandria, VA 22333-0001 |
| 2 | Director Federal Emergency Management Agency ATTN: Public Relations Office Technical Library Washington, DC 20472 | 1 | Commander US Army Laboratory Command ATTN: AMSLC-DL Adelphi, MD 20783-1145 |
| 1 | Director Defense Intelligence Agency ATTN: DT-2/Wpns & Sys Div Washington, DC 20301 | | |

DISTRIBUTION LIST

| <u>No. of</u> <u>Copies</u> | <u>Organization</u> | <u>No. of</u> <u>Copies</u> | <u>Organization</u> |
|--------------------------------|--|--------------------------------|--|
| 3 | Director US Army Harry Diamond Labs ATTN: SLCHD-NW-RA (L. Belliveau) SLCHD-NW-P (Gwaltney/Meszaros) SLCHD-TA-L (Tech Lib) 2800 Powder Mill Road Adelphi, MD 20783-1197 | 3 | Commander US Army Communications - Electronics Command (CECOM) HQ ATTN: AMSEL-RD AMSEL-IM-L AMSEL-RO-TPPO-P Fort Monmouth, NJ 07703-5301 |
| 2 | Commander Armament RD&E Center ATTN: SMCAR-TDC Dover, NJ 07801-5000 | 1 | Commander CECOM R&D Technical Library ATTN: ASNC-ELC-I-T, Myer Center Fort Monmouth, NJ 07703-5301 |
| 2 | Commander Armament RD&E Center ATTN: SMCAR-MSI Ficatinny Arsenal, NJ 07806-5000 | 1 | Commander US Army Missile Command ATTN: AMSMI-AS Redstone Arsenal, AL 35898-5000 |
| 1 | Commander Armament RD&E Center ATTN: SMCAR-TSS Dover, NJ 07801-5001 | 1 | Director US Army Missile and Space Intelligence Center ATTN: AIAMS-YDL Redstone Arsenal, AL 35898-5500 |
| 1 | Director Benet Weapons Laboratory Armament RD&E Center US Army AMCCOM ATTN: SMCAR-LCB-TL Watervliet, NY 12189-4050 | 1 | Commander US Army Tank Automotive Command ATTN: ASQNC-TAC-DI(Tech Lib) Warren, MI 48397-5000 |
| 1 | Commander US Army Armament, Munitions and Chemical Command ATTN: SMCAR-ESP-L Rock Island, IL 61299-5000 | 1 | Director US Army TRADOC Analysis Command ATTN: ATAA-SL White Sands Missile Range, NM 88002-5502 |
| 1 | Commander US Army Aviation Systems Command ATTN: AMSAV-DACL 4300 Goodfellow Boulevard St. Louis, MO 63120-1798 | 1 | Commandant US Army Infantry School ATTN: ATSH-CD-CSO-OR Fort Benning, GA 31905-5660 |
| 1 | Director US Army Aviation Research and Technology Activity Ames Research Center Moffett Field, CA 94035-1099 | | |

DISTRIBUTION LIST

| <u>No. of</u> <u>Copies</u> | <u>Organization</u> | <u>No. of</u> <u>Copies</u> | <u>Organization</u> |
|--------------------------------|--|--------------------------------|--|
| 1 | Commander US Army Foreign Science and Technology Center ATTN: Research & Data Branch 220 7th Street , NE. Charlottesville, VA 22901 | 1 | Commander US Army Research Office ATTN: SLCRO-D P.O. Box 12211 Research Triangle Park, NC 27709-2211 |
| 1 | Commander US Army Logistics Management Center ATTN: ATCL-O (R. Cameron) Fort Lee, VA 23801 | 3 | Commander US Army Nuclear & Chemical Agency ATTN: ACTA-NAW MONA-WE Tech. Lib. 7500 Backlick Rd, Bldg. 2073 Springfield, VA 22150 |
| 1 | Commander US Army Materials Technology Laboratory ATTN: AMXMR-ATL Watertown, MA 02172-0001 | 1 | Director Requirements and Programs Directorate HQ, TRADOC Analysis Command ATTN: ATRC-RP Fort Monroe, VA 23651-5143 |
| 1 | Commander US Army Strategic Defense Command ATTN: CSSD-H-MPL (Tech Lib) CSSD-H-XM (Dr. Davies) P.O. Box 1500 Huntsville, AL 35807 | 1 | Commander TRADOC Analysis Command ATTN: ATRC Fort Leavenworth, KS 66027-5200 |
| 2 | Commander US Army Natick Research and Development Center ATTN: AMDNA-D (Dr. D. Sieling) STRNC-UE (J. Calligeros) Natick, MA 01762 | 1 | Commander US Army Test & Evaluation Command Nuclear Effects Laboratory ATTN: STEWS-TE-NO (Dr. J.L. Meason) P.O. Box 477 White Sands Missile Range, NM 88002 |
| 1 | Commander US Army Engineer Division ATTN: HNDED-FD P.O. Box 1500 Huntsville, AL 35807 | 1 | Commander US Army Development & Employment Agency ATTN: MODE-ORO Fort Lewis, WA 98433-5000 |
| 3 | Commander US Army Corps of Engineers Waterways Experiment Station ATTN: CAWES-SS-R (J. Watt) CAWES-SE-R (J. Ingram) CAWES-TL (Tech Lib) P.O. Box 631 Vicksburg, MS 39180-0631 | 2 | Director Joint Strategic Target Planning Staff JCS ATTN: JLTW TPTP Offut AFB Omaha, NB 68113 |
| | | 1 | Commandant Interservice Nuclear Weapons School ATTN: Technical Library Kirtland AFB, NM 87115 |

DISTRIBUTION LIST

| <u>No. of Copies</u> | <u>Organization</u> | <u>No. of Copies</u> | <u>Organization</u> |
|--------------------------|--|--------------------------|---|
| 2 | Chief of Naval Operations ATTN: OP-03EG OP-985F Department of the Navy Washington, DC 20350 | 1 | Commander Naval Surface Weapons Center ATTN: Code DX-21 (Library) Dahlgren, VA 22448-5000 |
| 1 | Chief of Naval Research ATTN: N. Perrone Department of the Navy Arlington, VA 22217 | 2 | Commander Naval Surface Weapons Center ATTN: Code WA501 (Navy Nuclear Programs Office) Code WX21 (Tech Library) Silver Spring, MD 20902-5000 |
| 1 | Director Strategic Systems Projects Office ATTN: NSP-43, Tech Library Department of the Navy Washington, DC 20360 | 1 | Commander Naval Weapons Center ATTN: Code 533 (Tech Library) China Lake, CA 93555-6001 |
| 1 | Commander Naval Electronic Systems Command ATTN: PME 117-21A Washington, DC 20360 | 1 | Commander Naval Weapons Evaluation Fac ATTN: Document Control Kirtland AFB, NM 87117 |
| 1 | Commander Naval Facilities Engineering Command ATTN: Technical Library Washington, DC 20360 | 1 | Commander Naval Research Laboratory ATTN: Code 2027, Tech Library Washington, DC 20375 |
| 1 | Commander Naval Sea Systems Command ATTN: Code SEA-62R Department of the Navy Washington, DC 20362-5101 | 1 | Superintendent Naval Postgraduate School ATTN: Code 2124, Tech Library Monterey, CA 93940 |
| 5 | Officer-in-Charge Naval Construction Battalion Center Civil Engineering Laboratory ATTN: Code L64 (N. P. Clark) Code L54 (R. J. Odello) Code L51 (W. Keenan) Code LO6C/LO8A (Tech Lib) Port Hueneme, CA 93041 | 1 | AFSC/SDOA Andrews AFB, MD 20334 |
| 1 | Commander David W. Taylor Naval Ship Research & Development Command ATTN: Code 522 (Lib Div) Bethesda, MD 20084-5000 | 1 | Air Force Armament Laboratory ATTN: AFATL/DLODL Eglin AFB, FL 32542-5000 |
| | | 2 | Air Force Armament Laboratory ATTN: AFATL/DOIL AFATL/DLYV Eglin AFB, FL 32542-5000 |
| | | 1 | AFESC/RDCS ATTN: Paul Rosengren Tyndall AFB, FL 32403 |

DISTRIBUTION LIST

| <u>No. of</u> <u>Copies</u> | <u>Organization</u> | <u>No. of</u> <u>Copies</u> | <u>Organization</u> |
|--------------------------------|--|--------------------------------|---|
| 1 | RADC (EMTLD/Docu Library) Griffiss AFB, NY 13441 | 2 | Director Los Alamos Scientific Lab. ATTN: Doc Control for Rpts Library P.O. Box 1663 Los Alamos, NM 87544 |
| 1 | AFWL/SUL Kirtland AFB, NM 87117-5800 | 2 | Director Sandia Laboratories ATTN: Doc Control 3141 Sandia Rpt Collection L. J. Vortman P.O. Box 5800 Albuquerque, NM 87185-5800 |
| 2 | Air Force Weapons Laboratory ATTN: NTES, R. Henny NTED, J. W. Aubrey Kirtland AFB, NM 87117-6008 | 1 | Director Sandia Laboratories Livermore Laboratory ATTN: Doc Control for Tech Library P.O. Box 969 Livermore, CA 94550 |
| 2 | Commander-in-Chief Strategic Air Command ATTN: NRI-STINFO Lib Ofutt AFB, NB 68113 | 1 | Director National Aeronautics and Space Administration ATTN: Scientific & Tech Info Fac P.O. Box 8757, BWI Airport Baltimore, MD 21240 |
| 1 | AFIT ATTN: Tech Lib (Bldg. 640/B) Wright-Patterson AFB, OH 45433 | 1 | Director NASA-Langley Research Center ATTN: Tech Lib Hampton, VA 23665 |
| 1 | FTD/NIIS Wright-Patterson AFB Ohio 45433 | 1 | Director NASA-Ames Research Center Applied Computational Aerodynamics Branch ATTN: MS 202-14, Dr. T. Holtz Moffett Field, CA 94035 |
| 1 | U.S. Department of Energy Idaho Operations Office ATTN: Spec Programs (J. Patton) 785 DOE Place Idaho Falls, ID 83402 | 3 | Aberdeen Research Center ATTN: N.H. Ethridge J. Keefer Library P.O. Box 548 Aberdeen, MD 21001 |
| 2 | Director Idaho National Engineering Laboratory EG&G Idaho Inc. ATTN: Mr. W. C. Reed Mr. T. R. Reed P.O. Box 1625 Idaho Falls, ID 83415 | | |
| 1 | Director Lawrence Livermore Lab. ATTN: Tech Info Dept L-3 P.O. Box 808 Livermore, CA 94550 | | |

DISTRIBUTION LIST

| <u>No. of Copies</u> | <u>Organization</u> | <u>No. of Copies</u> | <u>Organization</u> |
|--------------------------|---|--------------------------|---|
| 1 | Aerospace Corporation ATTN: Tech Info Services P.O. Box 92957 Los Angeles, CA 90009 | 1 | EATON Corporation Defense Valve & Actuator Div. ATTN: Dr. J. Y. S. Yang 2338 Alaska Ave. El Segundo, CA 90245-4896 |
| 1 | Agbabian Associates ATTN: M. Agbabian 250 North Nash Street El Segundo, CA 90245 | 1 | Goodyear Aerospace Corporation ATTN: R. M. Brown, Bldg 1 Shelter Engineering Litchfield Park, AZ 85340 |
| 1 | Applied Research Associates, Inc. ATTN: R. L. Guice 7114 West Jefferson Ave., Suite 305 Lakewood, CO 80235 | 4 | Kaman AviDyne ATTN: Dr. R. Reutenick (2 cys) Mr. S. Criscione Mr. R. Milligan 83 Second Avenue Northwest Industrial Park Burlington, MA 01830 |
| 1 | The BDM Corporation ATTN: Richard Hensley P.O. Box 9274 Albuquerque, NM 87119 | 3 | Kaman Sciences Corporation ATTN: Library P. A. Ellis F. H. Shelton 1500 Garden of the Gods Road Colorado Springs, CO 80907 |
| 1 | Black & Veach Consulting Engineers ATTN: H. D. Laverentz 1500 Meadow Lake Parkway Kansas City, MO 64114 | 1 | Kaman Sciences Corporation ATTN: Mr. F. W. Balicki 6400 Uptown Boulevard N.E. Suite 300 Albuquerque, NM 87110 |
| 1 | The Boeing Company ATTN: Aerospace Library P.O. Box 3707 Seattle, WA 98124 | 2 | Kaman-TEMPO ATTN: DASIAC Don Sachs P.O. Drawer QQ 816 State Street Santa Barbara, CA 93102 |
| 1 | California Research & Technology, Inc. ATTN: M. Rosenblatt 20943 Devonshire Street Chatsworth, CA 91311 | 1 | Lockheed Missiles & Space Co. ATTN: J. J. Murphy, Dept. 81-11, Bldg. 154 P.O. Box 504 Sunnyvale, CA 94086 |
| 1 | Carpenter Research Corporation ATTN: H. Jerry Carpenter 27520 Hawthorne Blvd., Suite 263 P. O. Box 2490 Rolling Hills Estates, CA 90274 | 1 | Martin Marietta Aerospace Orlando Division ATTN: G. Fotieo P.O. Box 5837 Orlando, FL 32805 |
| 1 | Dynamics Technology, Inc. ATTN: D. T. Hove Suite 300 21311 Hawthorne Blvd. Torrance, CA 90503 | | |

DISTRIBUTION LIST

| <u>No. of Copies</u> | <u>Organization</u> | <u>No. of Copies</u> | <u>Organization</u> |
|--------------------------|---|--------------------------|---|
| 2 | McDonnell Douglas Astronautics Corporation ATTN: Robert W. Halprin K.A. Heinly 5301 Bolsa Avenue Huntington Beach, CA 92647 | 2 | S-CUBED ATTN: C. E. Needham Lynn Kennedy PO Box 8243 Albuquerque, NM 87198 |
| 2 | Physics International Corporation 2700 Merced Street San Leandro, CA 94577 | 3 | S-CUBED ATTN: Technical Library R. Duff K. Pyatt PO Box 1620 La Jolla, CA 92037-1620 |
| 2 | R&D Associates ATTN: Technical Library Allan Kuhl P.O. Box 9695 Marina Del Rey, CA 90291 | 1 | Texas Engineering Experiment Station ATTN: Dr. D. Anderson 301 Engineering Research Center College Station, TX 77843 |
| 1 | R&D Associates ATTN: G.P. Ganong P.O. Box 9330 Albuquerque, NM 87119 | 1 | Thermal Science, Inc. ATTN: R. Feldman 2200 Cassens Dr. St. Louis, MO 63026 |
| 2 | Science Applications, Inc. ATTN: W. Layson John Cockayne PO BOX 1303 1710 Goodridge Drive McLean, VA 22102 | 1 | TRW - Ballistic Missile Division ATTN: H. Korman, Mail Station 526/614 P.O. Box 1310 San Bernadino, CA 92402 |
| 1 | Science Applications International Corp. ATTN: Mr. J. Guest 4615 Hawkins Blvd. N.E. Albuquerque, NM 87109 | 1 | Battelle Memorial Institute ATTN: Technical Library 505 King Avenue Columbus, OH 43201 |
| 1 | Sparta, Inc. ATTN: I. B. Osofsky Suite 250, 23293 So. Pointe Dr. Laguna Hills, CA 92653 | 1 | California Institute of Technology ATTN: T. J. Ahrens 1201 E. California Blvd. Pasadena, CA 91109 |
| 1 | Sverdrup Technology, Inc. ATTN: R. F. Starr P. O. Box 884 Tullahoma, TN 37388 | 2 | Denver Research Institute University of Denver ATTN: Mr. J. Wisotski Technical Library PO Box 10127 Denver, CO 80210 |
| 1 | SRI International ATTN: Dr. G. R. Abrahamson 333 Ravenswood Avenue Menlo Park, CA 94025 | | |

DISTRIBUTION LIST

| <u>No. of Copies</u> | <u>Organization</u> | <u>Aberdeen Proving Ground</u> |
|--------------------------|---|---|
| 1 | Massachusetts Institute of Technology Aeroelastic and Structures Research Laboratory ATTN: Dr. E. A. Witmer Cambridge, MA 02139 | Dir, USAMSAA ATTN: AMXSY-D AMXSY-MP (H. Cohen) |
| 1 | Massachusetts Institute of Technology ATTN: Technical Library Cambridge, MA 02139 | Cdr, USATECOM ATTN: AMSTE-TO-F AMSTE-TE-F (L. Teletski) |
| 1 | New Mexico Engineering Research Institute (CERF) University of New Mexico ATTN: Dr. J. Leigh P.O. Box 25 Albuquerque, NM 87131 | Cdr, CRDEC, AMCCOM ATTN: SMCCR-RSP-A SMCCR-MU SMCCR-SPS-IL |
| 1 | Northrop University ATTN: Dr. F. B. Safford 5800 W. Arbor Vitae St. Los Angeles, CA 90045 | Cdr, USATHMA ATTN: AMXTH-TE |
| 2 | Southwest Research Institute ATTN: Dr. W. E. Baker A. B. Wenzel 8500 Culebra Road San Antonio, TX 78228 | |
| 1 | Stanford University ATTN: Dr. D. Bershader Durand Laboratory Stanford, CA 94305 | |

USER EVALUATION SHEET/CHANGE OF ADDRESS

This laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers below will aid us in our efforts.

1. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) _____

2. How, specifically, is the report being used? (Information source, design data, procedure, source of ideas, etc.) _____

3. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. _____

4. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) _____

BRL Report Number _____ Division Symbol _____

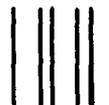
Check here if desire to be removed from distribution list. _____

Check here for address change. _____

Current address: Organization _____
Address _____

-----FOLD AND TAPE CLOSED-----

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T (NEI)
Aberdeen Proving Ground, MD 21005-5066

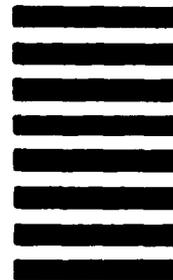


NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE \$300

BUSINESS REPLY LABEL
FIRST CLASS PERMIT NO. 12062 WASHINGTON D. C.

POSTAGE WILL BE PAID BY DEPARTMENT OF THE ARMY



Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T (NEI)
Aberdeen Proving Ground, MD 21005-9989