Fermilab
V1285-162

Fermi National Accelerator Laboratory
P O Box 500 • Batavia, Illinois • 60510

December 20, 1985

Cryogenic Consultants, Inc.
Attn: P. C. Vander Arend
1176 N. Irving Street
Allentown, PA 18103

SUBJECT: Subcontract No. SC-94362
Task Order #2 R-1

Dear Mr. Vander Arend:

This is the initial detailed Scope of Work for Task Order No. 2 R-1.

Enclosed are the following:

1. Details of the insulation system for the LAC as supplied by Mr. Bob Springer of CB&I.

2. A copy of the preliminary flow sheet - not numbered.

3. A copy of the flow diagram for the valve box - not numbered.

4. A copy of Anderson, Greenwood & Co. report No. 2-0175-128.

Drawings of the site, equipment, and assembly are being prepared for transmittal later.

Very truly yours,

L. C. Vonasch, Jr.
Sr. Contract Administrator

LOV/clr

cc: W. Baker (#220)
B. Cooper (#357)
K. Dixon (#310)
S. Stoy (#219)

12/19/85

CCI, ODH STUDY FOR E-706

Task Order No. 1

1. Calculate the relief capacity required to meet ASME and CGA S-1.3 fire condition requirements. Details of the insulation will be provided.

2. Calculate the relief capacity available with the existing relief devices including a consideration of relief system piping. The vent piping is to be run so that at no location routinely accessible to personnel does the partial pressure of oxygen fall below 135mm Hg.

3. If the present relief devices are marginal or inadequate to satisfy 1., calculate what devices and vent piping sizes are necessary. Consider two cases:

   a) increasing the size of one of the existing relief devices.

   b) the addition of a third relief device.

4. In either case, it appears that the use of the 24" manhole would be necessary to mount a relief device. Is this practical?

peed Letter. 44-912 GrayLine.

Speed Letter.

To DR F. KOBRUWICZ

From Fis Springer
NOE - OAKBROOK, IL

Subject DEWAR, ARGON

Date OCT 30 1985

MESSAGE

AS YOU REQUESTED, ATTACHED PLEASE FIND 2 COPIES OF: 1) NCFI URETHANE FOAM DATA SHEET 2) STAMTEX DATA SHEET 3) KNAUF DATA SHEET ON FIBERGLAS INSULATION 4) SKETCHES OF INSULATION DETAILS

"K" VALUES ARE MARKED ON EA. DATA SHEET, AUTO. 14 IS THE K VALUE FOR THE FOAM

IN GENERAL, UNDER NO CIRCUMSTANCES WILL URETHANE FOAM EXPLODE IN A SEWER FIRE SITUATION. (NOTE LOW FLAME SPREAD) AND WITH THE "STAMTEX" FIRE PROTECTION SYSTEM THE DEWAR SHOULD HOLD UP LONG AFTER OTHER SYSTEMS HAVE FAILED IN THE SAME VICINITY (i.e. GANTRY, BUILDING ECT)

HOPE THIS IS ENOUGH

LET ME KNOW IF YOU NEED EITHER MORE

Signed RG

Date 19

REPLY

Signed

NCFI

NORTH CAROLINA FOAM INDUSTRIES, INC.
P. O. BOX 1528 • MOUNT AIRY, N. C. 27030

11/84

ANOTHER NCFI QUALITY SPRAY URETHANE FOAM WITH SELF-ADHERING, SEAMLESS, DOUBLE INSULATING EFFICIENCY

NCFI SPRAY FOAM SYSTEM 363-82

NCFI Spray System 363-82 is a two part system that has been designed for good yield of chemicals per R value for spraying between studs in wall construction. It is pumped on a 1 to 1 ratio by volume.

Typical Physical Properties of foam made with NCFI Spray System 363-82:*

Core Density	1.7 lbs. per cubic foot
Moisture Vapor Transmission	2-3 perm in.
k Factor As with all insulating materials, the k Factor will vary with age and use conditions.	.14
Compressive Strength	20 psi
Max. Service Temp.	180°F (Note page 2 under proper temperature of optimum adhesion)

Result of ASTM E-84 on finished foam applied to asbestos cement board:

	2 in. thick
Flame Spread	25
Smoke Developed	Less than 450

This numerical flame spread rating is not intended to reflect hazards presented by this or any other material under actual fire conditions. For proper use refer to NCFI 363-82 Application information and any of the following codes or guides:

1. Southern Standard Building Code, Section 717 (1982 revision, 1983 amended)
2. BOCA Basic Building Code, Section 1319.0
3. NFPA No. 205M-T "Guide for Plastics in Construction"

Please see reverse side for application information.

CAUTION: Urethane foam produced from these chemicals may present a risk of fire in certain applications if exposed to excessive heat and oxygen, i.e., welding and cutting torches. See reverse side for prediction of fire hazard and guide for safe application.

*To serve only as a guide. Values shown are average values obtained from laboratory specimens.

NCFI 363-82 APPLICATION INFORMATION

EQUIPMENT AND COMPONENT RATIOS:

Required is standard airless urethane spray equipment. NCFI 363-R is connected to the resin pumps with NCFI 363-A being connected to the isocyanate pumps. The proportioning pump ratio is 1 to 1. Gusmer preheater temperature should be 120°F. Hose temperature should be approximately 100°F to give good pattern. Equipment which operates at higher pressures will require slightly lower temperature settings.

STORAGE OF CHEMICALS:

Keep temperature of chemicals above 65°F for several days before use. Cold chemicals can cause pump "cavitation", therefore incorrect metering. Storage temperature should not exceed 100°F. Do not store in direct sunlight. Keep drums tightly closed when not in use and under dry gas pressure of 2-3 psi after they have been opened. Shelf life of 363-82 is 6 months.

SAFE HANDLING OF LIQUID COMPONENTS:

Use caution in removing bungs from 55-gallon drum. Loosen 3/4" bung and let gas escape before completely removing. Avoid prolonged breathing of vapors. In case of chemical contact with eyes, flush with water for at least 15 minutes and get medical attention. For further information refer to "Guide for the Safe Handling and Use of Urethane Foam Systems" published by The Society of the Plastics Industry, 250 Park Ave., New York, N.Y.

PREPARATION OF SURFACE TO BE SPRAYED:

All surfaces to be sprayed should be dry and free of dew or frost. All metal to which foam is to be applied must be free of oil, grease, etc.

OPTIMUM ADHESION TEMPERATURE OF SURFACE TO BE SPRAYED:

In general work where the surface to be sprayed will remain at ambient temperature or cooler; the surface can be between 50°F and 120°F. When finished foam will have a service temperature in the range of 120°F-180°F (oil and resin tanks) the surface to be sprayed should be 120°F or above at the time of spraying. For temperature over 180°F please contact NCFI for special recommendations.

PREDICTION OF FIRE HAZARD IN CONSTRUCTION:

Where foam is sprayed over large areas of building interiors, its exposed surface should be protected from fire hazard by 1/2" portland cement plaster or 1/2" gypsum board or equivalent. For the prediction of fire hazard in construction, refer to NFPA No. 205M-T "Guide for Plastics in Construction."

The information on our data sheets is to assist customers in determining whether our products are suitable for their applications. The customers must satisfy themselves as to the suitability for specific cases. North Carolina Foam Industries, Inc. warrants only that the material shall meet its specifications; this warranty is in lieu of all other written or unwritten, expressed or implied warranties and North Carolina Foam Industries, Inc. expressly disclaims any warranty of merchantability, fitness for a particular purpose, or freedom from patent infringement. Accordingly, Buyer assumes all risks whatsoever as to the use of the material. Buyer's exclusive remedy as to any breach of warranty, negligence or other claim shall be limited to the purchase price of the material. Failure to adhere strictly to any recommended procedures shall relieve North Carolina Foam Industries, Inc. of all liability with respect to the material or the use thereof.

TECHNICAL BULLETIN

STAYTEX 4119A

GENERAL

STAYTEX 4119A is a fire resistant coating specifically developed as an ignition and thermal barrier for protecting foam plastic insulation and other combustible materials. It consists of inorganic hydrated salts within a polymer binder. As a result, it has a very good resistance to cracking and mechanical damage. STAYTEX 4119A contains 100 percent solids and does not contain any free water or solvents. In addition, its chemical structure limits moisture transfer and absorption of moisture to negligible amounts. It produces a relatively smooth surface free from excessive texture.STAYTEX 4119A may be topcoated with a variety of finishes.

PHYSICAL DATA

Fire Resistance Characteristics

STAYTEX 4119A in a minimum thickness of 1/16 inch applied over foam plastic insulation has been successfully tested by an accredited independent testing laboratory in accordance with the full scale fire test procedures specified in Bulletin PICC-401; March, 1980 published by The Society of the Plastics Industry, Inc. This test procedure is being accepted by building code officials and organizations as an acceptable diversified test specifically authorized and permitted by the three model building codes in the United States for acceptable installation of foam plastic insulation materials. This full scale fire test procedure and acceptance criteria requires the fire resistant coating to protect the foam plastic insulation and prevent fire growth during fire conditions having the severity of a thirty pound wood fuel source in an enclosed room for a fifteen minute period. Temperatures created in the room by the wood fuel source exceed 1500°F.

Solids Content:	100 percent
Color:	White. Other colors upon request.
Recommended Thickness:	1/16 inch minimum → 1/8" @ FERMILAB ON DEWAR
Coverage:	24.6 square feet per gallon
Application Temperature:	45°F. to 100°F.
Service Temperature:	-40°F. to 150°F.
Performance as a water vapor barrier:	Excellent; Permeability rating is .012 perm-inches at 100% relative humidity and 100°F.
Durability:	Excellent due to high density of 80 pounds per cubic foot.

BARRIER SYSTEMS INC.
Manufacturers of STAYTEX insulation and asbestos encapsulation systems.
One Playhouse Square • 1375 Euclid Avenue, Suite 400 • Cleveland, Ohio 44115
Office (216) 696-5778
Plant (216) 961-8095

August 6, 1985

Mr. William Riches
Fermi National Accelerator Laboratory
P.O. Box 500
Mail Station 119
Batavia, IL 60510

Dear Mr. Riches:

In regard to our telephone conversation regarding the use of our Staytex 4119A thermal barrier for fire protecting polyurethane foam insulation to be spray applied to your tank, we provide the following information which we believe justifies and substantiates the use of our product over seven inches of polyurethane foam being proposed:

1. Our product as well as other fire barriers such as gypsum wall board and other fire resistant coatings will protect the substrate regardless of thickness of the substrate. In othher words, the actual fire resistant performance of a fire barrier is not dependent upon the thickness of the substrate over which the fire barrier is applied.

2. Building codes vary their requirements for fire barriers and other protective measures assuming that the foam insulation could be used in very large quantities on walls and ceilings of such buildings and since foam insulation in such buildings is usually used at a one and two inch thickness, very few installations other than coolers and freezers utilize thicknesses greater than two inches. In your particular instance, even though seven inches of foam is being proposed, your total amount of foam insulation used is quite minor compared to hundreds of thousands of square feet of foam at a one and two inch thickness, and sometimes four inches that is typically installed.

3. The BOCA Research Report No. 8156 has no limitation on foam thickness to which our Staytex material can be applied. The SBCCI Report No. 8174 in item IX3. indicates that Staytex shall not be installed on foams exceeding four inches in thickness except as provided for in Section 717.2 (b). Section 717.2 (b) addresses major installations of freezers and coolers which, as previously mentioned, are the only locations where foam over one or two inches is typically used and other requirements do exist for freezer and cooler installations. Requirements covering tanks do not actually exist in building codes so this four inch limitation for major building uses is really not applicable to your particular circumstance.

4. Although these building code approvals and our insurance approvals authorize the use of our Staytex at 1/16 of an inch, you can give yourself a 100% safety factor by specifying Staytex at 1/8 of an inch since our fire resistance is directly proportional to thickness.

We believe our comments and enclosed information should give you comfort that our Staytex thermal barrier is suitable for installation over the seven inches of polyurethane foam on your tank, particularly if you specify 1/8 inch thickness therefore giving you that extra 100% margin of safety.

Please let us know if you have any additional questions. We are sending a copy of this letter overnight mail to Professor Slattery who called us today asking that we expedite this information due to your time table for this project.

Cordially,

BARRIER SYSTEMS, INC.

John A. Stahl
President

JAS/rld

Enclosure:

CC: Professor Paul Slattery
Department of Physics
University of Rochester

RESEARCH REPORT NO. 81-56
INSULATION

Building Officials and Code Administrators, Intl.
17926 South Halsted • Homewood, Illinois 60430 • 312/799-2300

STAYTEX 4119A

STAHL INDUSTRIES, INC.
8TH FLOOR DOLLAR BANK BUILDING
YOUNGSTOWN, OHIO 44503

October 1, 1983

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RESEARCH COMMITTEE RECOMMENDATION

LIMITATIONS FOR ACCEPTANCE

The Stahl Industries Staytex 4119A listed in this Report has been evaluated for conformance to the 1981 edition and 1983 supplement of the BOCA Basic Codes. These findings may be used as part of the technical data required for acceptance by jurisdictions administering these codes with the following limitations.

1. Acceptance of Staytex 4119A is limited to foam plastic insulation having a flame spread of 30 or less and a smoke development rating of 400 or less.

2. Staytex 4119A shall be installed in strict accordance with this report and the manufacturer's instructions.

IDENTIFICATION

All packages or containers of Stahl Industries Staytex 4119A shall be marked at the plant with the identifying symbol "See BOCA Research Report No. 81-56."

This report is subject to annual certification. The failure of the applicant to comply with this requirement will result in the lapse of this report. Further use of, or reference to this report is then no longer permitted.

PRODUCT: INSULATION

Trade Name: Staytex 4119A

Licensees:

Barrier Systems, Inc.
American Isowall Corporation
Woolley & Company
Polymer Development Laboratories, Inc.
Empro Corporation
W.A. Brown & Son, Inc.
K/C Insulation Supply, Inc.

PERFORMANCE OF PRODUCT FOR WHICH EVALUATION IS REQUESTED

Full scale fire performance in accordance with diversified test procedures specified in SPI Bulletin PICC-401

DESCRIPTION AND USE OF PRODUCT

Staytex 4119A is a coating designed to fire protect rigid polyurethane foam insulation from habitable or occupiable spaces.

Staytex is spray applied in a nominal 1/16" thickness. Application temperature must be within a range of 45° F. to 100° F. When used in areas of severe splash spillage or constant high moisture, a top coat shall be applied as recommended by the manufacturer.

Staytex 4119A is furnished in 55 gallon drums containing 50 gallons and should be thoroughly mixed by an agitator prior to spraying. A transfer pump is then placed directly in the drum for spraying.

The catalyst is placed in the proportioner. The proper catalyst ratio at 75° F. is 1% to 1½% by volume. Practical volume usage is roughly 1½ gallon per 50 gallon drums. This is adjusted by the catalyst tank air pressure. The exact amount will vary with the ambient temperature and desired curing time. Some heat is generated by the reaction.

A 1/16" coat may be sprayed in one application. A recoat may be applied in 10 minutes at 70° F.

Full cure to develop maximum hardness and adhesion is approximately 24 hours.

The application of Staytex 4119A requires that the installer use fresh air hoods, or such installer associated equipment as recommended by manufacturer's application instructions.

TEST RESULTS

I. Fire tests, project No. M-2311.2, Report No. 3 dated 12/30/80 and No. 4 dated 6/9/83, were prepared by Herron Consultants, Inc. The tests were conducted in accordance with the Enclosed Room Fire Test as described in the SPI Bulletin PICC-401.

The test specimen consisted of Staytex 4119A spray applied in an average weight of .55 pounds per square foot in a nominal 1/16" thickness over 2" thick Upjohn Company's Trymer U-Thane 190 foam plastic insulation. The wood crib fuel source weighed 30 pounds and was 15" square.

Observation of the test specimen and the thermocouple readings made continuously during the 15-minute period indicated that the Staytex was in place with little discoloration and prevented fire growth in a fire having temperatures exceeding 1,500° F.

II. Adhesion tests of Staytex 4119A to sprayed polyurethane foam insulation materials, File No. R8662 dated 7/8/83 were conducted by Herron Testing Laboratories, Inc. In all samples tested, adhesion of the Staytex was shown to exceed the strength of the polyurethane foam.

"THE STANDARD CODES"

SBCCI

REPORT OF THE COMMITTEE ON
RESEARCH AND COMPLIANCE
ON

THERMAL BARRIERS

SUBMITTED BY:

STAHL INDUSTRIES, INC.
NINTH FLOOR DOLLAR BANK BUILDING
YOUNGSTOWN, OHIO 44503

REPORT NO.
8174

EFFECTIVE DATE
9-1-81

The Committee on Research and Compliance recommends that the product, material, system or method of construction specifically identified in this report be accepted by the building official as complying with the Standard Codes, SUBJECT TO THE LIMITATIONS LISTED IN THIS REPORT.

SOUTHERN BUILDING CODE CONGRESS INTERNATIONAL, INC.
900 Montclair Rd. Birmingham, Alabama 35213

HE COMMITTEE ON RESEARCH AND COMPLIANCE HAS REVIEWED THE D...A SUBMITTED FOR COM-
LIANCE WITH THE STANDARD BUILDING CODE AND SUBMITS TO THE BUILDING OFFICIAL OR
THER AUTHORITY HAVING JURISDICTION THE FOLLOWING REPORT.

PRODUCT TRADE NAME

Staytex 4119A - Ignition and Thermal Barrier for Fire Protecting Foam Plastic Insulation Materials.

LICENSEES

Plas-Chem Coatings
Eagle-Picher Industries, Inc.
6300 Bartmer Industrial Dr.
St. Louis, MO 63130

W. A. Brown & Son, Inc.
P. O. Box 1408
Salisbury, NC 28144

American Isowall Corporation
8055 Production Avenue
Florence, KY 41042

Virginia Door Company
(Wayne Door Company)
Mt. Hope, Ohio 44660

Woolley & Company
6865 Mimms Drive
Atlanta, Georgia 30340

K/C Insulation Supply Inc.
1101 Guinotte Avenue
Kansas City, MO 64120

SYenergy Methods, Inc.
1367 Elmwood Ave.
Cranston, RI 02910

II. PERFORMANCE OF PRODUCT FOR WHICH EVALUATION IS REQUESTED

Fire performance as a thermal barrier over foam plastic insulation in accordance with diversified testing provisions of Section 717.

III. USES

Stahl Industries thermal barrier product is used as a thermal barrier over combustible rigid foam plastics.

IV. DESCRIPTION

Stahl Industries' Staytex 4119A is a spray applied coating that acts as a thermal barrier for foam plastics. The product is applied in a minimum thickness of 1/16 inch and bonded to the foam to form a barrier that functions to protect the foam insulation and prevent fire growth in a fire having the severity of a thirty pound wood fuel source in an enclosed room for 15 minutes. Sprinkler protection is not required.

V. INSTALLATION

The product is installed on foam plastic having a flamespread of 75 or less and a smoke developed rating of 450 or less when tested in accordance with ASTM E84.

Staytex 4119A shall be applied in strict accordance with the manufacturer's published instructions.

VI. SUBSTANTIATING DATA

1. Manufacturer's descriptive literature and application instructions.
2. Test report on Inspection of Fire Resistance Coating in accordance with the Small Enclosed Room Fire Test, prepared by Herron Consultants, Inc., project no. M-2311.2, report no. 3, dated December 30, 1980, signed by Jon B. Peterson, P. E.

VII. REFERENCES TO THE STANDARD BUILDING CODE - 1979 Edition - 1981 Amendments

Section 103.6	Alternate Materials & Alternate Methods of Construction
Section 704	Restrictions on Interior Use of Combustible Materials
Section 717	Foam Plastics

VIII. COMMITTEE RECOMMENDATIONS

The Committee on Research and Compliance in review of the data submitted finds that, in their opinion, Stahl Industries' Staytex 4119A thermal barrier conforms with or is a suitable alternate to that specified in the Standard Building Code or Supplements thereto.

The Committee recommends that Stahl Industries' Staytex 4119A thermal barrier be accepted by the building official or other authority having jurisdiction provided the conditions set forth in this report and in the Standard Codes are observed and the product is installed in compliance with the requirements herein and in accordance with the manufacturer's specifications.

IX. LIMITATIONS

1. Staytex 4119A shall not be installed on foam plastic having a flamespread greater than 75 or a smoke developed rating greater than 450 when tested in accordance with ASTM E84.

2. Staytex 4119A shall be installed in a minimum thickness of 1/16 inch.

3. Staytex 4119A shall not be installed on foams exceeding 4" in thickness except as provided for in Section 717.2(b).

4. Staytex 4119A shall not be diluted in accordance with the manufacturer's recommendations.

5. Only explosion proof equipment shall be used and Staytex 4119A shall not be stored or applied when sources of ignition are present.

X. IDENTIFICATION

Each container of Staytex 4119A shall bear the manufacturer's name and/or trademark, the expiration date, the Southern Building Code Congress International Seal and the number of this report for field identification.

XI. PERIOD OF ISSUANCE

SEE CURRENT SBCCI COMPLIANCE REPORT LISTING FOR STATUS OF THIS RESEARCH AND COMPLIANCE REPORT.

Report prepared by:

Glenn J. Winslow
Associate Research Engineer

Certified by:

William J. Tangye, P. E.
Director of Engineering Services

COMMITTEE ON RESEARCH AND COMPLIANCE
Southern Building Code Congress International

T. Hoyt Page, P. E.
Richardson, Texas

E. L. Woods, P. E.
Matthews, North Carolina

John A. McPherson, Jr., P.E.
State of South Carolina

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JAN 29 1982

Mr. John A. Stahl
Stahl Industries, Inc.
Ninth Floor Dollar Bank Bldg.
Youngstown, OH 44503

Dear Mr. Stahl:

Thank you for your December 4, 1981, letter about a wall and ceiling coating.

Your Staytex 4119A is chemically acceptable as a coating for application to structural surfaces or surfaces where there is a possibility of incidental contact with meat or poultry food product prepared under Federal inspection.

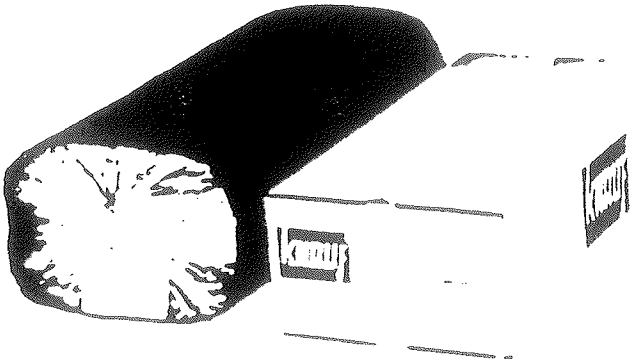
Application of this coating must be in accordance with the standard for equipment design and construction provided in the publication "Accepted-Meat and Poultry Equipment," MPI-2. This acceptance is valid as long as the composition and use remain as described to us. No endorsement of the material or of any concomitant claims is ~ded.

Sincerely,

Donald D. Derr, Chief
Product Safety Branch
Food Ingredient Assessment Division
Science

cc:
Charles Edwards

U.S. DEPARTMENT OF AGRICULTURE
Food Safety and Quality Service
OFFICIAL COPY
Date Issued FEB 16 1982



A. STORAGE

Protect stored insulation from water damage and other abuse. Cartons are not designed for outside storage. Vacuum packaged material can be stored outside if care is taken not to puncture the inner polybag. The outer sleeve will break if it becomes wet.

B. PREPARATION

Apply insulation only on clean, dry surfaces. Metal ducts must be sealed before application. Prescore rigid Insulation Board where necessary to conform to curved surfaces.

C. APPLICATION

1. General

All insulation joints must be firmly butted. Insulation can be secured with adhesive, mechanical fasteners, or banded. Minimum compression is to be used to assure firm fit and still maintain thermal performance.

Vapor barriers should overlap a minimum of 2" (5.08 cm) at all seams, and be sealed with appropriate pressure sensitive tape or mastic. Fasteners shall be located a maximum of 3" (7.62 cm) from each edge and spaced no greater than 12" (30.48 cm) on center.

Where vapor barrier performance is necessary, all penetrations and facing damage shall be repaired with tapes or mastic with a minimum 2" (5.08 cm) overlap. Tapes should be applied using a sealing tool and moving pressure. Use on ducts, plenums, vessels, tanks and equipment operating at temperatures of 450°F (232°C) or less.

Tapes and mastics (dry) should have a UL 723 rating of 25 flame spread, 50 smoke developed.

2. Ducts and Plenums

Use 3.0 pounds per cubic foot (48 kg/m³) Insulation Board in concealed areas.

Use 6.0 pounds per cubic foot (96 kg/m³) Insulation Board in exposed areas.

Insulation Board is not designed to be exposed to the airstream.

3. Vessels, Tanks and Equipment

For irregular surfaces, use 1.6 pound per cubic foot (26 kg/m³) Insulation Board and band with minimum compression.

For outdoor application, Insulation Board must be covered with appropriate jacketing, mastic or other vapor barrier. All exposed surfaces must be protected.

Apply jacketings, mastics and other vapor barriers in accordance with manufacturer's instructions.

The chemical and physical properties of [illegible] Insulation Board represent typical average values determined in accordance with accepted test methods. The data is subject to normal manufacturing variations. The data is supplied as a technical service and is subject to change without notice. References to numerical flame spread ratings are not intended to reflect hazards presented by these or any other materials under actual fire conditions. Check with your [illegible] regional office to assure information is current.

Notes

REGIONAL OFFICES
Northeast—Aberdeen Plaza, 142 Highway 34, Aberdeen, New Jersey 07747 (201) 583-6000
Southeast—30 Perimeter Center East, North East, Suite 218, Atlanta, Georgia 30346 (404) 396-9450
Southwest—Allied Bank Building, Suite 1004, 800 Airport Freeway, Box 6097, Irving, Texas 75062 (214) 438-9448
Western—Suite 304, 1500 Newell Avenue, Walnut Creek, California 94596 (415) 943-1222
Midwest—Midwest Plaza North, Suite 105, 2115 Butterfield Road, Oak Brook, Illinois 60521 (312) 932-9339
Central—Plaza South One, 7251 Engle Road, Cleveland, Ohio 44130 (216) 243-2240
EXPORT OFFICE 250 Bird Road, Suite 309, Coral Gables, Florida 33146 (305) 445-6947

Knauf
Fiber Glass GmbH
Shelbyville, Indiana 46176
(317) 398-4434

Product
Data Sheet

KNAUF INSULATION BOARD

KNAUF
FIBER GLASS

Description

Insulation Board is a thermal and acoustical insulation product made from inorganic glass fibers preformed into boards bonded by a thermosetting resin. The board is available plain, with a factory applied foil-skrim-kraft (FSK) or with a factory applied all service jacket (ASJ).

Applications

Insulation Board is a versatile product designed to be used on heating and air conditioning ducts, power and process equipment, boiler and stack installations and for all applications where insulating or acoustical efficiency is required

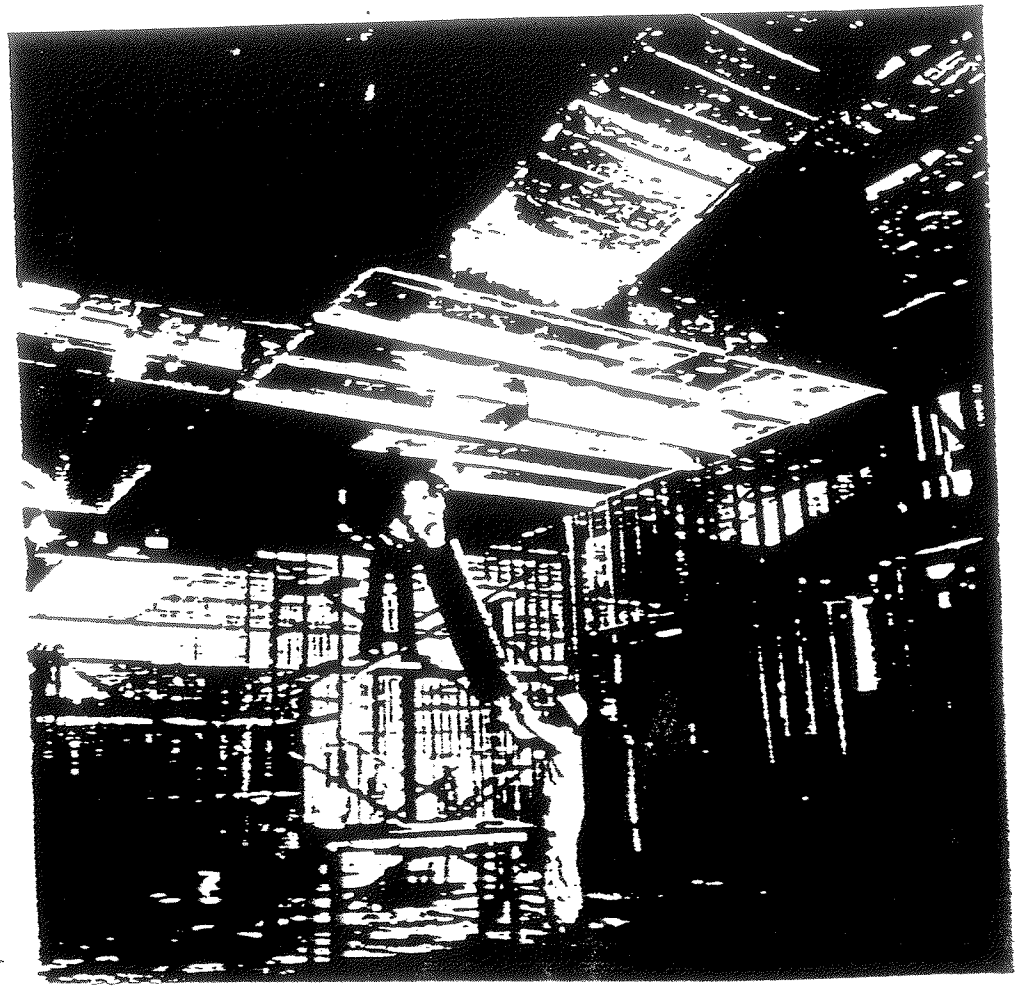
Benefits and Features

ENERGY CONSERVATION. Insulation Board has excellent thermal efficiency which results in lower operating costs.

LOW COST INSTALLATION. Insulation Board is lightweight, easy to handle and fabricate resulting in quicker, lower cost field installation and lower applied costs

NOISE REDUCTION. Excellent acoustical properties effectively reduce sound transmission.

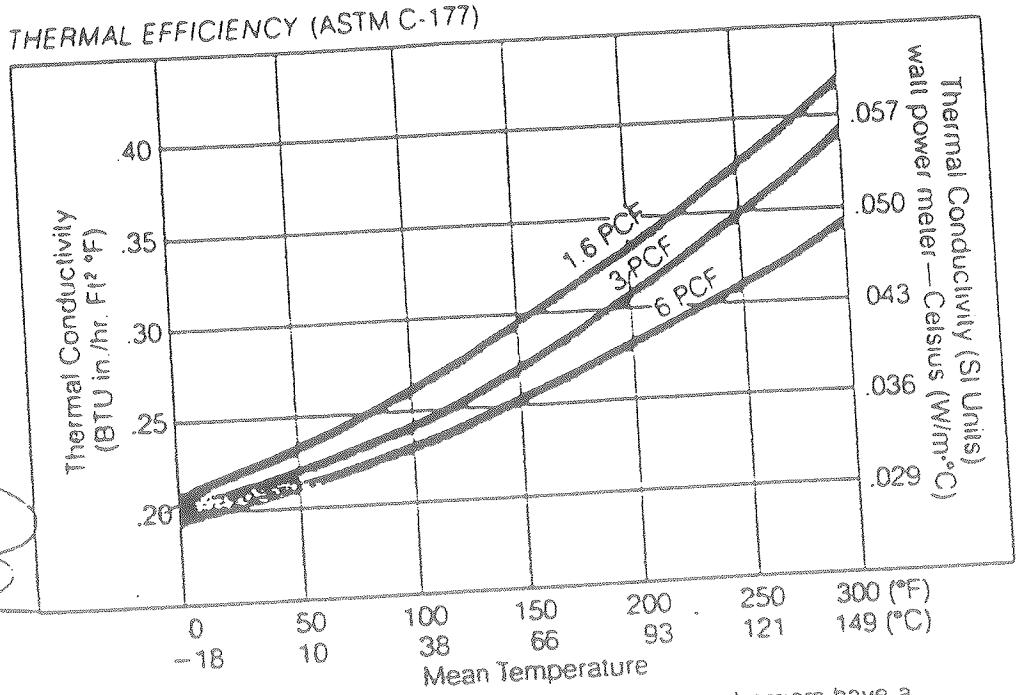
APPEARANCE. Both the FSK and ASJ vapor barrier facings provide a neat finished appearance.



SURFACE BURNING CHARACTERISTICS · Insulation Board (UL Classified) meets the requirements of NFPA-90A and NFPA-90B. When tested in accordance with ASTM E-84 and UL 723 as plain insulation or on a composite basis (insulation, facing and adhesive) · Insulation Board does not exceed
25 Flame spread
50 Smoke developed

TEMPERATURE RANGE · Insulation Board may be used at operating temperatures from −20°F to +450°F (−29°C to +232°C)

THERMAL EFFICIENCY (ASTM C-177)



@ ARGON K=.162
TEMP
-300 °F

VAPOR TRANSMISSION RATE Both FSK and ASJ vapor barriers have a maximum vapor transmission rate of .02 perms

BEACH PUNCTURE RESISTANCE. The FSK facing has a beach puncture resistance of 25 units. The ASJ facing has a resistance of 50 units

CORROSIVITY. Insulation Board will not cause corrosion of aluminum, steel or copper, and passes MIL-I-24244B for chemical and stress corrosion.

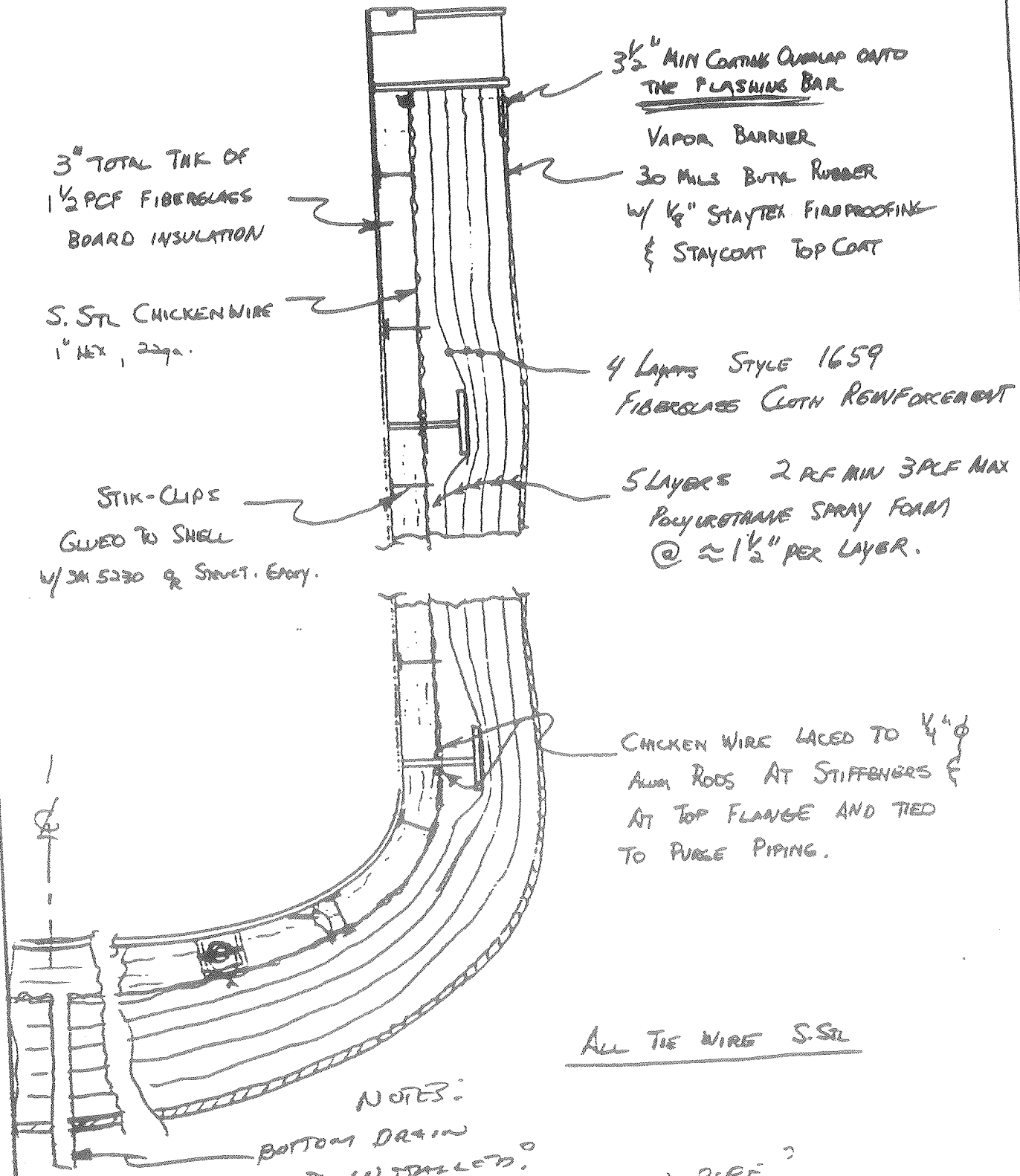
MOISTURE ABSORPTION. Less than 1% moisture absorption by volume when exposed to air at 120°F (49°C) and 95% relative humidity for 96 hours.

SHRINKAGE. Insulation Board exhibits less than 0.3% linear shrinkage when tested in accordance with ASTM C-356.

ACOUSTICAL EFFICIENCY Insulation Board when tested in accordance with ASTM C-423 (No. 6 mounting) has the following efficiencies.

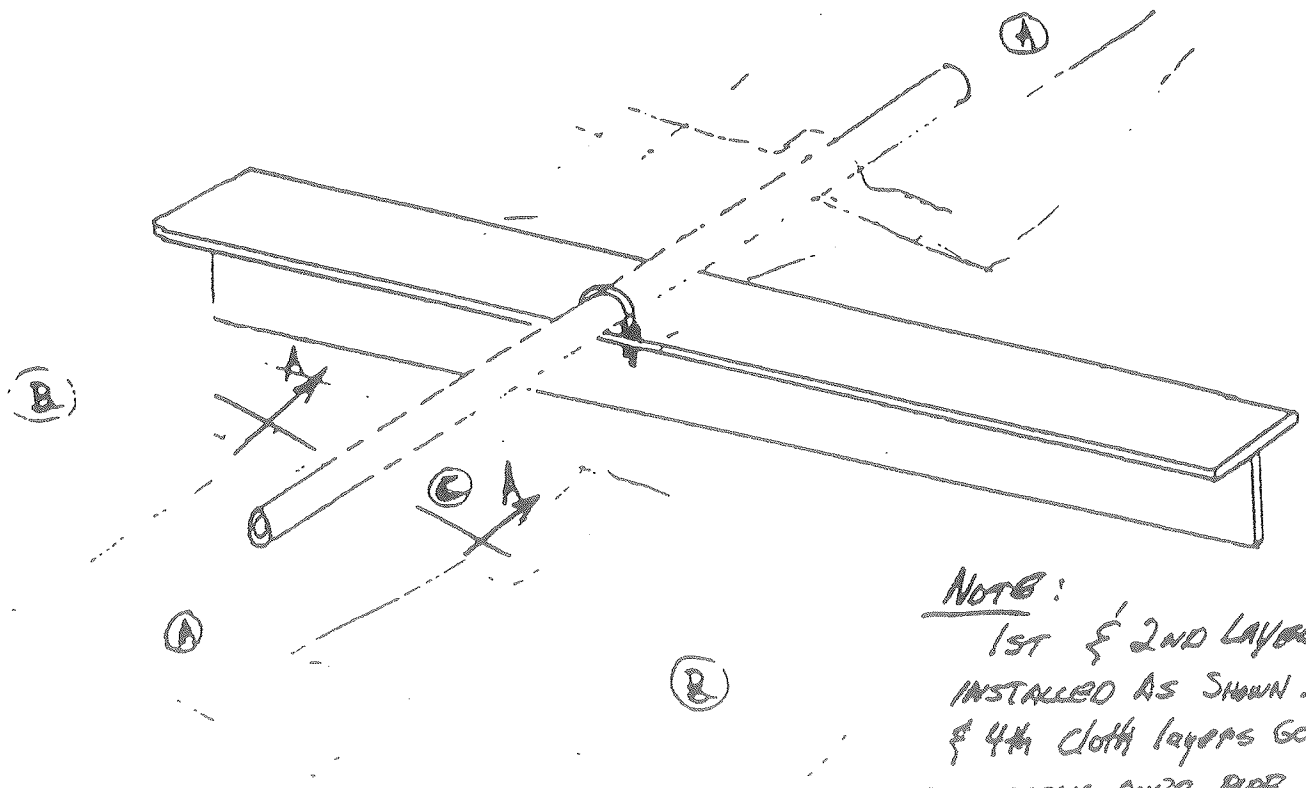
SOUND ABSORPTION COEFFICIENTS. Frequency Hz

Hz	1.6 PCF (26 kg/m³)	3 PCF (48 kg/m³)			6 PCF (96 kg/m³)		
	2" (5.08 cm)	1" (2.54 cm)			1" (2.54 cm)		
	Plain	Plain	FSK	ASJ	Plain	FSK	ASJ
125	.41	.28	.42	.41	.31	.57	.70
250	.74	.49	.51	.50	.46	.36	.42
500	.96	.61	.65	.75	.65	.49	.33
1000	1.01	.80	.89	.78	.95	.48	.48
2000	1.03	.89	.53	.32	1.00	.55	.43
4000	.94	.89	.19	.08	.91	.29	.16
NRC	.95	.70	.65	.60	.75	.45	.40



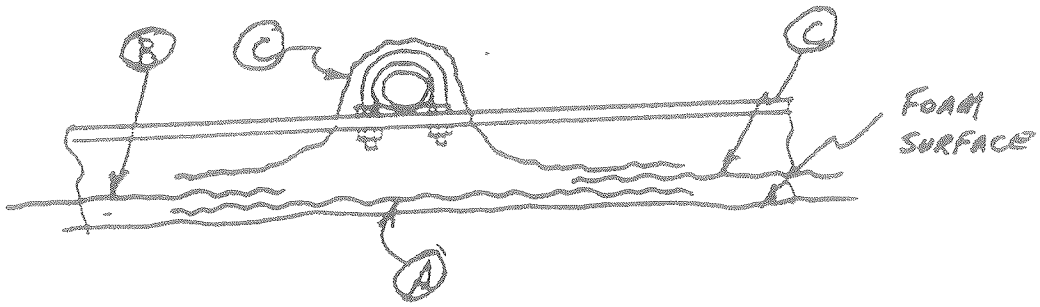
SUBJECT	OFFICE	REVISION		REFERENCE NO.
LIQUID ARGON DEWAR INSULATION DETAILS	OSI OSMS			851553
	MADE BY MPD / CHKD BY	MADE BY / CHKD BY		SHT. 2 OF ___
	DATE 4 OCT 85 / DATE	DATE / DATE		

SO 64 REV SEP 84



NOTE:
1ST & 2ND LAYERS INSTALLED AS SHOWN. 3rd & 4th cloth layers go completely over pipe and stiffener, no special detail

CLOTH LAYOUT



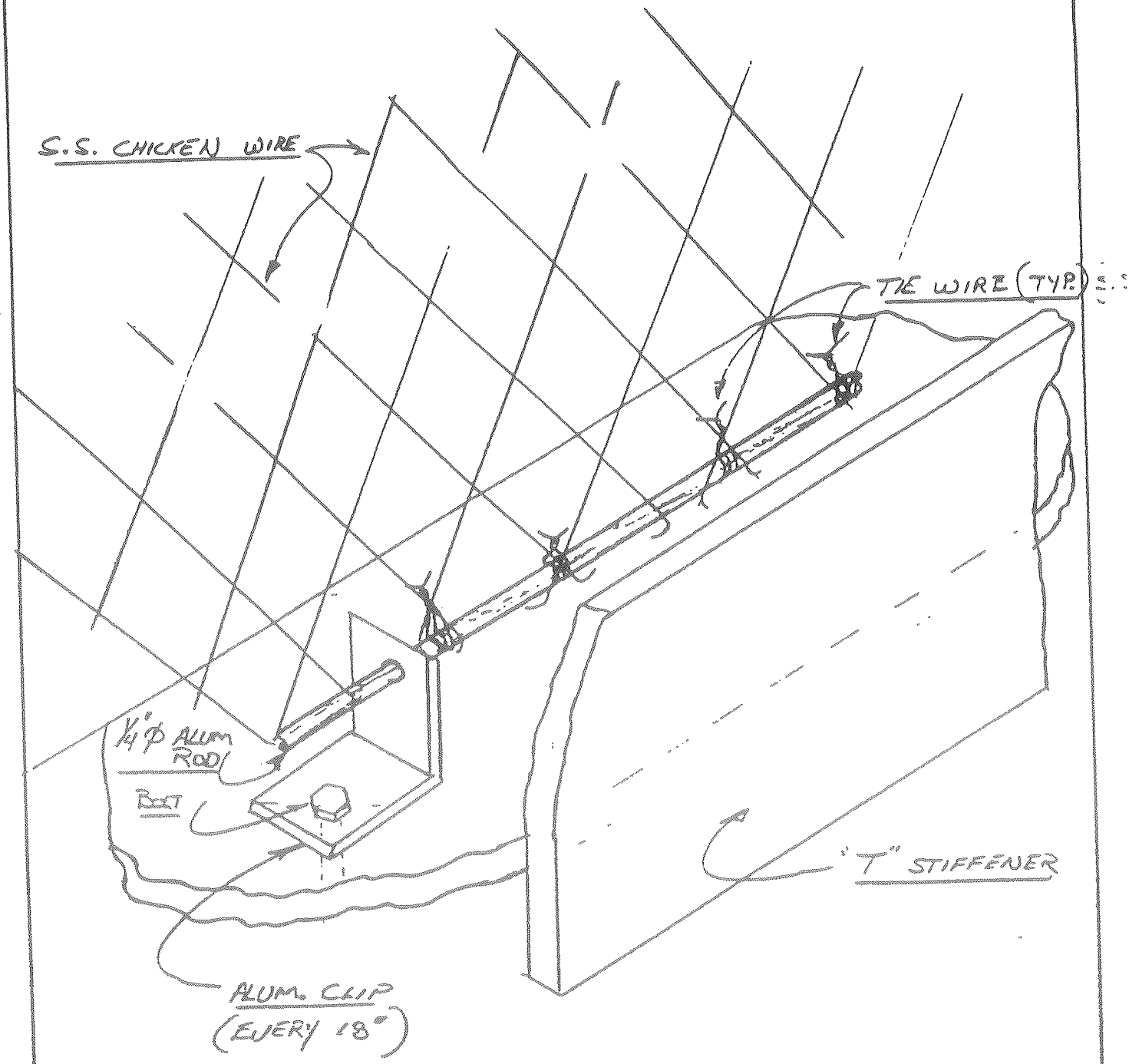
SECT A-A

REINFORCEMENT DETAILS AT PURGE PIPE

(FOAM NOT SHOWN)

SUBJECT	OFFICE	REVISION		REFERENCE NO.
LIQUID ARGON DEWAR INSUL. DETAILS	CBI OB Eng			851553
	MADE BY MKD	CHKD BY	MADE BY	CHKD BY	SHT 3 OF ___
	DATE 4 OCT 85	DATE	DATE	DATE	

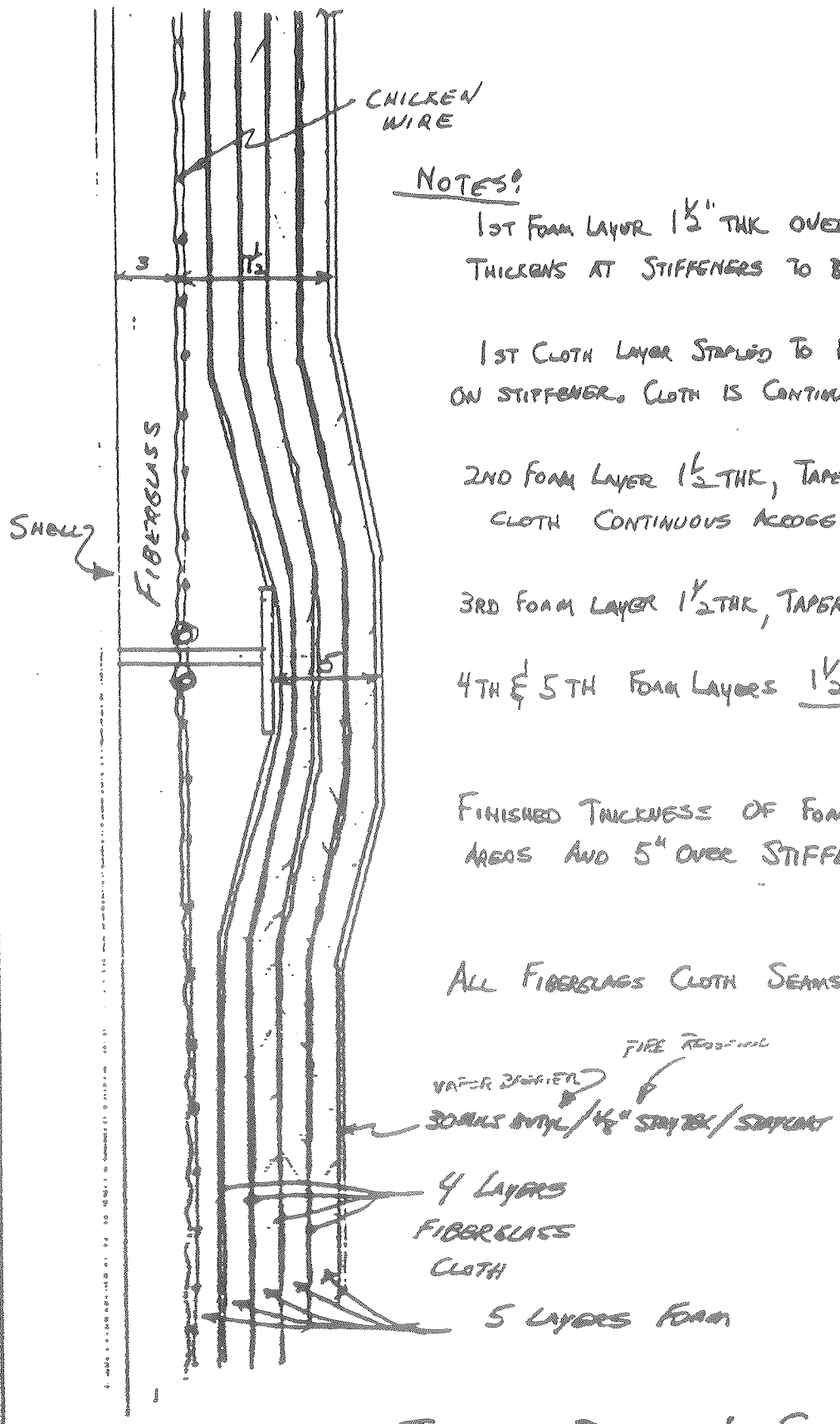
GO 64 REV SEP 8



SUBJECT	OFFICE	REVISION		REFERENCE NO.
LIQUID ARGON DEWAR INSULATION DETAILS	ADE NEW			BE 157
	MADE BY / CHKD BY	MADE BY	CHKD BY	SHT 4 OF —
	DATE 30 OCT 05 / DATE	DATE	DATE	

GO 64 REV SEP 64

Printed in USA



NOTES:

1ST FOAM LAYER 1½" THK OVER FIBERGLASS, AND THICKENS AT STIFFENERS TO BE FLUSH WITH FLANGES

1ST CLOTH LAYER STAPLED TO FOAM AND LAYS DIRECTLY ON STIFFENER. CLOTH IS CONTINUOUS ACROSS STIFFENER

2ND FOAM LAYER 1½ THK, TAPERS TO 1" OVER STIFF. CLOTH CONTINUOUS ACROSS STIFF., ALL LAYERS

3RD FOAM LAYER 1½ THK, TAPERS TO 1" OVER STIFF

4TH & 5TH FOAM LAYERS 1½" THICK OVER ALL

FINISHED THICKNESS OF FOAM IS 7½" IN OPEN AREAS AND 5" OVER STIFFENER.

ALL FIBERGLASS CLOTH SEAMS OVERLAPPED 4" MIN.

TYPICAL DETAIL AT STIFF

SUBJECT	OFFICE	REVISION		REFERENCE NO.
LIQUID ARGON DEWAR INSUL. DETAILS	CBI OR ENG.			851553
	MADE BY: MPO	CHKD BY:	MADE BY:	CHKD BY:	SHT. 1 OF ___
	DATE: 4 OCT 85	DATE:	DATE:	DATE:	

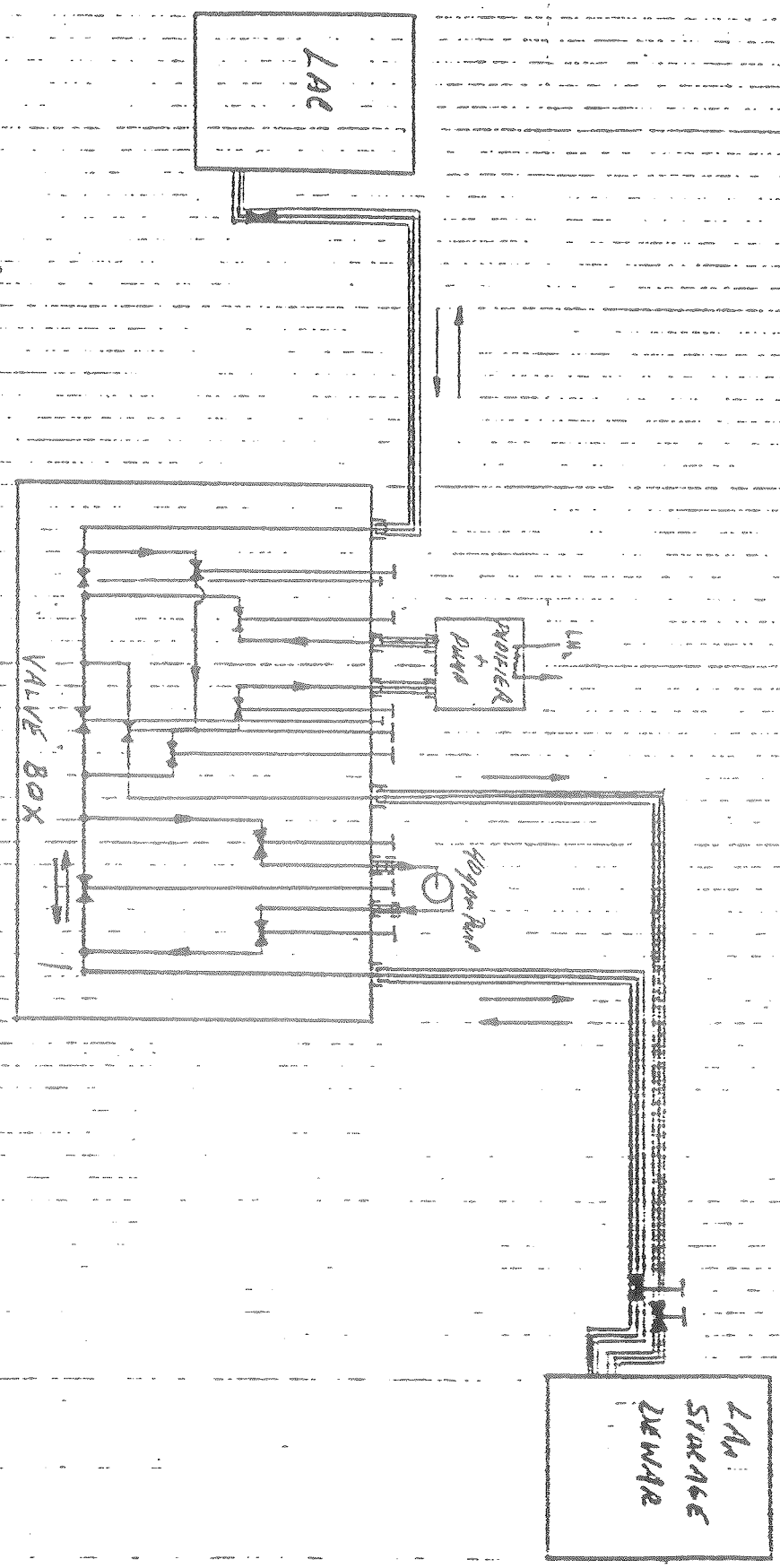
ENGINEERING NOTE	RA CRYO	E706		1

SUBJECT: FLOW DIAGRAM OF VALVE BOX FOR LA_r SYSTEM ON LAC

NAME: J. HARIN

DATE: 12 DEC 85

REVISION DATE:



CAPABILITIES:

1. PRIMARY LINES FILLING LAC
2. PRIMARY LINES DRAINING TO STORAGE DEWAR
3. PRIMARY STORAGE DEWAR LINES DYS — CONNECTION FROM LAC
4. PRE/DURING INTEGRATION (40 gpm PUMP AND FILL DRAIN)

ANDERSON, GREENWOOD & CO.

REPORT NUMBER
2-0175-128

DETERMINATION OF FLOW LOSSES IN INLET AND DISCHARGE HEADERS ASSOCIATED WITH SAFETY RELIEF VALVES

Written By: Walter W. Powell

Walter W. Powell
Vice President-Engineering

Checked By: Donald M. Papa

Donald M. Papa
Project Engineer

Date: 4/17/75

1.0 ABSTRACT

During the study of resonant phenomena in pilot operated safety relief valves described in AGCO Report 2-0175-51, pressure differentials between the reservoir and valve inlet for different riser lengths were measured. Attempts to correlate these measured numbers with those predicted by equations intended for use in low velocity flow (such as Darcy and Weymouth) were not particularly successful.

Additionally, we at Anderson, Greenwood have for years been interested in obtaining a method of calculating the pressure existent at any point in discharge headers (tailpipes) or if the header has zero length, safety valve outlets. The problem has not been in obtaining a theoretical method but rather a theoretical method which gives good correlation with test results and is easily used.

We contacted Dr. Allan J. Chapman of the Rice University for assistance. The method recommended by Dr. Chapman for pressures which produces nozzle choking involves the use of Fanno Lines and is presented here for the use of the Engineer who must install Relief Valves, who desires to obtain satisfactory performance from these valves, and who, like the writer, has been away from school long enough to realize that he requires assistance. The approach is pratical and those interested in theory are referred to Dr. Chapmans excellent book "Introductory Gas Dynamics" or any of the many other available texts. A

For subsonic Flow, a method is presented in Paragraph 5.0 which, while extremely simple, gives excellent results. A

2.0 NOMENCLATURE

L_e = Total Equivalent Length of Pipe (ft)

M_c = Local Mach No. (dimensionless)

Q = Mass Flow Rate (lb/hr)

P_d = Pressure Into Which The Jet Is Discharging (psia)

d_3 = Nozzle Inside Diameter (inches)

T_r = Temperature (° Rankine)

k = Ratio of Specific Heats $\frac{C_p}{C_v}$ (dimensionless)

M = Molecular Weight of Lading Fluid = 28.964 x G

P = Pressure (psia)

L = Equivalent Length of Pipe (inches)

G = Specific Gravity of Lading Fluid (dimensionless)

D = Pipe Diameter (ft)

d = Pipe Diameter (in)

A_n = Area Valve Nozzle (in.sq.)

K_d = Coefficient of Discharge of Valve (dimensionless)(NOTE: Does not contain .9 multiplier required by Winter, 1963 Addenda, Section VIII, ASME Code).

C = Constant for Gas or Vapor (ASME VIII Figure UA230)

P_{Flow} = Valve Inlet Stagnation Flowing Pressure, Normally Set Pressure + Overpressure + 14.7 (psia)

K = Friction Length Parameter $\left(\frac{fL}{d}\right)$

f = Moody Friction Factor for Turbulent Flow in a Pipe (dimensionless)

Q_v = Valve Capacity (scfm)

A

SUBSCRIPTS

0 Stagnation State (where velocity is zero)

1 Entrance of Inlet Pipe

2 Exit of Inlet Pipe (or inlet of safety valve)

3 Nozzle Exit

4 Valve Exit

5 Discharge Header Exit

SUPERSCRIPTS

* Point of Choking in Adiabatic Flow ($M_c = 1.0$)

DEFINITIONS

Adiabatic - Without Loss or Gain of Heat.

Isentropic - Constant Entropy.

Entropy - A Quantity That is the Measure of the Amount of Energy in a System Not Available for Doing Work; Numerical Changes in the Quantity Being Determinable From the Ratio dQ/T Where dQ is a Small Increment of Heat Added or Removed and T is Absolute Temperature.

3.0 INLET HEADERS

3.1 Limitations

The method as presented in Paragraphs 3.0 and 4.0 is limited to those valves having set pressures greater than 15 psig so that critical or choked ($M_c = 1.0$) flow exists at the valve nozzle during the relief cycles. Subsonic valves and headers are covered in Paragraph 5.0. The examples will evaluate only static and total pressure. Temperature may also be determined by Fanno Lines but will not be included in this report. A

3.2 Header Evaluation

Evaluation of either inlet or discharge headers is accomplished by the well accepted method of Equivalent Lengths as outlined in Crane Technical Paper 410 and others. Factors which will influence flow such as entrances, elbows, tees, valves, etc. are expressed as Equivalent Lengths of Pipe. The Equivalent Length of all pipe anomalies affecting flow of the duct in question are added to the actual length to obtain the Total Equivalent Length (Le) of the pipe. Some typical Equivalent Lengths are listed in Figures I and II. The Friction Length Parameter $K = \frac{f(Le)}{d}$ is then determined using Figure III to obtain f.

3.3 Condition One - Nozzle Area Same As Inlet Pipe Area

(A length of pipe only with no valve)

The pressure drop due to adiabatic frictional flow in the inlet pipe is calculated by assuming choked flow ($M_c = 1.0$) at the pipe (or nozzle) exit and by assuming that the inlet of the valve to the nozzle face (if a valve is used) is simply an extension of the pipe. This length is normally very short and practically can be neglected. The Mach No. at the exit may be checked, if desired, from the equation

$$M_{c2} = .00245 \frac{Q}{P_2 \; d^2} \sqrt{\frac{T_r}{k\,M}} \qquad \text{(Note 1)}$$

If the calculated Mach No. is greater than 1.0 (which cannot happen physically due to the choking) the pressure P_2 will readjust itself so that M_{c2} will equal 1.0. Where the calculated Mach No. is equal to or greater than 1.0 this method is applicable. By knowing the Mach No. at the exit, stagnation pressure (P_o) in the tank and properly evaluating the inlet pipe, fluid properties can be evaluated at any point in the pipe.

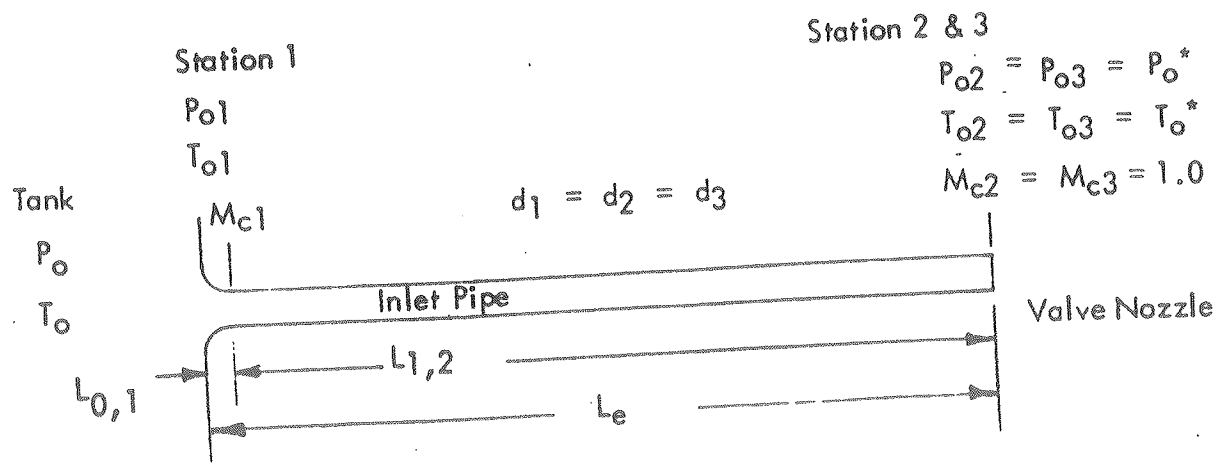
3.3.1 Example

Anderson, Greenwood Type 273, 3 x 44, Set Pressure 490 psig (505 psia). Header is 15 ft (180 in.) of 3 inch schedule 80 pipe (2.9 inch I.D.). Header to tank connection is a 12 inch to 3 inch concentric reducer (L entry = 0 from Figure II) Lading Fluid is natural gas with k = 1.3, G = .60, T = 60°F (520°R).

This condition is a comparatively rare instance and will exist only with full bore pipeline valves, such as the AGCO Series 70, USI Type D and some Farriservo Valves. On these valves, the inlet piping should either be zero length (valve mounted directly on tank) or one pipe size larger and swaged down at the valve to obtain satisfactory performance. Note that the pressure drop between the tank (1) and valve (2) is the change in stagnation pressures.

(DATA SHEET NO. 1)

3.3.2 Solution - Nozzle Same Area As Inlet Pipe Area



1) Known Parameters

Set Pressure,	P_{o1}	= 505 psia
Ratio Specific Heat,	k	= 1.3
Temperature,	T_o	= 60°F
Specific Gravity,	G	= 0.60
Moleclular Weight,	M = 28.964(G)	= 17.38
Inlet Pipe Diameter,	$d_1 = d_2 = d_3$	= 2.9 in.
Inlet Pipe Length,	$L_{1,2}$	= 180 in.

2) Header Evaluation

Header Section	L/d	L	K = fL/d
Entrance	0	0	0
Pipe	62.07	180	1.67
Fittings	0	0	0
Total	62.07	180	1.67

Where: f = .027 (Figure III)

$$L/d = \frac{180}{2.9} = 62.07$$

$$K = fL/d = .027\ (62.07) = 1.67$$

3) From Figure IV, The Mach No. At The Inlet For

$k = 1.3$ and $K = 1.67$, is: $\underline{M_{c1} = .455}$

4) From Figure V, The Stagnation Pressure Ratio For

$k = 1.3$ and $M_{c1} = .455$ is: $\underline{\frac{P_{o1}}{P_{o*}} = 1.42}$

Therefore, the stagnation pressure at the exit (Station 2)

is: $P_{o*} = \frac{P_{o1}}{1.42} = \frac{505}{1.42} = \underline{355.63 \text{ psia}}$

5) The Inlet Pressure Loss is: $P_{o1} - P_{o*} = 505 - 355.63 = \underline{149.37 \text{ psi}}$

3.4 Condition Two - Nozzle Area Smaller Than Inlet Pipe Area

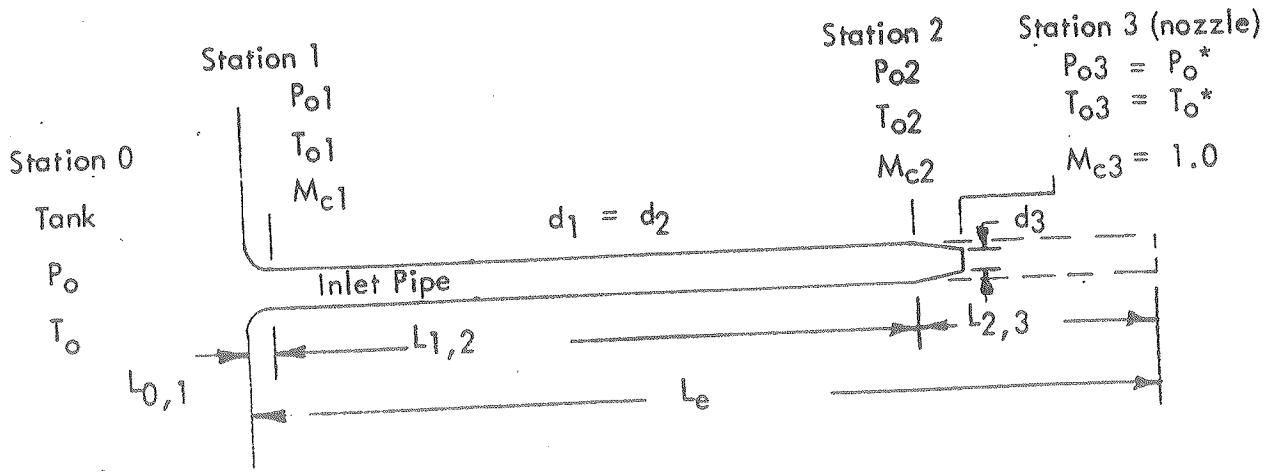
This condition is far more common than Condition One and is found in all "Nozzle" Valves (D thru T Orifice - API 526) or, as in this instance, where the inlet header is one pipe size larger than the valve. The pressure drop due to adiabatic frictional flow in the pipe is calculated by assuming choked flow (sonic) at the nozzle exit as in Condition One and isentropic flow in the nozzle. Knowing the Mach No. ($M_{c3}^* = 1.0$) at the nozzle exit and the effective area ratio A2/A3, the Mach No. (M_{c2}) at the valve entrance is found from Figure VII. Note that the actual nozzle area of the valve (A_n) is multiplied by the Discharge Coefficient K_d to obtain A3. Utilizing the Mach No. (M_{c2}) just found, the Friction Length Parameter $\frac{fL}{d}$ for a theoretical pipe length which would be required to accelerate the flow from M_{c2} to $M_{c3} = 1.0$ is found from Figure IV. This theoretical length replaces the nozzle. The Friction Length Parameter of the inlet pipe $\frac{fL_{1,2}}{d_1}$ is added to the theoretical expression $\frac{fL_{2,3}}{d_1}$ to obtain $\frac{fL_e}{d_1}$ Conditions at any point in the pipe (Such as at Station 2) are then readily determined.

3.4.1 Example

Same as 3.3.1 except that inlet header size has been changed from 3 inch to 4 inch (3.9 inch Inside Diameter) The actual coefficient of discharge $K_d = .809/.9 = .90$. If desired, Temperatures and/or Static Pressures may be simularly found in the same manner from the appropriate curves which are included. Additionally, now that the actual conditions at the valve inlet during flow are known, the capacity which the valve will deliver can be readily determined from standard sizing formulae.

(DATA SHEET NO. 2)

3.4.2 Solution - Nozzle Area Smaller Than Area of Inlet Pipe



1) Known Parameters

Set Pressure,	P_{o1}	= 505 psia
Ratio Specific Heat,	k	= 1.3
Temperature,	T_o	= 60°F
Specific Cravity,	G	= 0.60
Molecular Weight,	M = 28.964(G)	= 17.38
Inlet Pipe Diameter,	$d_1 = d_2$	= 3.9 in.
Valve Nozzle Diameter,	d_3	= 2.9 in.
Valve Coefficient of Discharge	K_d	= 0.90
Inlet Pipe Length,	$L_{1,2}$	= 180 in.

2) Header Evaluation

Header Section	L/d	L	K = fL/d
Entrance	0	0	0
Pipe	46.15	180	1.15
Fittings	0	0	0
Total	46.15	180	1.15

Where: f = .025 (Figure III)

$$L/d = \frac{180}{3.9} = 46.15$$

$$K = fL/d = .025\,(46.15) = 1.15$$

3) The Isentropic Area Ratio of the Valve Inlet to the Valve Nozzle is: $\frac{A2}{A3} = \frac{(d_2)^2}{(d_3)^2 K_d} = \frac{(3.9)^2}{(2.9)^2 (.90)} = \underline{2.00}$

From Figure VII, the Mach No. at Station 2 (M_{c2}) = $\underline{0.31}$ for k = 1.3 and Isentropic Area Ratio of 2.00.

4) From Figure IV, the Friction Length Parameter (fL/d) of a theoretical pipe length required to accelerate the flow from $M_{c2} = 0.31$ to $M_{c3} = 1.00$ is $\underline{5.25}$ for k = 1.3.

5) From Figure V, the Stagnation Pressure Ratio $\frac{P_{o2}}{P_o^*}$ is $\underline{2.00}$ for k = 1.3 and a Mach No. (M_{c2}) of 0.31 as determined in Step 3.

6) The Total Friction Length Parameter (fL/d) of the actual plus theoretical pipe is $\frac{fL_{1,2}}{d_1} + \frac{fL_{2,3}}{d_2} = 1.15 + 5.25 = \underline{6.40}$

$\frac{fL_{1,2}}{d_1}$ was determined in Step 2, $\frac{fL_{2,3}}{d_2}$ was determined in Step 4.

7) From Figure IV, the Mach No. at Station 1 (M_{c1}) is $\underline{0.29}$ for a Friction Length Parameter of 6.40.

8) From Figure V, the Stagnation Pressure Ratio $\frac{P_{o1}}{P_o^*}$ is 2.11 for k = 1.3 and a Mach No. (M_{c1}) of 0.29 as determined in Step 7.

9) The Stagnation Pressure at Station 3 (the exit) is:

$$P_o^* = \frac{P_{o1}}{2.11} = \frac{505}{2.11} = \underline{239} \text{ psia}$$

10) The Stagnation Pressure at Station 2 (the valve inlet) is $P_{o2} = 2.00\ P_o^*$ from Step 5. Using $P_o^* = 239$ as determined in Step 9, $P_{o2} = 239\ (2.00) = \underline{478}$ psia

11) The Inlet Pressure Loss is: $P_{o1} - P_{o2} = 505 - 478 = \underline{27}$ psi

4.0 DISCHARGE HEADERS (TAILPIPES)

4.1 Theory

The approach used in Discharge Headers is singularly different to that used on Inlet Headers. The Inlet Header calculation described in Paragraph 3.0 uses two known conditions. These are 1) Tank Stagnation Pressure and 2) Mach No. at the valve nozzle ($M_c = 1.0$). Neither of these conditions is known to the engineer when designing discharge headers, and as a consequence, the approach must be different. As presented here, one must first calculate the mass flow rate of the safety valve from the normal valve sizing formulae using the actual inlet condition to the valve as determined in Section 3.0. Note that again the actual coefficient of the valve K_d is used.

Knowing the Mass Flow Rate, Q and applying the equation from Paragraph 3.3 $M_{c5} = \frac{.00245\,Q}{P_5 (d_5)^2} \sqrt{\frac{T_r}{k\,M}}$ The Exit Mach No. (M_{c5}) A

can be determined by assuming $P_5 = 14.7$ psia.

If the expression yields a Mach No. equal to one or less, the assumed pressure of 14.7 psia for P_5 was correct. If the Mach No. calculates to be greater than one, the assumed pressure for P_5 was incorrect. The correct Static exit pressure, P_5, may be determined by letting $Mc5 = 1.0$ and calculating P_5. P_5 may also be calculated by multipling the assumed pressure (14.7 psia) used in the first trial, by the calculated Mach No. We therefore know the Exit Mach No. (M_{c5}) and the Exit Static Pressure (P_5). See Paragraph 4.3 for M_{c5} less than 1.0.

Knowing these conditions, Fanno Lines can be used to determine the static pressures anywhere in the discharge header. If Stagnation pressures are desired, they may be readily obtained using the Mach No. at the Station in question and calculating the Stagnation Pressure using Figure VIII, which is a plot of

$$P_o = P\left(1 + \left(\frac{k-1}{2}\right) M^2\right)^{\frac{k}{k-1}} \qquad \text{(Note 2)}$$ A

Of interest to the writer is the fact that while Stagnation Pressures (P_o) are unmistakeably used to determine inlet loss to the valve and subsequent valve capacity, there seems to be inconsistency relating to pressures in the discharge header. Considering the effect of back pressure on a theoretically perfect nozzle in a duct, critical (choked) flow will exist until the ratio of stagnation pressures approaches 0.5. (Note 3) The writer thus believes that stagnation pressures should be used to evaluate discharge headers also and that valve performance is affected by stagnation pressures. The, study of available documents either finds no reference as to whether the type of pressure is static or stagnation (API RP 520 Part 1, Figure 4 and Figure 6) or where reference is made, graphically shows it to be static. (API RP 525). The Study of the Outlet Area/Orifice Area ratios of the various valve sizes in API 526 shows that this ratio will vary from approximately 40/1 to 2.6/1. Thus the velocity will vary greatly at the valve outlet and as a consequence the ratio of Stagnation Pressure/Static Pressure will also vary. Figure VIII shows this variation will be in the order of 2/1.

The performance of a valve with a relatively large outlet area would not be indicative of the performance of a valve with a small outlet in the same geometric line. The consequences of this implication could be that 1) 150 lb. discharge flanges could be selected where 300 lb. flanges are needed or 2) use of static pressures could show that the valve capacity might be essentially unaffected by a calculated 10% back pressure (API RP 520 Figure 6) whereas Stagnation Pressure could be twice as great and the valve would have zero capacity. This paper does not recommend the use of either static or stagnation pressure values, but leaves the selection to the users judgement. Should the pressures developed in the discharge header affect valve capacity, an iterative approach is required on both inlet and outlet header due to the interaction between the two.

A

4.2 Condition One - Theoretical Mach No. at Discharge Header Outlet Equal to or Greater Than One

4.2.1 Example

Anderson, Greenwood Type 2J3, Series 100, Set Pressure is 175 psia. Valve nozzle diameter is 1.347 inches and nozzle coefficient is .975. Discharge header is 29.5 inches of 3 inch Schedule 40 pipe (3.06 inch I.D.). Lading fluid is natural gas with $k = 1.3$, $G = 0.60$, $C = 345$ and $T = 45°F$.

(DATA SHEET NO. 3)

4.2.2 Solution - Discharge Header Exit Mach No., $M_{c5} = 1.0$

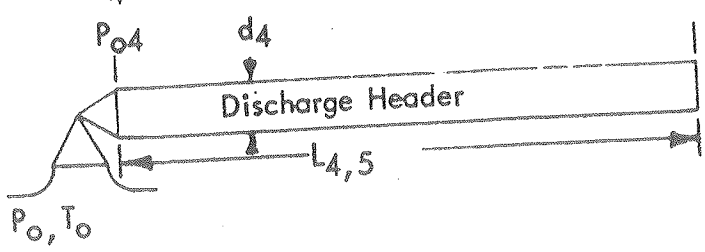
Station 4

M_{c4}
P_4
P_{o4}

Station 5

$M_{c5} \geqq 1.0$

$P_5 = P^*$ 14.7 psia (assumed)



NOTE: If valve discharges into a constant pressure header, use known pressure.

1) Known Parameters

Set Pressure,	P_o	= 175 psig
Ratio Specific Heat,	k	= 1.3
Temperature,	T_o = 45°F	= 505°R
Specific Gravity,	G	= 0.60
Molecular Weight,	$M = 28.964(G)$	= 17.38
Gas Constant,	C	= 345
Valve Nozzle Diameter,	d_3	= 1.347 in.
Valve Coefficient of Discharge,	K_d	= 0.975
Discharge Header Diameter,	d_4	= 3.06 in.
Discharge Header Length,	$L_{4,5}$	= 29.5 in.

2) Header Evaluation

Header Section	L/d	L	K = fL/d
Pipe	9.6	29	.24
Fittings	0	0	0
Total	9.6	29	.24

Where: $f = .025$ (Figure III)

$$L/d = \frac{29.5}{3.06} = 9.6$$

$$K = fL/d = .025\,(9.6) = .24$$

B

3) Capacity, $Q = \frac{C K_d (d_3)^2 \pi}{4} [P_o(1.1) + 14.7] \sqrt{\frac{M}{T_r}}$ (lb/hr)

$$Q = \frac{345(.975)(1.34)^2 \pi [175(1.1) + 14.7]}{4} \sqrt{\frac{17.38}{505}}$$

$$Q = 18425 \text{ lb/hr}$$

4) Mach No. $M_{c5} = \frac{.00245\,Q}{P_5 (d_4)^2} \sqrt{\frac{T_r}{k\,M}}$

Assuming $P_5 = 14.7$ psia,

$$M_{c5} = \frac{.00245(18,425)}{14.7(3.06)^2} \sqrt{\frac{505}{1.3(17.38)}}$$

$$M_{c5} = 1.545$$

Since the Mach No., M_{c5} is greater than one, the actual Static exit pressure,

$$P_5 = M_{c5}\,(14.7) = 1.545\,(14.7)$$
$$= 22.71 \text{ psia}$$

5) From Figure IV, the Mach No. at the inlet to the discharge header (valve outlet) for k = 1.3 and K = .24 is:

$$\underline{M_{c4} = .695}$$

6) From Figure VI, the Static Pressure Ratio at the inlet to the outlet of the header for k = 1.3 and $M_{c4} = .695$ is:

$$\underline{\frac{P_4}{P^*} = 1.46}$$

Therefore, Static Pressure at valve outlet (discharge header inlet), $P_4 = P^*\,(1.46) = P_5\,(1.46) = 22.71\,(1.46)$

$$P_4 = 33.15 \text{ psia}$$

7) From Figure VIII, the ratio of Stagnation Pressure/Static Pressure at the valve outlet (discharge header inlet) for k = 1.3 and $M_{c4} = .695$ Is:

$$\frac{P_{o4}}{P_4} = 1.35$$

Therefore, the Stagnation Pressure at the valve outlet

$$P_{o4} = 1.35\,P_4 = 1.35\,(33.15) = 44.75 \text{ psia}$$
$$= 30 \text{ psig}$$

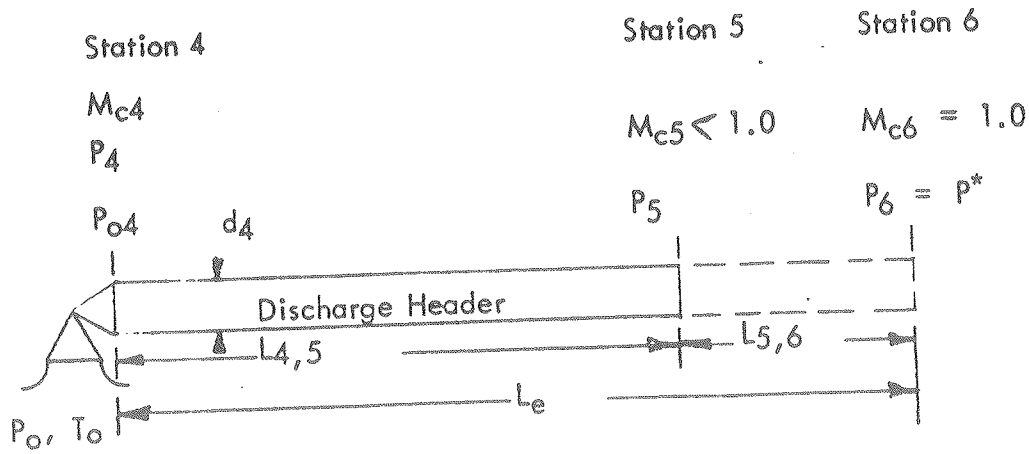
4.3 Condition Two - Theoretical Mach No. at Discharge Header Outlet Less Than 1.0.

4.3.1 Example

Anderson, Greenwood Type 2J3, Series 100 Set Pressure is 15 psig, valve nozzle diameter is 1.347 in., nozzle coefficient is .975. Discharge header is 29.5 inches of Schedule 40 pipe (3.06 inch I.D.). Lading fluid is natural gas with $k = 1.3$, $G = 0.60$, $C = 345$ and $T = 45°F$.

(DATA SHEET NO. 4)

4.3.2 Solution - Discharge Header Exit Mach No. $M_{c5} < 1.0$



1) Known Parameters

Set Pressure,	P_o	= 15 psig
Ratio Specific Heat,	k	= 1.3
Temperature,	T_o	= 45°F
Specific Gravity,	G	= 0.60
Molecular Weight,	M = 28.964(G)	= 17.38
Gas Constant,	C	= 345
Valve Nozzle Diameter,	d_3	= 1.347 in.
Valve Coefficient of Discharge,	K_d	= .975
Discharge Header Diameter,	d_4	= 3.06 in.
Discharge Header Length,	$L_{4,5}$	= 29.5 in.

2) Header Evaluation

Header Section	L/d	L	K = fL/d
Pipe	9.6	29.5	.24
Fittings	0	0	0
Total	0	0	.24

Where: f = .025 (Figure III)

$$L/d = \frac{29.5}{3.06} = 9.6$$

$$K = fL/d = .025\,(9.6) = .24$$

3) Capacity, $Q = \dfrac{C K_d (d_3)^2 \pi \left[P_o(1.1) + 14.7\right]}{4} \sqrt{\dfrac{M}{T_r}}$ (lb/hr

$$Q = \frac{345(.975)(1.347)^2 \pi \left[15(1.1) + 14.7\right]}{4} \sqrt{\frac{17.38}{505}}$$

$$Q = 2774.5 \text{ lb/hr}$$

4) Mach No. $M_{c5} = \dfrac{.00245\,Q}{P_5 (d_4)^2} \sqrt{\dfrac{T_r}{k\,M}}$

$$M_{c5} = \frac{.00245(2774.5)}{14.7(3.06)^2} \sqrt{\frac{505}{1.3(17.38)}}$$

$$M_{c5} = 0.233$$

Since the Mach No., M_{c5} is less than one, the assumption that P_5, the Static exit pressure was 14.7 psia is correct.

5) From Figure IV, the Friction Length Parameter of a theoretical pipe attached to the header exit in which the flow is accelerated to Mach one at its exit for $k = 1.3$ and $M_{c5} = .233$

Is 11.0.

6) From Figure VI, the Static Pressure Ratio at the inlet to the outlet of the theoretical pipe exit for $k = 1.3$ and $M_{c5} = .233$

Is $\dfrac{P_5}{p^*} = 4.5$

7) The Friction Length Parameter of Actual Header plus theoretical extension Is $\dfrac{fL_{4,5}}{d_4} - \dfrac{fL_{5,6}}{d_4} = .24 - 11.0 = 11.24$

8) From Figure IV, the Mach No., M_{c4}, at the inlet to the discharge header (valve outlet) for $k = 1.3$ and $K = 11.24$

Is $M_{c4} = .230$

9) From Figure VI, the Static Pressure Ratio at the inlet of the actual header to the outlet of the theoretical extension

$\dfrac{P_4}{p^*} = 4.55$ for $k = 1.3$ and $M_{c4} = .230$

10) The Static Pressure at the exit of the theoretical pipe extension,

$$P^* = \frac{P_5}{4.5} \quad \frac{14.7}{4.5} = \underline{3.266 \text{ psia}}$$

11) The Static pressure at the actual header inlet (valve outlet),

$$P_4 = 4.55\, P^* = 4.55\,(3.266) = \underline{14.86 \text{ psia}}$$

$$= \underline{.16 \text{ psig}}$$

12) From Figure VIII, the ratio of Stagnation pressure to Static pressure at Station 4 for $k = 1.3$ and $M_{c4} = .230$ is

$$\frac{P_{o4}}{P_4} = 1.15$$

$$P_{o4} = 1.15\,(14.86)$$

$$= \underline{17.09} \text{ psia}$$

$$\underline{2.39} \text{ psig}$$

5.0 SUBSONIC FLOW

5.1 Theory

In subsonic flow all valves (including the safety valve), pipe, and fittings in both the inlet and discharge headers affect the flow rate through the system (since choked flow does not exist). The approach presented here is somewhat unconventional in that after properly evaluating the equivalent lengths of all involved plumbing, the pressure loss is assumed to be linear between the static tank pressure and the static pressure into which the system is discharging (normally atmosphere). The pressure at any desired point may now be found by pressure - length ratio. Knowing the pressures existant at the valve inlet and outlet, the capacity of the valve is readily calculated by appropriate formulae and the pressure drop between the valve and tank is determined by simple subtraction. This method is applicable only to installations where the tank pressure does not exceed 15 psig and where the Mach No. (M_{c5}) at Station 5, discharge header exit, does not exceed 1.0. The Mach No., M_{c5}, may be determined using the equation

$$M = .00245 \frac{Q}{P_2 d^2} \sqrt{\frac{T_r}{k M}}$$

where d is the diameter of the inlet pipe ($d_{1,2}$) and P_2 is the absolute pressure at the discharge header exit. (1)

This approach to subsonic headers has been verified by extensive tests at the Anderson, Greenwood ASME certified laboratory in El Campo and agreement between measured and calculated results are within +/- 2%.

(1) The inlet pipe I D must be used since the actual discharge header, being normally larger than the inlet pipe is replaced by its equivalent length of inlet pipe in the calculations. The Mach No. (M_{c5}) in this equivalent pipe must be lower than 1.0 for the method to be applicable.

5.2 Condition One - Inlet Header, Safety Valve & Discharge Header

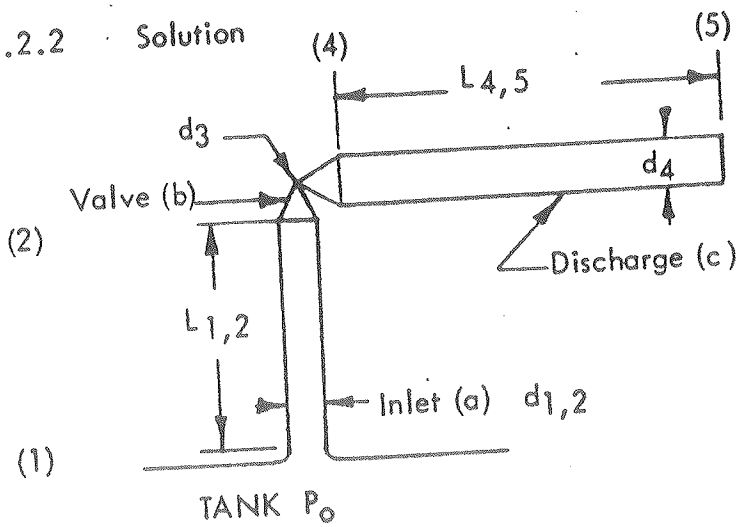
5.2.1 Example

Anderson, Greenwood 2 x 3 Type 93, set pressure 5.0 psig. L/D from Figure X is 79, Inlet Header is 45.0 inches, 2 inch schedule 40 steel pipe (2.067 in I D), Discharge Header 91 inches, 3 inch schedule 40 pipe (3.068 I D). Lading Fluid is natural gas with k = 1.3, G = .60, T = 60°F. Valve is assumed to have remote pickup so that it is fully open at set and stays fully open irrespective of inlet pressure loss.

C

(DATA SHEET NO. 5)

5.2.2 Solution



1) Known Parameters

Set Pressure,	P_o	= 5.0 psig	
Ratio Specific Heat,	k	= 1.3	
Temperature,	T_o = 60°F	= 520°R	
Specific Gravity,	G	= .60	
Molecular Weight,	$M = 28.964\ (G)$	= 17.38	
Equivalent Length,	L/D	= 79	B
Inlet Header Length,	$L_{1,2}$	= 45.0 inches	
Inlet Header Diameter,	$d_{1,2}$	= 2.067 inches	
Discharge Header Length,	$L_{4,5}$	= 91.0 inches	
Discharge Header Diameter,	$d_{4,5}$	= 3.068 inches	
Coefficient of Discharge	$K_d = \frac{K}{.9}$	$\frac{.845}{.9} = .939$	
Header Exit Pressure	P_5	= 0 psig	B
Valve Orifice Area	A	= 2.29 in^2	B

2) System Evaluation

Section	L/d	L
Inlet Header	21.8	45.0
Valve	79 (a)	164
Discharge Header	6.1	12.63 (b)
Inlet	0	0
Total		221.16

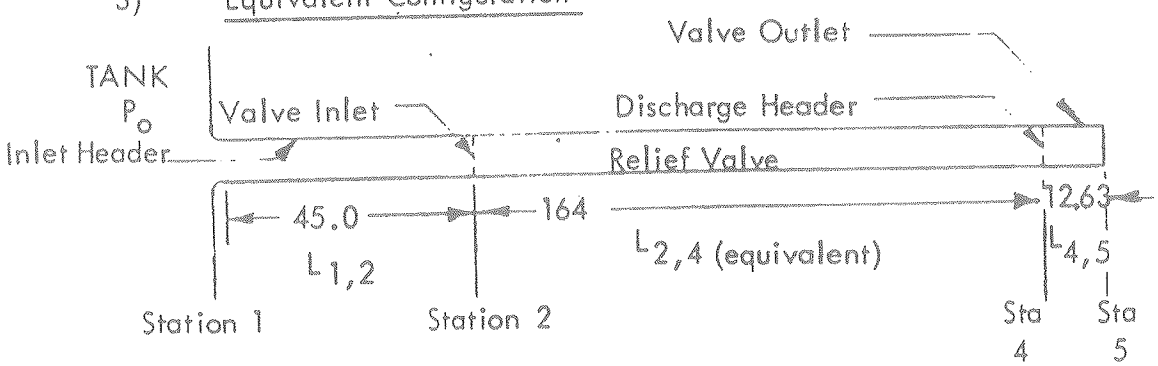
(a) From Figure X

(b) Discharge header length = 91.0 inches of 3.068 I D pipe. Since the equivalent length given in terms of pipe diameter, is a function of the fourth power of the pipe diameter,

$$\frac{L}{D} = \frac{91.0}{3.068} \cdot \left(\frac{2.067}{3.068}\right)^4 = 6.111$$

$$L = 2.067\,(6.111) = 12.63 \text{ in.}$$

3) Equivalent Configuration



4) Pressure Calculation Stations 1, 2, 4, & 5

$$P_1 = P_o = 5.0 \text{ psig}$$

$$P_5 = P_{atmos.} = 0 \text{ psig}$$

$$P_2 = 5.0 - 5.0\,\frac{(45.0)}{(221.16)} = 3.98 \text{ psig}$$

$$P_4 = 5.0 - 5.0\,\frac{(164 + 45.0)}{(221.16)} = .285 \text{ psig}$$

Note that the pressure differential across the valve, $P_2 - P_4$, is 3.69 psi, not 5.0 psi as would have been assumed without piping calculations.

5) Valve Capacity

$$Qv = \frac{863\ K_d\ AF \sqrt{\Delta P\ (P)}}{GT} \quad \text{SCFM}$$

Where K_d = Valve nozzle coefficient of discharge

A = Valve nozzle area (in.)

F = Factor based on ratio of specific heats C_p/C_v *

ΔP = Inlet Pressure (psig) minus outlet pressure (psig) B

P = Outlet Pressure (psia)

G = Specific Gravity

T = Inlet Temperature, °R (°F + 460)

a) Rated Capacity

$$Qv = \frac{863\ (.939)(2.29)(.976)\ \sqrt{5(14.7)}}{\sqrt{.60\ (520)}}$$ B

Qv = 879.15 SCFM B

NOTE: The actual nozzle coefficient, K_d = .939, was used. The .9 multiplier required by the ASME code is not used in pressure drop calculations. The valve is assumed to fully open and piping pressure losses are ignored.

b) Actual Capacity

The actual capacity of the valve (with remote pressure pickup to insure full lift at set pressure) is:

$$Qv = \frac{863\ (.939)(2.29)(.982)\ \sqrt{(3.98 - .285)(.285 + 14.7)}}{\sqrt{.60\ (520)}}$$ B

Qv = 768.09 SCFM B

c) Comparing capacities, we find that the valve is flowing 111.06 SCFM or 13% less than design. The maximum recommended pressure drop per API RP 520 is 3%. B

* AGCO Catalog 1800

6) The Mach No. of the Theoretical 2 Inch Discharge Pipe is:

$$M_{c5} = .00245 \frac{Q}{P_5 d^2} \sqrt{\frac{T_r}{k M}}$$ B

Where $Q = 768.09 (.0749)(.6)(60) = 2071$ lbs./hr. B

P_5 = 14.7 psia, pressure at discharge header exit. B

d = 2.068 in., dia. of inlet pipe.

T_r = 520°R, Temperature of Lading Fluid

k = 1.3, Ratio of Specific Heats.

M = 17.38, Molecular Wt. of Lading Fluid

Q_v = 807 SCFM B

$$M_{c5} = \frac{.00245(2071)}{(14.7)(2.068)^2} \sqrt{\frac{520}{1.3(17.38)}}$$ B

$M_{c5} = .387$ Therefore this approach is applicable since Mach No. is less than one 1.0 (choked flow does not exist) B

NOTES:

(1) Compressed Gas Handbook SP 3045 NASA

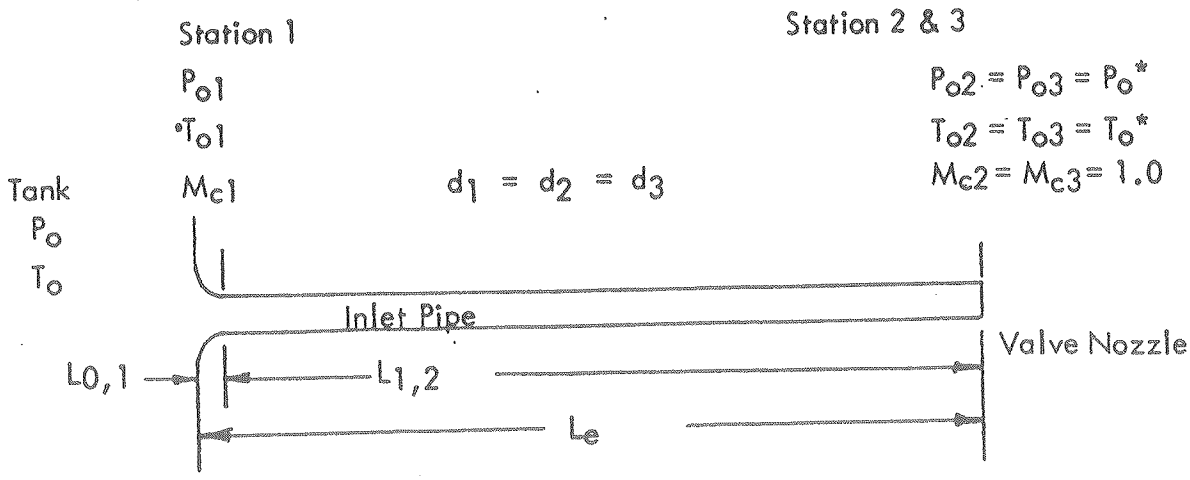
(2) Equation 5.31 Compressed Gas Handbook SP 3045 NASA

(3) Figure 6.10 Chapman

(4) Pages 37 and 38 used with permission of Crane Co.

DATA SHEET NO. 1

(Nozzle Area Same As Inlet Pipe Area)



1. Known Parameters

Set Pressure,	P_{o1}	=	psia
Ratio Specific Heat,	k	=	
Temperature,	T	=	°F
Specific Gravity,	G	=	
Molecular Weight,	M = 28.964(G)	=	
Inlet Pipe Diameter,	$d_1 = d_2$	=	in.
Inlet Pipe Length	$L_{1,2}$	=	in.

2. Header Evaluation

Header Section	L/d	L	K = fL/d
Entrance			
Pipe			
Fittings			
Total			

Where: f = (From Figure III)

3. Mach No. at inlet (From Figure IV), M_{c1} =
using k and K above.

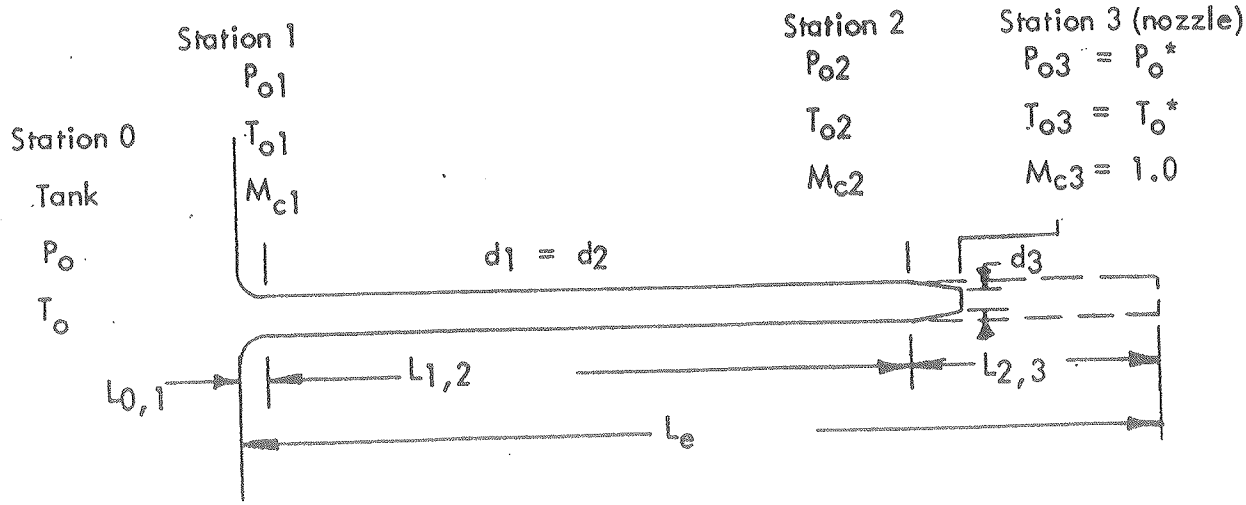
4. Stagnation Pressure Ratio (From FigureV), $\frac{P_{o1}}{P_{o*}}$ =

using k and M_{c1} above.
Stagnation Pressure at exit, P_{o*} is calculated using P_{o1} and Stagnation Pressure Ratio above.

5. Inlet pressure loss = $P_{o1} - P_{o*}$ =

DATA SHEET NO. 2

(Nozzle Area Smaller Than Inlet Pipe Area)



1. Known Parameters

Set Pressure,	P_{o1}	=	psia
Ratio Specific Heat,	k	=	
Temperature,	T_o	=	°F
Specific Gravity,	G	=	
Molecular Weight	$M = 28.964(G)$	=	
Inlet Pipe Diameter	$d_1 = d_2$	=	in.
Valve Nozzle Diameter	d_3	=	in.
Valve Coefficient of Discharge,	K_d	=	
Inlet Pipe Length	$L_{1,2}$	=	in.

2. Header Evaluation

Header Section	L/d	L	K = fL/d
Entrance			
Pipe			
Fittings			
Total			

Where: f = (From Figure III)

3. Isentropic Area Ratio of Valve Inlet to Valve Nozzle

$$\frac{A2}{A3} = \frac{(d_2)^2}{(d_3)^2 K_d} =$$

Mach No. at valve inlet (From Figure VII), M_{c2} =

using k and Isentropic area ratio above.

4. Friction Length Parameter (From Figure IV), $\frac{fL_{2,3}}{d_2}$ =

to accelerate flow to M_{c3} = 1.0 using inlet Mach No. M_{c2} determined above and k.

5. Stagnation Pressure Ratio (From Figure V), $\frac{P_{o2}}{P_{o*}}$ =

using k and M_{c2} above.

6. Total Friction Length Parameter, $\frac{fL_{1,2}}{d_1} + \frac{fL_{2,3}}{d_2}$ =

using values determined in Steps 2 and 4.

7. Mach No. at Station 1 (From Figure IV) M_{c1} =

using total Friction Length Parameter and k above.

8. Stagnation Pressure Ratio (From Figure V), $\frac{P_{o1}}{P_{o*}}$ =

using M_{c1} and k above.

9. Stagnation Pressure at Station 3 is, $P_{o*} = \frac{P_{o1}}{\text{S.P. Ratio}}$

using Set Pressure of valve and Stagnation Pressure Ratio from Step 8.

10. Stagnation Pressure at Station 2 is, $P_{o2} = P_{o*}$ (S.P. RATIO)

using P_{o*} above and Stagnation Pressure Ratio from Step 5.

11. Inlet Pressure Loss $P_{o1} - P_{o2}$ = using set pressure of valve and P_{o2} above.

DATA SHEET NO. 3

(Discharge Header Exit Mach No. M_{c5} = 1.0)

Station 4

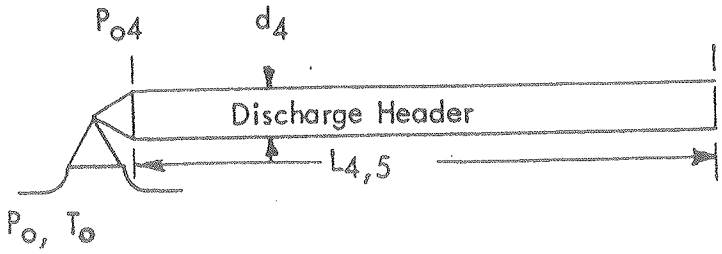
M_{c4}

P_4

Station 5

$M_{c5} \geq 1.0$

$P_5 = P^*$ 14.7 psia (assumed)



NOTE: If valve discharges into a constant pressure header, use known pressure.

1. Known Parameters

Set Pressure,	P_o	=	psig
Ratio Specific Heat,	k	=	
Temperature,	T_o = °F	=	°R
Specific Gravity,	G	=	
Molecular Weight	M = 28.964(G)	=	
Gas Constant,	C	=	
Valve Nozzle Diameter	d3	=	in.
Valve Coefficient of Discharge,	K_d	=	
Discharge Header Diameter,	d_4	=	in.
Discharge Header Length,	$L_{4,5}$	=	in.

2. Header Evaluation

Header Section	L/d	L	K = fL/d
Pipe			
Fittings			
Total			

Where: f = · (From Figure III)

3. Capacity, $Q = C K_d (d_3)^2 \frac{\pi}{4} [P_o(1.1) + 14.7] \sqrt{\frac{M}{T_r}}$ (lb/hr)

4. Mach No., $M_{c5} = \frac{.00245\,Q}{P_5 (d_4)^2} \sqrt{\frac{T_r}{k\,M}}$

Where P_5 assumed to be 14.7 actual Static exit pressure,

$$P_5 = M_{c5} (14.7)$$

5. Mach No. at Discharge Header Inlet (From Figure IV), M_{c4} = using k and K above.

6. Static Pressure Ratio, inlet to outlet of header (From Figure VI),

$$\frac{P_4}{P^*} = \text{using k and } M_{c4} \text{ above.}$$

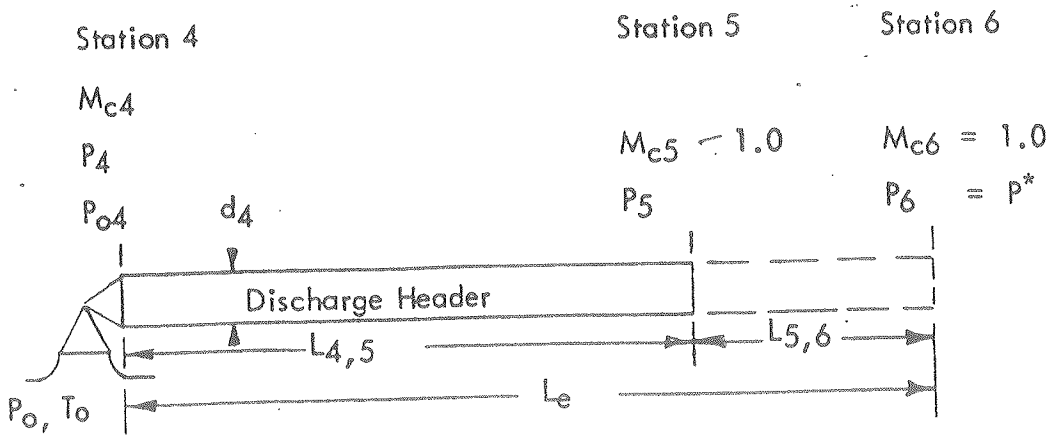
Static Pressure at discharge header inlet (valve outlet), P_4 = (S.P. Ratio) P^* using S.P. Ratio above and P^* determined in Step 4.

7. Stagnation Pressure/Static Pressure Ratio (From Figure VIII), at the Discharge Header inlet (valve outlet) $\frac{P_{o4}}{P_4}$ = using k and M_{c4} above.

Stagnation Pressure at valve outlet P_{o4} = (S.P. Ratio) P_4 using Stagnation/Static Pressure Ratio above and P_4 from Step 6.

DATA SHEET NO. 4

(Discharge Header Exit Mach No. $M_{c5} < 1.0$)



1. Known Parameters

Set Pressure,	P_o	=	psig
Ratio Specific Heat,	k	=	
Temperature,	T_o = °F	=	°R
Specific Gravity,	G	=	
Molecular Weight,	M = 28.964(G)	=	
Gas Constant,	C	=	
Valve Nozzle Diameter	d_3	=	in.
Valve Coefficient of Discharge,	K_d	=	
Discharge Header Diameter,	d_4	=	in.
Discharge Header Length,	$L_{4,5}$	=	in.

2. Header Evaluation

Header Section	L/d	L	K = fL/d
Pipe			
Fittings			
Total			

Where: f = (From Figure III)

3. Capacity, $Q = CK_d (d3)^2 \frac{\pi}{4} [P_o(1.1) + 14.7] \sqrt{\frac{M}{T_r}}$ (lb/hr)

4. Mach No., $M_{c5} = \frac{.00245\,Q}{P_5(d_4)^2} \sqrt{\frac{T_r}{k\,M}}$

Where P_5 assumed to be 14.7. Assumption is correct if $M_{c5} < 1.0$.

5. Friction Length Parameter (From Figure IV) of theoretical pipe attached to header exit, $\frac{fL_{5,6}}{d_4}$ = using k and M_{c5} above.

6. Static Pressure Ratio (From Figure VI) at the inlet to outlet of theoretical pipe, $\frac{P_5}{P^*}$ = using k and M_{c5} above.

7. Total Friction Length Parameter of actual header plus theoretical extension is $\frac{fL_{4,5}}{d_4} + \frac{fL_{5,6}}{d_4}$ = using $\frac{fL}{d}$ from Steps 2 & 5.

8. Mach No. at discharge header inlet (From Figure IV) M_{c4} = for k and total $\frac{fL}{d}$ above.

9. Static Pressure Ratio at inlet to actual header to outlet of theoretical extension (From Figure VI) $\frac{P_4}{P^*}$ = using k and M_{c4} above.

10. Static Pressure at exit of theoretical pipe extension, $P^* = \frac{P_5}{\text{S. P. Ratio}}$

using P_5 = 14.7 psia and Static Pressure Ratio from Step 6.

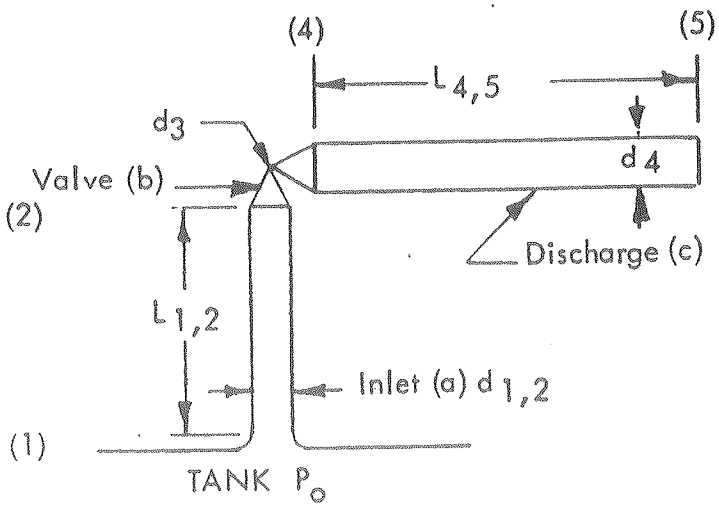
11. Static pressure at actual header inlet, P_4 = (S.P. Ratio) P^* using P^* from Step 10 and Static Pressure Ratio from Step 9.

12. Ratio of Stagnation to Static Pressure at the discharge header inlet (From Figure VIII) $\frac{P_{o4}}{P_4}$ = using k and M_{c4} above.

P_{o4} = (Ratio) P_4 using P_4 from Step 11.

DATA SHEET NO. 5

Subsonic Flow



1) Known Parameters

Set Pressure,	P_o		=	psig
Ratio Specific Heat,	k		=	
Temperature,	T_o = °F		=	°R
Specific Gravity,	G		=	
Molecular Weight,	M = 28.964(G)		=	
Equivalent Length,	L/D		=	
Inlet Header Length,	$L_{1,2}$		=	inches
Inlet Header Diameter,	$d_{1,2}$		=	inches
Discharge Header Length,	$L_{4,5}$		=	inches
Discharge Header Diameter,	$d_{4,5}$		=	inches
Coefficient of Discharge	K_d =		=	
Header Exit Pressure	P_5		=	psig
Valve Orifice Area	A		=	In^2

B

B

B

B

2) System Evaluation

Section	L/D	L
Inlet Header		
Valve (a)		
Discharge Header (b)		
Inlet		
Total		

(a) From Figure X

(b) For Discharge Header:

$$\frac{L}{D} = \left(\frac{L_{4,5}}{d_{4,5}} \quad \frac{d_{1,2}}{d_{4,5}}\right)^4$$

$$L = d_{1,2} \quad \frac{L}{D}$$

B

3) Pressures at Station 1, 2, 4, and 5

$P_1 = P_o$ = psig

$P_5 =$ = psig

$P_2 = P_o - P_o \left(\frac{L_{1,2}}{L_{1,5}}\right) + P_5 \left(\frac{L_{1,2}}{L_{1,5}}\right)$ = psig B

$P_4 = P_o - P_o \left(\frac{L_{1,4}}{L_{1,5}}\right) + P_5 \left(\frac{L_{1,4}}{L_{1,5}}\right)$ = psig B

4) Valve Capacity

a) Rated

$$Q_v = \frac{863 K_d A F \sqrt{\Delta P (P)}}{\sqrt{G T}}$$

= = SCFM

b) Actual

$Q_v =$ = SCFM

5) Discharge Mach No.

$$M_{c5} = .00245 \frac{Q}{P_5 d^2} \sqrt{\frac{T_r}{k M}}$$ B

= =

Resistance of Valves and Fittings to Flow of Fluids

Example

The dotted line shows that the resistance of a 6-inch Standard Elbow is equivalent to approximately 16 feet of 6-inch Standard Pipe.

Note

For sudden enlargements or sudden contractions, use the smaller diameter, d, on the pipe size scale.

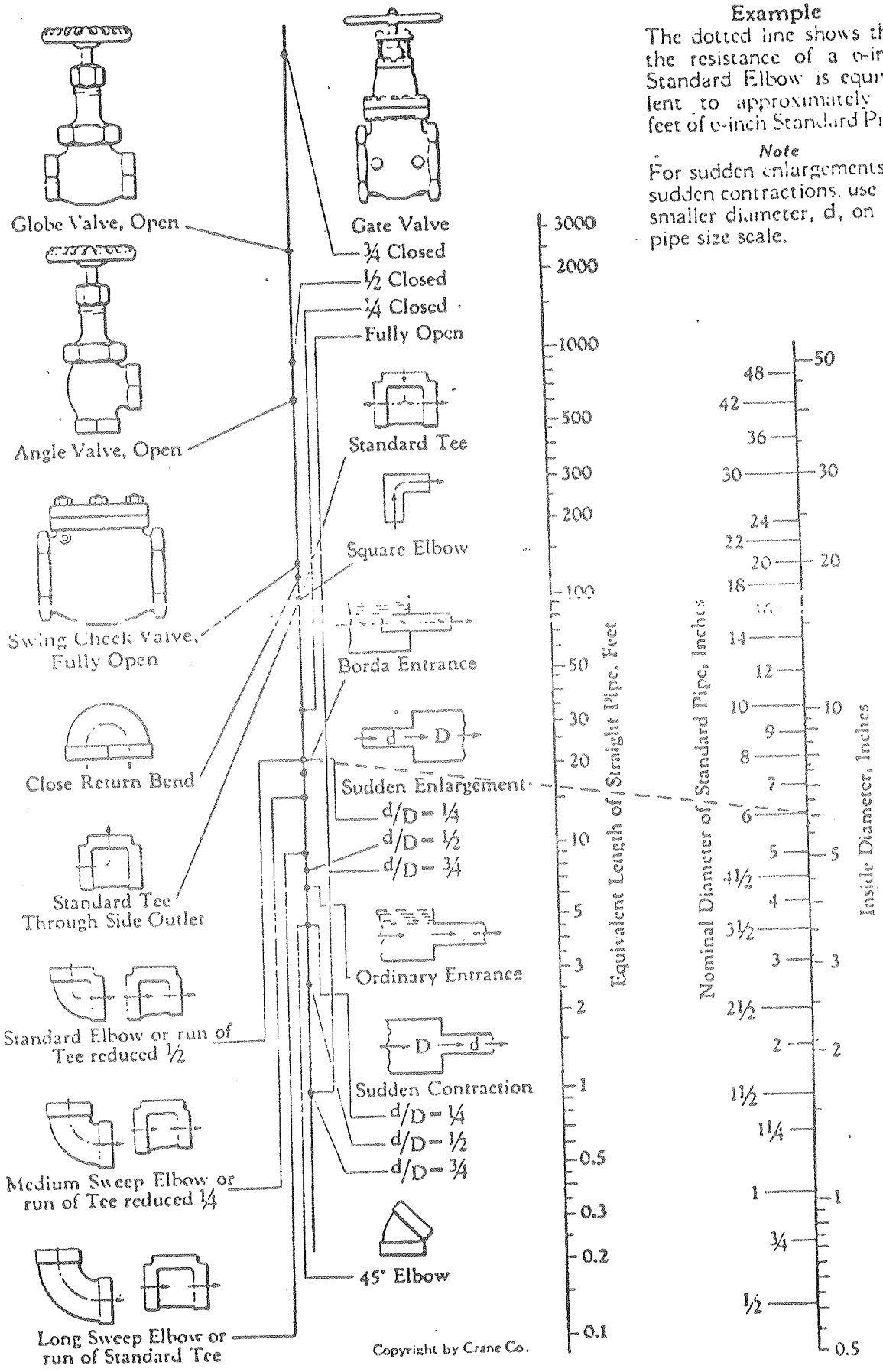


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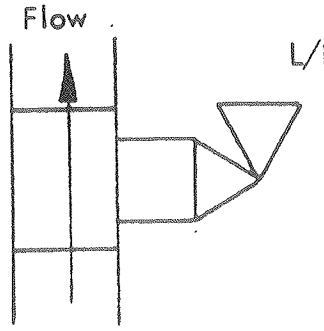
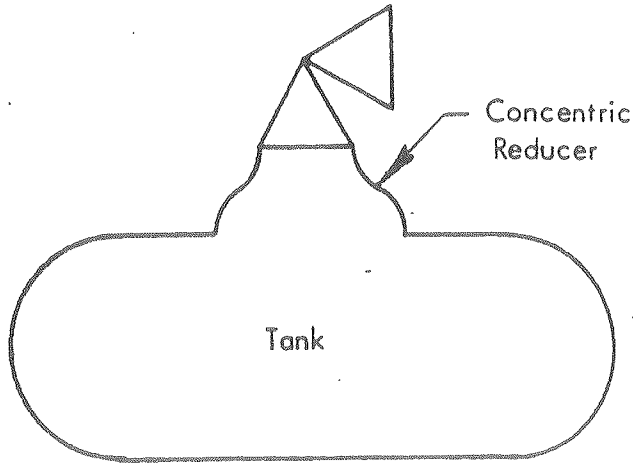
FIGURE 1

EQUIVALENT LENGTHS OF VARIOUS FITTINGS (1) (4)

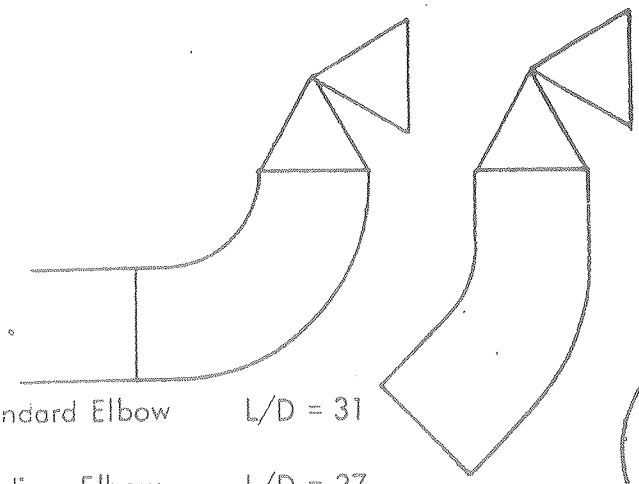


L/D = 66.7

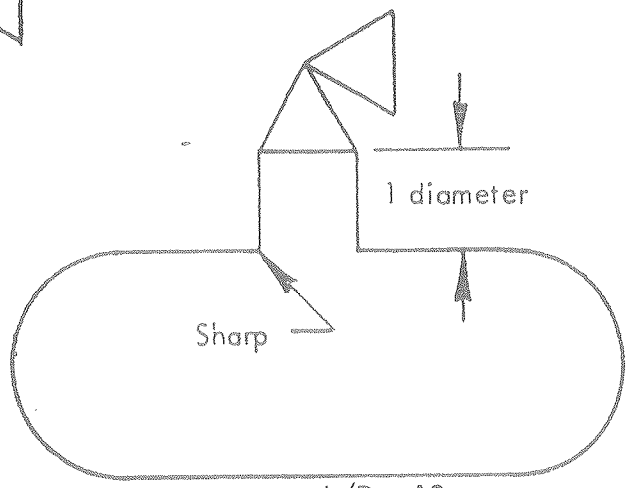
Standard Tee (Equal Dia. Legs)
With Valve on Side Outlet



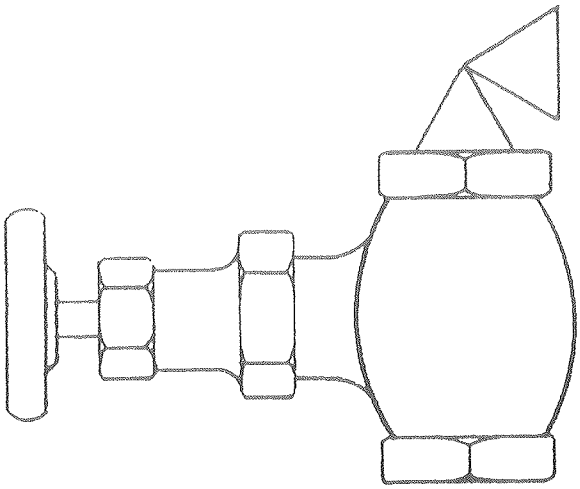
L/D = 0



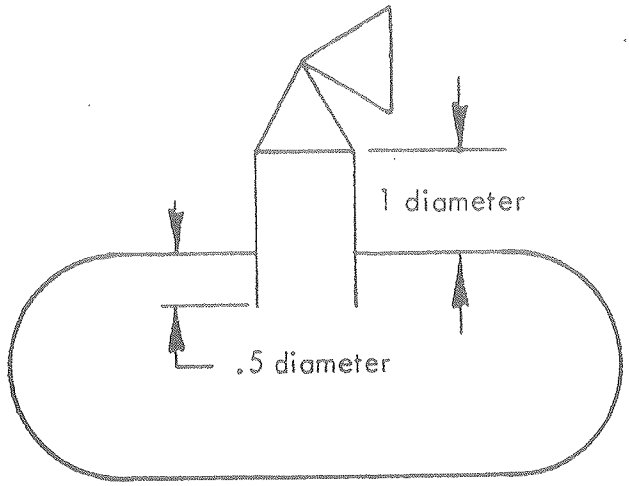
Standard Elbow	L/D = 31
Medium Elbow	L/D = 27
Long Radius Elbow	L/D = 21
45° Elbow	L/D = 17



L/D = 18



Globe Valve, Open L/D = 315



L/D = 31

(1) Crane "Resistance of Valves and Fittings to the Flow of Fluids"

FIGURE II

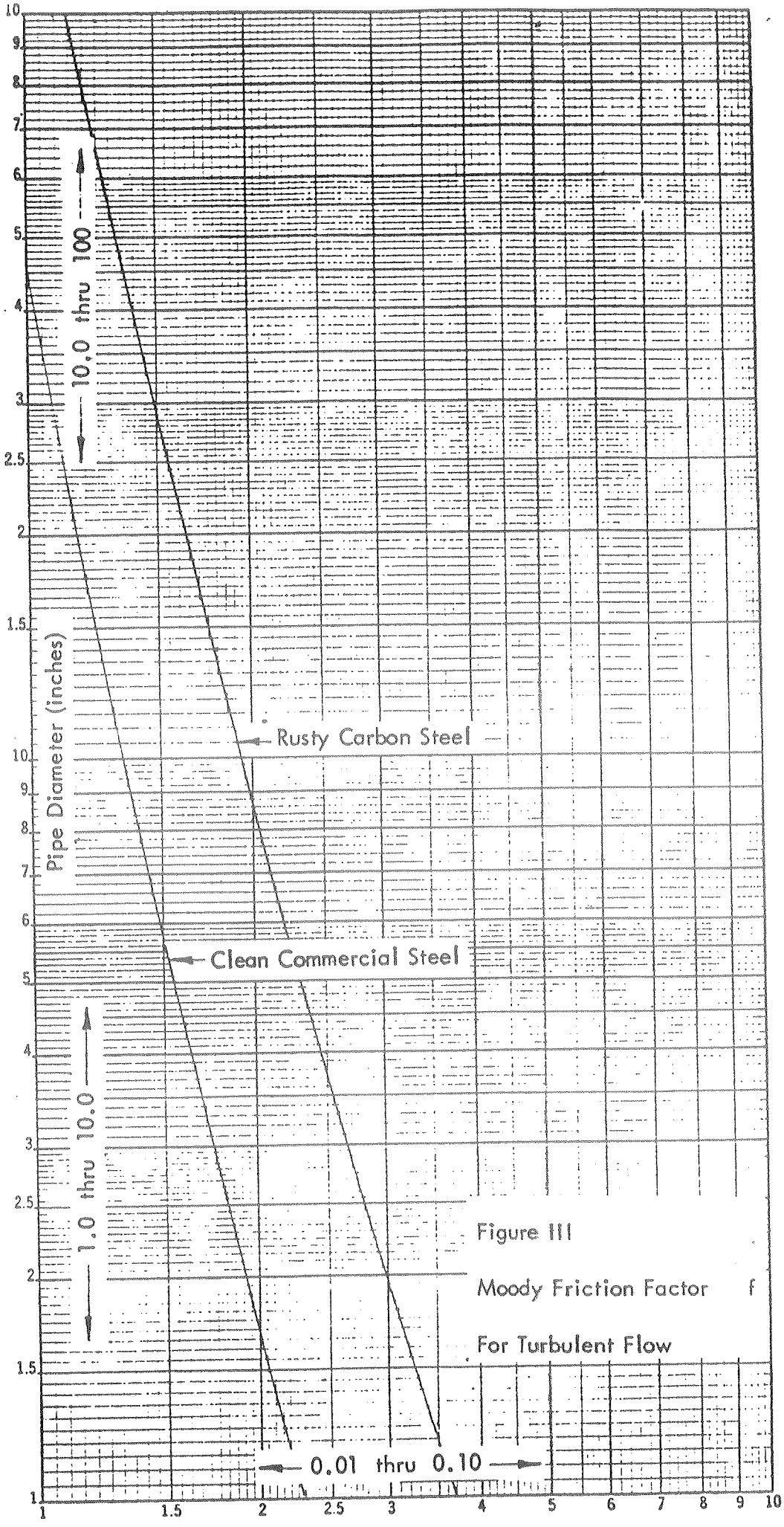


Figure III

Moody Friction Factor f

For Turbulent Flow

K+E LOGARITHMIC 46 7083
2 X 1 CYCLES MADE IN U.S.A.
KEUFFEL & ESSER CO.

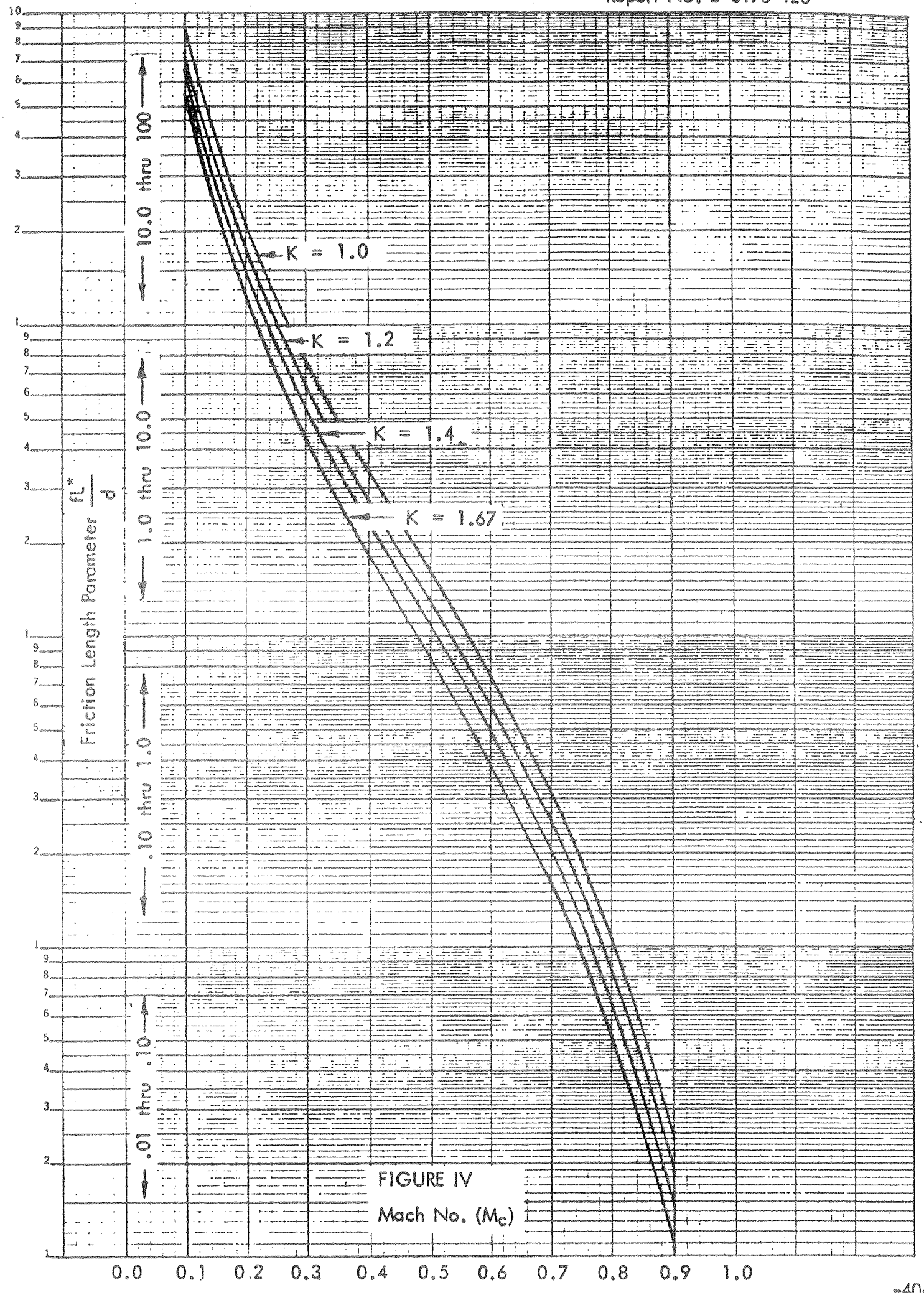
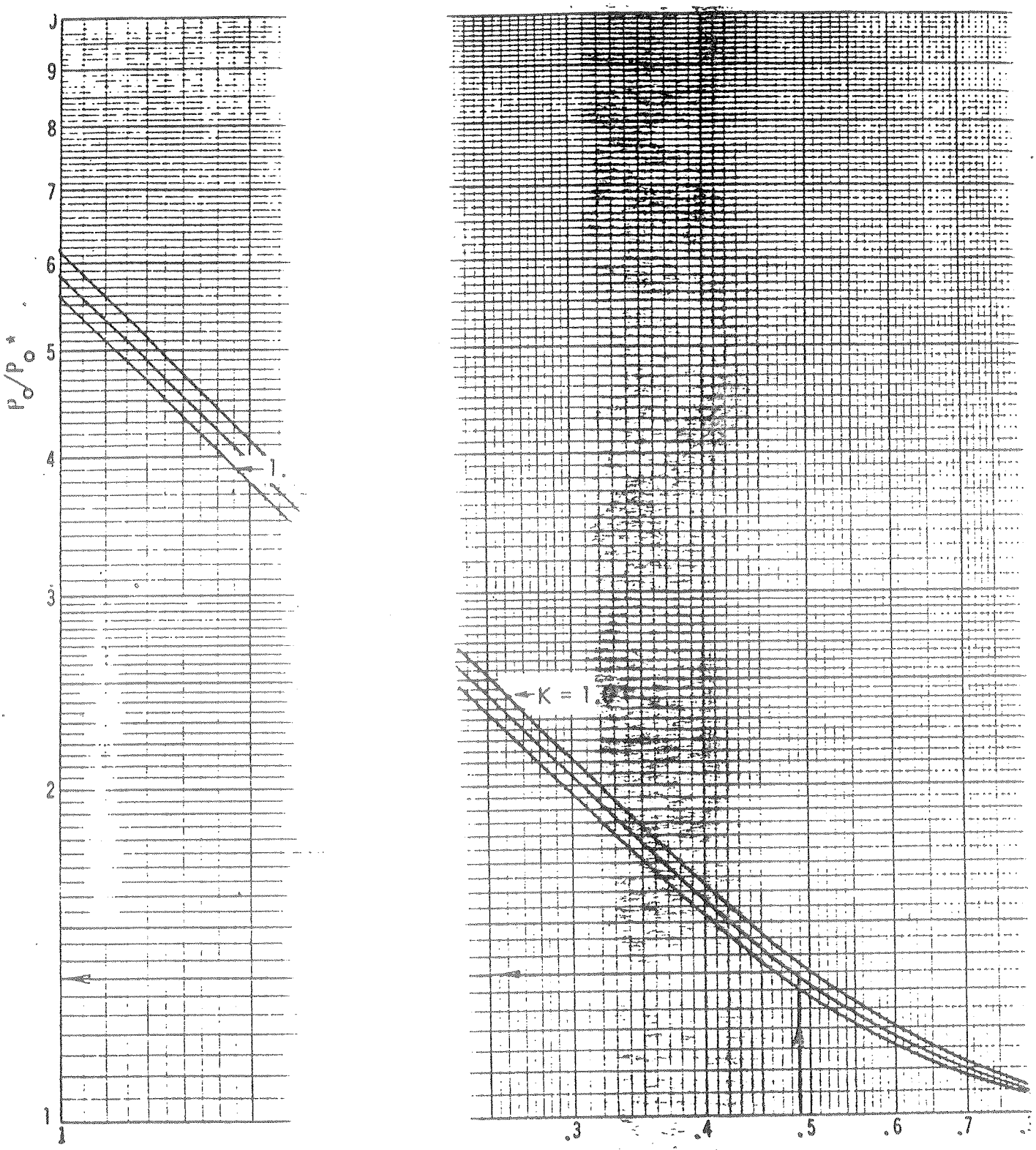

Friction Length Parameter $\frac{fL^*}{d}$
.01 thru .10
.10 thru 1.0
1.0 thru 10.0
10.0 thru 100
K = 1.0
K = 1.2
K = 1.4
K = 1.67
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Mach No. (M_c)

FIGURE IV

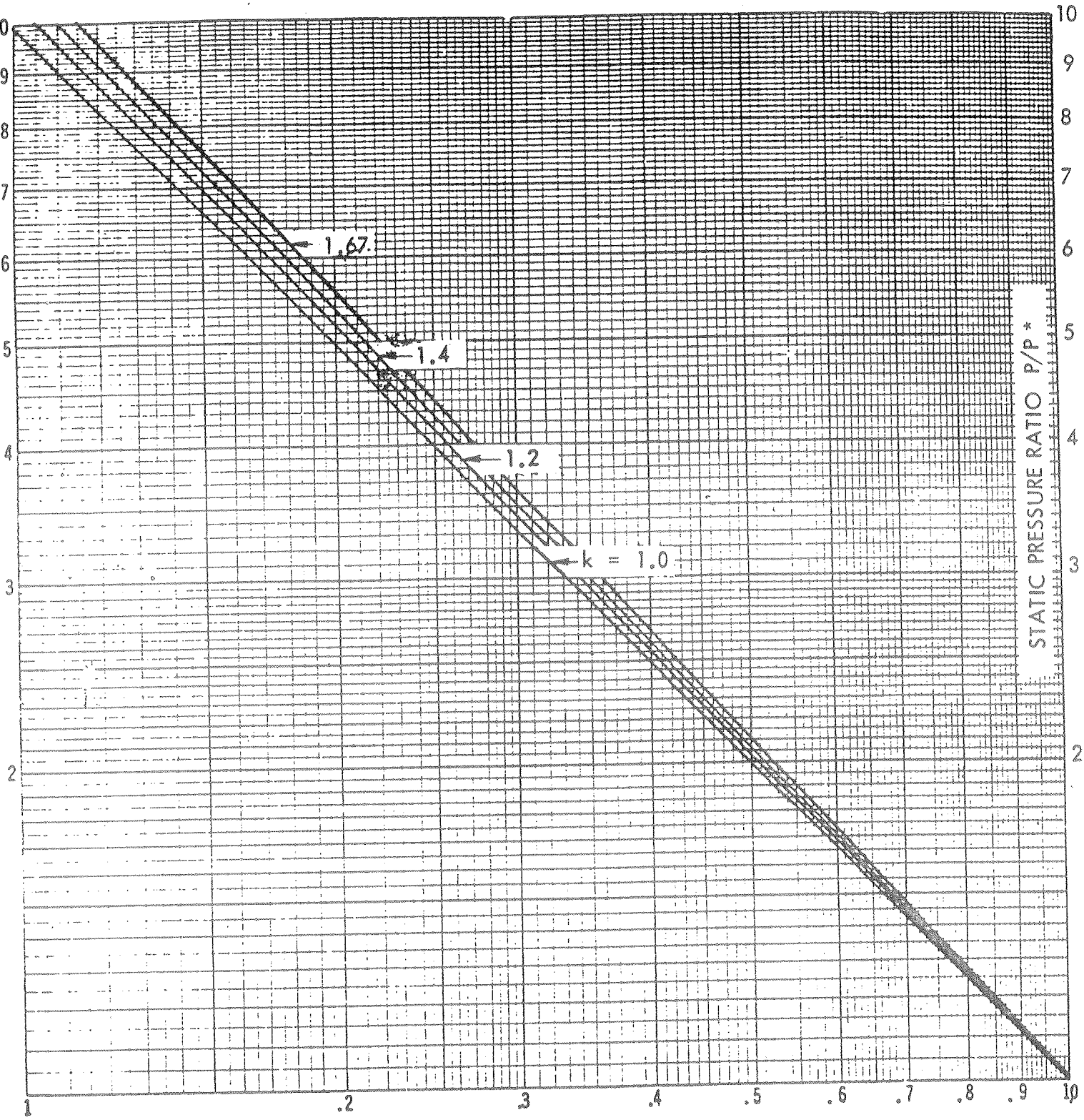
Stagnation Pressure Ratio



ubsonic Mach Number

FIGURE V

Static Pressure Ratio



Subsonic Mach Number

FIGURE VI

Isentropic Area Ratio

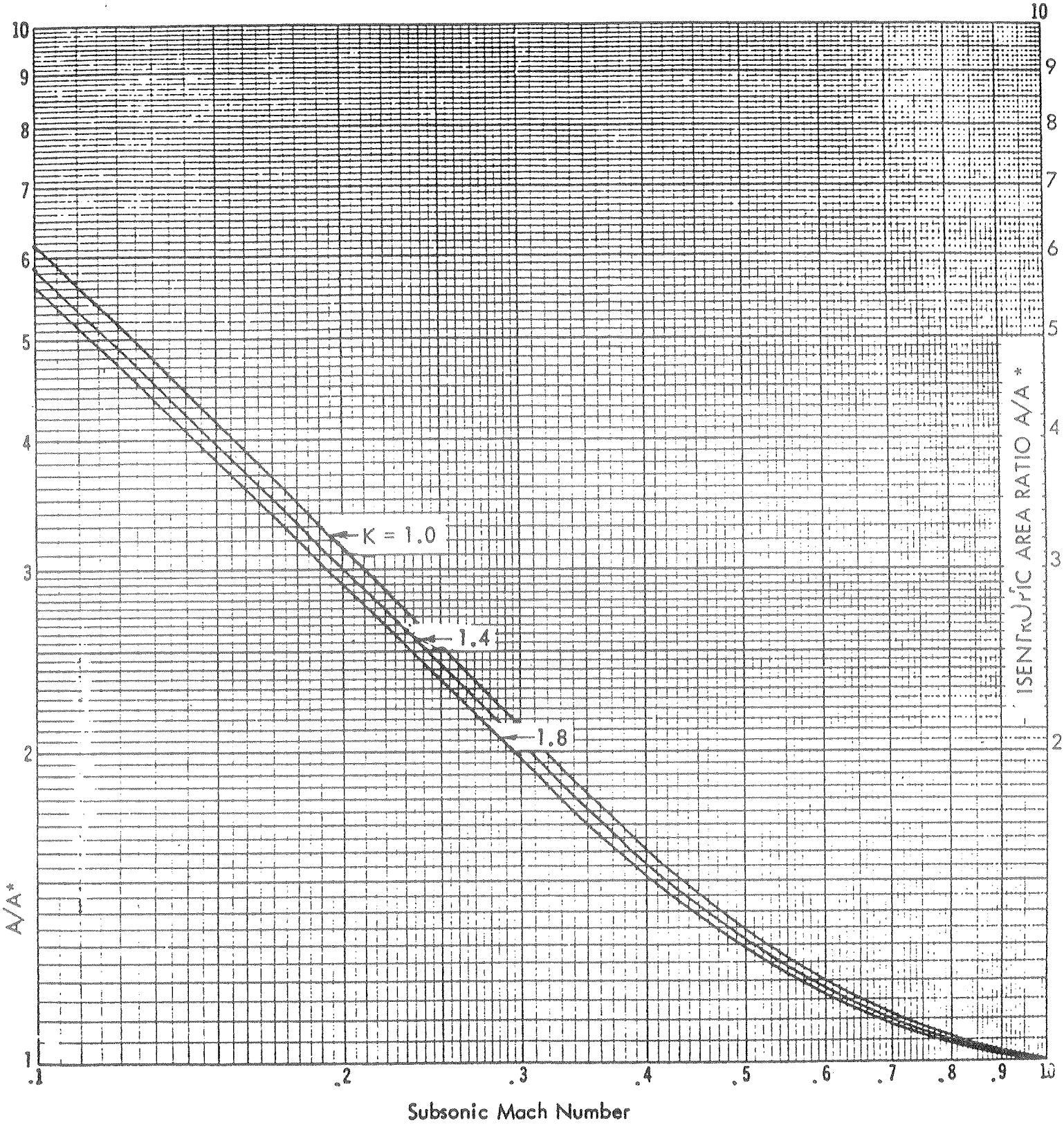


FIGURE VII

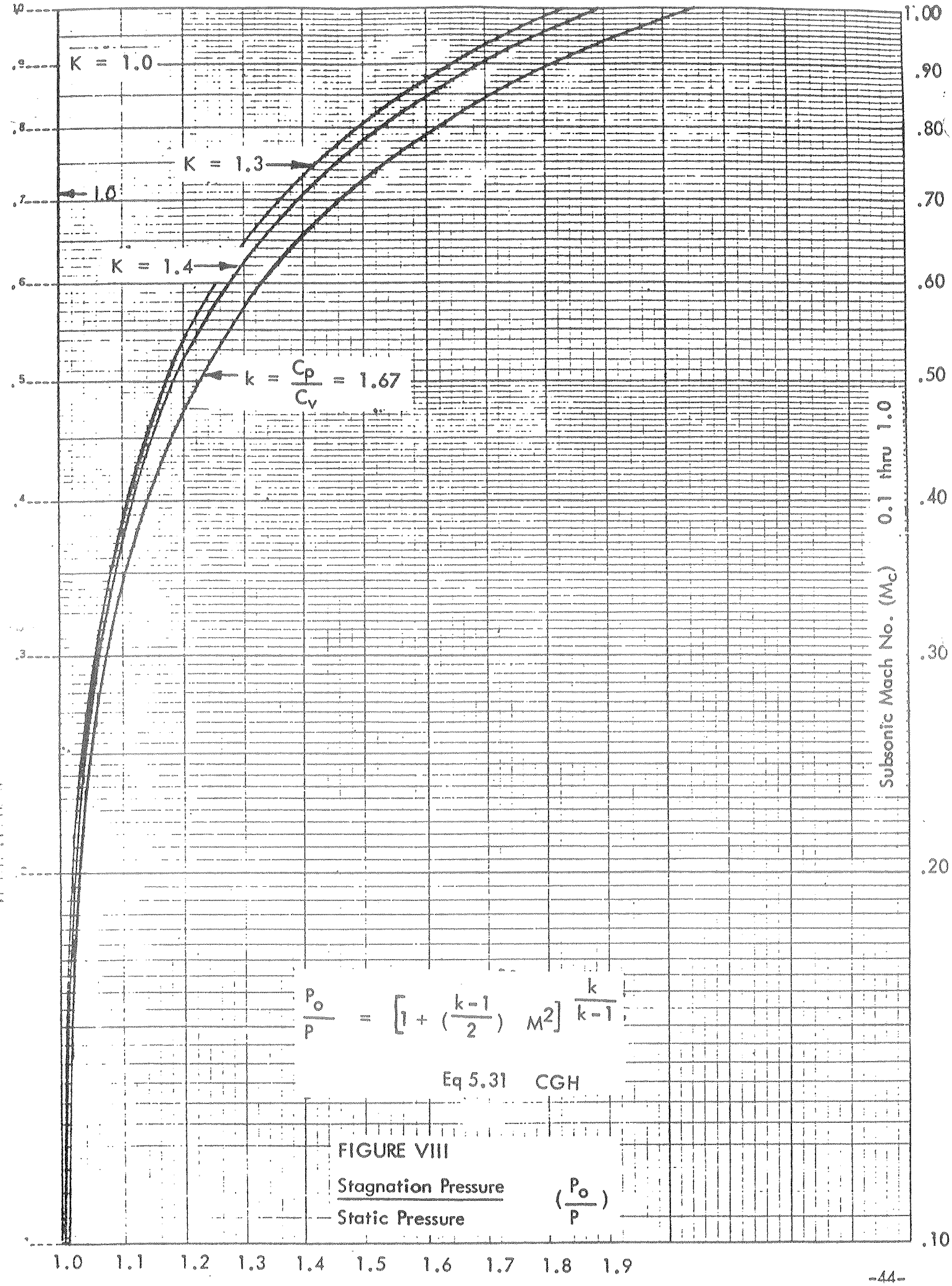


FIGURE VIII

Stagnation Pressure / Static Pressure $\left(\frac{P_o}{P}\right)$

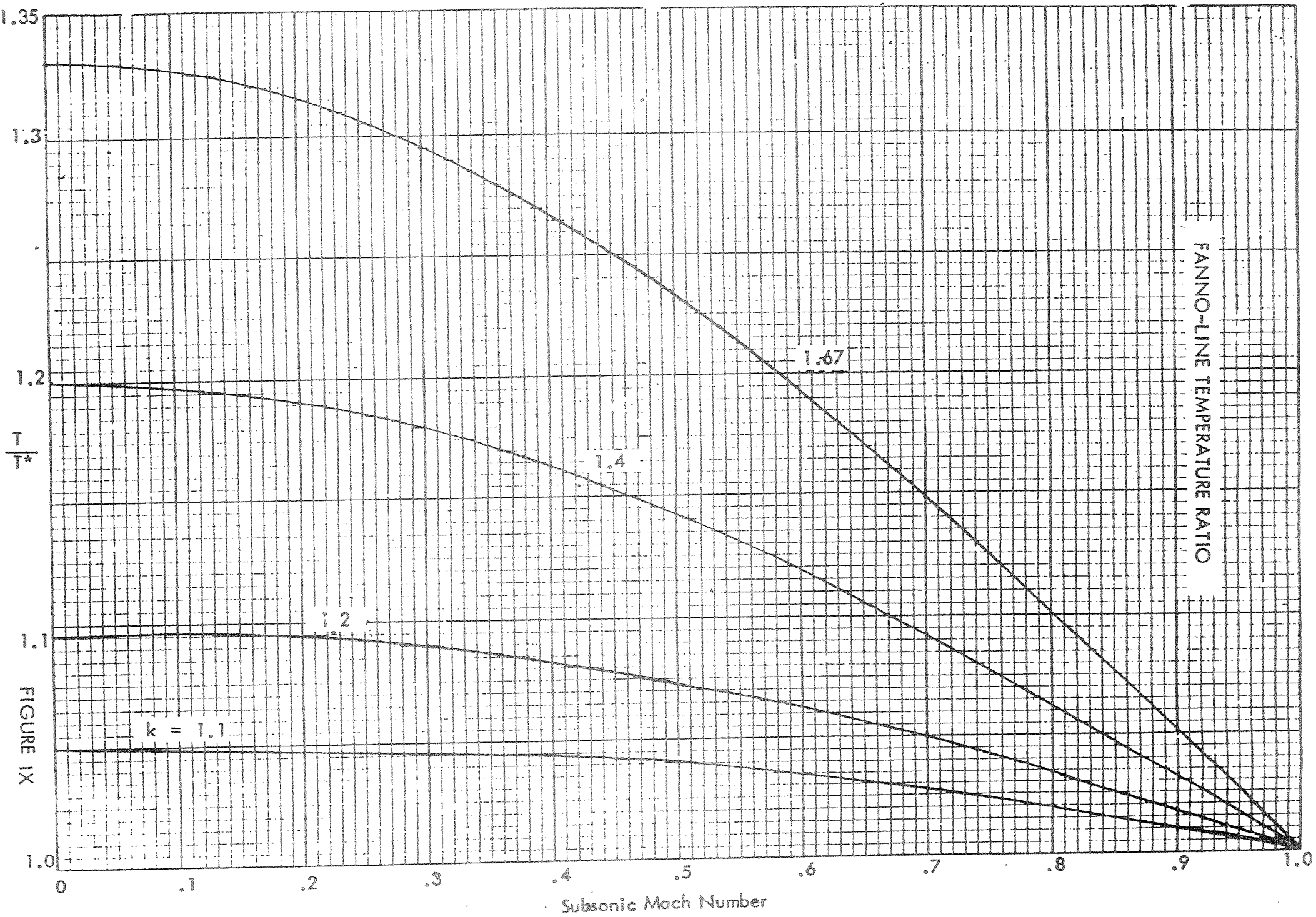

FANNO-LINE TEMPERATURE RATIO
1.35
1.3
1.2
1.1
1.0
T/T*
1.67
1.4
1.2
k = 1.1
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Subsonic Mach Number

FIGURE IX

FIGURE X

B

TYPE 91/94

$K_d = .855$

Valve Size	Stainless Steel * L/D	Stainless Steel * L (In.)	Carbon Steel * L/D	Carbon Steel * L (In.)
2 x 3	111	239	58	119
3 x 4	140	456	68	208
4 x 6	158	673	80	321
6 x 8	184	1168	102	618
8 x 10	181	1507	101	805
10 x 12	228	2375	129	1292
12 x 16	187	2316	111	1332

D

TYPE 93

$K_d = .939$

Valve Size	Stainless Steel * L/D	Stainless Steel * L (In.)	Carbon Steel * L/D	Carbon Steel * L (In.)
2 x 3	149	321	79	160
3 x 4	170	554	83	254
4 x 6	183	779	93	373
6 x 8	197	1250	109	660
8 x 10	178	1482	99	790
10 x 12	232	2417	132	1322
12 x 16	177	2193	105	1260

D

Equivalent Lengths (L/D) of AGCO Type 91/94 and 93 Pilot Operated Relief Valves As Evaluated By:

$$\frac{L}{D} = .6 \qquad \frac{d^4}{K_d^2 A^2 f}$$

D

$$f = \frac{1}{4\left[.57 - \log_{10}\left(\frac{e}{d/12}\right)\right]^2}$$

* e : Absolute Roughness
For Stainless Steel : e = .00015 : L/D Based on Schedule 10 Pipe
For Carbon Steel : e = .00085 : L/D Based on Schedule 40 Pipe
d = $d_{1,2}$

D

ANDERSON, GREENWOOD & CO.

REPORT NUMBER
2-0175-128

REVISIONS

SYM	DESCRIPTION	APVD	DATE
A	Revised Pages 1, 2, 4, 11, & 12; Added 5.0; Renumbered Pages 20 thru 36.		6-2-75
B	Revised Pages 14,22, 23, 24, 25, 35, 36 & 46; Added page 35a.		7-11-75
C	Revised Page 21, 32,		7-23-75
D	Revised Figure X Page 46.		9-2-75

01/14/86

E-706
CCI TASK ORDER 2
ODH ANALYSIS OF LAC BUILDING

Part A: Analysis of building excluding the spill trough, pit and Faraday cage.

Fermilab Safety Manual Section 15.1 is the basis for the analysis. The task is to determine whether this portion of the building can be calssified ODH=Ø.

In the absence of a detailed knowledge of probabilities of various failure modes, it is sufficient to demonstrate that PO_2 remains above 135mm Hg for the most severe failure modes.

Two failure modes are to be considered:

1. Complete failure of the 2" diameter beam window.

2. Total failure of the 3" diameter Argon line near the bottom of the LAC vessel.

It is assumed that all other cryogen lines will be equipped with automatic shutoff valves at each end which are closed upon detection of a line failure.

For each of the two postulated failure modes the following questions are to be answered:

1. What is the spill rate (and accumulated spill) versus time? Assume an initial liquid Argon temperature of 160°R and an initial Argon gas pressure of 7 psig.

2. What is the vapor generation rate (and accumulated vapor generation) versus time?

3. What assumptions of spill containment measures, spill discharge ducting, trough insulation, protection of nearby carbon steel components and pit insulation were made in answering 2.?

4. What ventilation rate and ducting is needed to maintain PO_2 ≥135mm Hg in all areas under consideration at a height 6" above the experimental hall floor level?

5. What ventilation system exhaust ducting is needed to

ensure PO_2 remains above 135mm Hg in the vicinity of the exhaust?

6. What (if any) area of restricted access is needed at the exhaust point?

7. What are the ventilation system blower requirements (size, pressure head, blower speed, motor horsepower & speed)?

8. What (if any) building air intake areas and locations are needed?

Part B: Analysis of trough

Perform a Section 15.1 Analysis of probable failure modes for a height 6" above the trough floor. Determine what ODH classification is appropriate assuming all the recommendations of Part A are met.

Part C: Analysis of Pit

Perform a Section 15.1 Analysis of probable failure modes for a height 6" above the experimental hall floor. Determine what ODH classification is appropriate.

Part D: Analysis of Faraday cage

Details and testing of penetrations into the Faraday cage will be provided when they are available. Determine what air exchange rate is needed for the Faraday cage to enable this area to be classifiec ODH=Ø.

STS/bf

Fermilab

Fermi National Accelerator Laboratory
P.O. Box 500 • Batavia, Illinois • 60510

215-439-0419

February 12, 1986

Cryogenic Consultants, Inc.
Attn: Jerry Gibbs
1176 N. Irving Street
Allentown, PA 18103

SUBJECT: Subcontract No. SC-94362
Task Order #002, R-2

Dear Mr. Gibbs:

Enclosed is the detailed Scope of Work for subject Task Order No. 002, R-2 as follows:

1) Detailed Scope Memo dated 01/14/86 - ODH of LAC Building

2) Drawing List dated 01/15/86

Very truly yours,

L. O. Vonasch, Jr.

L. O. Vonasch, Jr.
Sr. Contract Administrator

LOV/clr

Enclosures

cc: W. Baker (#220)
B. Cooper (#357)
K. Dixon (#310)
S. Stoy (#219)

01/14/86

E-706
CCI TASK ORDER #002, R-2
ODH ANALYSIS OF LAC BUILDING

Part A: Analysis of building excluding the spill trough, pit and Faraday cage.

Fermilab Safety Manual Section 15.1 is the basis for the analysis. The task is to determine whether this portion of the building can be calssified ODH=Ø.

In the absence of a detailed knowledge of probabilities of various failure modes, it is sufficient to demonstrate that PO_2 remains above 135mm Hg for the most severe failure modes.

Two failure modes are to be considered:

1. Complete failure of the 2" diameter beam window.

2. Total failure of the 3" diameter Argon line near the bottom of the LAC vessel.

It is assumed that all other cryogen lines will be equipped with automatic shutoff valves at each end which are closed upon detection of a line failure.

For each of the two postulated failure modes the following questions are to be answered:

1. What is the spill rate (and accumulated spill) versus time? Assume an initial liquid Argon temperature of 160°R and an initial Argon gas pressure of 7 psig.

2. What is the vapor generation rate (and accumulated vapor generation) versus time?

3. What assumptions of spill containment measures, spill discharge ducting, trough insulation, protection of nearby carbon steel components and pit insulation were made in answering 2.?

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ensure PO_2 remains above 135mm Hg in the vicinity of the exhaust?

6. What (if any) area of restricted access is needed at the exhaust point?

7. What are the ventilation system blower requirements (size, pressure head, blower speed, motor horsepower & speed)?

8. What (if any) building air intake areas and locations are needed?

Part B: Analysis of trough

Perform a Section 15.1 Analysis of probable failure modes for a height 6" above the trough floor. Determine what ODH classification is appropriate assuming all the recommendations of Part A are met.

Part C: Analysis of Pit

Perform a Section 15.1 Analysis of probable failure modes for a height 6" above the experimental hall floor. Determine what ODH classification is appropriate.

Part D: Analysis of Faraday cage

Details and testing of penetrations into the Faraday cage will be provided when they are available. Determine what air exchange rate is needed for the Faraday cage to enable this area to be classifiec ODH=Ø.

STS/bf

Cam Corr & Stefan

January 15, 1986

1. Fermilab Safety Manual Section 15.1

2. Dwg No. 8-1-48 A-6 Rev. 20
   MW Experimental Hall Plan

3. Dwg No. 8-1-48 A-7 Rev. 4
   MW Experimental Hall Elevations

4. Dwg No. 8-1-48 M-1 Rev. 17
   MW Exp. Hall & Counting House
   HVAC & Plumbing Plans

5. Dwg No. 8-1-48 M-4 Rev. 22
   Schedules & Control Diagrams

6. Dwg No. 8-1-47 SC-13 Rev. 10
   Dewar Foundations Plans,
   Sections, and Details.

7. Dwg 9220.706-ME-202359 Sht 1 of 2
   Hadron Pack Information Dwg.

8. Dwg 9220.706-ME-202359 Sht 2 of 2
   Hadron Pack Information Dwg.

9. Dwg 9220.706-ME-202831 Rev. A
   Hadron & Photon Assy Frame

10. Dwg 2220.1-MD-183271
    L.A.C. Calibration & On Line
    Positions

11. Dwg 2802.150-SE-177051
    M.W. Faraday Room Construction
    Details

12. Chicago Bridge and Iron Co.
    Dwg Contract No. 851553
    General Plan

13. Dwg - No Number or Title
    Showing M.W. Exp. Hall Pit
    Ventilation Location - For
    Reference Only

14. Dwg - No Number or Title
    Showing M.W. Exp. Hall Trough
    Skirt Proposal - For Reference
    Only

15. Dwg - No Number or Title
    Showing Location of Exp.
    Apparatus in M.W. Exp. Hall.
    Preliminary, for Reference Only

16. Paper E706-140 By F. Lobkowicz
    Dated 1-3-86 Titled
    "Cold Steel Through My Heart"
    For Reference Only

17. Paper Titled "Cooldown
    Of Steel" by F. Lobkowicz
    For Reference Only

Relief Sizing

16 Jan 86
KL

$P_o = 1.21 \times MAWP = 1.21\,(16\,psig) = 19.4\,psig$
$= 34.1\,psia \quad T_o = 96.1\,K = 173\,°R$

$$\left.\frac{P_e}{P_o}\right|_{crit} = \left[\frac{2}{k+1}\right]^{\frac{k}{k-1}} = 0.487$$

$$\left.\frac{P_e}{P_o}\right|_{design} = \frac{14.7}{34.1} = 0.432$$

Since $0.432 < 0.487$, sonic flow

Req'd Flow Rate per CGA S1.3 - 5.3.3

$V_{req'd} = Q_a = G_n A^{0.82}$

A = surf area for fire cond'n
$\cong$ " " of insulation*
$= \pi d_{cyl} L + 2\pi r_{head} d_{head}$
$= \pi(205)(225) + 2\pi(205)(41.5)$
$= 198{,}000\ in^2 = 1380\ ft^2$

$$G_n = \frac{6.33 \times 10^5}{LC}\left(\frac{ZT}{M}\right)^{1/2}$$

$L = h_{fg} = 154\ Btu/lb = 66.2\ BTU/hr$

* this area actually larger than wetted area

$$G_{2u} = \frac{6.33 \times 10^5}{66.2 \times 377} \left(\frac{173}{40}\right)^{1/2}$$

$= 19{,}800$ SCFM air req'd flow

<u>Actual flow w/o Δp included due to piping</u>

$$\dot{V}_{rv} = \frac{6.32\, A C K P_1}{\sqrt{MTZ}}$$ Anderson-Greenwood Catalogue

$$= \frac{6.32\,(19.56)(356)(0.845)(34.1)}{\sqrt{29\,(520)(1)}}$$

$= 10300$ SCFM

$$\dot{V}_{rd} = \frac{260\, A P_1}{\sqrt{Sp.Gr.\,(T)}}$$ BS&B Catalogue

$$= \frac{260\left(\frac{\pi}{4}\right)(6)^2(34.1)}{\sqrt{520}}$$

$= 11000$ SCFM

$\dot{V}_{tot}$ w/o $\Delta p_L = 21300$ SCFM air

6 Nov 85
KD

check Δp in pipe:

Worst case is relief piping which is 126" lg sch 40, 6" pipe $\dot{m} = 28.4$ lbm/s

$d_i = 6.065$ in $= 0.505$ ft

$L_p = 10.5$ ft

$K_{inlet} = 0.5$ if pipe is cut flush

$$V = \frac{\dot{m}}{\rho A} = \frac{25.5 \text{ lbm/s}}{0.780 \text{ lbm/ft}^3 \left(\frac{\pi}{4}\right)(.505 \text{ ft})^2} = 162 \text{ ft/s}$$

$$k = \sqrt{\gamma R T}$$
$$\cong 577 \text{ ft/s}$$

$M = 0.281$ ~~marginal, but probably can~~ still assume incomp. flow

$$\Delta p = \left[f \frac{L}{D} + K\right]\left[\frac{\dot{m}^2}{A^2 2 \rho g_c}\right]$$

$$R_D = \frac{\rho V D}{\mu} = \frac{(0.780 \text{ lbm/ft}^3)(182 \text{ ft/s})(0.505 \text{ ft})}{0.538 \times 10^{-5} \text{ lb/ft}\cdot\text{s}}$$

$R_D = 9.3 \times 10^6$ $\quad f = .015$ from Crane Flow of Fluids

$$\Delta p = 0.812\left[\frac{(25.5 \text{ lbm/s})^2}{2(0.2 \text{ ft}^2)^2(.780 \text{ lbm/ft}^3)\left(32.2 \frac{\text{ft}}{\text{s}^2}\frac{\text{lbm}}{\text{lbf}}\right)}\right]$$

$= 2.63$ psf

$\boxed{= 1.8 \text{ psi drop}}$

Allowable Pressure Drop Through Exit Piping

- Let flow through relief at std cond'ns w/ air = $\dot{V}_{rv}$ = 9800 SCFM
- Let flow through rupture disk at std cond'ns w/ air = $\dot{V}_{rd}$ = 10400 SCFM
- Let Δp through both inlets to rd and rv = Δp_{inlet} = 1.7 psi

$$\dot{m}^{argon}_{rv} = \dot{V}_{rv}\left(\frac{M_{argon}}{M_{air}}\right)^{1/2}\left(\frac{C_{argon}}{C_{air}}\right)\left(\frac{P_2}{P_2-\Delta p_{inlet}}\right)\left(\frac{T_{inlet}}{T_2}\right)\rho^{std}_{inlet}\left(\frac{lbm/ft^3}{cu\,ft/s/min}\right)$$

$$= 9800\left(\frac{40}{29}\right)^{1/2}\left(\frac{0.99}{0.82}\right)\left(\frac{14.7}{13.4}\right)\left(\frac{492}{520}\right)\left(\frac{0.08}{60}\right)$$

$$= 23.9\ lbm/s \text{ std argon}$$

$$\dot{m}^{argon}_{rd} = \frac{10400}{9800}(23.9)$$

$$= 25.4\ lbm/s \text{ std argon}$$

$$\Delta p = \left[\frac{f L_e}{D} + K\right]\left[\frac{\dot{m}^2}{2A^2\rho g_c}\right]$$

$$\Delta p_{rv} = \frac{(0.31+0.5)(254)}{144}$$

$$= 1.60\ psi$$

$$\Delta p_{rd} = \frac{(0.28+0.5)(321)}{144}$$

$$= 1.74\ psi$$

now check V for both reliefs:

$$\dot{V}_{rv} = \frac{6.32\, A C K P_1}{\sqrt{MTZ}}$$ Anderson Greenwood Catalogue

$$= \frac{6.32\,(19.56)(356)(0.845)(32.5)}{\sqrt{(29)(520)(1)}}$$

$$= 9840 \text{ SCFM}$$

$$\dot{V}_{rd} = \frac{260\, A P_1}{\sqrt{SG\,(T)}}$$ BS & B Catalogue

$$= \frac{260\,(\frac{\pi}{4})(6)^2(32.4)}{\sqrt{520}}$$

$$= 10440 \text{ SCFM}$$

$$\dot{V}_{total} = 9840 + 10440$$

$$\boxed{\dot{V}_{total} = 20300 \text{ SCFM}}$$

$$\left.\frac{P_e}{P_o}\right|_{design} = \frac{14.7 + \epsilon}{34.1 - 1.7}$$

$$\left.\frac{P_e}{P_o}\right|_{design} \leq \left.\frac{P_e}{P_o}\right|_{crit}$$

for sonic flow to exist, $\dot{V} \neq f(P_e)$

$$\frac{14.7 + \epsilon}{34.1 - 1.7} \leq \left[\frac{2}{k+1}\right]^{\left(\frac{k}{k-1}\right)} = 0.487$$

$$14.7 + \epsilon \leq 0.487(34.1 - 1.7)$$

$$\epsilon \leq 0.487(34.1 - 1.7) - 14.7$$

$$\epsilon \leq 1.08 \text{ psi}$$

$\therefore$ Pressure drop through exit piping should be no greater than 1psi at full flow conditions.

Fermilab

Fermi National Accelerator Laboratory
P.O. Box 500 • Batavia, Illinois • 60510

February 12, 1986

Cryogenic Consultants, Inc.
Attn: Peter C. Vander Arend
1176 N. Irving Street
Allentown, PA 18103

SUBJECT: Subcontract No. SC-94362
Task Order #002, R-2

Dear Mr. Vander Arend:

Enclosed is the detailed Scope of Work for subject Task Order No. 002, R-2 as follows:

1) Pages 333 and 335 from "Calorimetry"

2) Drwg. #9220.706-ME-202715,
Plan View Calorimeter and Argon Dewar

Very truly yours,

L. O. Vonasch, Jr.

L. O. Vonasch, Jr.
Sr. Contract Administrator

LOV/clr

Enclosures

cc: W. Baker (#220)
B. Cooper (#357)
K. Dixon (#310)
S. Stoy (#219)

January 27, 1986

E-706

CCI TASK ORDER NO. 002, R-2

COOLDOWN AND WARM-UP OF LAC

The details of the internal components of the E-706 LAC have been fixed. Given this information it is desirable to understand the cooldown and warm-up techniques for the LAC. Particular attention must be given to determining the thermal gradients that will exit across various components in the LAC and consequents of these gradients.

The following questions need to be addressed.

1. What is the most desirable location for the finned tubing in the top of the LAC for the cooldown coils and the steady state coil?

2. What if any shrouds are required to control the cooldown procedure? How should these be made and installed?

3. What is the calculated temperature vs time history for various components in the LAC? Particular concern has been expressed for the super plates, adsorber plates and hadron detector support structure. Will any excessive stresses be developed on any members as a result of temperature gradients? What are the nitrogen/argon flow rates as a function of time that are required to achieve the cooldown detailed?

4. What if any special provisions will be required to maintain the desired temperature gradients? i.e. Copper fingers attached to some components, special manifolding, etc.

5. If the occasion arises that the argon must be removed to warm-up the LAC quickly for any reason, what is the most effective way to remove the liquid argon and warm-up the internal components of LAC? Particular attention must be given to the thermal gradient [illegible] the internal components so that excessive stresses are [illegible] What is the warm-up time and the temperature [illegible] history for the critical components?

6. What if any special provisions will be required to warm-up the components or the LAC according to the schedule detailed in No.5

STS/bf

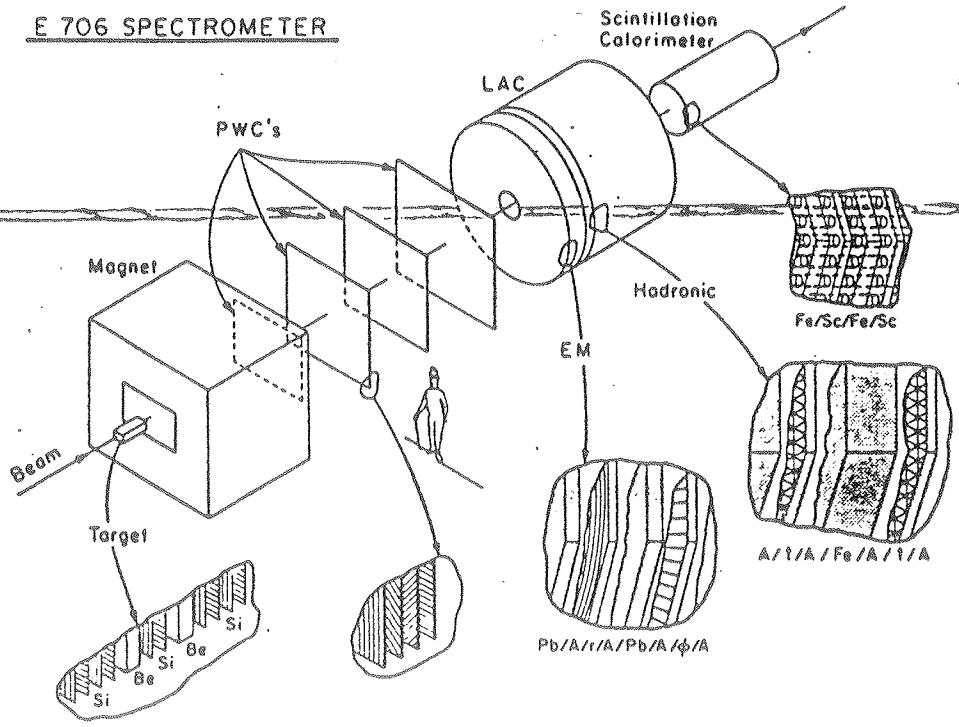

Fig. 1. The layout of the complete E706 spectrometer showing the target surrounded by silicon strip detectors, the PW's following the magnet, the Liquid Argon Calorimeter and the forward scintillation calorimeter.

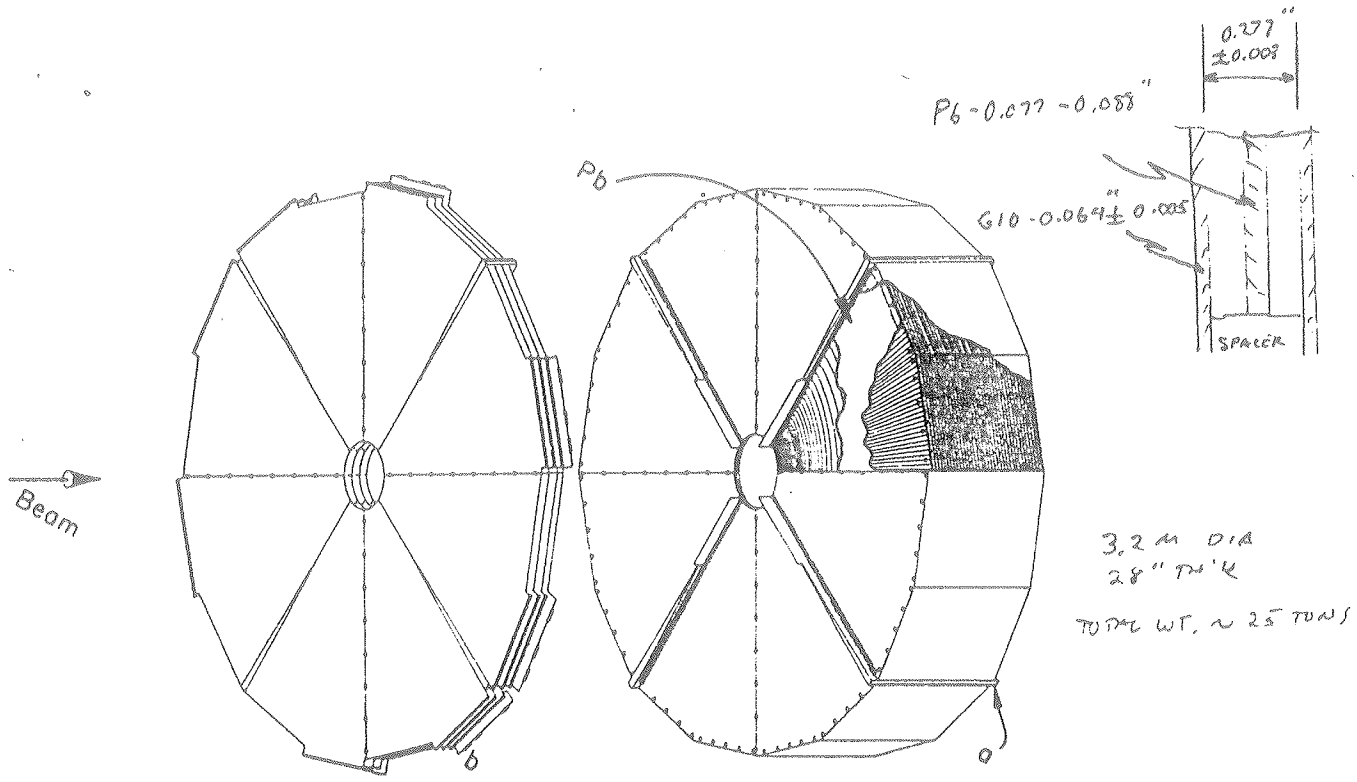

Fig. 2. A blowup of the photon detector. The quadrants are separated by stainless steel plates (a); special boards (b) connect individual readout strips to connectors along the circumference.

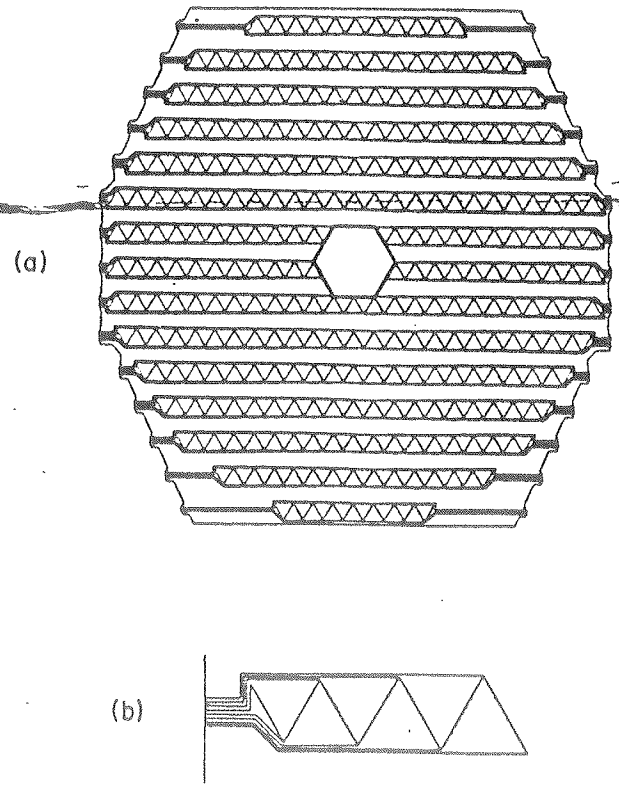

Fig. 4. (a) A single hadron calorimeter readout board; (b) detail of the readout scheme.

There are two sets of three special "readout boards," one in front and one in the back of the photon detector assembly; one of these triplets is shown in the exploded view of fig. 2. These provide leads from the inner ϕ strips as well as from the r strips to the outer edge of the detector where external cables are connected to the detector. The first $\frac{1}{3}$ of the detector (22 layers, 10 radiation lengths) is read out via the front readout boards, the last $\frac{2}{3}$ (44 layers, 20 r.l.) is read out via the back readout planes.

In contrast to the photon detector, the hadron detector has a tower readout structure. Each tower consists of a series of triangular readout pads, as illustrated in fig. 4. The need to have electrical connections from each pad to the edge of the detector necessitates the subdivision of readout planes into pairs, one of which is shown in fig. 4. Each of the readout planes covers one-half of the area with pads, leaving the space between two rows for the readout lines. As illustrated in fig. 5, during assembly, the readout lines are covered with horizontal spacer strips which are glued to the readout boards and provide mechanical stability. Since only 4 ft × 12 ft G-10 boards are available commercially, each plane consists of three such boards. Vertical ribs hold the individual boards together and add to the rigidity of the whole assembly. Each layer (fig. 5b) has in sequence a H.V. board, a layer of horizontal strips that define the 3 mm argon gap and shadow half of the area of the pads,

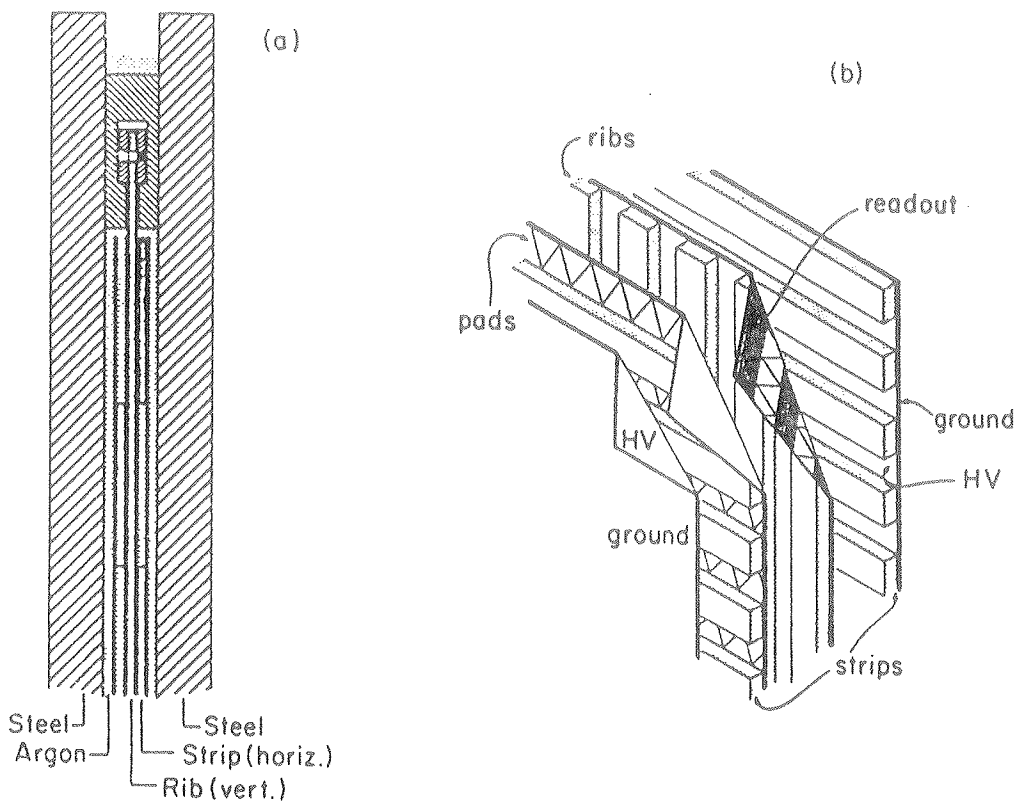

Fig. 5. One readout layer of the hadron detector: (a) a side view showing suspension system; (b) exploded view of one readout layer.

References

1. Prebys, E. "Summary of Signal Feed Through Tests for the E-706 LAC", Fermilab internal report, 5/7/86

2. Sullivan, J.J., Ewing, J.H., Jacobs, R.P., "Calibration Techniques for Thermal-Mass Flowmeters", MKS Instruments, Inc. publication, Burlington, MA

3. Souders, Mott, "The Engineer's Companion", John Wiley and Sons, Inc., N.Y. 1967, Section 3, Fluid Mechanics, Pg. 145