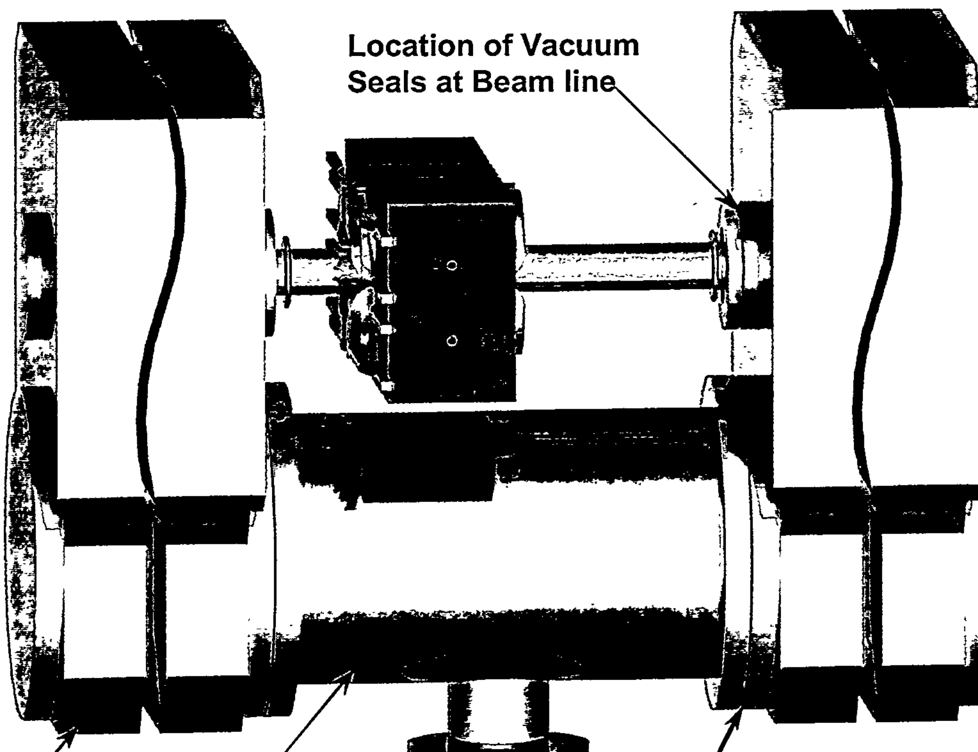
LA-13698-MS

Vacuum Seals Design and Testing for a Linear Accelerator of the National Spallation Neutron Source



Los Alamos
NATIONAL LABORATORY
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Cover photo: Typical locations of the metal seals in the SNS Linac are shown in the following intersegment. There are a total of over 340 intersegments in the Linear Accelerator.

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Vacuum Seals Design and Testing for a Linear Accelerator of the National Spallation Neutron Source

Z. Chen
C. Gautier
F. Hemez
N. K. Bultman

Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545

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Vacuum Seals Design and Testing

for a Linear Accelerator of the National Spallation Neutron Source

By

Z. Chen, C. Gautier, F. Hemez, and N. K. Bultman

ABSTRACT

Vacuum seals are very important to ensure that the Spallation Neutron Source (SNS) Linac has an optimum vacuum system. The vacuum joints between flanges must have reliable seals to minimize the leak rate and meet vacuum and electrical requirements. In addition, it is desirable to simplify the installation and thereby also simplify the maintenance required. This report summarizes an investigation of the metal vacuum seals that include the metal C-seal, Energized Spring seal, Helcoflex Copper Delta seal, Aluminum Delta seal, delta seal with limiting ring, and the prototype of the copper diamond seals. The report also contains the material certifications, design, finite element analysis, and testing for all of these seals. It is a valuable reference for any vacuum system design.

To evaluate the suitability of several types of metal seals for use in the SNS Linac and to determine the torque applied on the bolts, a series of vacuum leak rate tests on the metal seals have been completed at Los Alamos Laboratory. A copper plated flange, using the same type of delta seal that was used for testing with the stainless steel flange, has also been studied and tested. A vacuum seal is desired that requires significantly less loading than a standard ConFlat flange with a copper gasket for the coupling cavity assembly. To save the intersegment space we use thinner flanges in the design. The leak rate of the thin ConFlat flange with a copper gasket is a baseline for the vacuum test on all seals and thin flanges. A finite element analysis of a long coupling cavity flange with a copper delta seal has been performed in order to confirm the design of the long coupling cavity flange and the welded area of a cavity body with the flange. This analysis is also necessary to predict a potential deformation of the cavity under the combined force of atmospheric pressure and the seating load of the seal. Modeling of this assembly has been achieved using both HKS/Abaqus and COSMOS/M, which are finite element packages for analysis of coupled, nonlinear problems. From these studies, the appropriate seals that are reliable for SNS long coupling cavities and beamline joints were determined.

I. INTRODUCTION

Vacuum seals are very important for ensuring that the SNS Linac has an optimum vacuum system. The vacuum joints between flanges must have reliable seals to minimize the leak rate and meet vacuum and electrical requirements. The seals should also be easy to install and to replace for maintenance purposes. In this document, the vacuum seal selection for beam line and long coupling cavities will be described.
A vacuum seal is desired that requires significantly less loading than a standard ConFlat and good electrical conductivity for RF coupling cavities. A vacuum seal is also required at the beam line, because some intersegments have very little space where various hardware items have to be installed. To save intersegmental space, we use thinner flanges in the design. The leak rate and torque applied to the thin ConFlat flange with a copper gasket are a baseline for the vacuum test on all seals and thin flanges. We have prototypes of 3-3/8 thin ConFlat flange with a copper gasket for beamline vacuum joints. The tests were completed by VARIAN, and the results are shown in Appendix [C]. The estimated sealing load is too high at 4,173 pounds per inch of sealing circumference for the beamline flanges. On the other hand, the knife edges of ConFlat flanges lose their sealing function after being exposed to 450^{0}F. Furnace brazing of the accelerating cavities requires temperatures far in excess of 450^{0}F. Apparently, the ConFlat flange and copper gasket cannot be used in the SNS Linac beam line and long coupling cavities.

To meet the vacuum requirements, RF, installation, and structural design, the metal C-seal, energized spring seal, Helcoflex copper delta seal, and aluminum delta seal were selected in an R & D study and vacuum test. A special effort was made to produce a prototype of a copper diamond seal referencing the aluminum diamond seal that was used in the beamline at CERN. Two prototypes of the diamond seal have also been tested. All the test results helped us to determine the appropriate seals that are reliable for SNS long coupling cavities and beam-line joints as compared with ConFlat flanges and copper gasket joints.

ECE Metal C-Ring is an excellent externally pressurized static face seal. Its moderate load permits the use of lighter and thinner flanges with fewer bolts. Part of the C-seal is shown in Figure 1.

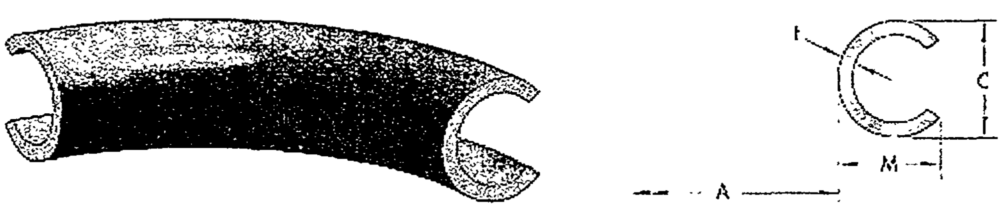


Figure 1: Metal C-ring.

ESE Spring Energized Metal C-Ring shown in Figure 2 is similar to the ECE, but provides higher loads for use with a rougher mating surface. The spring seal provides the lowest leak rate.

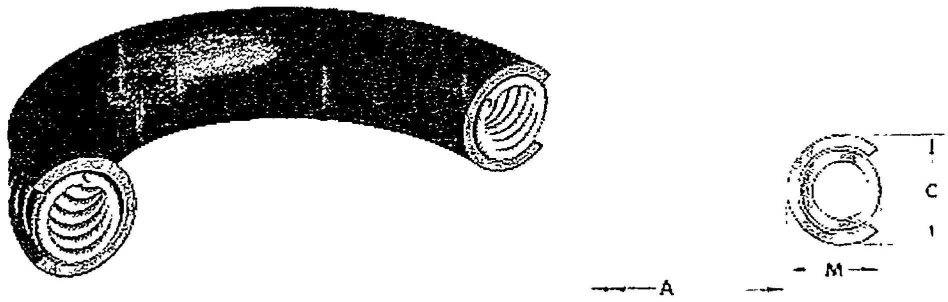
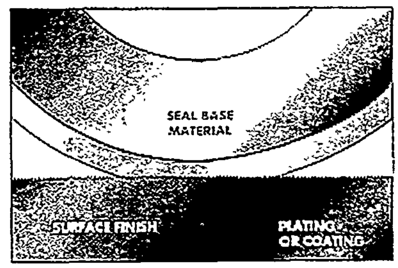


Figure 2: Energized spring C-ring.

Both the ECE and ESE seals have specialized silver plates that modify the surface properties of the seals to create a ductile, low hardness outer surface layer. This ensures optimum sealing despite mating surface Imperfections. The narrow footprint of the seal produces highly localized contact stress without excessive bolt-up loads. Figure 3 shows the detail of plating or coating.

Figure 3: Silver plating on the seal base material.



<u>Delta Copper (Aluminum) Seal</u> is a low load version of the seals. The delta features two delta-shaped ridges at the mean diameter of the torus. In the case of ductile copper lining, the height and shape of these deltas are designed to be flattened after compression. Delta seals were specifically designed to provide the lowest leak rate possible for an ultrahigh vacuum. The delta seal cross section is shown in Figure 4.

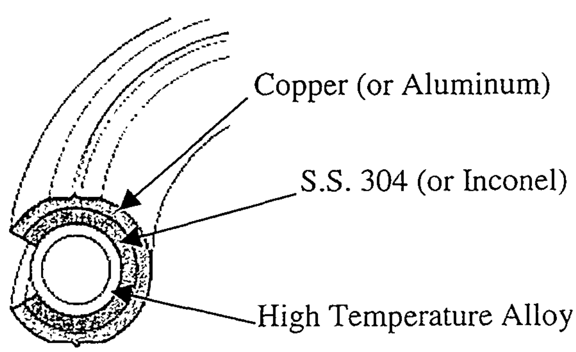


Figure 4: Helicoflex delta copper seal.

Copper delta seals are used for the vacuum joints between coupling cavities and accelerator cavities. Copper provides electrical conductivity for RF coupling cavities. Aluminum delta seals are for accelerator beamline vacuum joints. The groove has to be designed at one flange to house and locate the seal.

Special Copper Diamond Seal is a special vacuum seal for the vacuum joints and electrical conductivity of long coupling cavities. To simplify the coupling cavity design, the grooves on coupling cavity flanges are eliminated. Thus, the installation and maintenance of the long coupling cavities will be performed easily.
The cross-sectional view is shown in Figure 5. Figure 6 is a photo of a partial copper diamond seal.

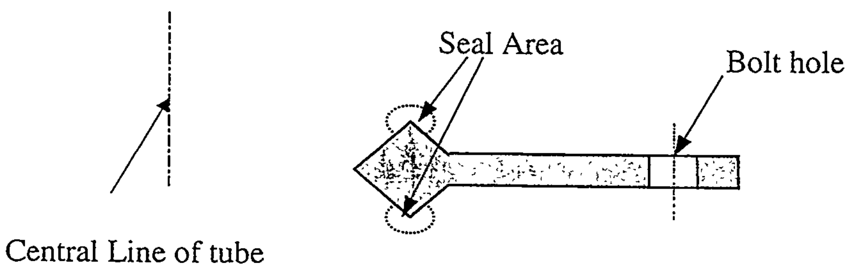


Figure 5: Cross section of special copper diamond seal.

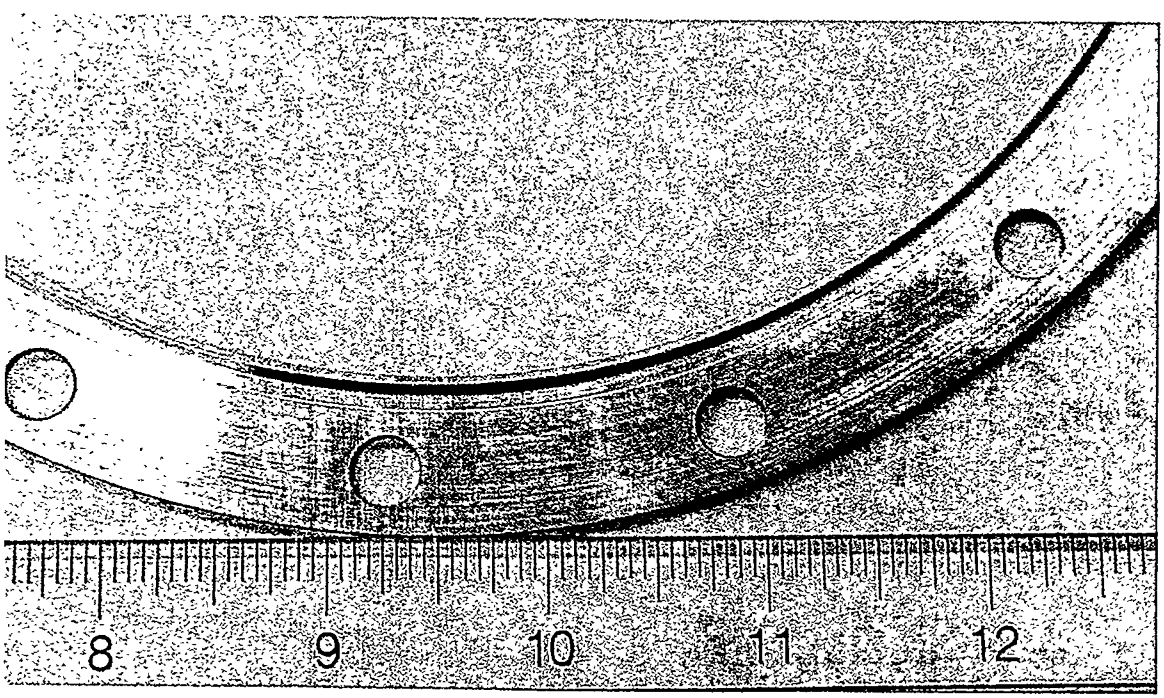


Figure 6: A: Photo of a partial copper diamond seal.

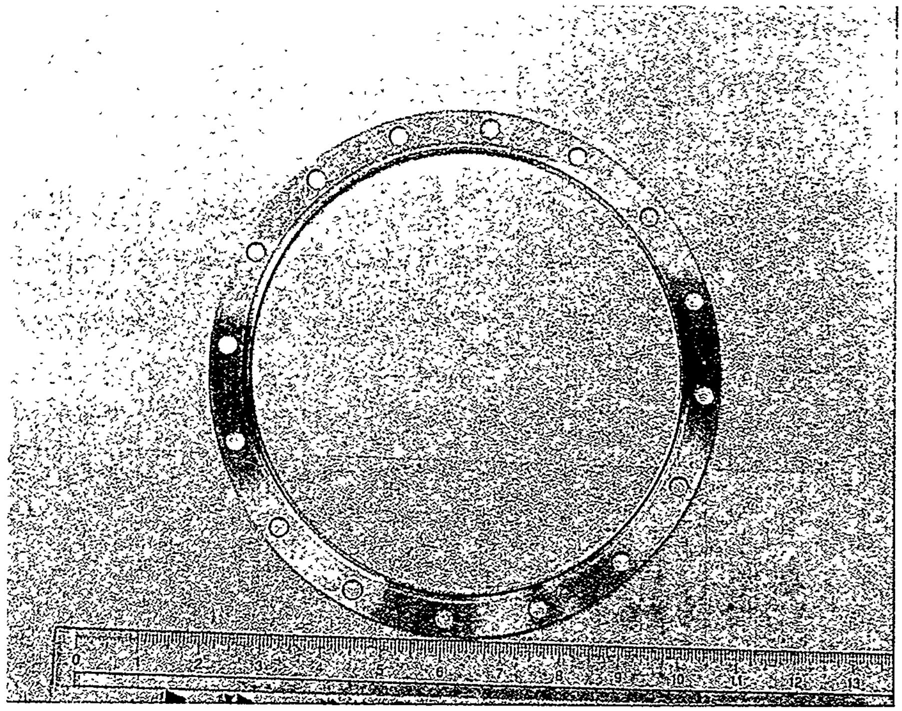


Figure 6: B: The copper diamond seal is ready for a vacuum test.

The delta copper seal with a pressurized limiting ring is developed from the delta seal. The delta seal will be attached to the limiter instead of using a groove on the flange surface to locate the seal. It has the same advantage as a copper diamond seal. They all can make installation and maintenance easier than the one that has a groove at the coupling cavity flange. To eliminate the vacuum test, we take the results of the delta seal test into account. The seal load is 1,050 lb per circumference inch of seal. The seal cross section is 0.126 in. before using the delta seal. The design is detailed in the following figures on the next page.

Figure 7: The copper delta seal with a limiting ring.

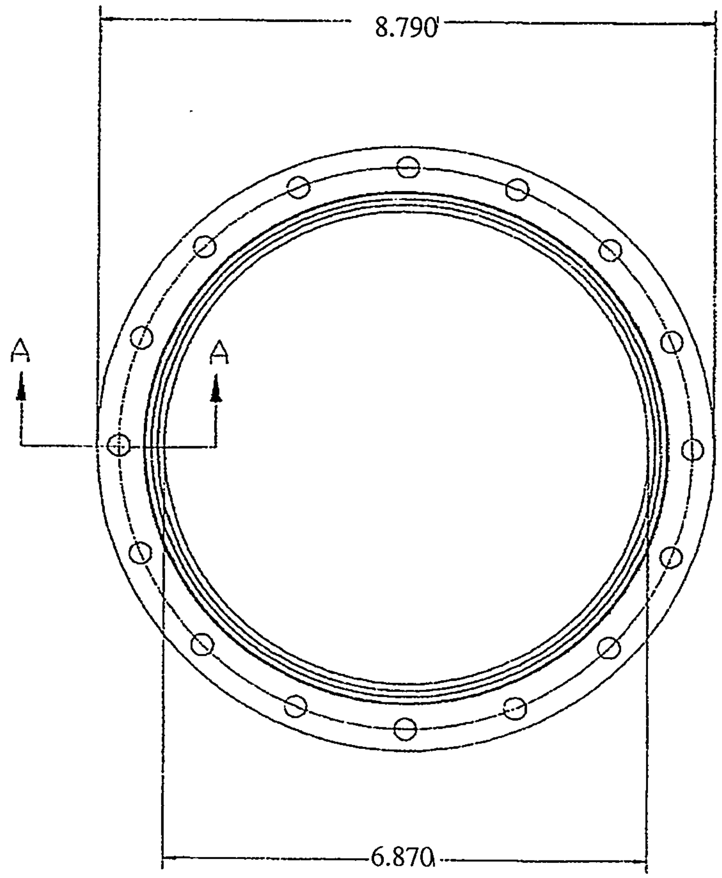
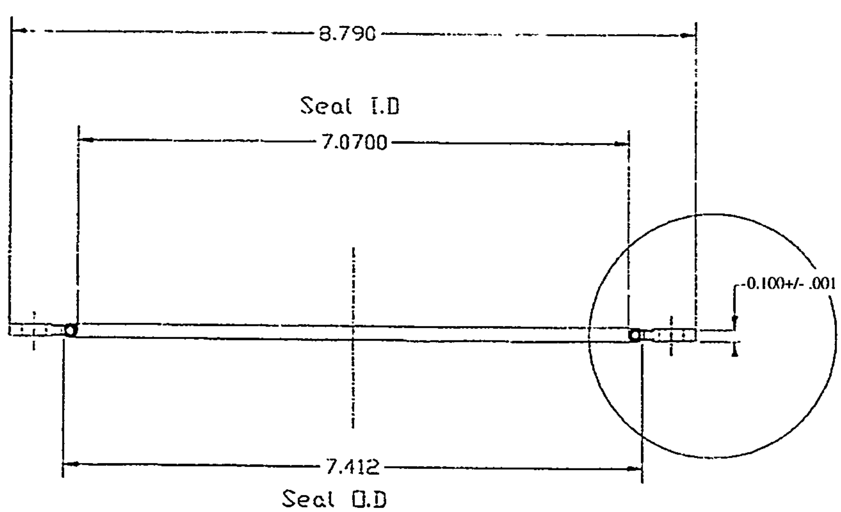


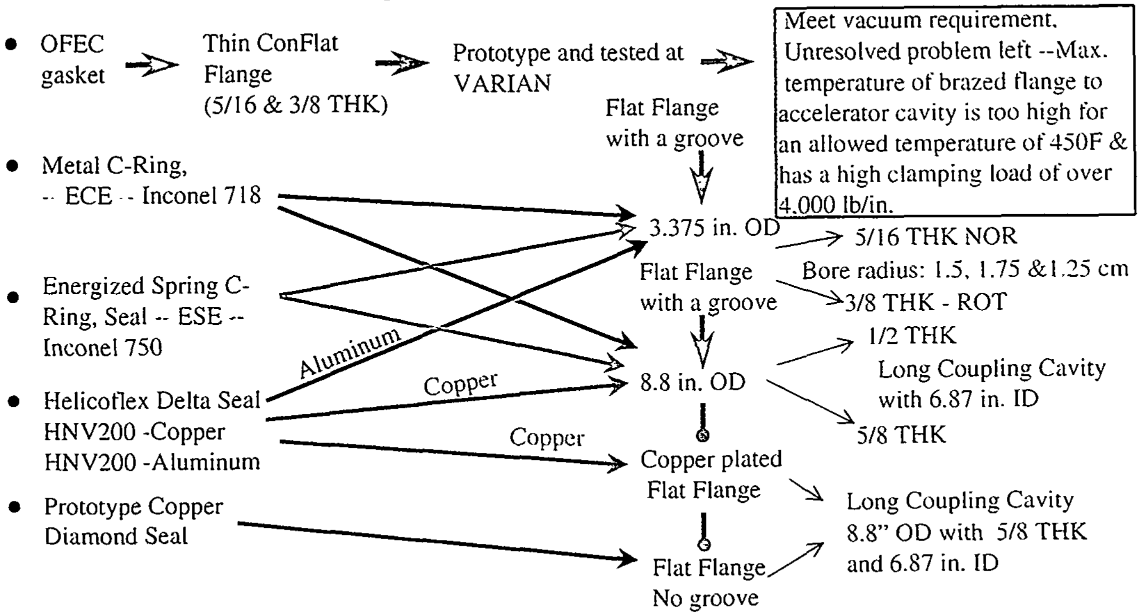
Figure 8: Key dimensions of the proposed copper delta seal with a stainless steel limiter.



Overview of the Vacuum Seal Test Plan for the SNS LINAC

Objective: To meet vacuum and RF requirements; to reduce the seating load of seals on the long coupling cavity; to save the intersegmental space for fitting requested hardware in the beamline; to have accessibility for maintenance;

Task: Seal test hardware design, fabrication, vacuum leak rate test and documentation.



II. MATERIAL CERTIFICATION OF METAL SEALS

All metal seals have their material certifications, which include purchased seals and fabricated seals. In this document, the purchase orders and fabrication processing record for all metal seals are not included. They are to be found in the SNS Project Files and the ESA-DE vault.

THE ADVANCED PRODUCTS COMPANY
33 Defco Park Rd.
North Haven, Ct. 06473

MATERIAL AND PROCESS CERTIFICATION

		Internal Code #	B3232
Material Supplier:	ULBRICH	Specification:	AMS 5596 Rev. H
Size:	.01 X .186	Heat Number:	HT4723EK

CHEMICAL ANALYSIS

Carbon	0.04	Columbium	4.94
Manganese	0.08	Titanium	1.05
Silicon	0.08	Aluminum	0.56
Phosphorus	0.01	Cobalt	0.03
Sulfur	0	Tantalum	0.01
Chromium	18.3	Boron	0
Nickel	53.9	Copper	0.03
Molybdenum	2.86	Iron	18

PHYSICAL PROPERTIES

Solution Heat Treated Tensile:			Precipitation Tensile:	
Tensile	113000		Tensile	206000
Yield	58000		Yield	175000
Elongation	24.5		Elongation	19.5
Hardness	B79		Hardness	44RC
Bend	Accept			
Grain Size	9		Tensile at 1200F:	
Surface Microstructure		Accept	Tensile	161000
			Yield	00144
			Elongation	7

Stress Rupture:	Temperature	00000	Stress	95000
	Time	57	Elong.	3

PARTS HAVE RECEIVED THE FOLLOWING PROCESSING/INSPECTIONS/TESTS
HEAT TREAT PER APCO SPEC P1307-6
SILVER PLATING PER APCO SPEC 52258

Customer:	LOS ALAMOS NAT'L LABS	Part Number:	
P.O.	I1699TEL9-9R	Quantity:	5
Item #	003	Packing Slip:	036655
Date Shipped	04/19/99	APCO PN:	ECE 001802-07-14-6 ZSF

It is hereby certified that the items specified above have been manufactured, tested, and inspected in full accordance with all purchase order and drawing requirements. Results of all tests and inspections are on file at our plant. Equipment containing mercury or mercury compounds was not used for fabrication, assembly, packaging, installation or examination of the parts on this order. Note: The recording of false, fictitious or fraudulent statements or entries on this document may be punished as a felony under Federal Statues including Title 18, Chapter

The Advanced Products Company

Quality Department

THE ADVANCED PRODUCTS COMPANY
33 Defco Park Rd.
North Haven, Ct. 06473

MATERIAL AND PROCESS CERTIFICATION

		Internal Code #	B3217
Material Supplier:	ULBRICH	Specification:	AMS 5596 Rev. H
Size:	.015 X .244	Heat Number:	057164-02

CHEMICAL ANALYSIS

Carbon	0.05	Columbium	5.08
Manganese	0.07	Titanium	1.03
Silicon	0.05	Aluminum	0.55
Phosphorus	0.01	Cobalt	0.17
Sulfur	0	Tantalum	0.02
Chromium	18.4	Boron	0
Nickel	52.9	Copper	0.04
Molybdenum	2.93	Iron	18.3

PHYSICAL PROPERTIES

Solution Heat Treated Tensile:		Precipitation Tensile:	
Tensile	134300	Tensile	209700
Yield	63300	Yield	175000
Elongation	42	Elongation	16
Hardness	B93	Hardness	C46
Bend	Accept		
Grain Size	0	Tensile at 1200F:	
Surface Microstructure	Accept	Tensile	161200
		Yield	134600
		Elongation	12.5
Stress Rupture:	Temperature	Stress	100000
	Time 28.4	Elong.	6.5

PARTS HAVE RECEIVED THE FOLLOWING PROCESSING/INSPECTIONS/TESTS
SILVER PLATE PER AMS 2410

Customer:	LOS ALAMOS NAT'L	Part Number:	
P.O.	I1699TEL9-9R	Quantity:	5
Item #	001	Packing Slip:	036927
Date Shipped	05/05/99	APCO PN:	ECE 007000-09-14-6 ZSF

It is hereby certified that the items specified above have been manufactured, tested, and inspected in full accordance with all purchase order and drawing requirements. Results of all tests and inspections are on file at our plant. Equipment containing mercury or mercury compounds was not used for fabrication, assembly, packaging, installation or examination of the parts on this order. Note: The recording of false, fictitious or fraudulent statements or entries on this document may be punished as a felony under Federal Statues including Title 18, Chapter

The Advanced Products Company

Quality Department

THE ADVANCED PRODUCTS COMPANY
33 DEFCO PARK ROAD
NORTH HAVEN, CONNECTICUT 06473
CERTIFICATION

			INTERNAL CODE		B2186
MATERIAL SUPPLIER:	ULBRICH	TYPE:	ALLOY 718	SIZE:	.006 X .124
SPECIFICATION	AMS 5596 G		HEAT NUMBER		HT4920EK

CHEMICAL ANALYSIS

CARBON	0.04	CHROMIUM	18.26
MANGANESE	0.06	NICKEL	53.79
IRON	18.41	Cb + Ta	4.99
SULFUR	0.001	COPPER	0.01
SILICON	0.11	TITANIUM	0.96
COBALT	0.03	ALUMINUM	0.38
PHOSPHORUS	0.008	BORON	0.002
MOLYBDENUM	2.95		

PHYSICAL PROPERTIES

AS RECIEVED:		HEAT TREATED:		HEAT TREATED AT 1200F	
TENSILE	136000	TENSILE	221900	TENSILE	181600
YIELD	64700	YIELD	191100	YIELD	152100
ELONGATION	35.5	ELONG	15	ELONGATIO	21
HARDNESS	B 94	HARDNESS	C 46		

PARTS HAVE PASSED THE FOLLOWING TESTS:
MICROSTRUCTURE
BEND
GRAIN SIZE 10
PRESSURE TEST

PARTS HAVE RECEIVED THE FOLLOWING PROCESS SPECIFICATIONS:
SILVER PLATED PER AMS 2410
HEAT TREATED PER PER P1307-6

CUSTOMER	LOS ALMOS NATL.	PART NUMBER	
P/O NUMBER	11699TEL9-9R	AMOUNT	5
ITEM NUMBER	002	PACKING SLIP	037056
DATE SHIPPED	05/13/99	APCO PART NUMBER	ECE 001594-05-14-6 ZST

IT IS HEREBY CERTIFIED THAT THE ITEMS SPECIFIED ABOVE, HAVE BEEN MANUFACTURED, TESTED, AND INSPECTED IN FULL ACCORDANCE WITH ALL PURCHASE ORDER AND DRAWING REQUIREMENTS. RESULTS OF ALL TESTS AND INSPECTIONS ARE ON FILE AT OUR PLANT.
EQUIPMENT CONTAINING MERCURY OR MERCURY COMPOUNDS WAS NOT USED FOR FABRICATION ASSEMBLY, PACKAGING, INSTALLATION, EXAMINATION OR TESTING OF PARTS OR ASSEMBLIES ON THIS ORDER.
NOTE: THE RECORDING OF FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHED AS A FELONY UNDER FEDERAL STATUTES INCLUDING TITLE 18, CHAPTER 47.

THE ADVANCED PRODUCTS COMPANY

QUALITY MANAGER

THE ADVANCED PRODUCTS COMPANY
33 Defco Park Rd.
North Haven. Ct. 06473

MATERIAL AND PROCESS CERTIFICATION

		Internal Code #	B3185
Material Supplier:	ULRICH	Specification:	AMS 5598 Rev. C
Size:	.015X.244	Heat Number:	HT7008XK

CHEMICAL ANALYSIS

Carbon	0.04	Cb. and Ta.	0.96
Manganese	0.06	Titanium	2.57
Silicon	0.14	Aluminum	0.85
Phosphorus	0.01	Cobalt	0.05
Sulfur	0	Copper	0.01
Chromium	15.6		
Nickel + Cobalt	72.5		
Iron	7.27		

PHYSICAL PROPERTIES

Solution Heat Treated Tensile:		Precipitation Tensile:	
Tensile	####	Tensile	####
Elongation	48	Elongation	20
Bend	Accept	Hardness	C40
Grain Size	8		

PARTS HAVE RECEIVED THE FOLLOWING PROCESSING/INSPECTIONS/TESTS
SILVER PLATED

Customer:	LOS ALAMOS NAT'L LABS	Part Number:	0
P.O.	I1699TEL9-9R	Quantity:	4
Item #	004	Packing Slip:	037312
Date Shipped	06/03/99	APCO PN:	ESE 007000-09-06-1 ZSF

It is hereby certified that the items specified above have been manufactured. tested, and inspected in full accordance with all purchase order and drawing requirements. Results of all tests and inspections are on file at our plant. Equipment containing mercury or mercury compounds was not used for fabrication. assembly, packaging, installation or examination of the parts on this order. Note: The recording of false, fictitious or fraudulent statements or entries on this document may be punished as a felony under Federal Statues including Title 18, Chapter

The Advanced Products Company

Quality Department

THE ADVANCED PRODUCTS COMPANY
33 Defco Park Rd.
North Haven, Ct. 06473

MATERIAL AND PROCESS CERTIFICATION

		Internal Code #	B3185
Material Supplier:	ULRICH	Specification:	AMS 5598 Rev. C
Size:	.015X.244	Heat Number:	HT7008XK

CHEMICAL ANALYSIS

Carbon	0.04	Cb. and Ta.	0.96
Manganese	0.06	Titanium	2.57
Silicon	0.14	Aluminum	0.85
Phosphorus	0.01	Cobalt	0.05
Sulfur	0	Copper	0.01
Chromium	15.6		
Nickel + Cobalt	72.5		
Iron	7.27		

PHYSICAL PROPERTIES

Solution Heat Treated Tensile:		Precipitation Tensile:	
Tensile	####	Tensile	####
Elongation	48	Elongation	20
Bend	Accept	Hardness	C40
Grain Size	8		

PARTS HAVE RECEIVED THE FOLLOWING PROCESSING/INSPECTIONS/TESTS
SILVER PLATED

Customer:	LOS ALAMOS NAT'L LABS	Part Number:	
P.O.	I1699TEL9-9R	Quantity:	1
Item #	004	Packing Slip:	037362
Date Shipped	06/08/99	APCO PN:	ESE 007000-09-06-1 ZSF

It is hereby certified that the items specified above have been manufactured, tested, and inspected in full accordance with all purchase order and drawing requirements. Results of all tests and inspections are on file at our plant. Equipment containing mercury or mercury compounds was not used for fabrication, assembly, packaging, installation or examination of the parts on this order. Note: The recording of false, fictitious or fraudulent statements or entries on this document may be punished as a felony under Federal Statues including Title 18, Chapter

The Advanced Products Company

[signature]

Quality Department

Coltec Industries

Garlock Helicoflex
2770 The Boulevard
PO Box 9889
Columbia, SC 29209
1-803-783-1880
FAX: 1-803-783-4279 or
1-803-783-9003

Helicoflex WO Number:	99-0995-1
Helicoflex Part Number:	H-306124 REV. NC
Date Shipped:	6-9-99
Quantity:	5

Outer Jacket:	Copper	**Material Lot:**	9363
Inner Lining:	S.S. 304	**Material Lot:**	9384
Spring Type:	Alloy 90	**Material Lot:**	11276
Limiter:	Aluminum	**Material Lot:**	N/A

Customer:	University of California (Los Alamos Natn'l Lab.)
Customer PO:	18155SML9-87
Customer P/N:	N/A

Certification

I hereby certify that the items delivered on this purchase order comply to all applicable drawing/ specification requirements. Evidence of such inspections and tests are on file for review for a minimum of seven (7) years.

I hereby certify that the materials furnished on this order are free from contamination by the presence of Mercury and that no Mercury-bearing instruments and/or equipment which might cause contamination have been used in the manufacture, fabrication, or testing of any material furnished on this order.

The recording of false, fictitious, or fraudulent statements or entries on this or supporting documents may be punishable as a felony under Federal Statutes, including Federal Law, Title 18, Chapter 47.

J Powell

Jim Powell
Quality Assurance Manager

MATERIAL CODE NO. 9363

outokumpu
Copper R&D/QA, Pori HHA

EN 10 204
Test report 2.2
16.2.1998

Page 1 (1)

Copper and Brass Sales
Corporate Services Division
17401 Ten Mile Road
EASTPOINTE MI 48021
USA

Your order
Made in Finland
PO 894835/OB-2629

Our reference
008467

Invoice / date
VA31507431
13.02.1998

Marks
894835/OB-2629

Item	Product, Grade and Size			
001	COPPER STRIP OF-OK C102 .015x13" DEEP DRAWING ANNEALED 0,381x330,2 MM ASTM B152 PN 600230-7	3018 6653.4	KG LBS	VA026915

CUSTOMER: HELICOFLEX
CUSTOMER PO: 028146
W.O./PT. NO.: 870406
DATE: 8/7/98
LBS. SHIPPED: 190

Mechanical properties

Item	Tensile strength R_m N/mm²	0.2 % proof strength $R_{p0.2}$ N/mm²	Elongation %	Hardness	Grain size mm
001	229	77	A100 40	HRF 43	0,025
	33214	11168			

Reviewed and approved by
Helicoflex Quality Assurance
[signature]
Date: 8/13/98

Chemical composition %
Cu min 99,99
O <0,0005

LOT NO.: 9384

Integrity
Metals & Slitting

592 W. Explorer Street • Brea, CA 92821
Phone: (714) 529-7920 • Fax: (714) 529-7824

Certificate of Test

SOLD TO	SHIP TO
Garlock Helicoflex P.O. Box 9889 Columbia, SC 29290	Garlock Helicoflex 2770 The Boulevard Columbia Industrial Park Columbia, SC 29209

Date	Purchase Order	Work Order	Control#	Heat
3/30/99	028895	WI00484C	B0130	253018

Type	Condition	Thickness	Width	Length	Quantity
304L	Annealed	.0120	24.00"	Coil	106# (1 Coil)

Specifications

AMS-5511-G

Chemistry

C *Carbon*	0.0160	N2 *Nitrogen*	0.0800
Mn *Manganese*	1.4800	Co *Cobalt*	0.1400
Si *Silicon*	0.4100		
P *Phosphorus*	0.0320		
S *Sulfur*	0.0070		
Cr *Chromium*	18.3400		
Ni *Nickel*	8.9500		
Mo *Molybdenum*	0.2000		
Cu *Copper*	0.1600		

Reviewed by Helicoflex Quality Assurance: ____

Date: 4-2-99

Mechanical Properties

Condition/ Heat Treat	Annealed			
Hardness	RB-72			
Tensile Strength	96.00 - 97.00			
Yield Strength @ 2% (KSI)	41.00 - 42.00			
% Elong. in 2" (50.8mm)	70.0 - 74.0			
Bend Test	OK			
Embrittlement	OK			
Grain Size				

Notes

This is to certify, to the best of our knowledge and belief, that the values shown are correct and true, that the material complies with the requirements of the specifications shown, and are recorded in company files.

Albert J. Toscano, QA Manager

Form Q/M1/31

LOT NO.: 11276

HAMDEN METAL SERVICE CO., INC.
2 BROADWAY, HAMDEN, CONNECTICUT 06518
PHONE (203) 281-1522 FAX (203) 287-0851 FAX (800) 611-9993

Date: 04/14/98
Sales order: 22375

SOLD TO: HELICOFLEX
2770 THE BOULEVARD
COLUMBIA SC 29209

Quantity ordered: 30
Quantity shipped: 37.86

CUSTOMER P.O. 027694

Consisting of:
.010 PYROMET 90 SPRING

Specification:

As drawn tensile	Yield	Elongation %	Hardness	Wrap	Bend
190,281				SAT.	SAT

After H.T.Tensile

GARLOCK HELICOFLEX AFTER HEAT TREAT
TENSILE: 229. 299
INSPECTION BY: [signature] DATE: 4-21-98

Reviewed by Helicoflex Quality Assurance: [signature]
Date: 4-21-98

HEAT NUMBER: 203400 LOT # 8796

C	Mn	Si	S	P	Cr	Ni	Cu
.026	<.01	.02	<.001	.002	19.97	59.52	.01
B	**Fe**	**Al**	**Ti**	**Cb+Ta**	**Co**	**Mo**	**V**
.003	.66	1.57	2.48		15.50		
Mc	**Ca**	**N**	**Ag**	**H**	**W**	**Cb**	**Ta**
			<.0005				
Pb	**Sn**	**Zr**	**Nb**	**N2**	**Bi**		
<.002		.05			<.00003		

This material has been manufactured mercury free at Hamden Metal Service Co.

[signature]
Authorized Signature

Coltec Industries

Garlock Helicoflex
2770 The Boulevard
PO Box 9889
Columbia, SC 29209
1-803-783-1880
FAX: 1-803-783-4279 or
1-803-783-9003

Helicoflex WO Number: 99-2054-1
Helicoflex Part Number: H-306290 Rev. NC
Date Shipped: 12-6-99
Quantity: 5

Outer Jacket:	Aluminum	**Material Lot:**	9380
Inner Lining:	Alloy 600	**Material Lot:**	9394
Spring Type:	Alloy90	**Material Lot:**	11294
Limiter:	Aluminum	**Material Lot:**	970L163A

Customer: University of California
(Los Alamos Natn'l Lab.)
Customer PO: 26CY-8U
Customer P/N: N/A

Certification

I hereby certify that the items delivered on this purchase order comply to all applicable drawing/ specification requirements. Evidence of such inspections and tests are on file for review for a minimum of seven (7) years.

I hereby certify that the materials furnished on this order are free from contamination by the presence of Mercury and that no Mercury-bearing instruments and/or equipment which might cause contamination have been used in the manufacture, fabrication, or testing of any material furnished on this order.

The recording of false, fictitious, or fraudulent statements or entries on this or supporting documents may be punishable as a felony under Federal Statutes, including Federal Law, Title 18, Chapter 47.

J Powell

Jim Powell
Quality Assurance Manager

LOT NO.: 9386

ALTEMP ALLOYS, INC. 1630 So. Sunkist St. Suite E, Anaheim, CA 92806
Ph: (714) 938-0601 * Fax (714) 938-0971 E-mail: altempalloys@worldnet.att.net
Web Site: www.altempalloys.com

CUSTOMER:	HELICOFLEX COMPONENTS
CUSTOMER Po#	29114
OUR SO#	S11487
DATE:	S11487

CERTIFICATE OF CHEMICAL ANALYSIS AND PHYSICAL PROPERTIES

ITEM NO.	DESCRIPTION	MATERIAL	HEAT NO.
	AMS 5596H .008 X 7.25" 1 COIL 16#	718	055832-02

CHEMICAL ANALYSIS

ITEM NO.	C	MN	SI	P	S	CR	V	NI	MO	CU	CO	W
	0.05	0.07	0.11	0.003	0.001	18.2		52.42	3.02	0.04	0.13	

ITEM NO.	N	FE	AL	O	H	ZR	Y	B	PB	TI	CB+TA	SN
		BAL.	0.52					0.004		0.94		

	TA	CB
	0.02	5.06

PHYSICAL PROPERTIES

TEMP.	DIRECT.	YIELD POINT P.S.I.	TENSILE STRENGTH P.S.I.	ELONGATION %	REDUCTION AREA %	MACRO	GRAIN SIZE	HARDNESS	BEND
RM.1	L/T	68,200/73,600	138,900/139,000	37.5/43.0			9	RB 99.0	OK
RM.2		184,100	221,000	15					
RM.3		165,100	204,000	14.5					

ITEM NO.	MICRO	RA MICRO INCH
		L3 T5

ITEM NO.	TEMP	STRESS P.S.I.	HOURS	ELONGATION %	REDUCTION AREA %	MILL SOURCE:
	1200F	95,000/130,000	78.9	8		AS

RM. 1: AS SHIPPED - ROOM TEMP. RM. 2: AGED- ROOM TEMP. RM. 3: ELEVATED

THIS IS TO CERTIFY, TO THE BEST OF OUR KNOWLEDGE AND BELIEF, THAT THE VALUES SHOWN ARE CORRECT AND TRUE AND THAT THE MATERIAL COMPLIES WITH THE REQUIREMENTS OF THE SPECIFICATION SHOWN. WE DISCLAIM ANY LEGAL LIABILITY FROM USE OF THIS CERTIFICATE.

ALTEMP ALLOYS, INC.
BY: JaneRiddle, Quality Control
Jane Riddle

ATA 2

Reviewed by Helicoflex Quality
Assurance: S
Date: 5-19-99

LOT NO.: 9394

ALTEMP ALLOYS, INC. 1630 So. Sunkist St. Suite E, Anaheim, CA 92806
Ph: (714) 938-0601 * Fax (714) 938-0971 E-mail: altempalloys@worldnet.att.net
Web Site: www.altempalloys.com

CUSTOMER:	HELICOFLEX COMPONENTS
CUSTOMER Po#	29190
OUR SO#	S11654
DATE:	6/9/99

COMPONENTS

ITEM NO.	DESCRIPTION	MATERIAL	HEAT NO.
	AMS 5540L .010 X 24" X 1378" 1 COIL 102#	600	ONH23HH-02
	ANNEALED		

CHEMICAL ANALYSIS

ITEM NO.	C	MN	SI	P	S	CR	V	NI	MO	CU	CO	TA
	0.06	0.28	0.2	0.007	0.009	15.89		74.8		0.15	0.47	<.01

ITEM NO.	N	FE	AL	O	H	ZR	Y	B	PB	TI	CB+TA	CB
		7.67	0.19							0.27		<.01

PHYSICAL PROPERTIES

ITEM NO.	TEMP	YIELD POINT P.S.I.	TENSILE STRENGTH P.S.I.	ELONGATION %	REDUCTION AREA %	MACRO	GRAIN SIZE	HARDNESS	BEND
		L 35,500	L 94,600	41.5			8	RB 78.0	OK
		T 35,800	T 93,700	43.5					

ITEM NO.	MICRO	RA MICRO INCH

ITEM NO.	TEMP	STRESS P.S.I.	HOURS	ELONGATION %	REDUCTION AREA %	MILL SOURCE:
						ALLEGHENY LUDLUM

THIS IS TO CERTIFY, TO THE BEST OF OUR KNOWLEDGE AND BELIEF, THAT THE VALUES SHOWN ARE CORRECT AND TRUE AND THAT THE MATERIAL COMPLIES WITH THE REQUIREMENTS OF THE SPECIFICATION SHOWN. WE DISCLAIM ANY LEGAL LIABILITY FROM USE OF THIS CERTIFICATE.

ALTEMP ALLOYS, INC.
BY: JaneRiddle, Quality Control
Jane Riddle

Reviewed by Helicoflex Quality
Assurance: ________
Date: 6-14-99

MATERIAL CODE NO. 11294
Form O/M1/31

HAMDEN METAL SERVICE CO., INC.

2 BROADWAY, HAMDEN, CONNECTICUT 06518
PHONE (203) 281-1522 FAX (203) 287-0851 FAX (800) 611-9993

Date: 08/27/98
Sales order: 32883

SOLD TO: HELICOFLEX
2770 THE BOULEVARD
COLUMBIA SC 29209

CUSTOMER P.O. 027995

Quantity ordered: 15
Quantity shipped: 16.78

Consisting of:
.008 PYROMET 90 SPRING

Specification:

As drawn tensile	Yield	Elongation	Hardness	Wrap	Bend
211,155				SAT	SAT

GARLOCK HELICOFLEX AFTER HEAT TREAT
TENSILE: 239,044
INSPECTION BY: [signature] DATE: 8-31-98

After H.T.Tensile

HEAT NUMBER: 204103 LOT # 9130

C	Mn	Si	S	P	Cr	Ni	Cu
.08	<.01	.03	<.001	.002	19.81	58.68	.01
B	**Fe**	**Al**	**Ti**	**Cb+Ta**	**Co**	**Mo**	**V**
.01	1.48	1.47	2.63		15.69		
Mg	**Ca**	**N**	**Ag**	**H**	**W**	**Cb**	**Ta**
			<.0005				
Pb	**Sn**	**Zr**	**Nb**	**N2**	**Bi**		
<.002		.06			<.00003		

This material has been manufactured mercury free at Hamden Metal Service Co.

Reviewed by Helicoflex Quality
Assurance: [signature]
Date: 8-31-98

[signature]
Authorized Signature

Prototype Copper Diamond Seal fabrication Information

SNS-042

CORONADO MACHINE, INC.
Material Parts List

P.O.#9906-07

CMI-OA-4

Approved for Purchase ____ Date ____
Quotation Due Date ____

Estimating ☑ Date 6-30-99
Purchasing ✓ Date 6-30-99

Sheet 1 of 1
Customer Los Alamos
Req No SNS-042
Date ____
Rou. Rec'd P.O.#9906-07

QTY.	PART NO.	DESCRIPTION OF MATERIAL OR OPERATION	VENDOR/CONTACT	VENDOR/CONTACT	VENDOR/CONTACT	VENDOR/CONTACT
7	LM2	~~9 1/4" Ø × 1/4" thk~~ 1/4" × 9 1/2" Ø	Annealed Copper →	245.00	1 wk	
				Marco	Bob	
					6/30	

NOV 05 99 08:35a CORNADO MACHINE 505 243 1944 p.1

JUN-30-99 WED 13:17 MARCO STEEL FAX NO. 5053457398 P.01

JUN-30-99 WED 14:21 CORONADO MACHINE 5052451514 P.01

SNS-042

MARCO STEEL & ALUMINUM
P.O. Box 93577
Albuquerque, NM 87199-3577
(505) 345-3555
(800) 235-3034
Fax (505) 345-7398

TO: Coronado Mach

TIC#

DATE: 7/7/99

PO NO:

P/O # SNS-042
W/O # 9906-07

CORONADO MACHINE, INC.
1308 FIRST STREET N.W.
ALBUQUERQUE, N.M. 87102
505-243-1944

WE HEREBY CERTIFY THAT MATERIALS FURNISHED ON THIS ORDER HAVE BEEN PRODUCED TO MEET CHEMICAL AND PHYSICAL REQUIREMENTS OF THE FOLLOWING SPECIFICATIONS:

DESCRIPTION		PHYSICAL PROPERTIES					
MATERIAL AND SPECIFICATION	HEAT NO.	YIELD PSI	TENSILE PSI	ELONG %	RED OF AREA	HARDNESS BRINELL	HARDNESS ROCKWELL
Copper Sheet, Cond A		42.0	36.0	14%			B-40
ASTM-B-152-110							

CHEMICAL COMPOSITION IN PERCENTAGE

C.	Si.	Mn.	P.	S.	Ni.	Cr.	Mo.	Cu.	CO/N		
99.9											

THE DATE HEREIN HEREIN DESCRIBED REPRESENTS:

☐ TEST RESULTS
☒ NOMINAL

MARCO STEEL

BY: [signature]

III. VACUUM TEST HARDWARE DESIGN

-SNS LINAC Vacuum Joint Improvement Design for Beamline Components and Coupling Cavities

ECE METAL C-RING, EXTERNAL PRESSURE FACE SEAL

Coupling cavity vacuum joint design parameters: (Unit: inch)

1. Coupling cavity flange OD:	8.80
2. Coupling cavity ID:	6.87
3. Flange thickness:	0.50 & 0.625
4. Bolt circle:	8.165
5. Fastener:	(16) 5/16-24 x 1.5 Grade 8, with a .065 thick washer.

Metal "C" seal dimensions:

1. Seal material:	Alloy 718
2. Seal diameter:	A = 7.00 (-0.0 / + 0.01)
3. C seal free height:	C = 0.125 ± 0.003
4. Diameter clearance:	Z = 0.012
5. Max. radial width:	M = 0.100
6. Material thickness:	t = 0.015
7. Finishing material:	Silver with thickness 0.003 – 0.004
8. Seal OD (=A+2M):	D_{so} = 7.2 (+0.0 / -.01)

Seal siting groove dimensions:

1. Seal siting groove ID:	D = 6.981(+0.0 / -. 006)
2. Depth:	F = 0.105 (+. 000 / - .005)
3. Minimum width:	G = 0.135
4. Max. Radius:	R = 0.030
5. Groove OD (=D+2G):	D_{go} = 7.251(-0.0 /+. 006)

Part Number: **ECE – 007000 – 09 – 14 – 6 - SPF**

Beamline vacuum joint design parameters for bore radius of 1.5 cm, 1.75 cm and 2.00 cm:

1. Beamline tube and beam diagnostics devices flange OD: 3.375
2. Beam tube ID or minimum inner diameter, such as bellows, Beam diagnostics devices, which should not interfere with the required beam to stay clear:
   - a) 1. 5 cm bore radius: Beam tube ID - 1.18 (2.997 cm)
   - b) 1.75 cm bore radius: Beam tube ID - 1.43 (3.632 cm)
   - c) 2.00 cm bore radius: Beam tube ID - 1.62 (4.115 cm)
3. Flange thickness:
   - a) Nonrotatable: 5/16
   - b) Rotatable: 3/8
4. Bolt Circle: 2.85
5. Fastener: (8) 5/16 - 24 x .875

Metal "C" seal dimensions:

1. Seal material: Alloy 718
2. Seal diameter (ID): A = 1.802(-0.0 / +.006)
3. C seal free height: C = .094 ± .002
4. Diameter clearance: Z = .008
5. Max. radial width: M = .075
6. Material thickness: t=.01
7. Finishing material: Silver with thickness .003-.004
8. Seal OD (= A+2M): D_{so} = 1.952(+0.0 / -.006)

Seal siting groove dimensions:

1. Seal siting groove ID: D = 1.786 (+0.0 / - .004)
2. Depth: F = .077 ± .002
3. Minimum width: G = .105
4. Max. Radius: R = .020
5. Groove OD (= D+2G): D_{gv} = 1.996 (-0.0 / + .004)

Part Number: **ECE – 001802 – 07 – 14 – 6 – SPF**

<u>Beamline vacuum joint design parameters for bore radius of 1.25 cm:</u>

(Removed from vacuum test)

1. Beamline tube and beam diagnostics devices flange OD:
   2.75 (Removed from the test, because there is no 1.25 cm bore radius any more.)
   Beam tube ID or minimum inner diameter, such as bellows,
   Beam diagnostics devices that should not interfere with the
   officially required beam to stay clear:
   a) For 1.25 cm bore radius: 0.995
   Flange thickness:
   a) Nonrotatable: 5/16
   b) Rotatable: 3/8
4. Bolt Circle: 2.312
5. Fastener: (6) ¼ - lengths.

Metal "C" seal dimensions:

1. Seal material: Alloy 718
2. Seal diameter: A = 1.594 (-0.0 / +.006)
3. C seal free height: C = 1/16± .002
4. Diameter clearance: Z = .006
5. Max. radial width: M = .05
6. Material thickness: t = 006
7. Finishing material: Silver with thickness .002-.003
8. Seal OD(= A+2M): D_{so} = 1.694 (+0.0 / - .006)

Seal siting groove dimensions:

1. Seal siting groove ID: D = 1.582 (+0.0 / - .004)
2. Depth: F = .052 ± .002
3. Minimum width: G = .075
4. Max. Radius: R = .015
5. Groove OD (= D+2G): D_{go} = 1.732 (-0.0 / +. 004)

Part Number: **ECE – 001594 – 05 – 14 – 6 - SPD**

<u>ESE SPRING ENERGIZED METAL C-RING,</u>
<u>EXTERNAL PRESSURE FACE SEAL</u>

Coupling cavity flange design parameters (unit: inch):

1. Coupling cavity flange OD:	8.80
2. Coupling cavity ID:	6.87
3. Flange thickness:	0.625
4. Bolt circle:	8.165
5. Fastener:	(16) 5/16-24 x 1 Grade 8, with a .065 thick washer.

ESE Spring Energized Metal C-Ring dimensions:

9. Seal material:	Alloy X - 750
10. Seal diameter:	A = 7.00
11. C seal free height:	C = 0.125 + .004 / - .003
12. Diameter clearance:	Z = 0.012
13. Max. radial width:	M = 0.114
14. Finishing material:	Silver with thickness 0.003 – 0.004

Seal siting groove dimensions:

1. Seal siting groove ID:	D = 6.9811 +0.0 /- .006
2. Depth:	F = 0.105 +. 005 /- .000
3. Minimum width:	G = 0.160 (Cavity OD: -0.0 / +. 007)
4. Max. radius:	R = 0.030

Part Number: **ESE – 007000 – 09 – 06 – 1 - SPF**

Beam-line vacuum joint design parameters for bore radius of 1.5, 1.75 and 2.00 cm:

2. Beamline tube and beam diagnostics devices flange OD:
   3.375 in.
4. Beam tube ID or minimum inner diameter, such as bellows, Beam diagnostics devices, which should not interfere with the required beam to stay clear:
   - a) For 1. 50 cm bore radius: 1.18 in. (1.25 in. tube w/ .035 wall thick)
   - b) For 1.75 cm bore radius: 1.43 in. (1.5 in. tube w/ .035 wall thick)
   - c) For 2.00 cm bore radius: 1.62 in. (1.75 in. tube w/ .065 wall thick)
5. Flange thickness:
   - a) Nonrotatable: 5/16 in.
   - b) Rotatable: 3/8 in.
4. Bolt circle: 2.85 in.
5. Fastener: (8) 5/16 - 24

ESE Spring Energized Metal C-Ring dimensions:

9. Seal Material:	Alloy X - 750
10. Seal Diameter:	A = 1.802
11. C seal free height:	C = 0.094 +0.004 / -0.002
12. Diameter clearance:	Z = 0.008
13. Max. radial width:	M = 0.087
14. Finishing material:	Silver with thickness 0.003 – 0.004

Seal siting groove dimensions:

1. Seal siting groove ID: D = 1.786 –0.0 / +0.004
2. Depth: F = 0.077 ± .002
3. Minimum width: G = 0.125 (Cavity OD: -0.0 / +. 004)
4. Max. radius: R = .0.020

Part Number: **ESE – 001802 – 07 – 06 – 1 – SPF**

<u>Beamline vacuum joint design parameters for bore radius of 1.25 cm:</u>

2. Beamline tube and beam diagnostics devices flange OD:
   2.75 inch
   Beam tube ID or minimum inner diameter, such as bellows, Beam diagnostics devices, that should not interfere with the officially required beam staying clear:
   a) For 1.75 cm bore radius: 1.402 in. (1.5in. tube w/. 035 wall thick)
   b) For 1.5 cm bore radius: 1.18 in. (1.25in. tube w/ .035 wall thick)

2. Flange thickness:
   a) Nonrotatable: 5/16 in.
   b) Rotatable: 3/8 in.
4. Bolt circle: 2.312 in.
5. Fastener: (6) 0.25 - 28

ESE Spring Energized Metal C-Ring dimensions:

9. Seal material: Alloy X -750
10. Seal diameter: A = 1.594
11. C seal free height: C = 0.062 +0.003 / -0.002
12. Diameter clearance: Z = 0.006
13. Max. radial width: M = 0.059 (Cavity OD: -0.0 / +. 004)
14. Finishing material: Silver with thickness 0.002-0.003

Seal siting groove dimensions:

1. Seal siting groove ID: D =1.582+0.0 / -0.004
2. Depth: F = 0.052±0.002
3. Minimum width: G = 0.090
4. Max. radius: R = 0.015

Part Number: **ESE – 001594 – 05 – 06 – 1 – SPD**

HELICOFLEX STANDARD COPPER DELTA SEAL DESIGN

Coupling cavity vacuum joint design parameters (unit: inch):

1. Coupling cavity flange OD:	8.80
2. Coupling cavity ID:	6.87
3. Flange thickness:	0.625
4. Required hardness:	120 Vickers
4. Bolt circle:	8.165
5. Fastener:	(16) 5/16-24 x 1 Grade 8, with a .065 thick washer.

Copper delta seal dimensions:

1. Seal material:	Jacket: Copper Liner: Stainless steel 300 series Inner: High temperature alloy spring
2. Seal diameter:	OD: 7.330 +/- .005 ID: 7.098 (Ref.)
3. Delta seal free height:	Before delta: 0.124 After delta: 0.120

Seal siting groove dimensions:

1. Seal siting groove ID:	6.990 +/- .005
2. Seal siting groove OD:	7.350+/- .005
2. Depth:	0.100 +/- .001
3. Required finish:	32 rms. or better lathe turned finish No radial marks

Part Number: **HN200 – H-306124 Rev NC**

COPPER DELTA SEAL WITH LIMITING RING DESIGN

Coupling cavity flange design parameters are the same as the previous ones.
Copper delta seal dimensions:

1. Seal material:	Jacket: Copper Liner: Stainless steel 300 series Inner: High temperature alloy spring
2. Seal diameter:	OD: 7.412 ID: 7.07 (Ref.)
3. Delta seal free height:	Before delta: 0.126 After delta: limited by the ring.

Limiting ring dimensions:

1. Material:	Stainless steel
2. Limiting ring diameter:	8.790
3. Thickness of the ring:	0.100 +/- 0.001

HELICOFLEX ALUMINUM DELTA SEAL DESIGN

Beamline vacuum joint design parameters (unit: inch):

1. Beamline flange OD:	3.38
2. Flange ID:	1.18—for 1.5 cm bore radius with 1.25-in. tube.
	1.43—for 1.75 cm bore radius with 1.5-in. tube.
	1.62—for 2.0 cm bore radius with 1.75-in. tube.
3. Flange thickness:	Rotatable: 0.375; Nonrotatable: 0.3125
4. Required hardness:	65 Vickers
4. Bolt circle:	2.85
5. Fastener:	(8) 5/16-24 x 1 Grade 8, with a .065 thick washer.

Aluminum delta seal dimensions:

1. Seal material:	Jacket: Aluminum
	Liner: Inconel Alloy 600
	Inner: High temperature alloy spring
2. Seal diameter:	OD: 2.265+/- .005
	ID: 2.015 (Ref.)
3. Delta seal free height:	Before delta: 0.134
	After delta: 0.130

Seal siting groove dimensions on the flange surface:

1. Seal siting groove ID:	1.786 (Ref)
2. Seal siting groove OD:	2.236 + 0.005/- 0.0
2. Depth:	0.099 +/- .001
3. Required finish:	32 to 63 rms circular
	No radial marks

Part Number: **HN200 – H-306290 Rev NC**

PROTOTYPED COPPER DIAMOND SEAL DESIGN

Coronado machining company fabricated two prototypes of the copper diamond seal for the vacuum leak rate test. They simulated the aluminum diamond seal that was used in the beamline of the accelerator at CERN. The copper diamond seal is for the vacuum joint of coupling cavities with the accelerator cavities.

Copper diamond seal dimensions:

1. Seal diameter:	OD: 8.79
	ID: 7.28
2. Seal thickness:	0.038
3. Diamond thickness:	0.100
4. Figuration:	16 boltholes with 0.344 diameter.

IV. VACUUM SEAL TEST SPECIFICATION
- DRAWING CONTROL FILE

SNS LINAC Vacuum Seal Test Specification

(Seals for Coupling Cavities joints and Beamline joints)

June 10, 1999

Objective of Vacuum Seal Test:

The purpose of the vacuum seal test is to evaluate the suitability of several types of metal seals for use in the SNS Linac Beamline and long Coupling cavities. A vacuum seal is desired that requires significantly less loading than a standard conflat for the coupling cavity assembly. We will conduct a series of tests to determine the leakage rates and loading characteristics of the different seals. The standard knife-edged flange and copper seal will be used as a baseline. A leakage rate should be lower than 8×10^{-11} torr-ℓ/s/mm is required in order to maintain the operation vacuum requirement of 5×10^{-8} torr. Because the required leakage rate is on the lower end of the manufacturer-published values, these tests must be done whether or not these types of seals are suitable for use in the SNS Linac.
The test is also a study of the coupling cavity assembly in order to determine the method and the tightening sequence for the fasteners and also to verify the amount of flange warpage when tightening bolts and the maximum torque to be applied.

Immediate test hardware package list:

Stainless Steel Flanges	8.8 in. OD w/ .625 thick	8.8 in. OD w/ .50 thick	3.38 OD w/ .375 thick, ROT	3.38 OD w/ .312 thick, NR
Metal "C – Seal" ECE	ECE-007000-09-14-6-SPF	ECE-007000-09-14-6-SPF	ECE-001802-07-14-6-SPF	ECE-001802-07-14-6-SPF
Energized Spring "C-Ring" ESE	ESE-007000-09-06-1-SPF	None	ESE-001802-07-06-1-SPF	ESE-001802-07-06-1-SPF
Helicoflex Delta Seal Copper	HNV200 7.33 OD w/ groove depth .100	None	N/A	N/A
Helicoflex Delta Seal Aluminum	N/A	N/A	HNV200 2.265 OD w/ groove depth .099	HNV200 2.265 OD w/ groove depth .099
Special Copper Diamond Seal	Prototype Made in NM Coronado Machine, Inc.	None	N/A	N/A

Test Equipment and tools required:

The Balzers QualyTest™ helium leak detector is used to test the seals. The lowest detectable leak rate of the detector is less than 5×10^{-12}mbar-ℓ/s, which is capable of detecting leakage of less than 5×10^{-10} torr-ℓ/s from the expected leakage rate of the test seals.

1. Balzers QualyTest™ helium leak detector
2. 400 ℓ/s Turbo pump
3. Dry piston roughing pump
4. ion gauges
5. Torque indicated tools.
6. Auxiliary tools for vacuum parts handling

Procedures:

Preparation:

1. All seals, flanges and test hardware components will be cleaned and bagged in a class 100 clean room according to SEMI guidelines.
2. Clean parts should only be handled by clean, power free latex gloves.
3. Wrap clean parts in lint-free tissue and clean aluminum foil, label with the part number and store in a clean tote.

Assembly:

1. Flanges are to be assembled on the test stand with bolts of 5/16-24.
2. Flange sealing surface should be visually inspected for surface aberrations.
3. Take initial measurement on the seal free height, then align the seal in a flange groove. Use caution to avoid damaging the seal.
4. Tighten flange pairs evenly using a "star" pattern with your hands until the flanges are snug.
5. All bolts should be tightened using the same torque wrench, and following a standard "star" pattern of tightening sequence to specified loading levels.
6. Flange tightening will occur in steps (i.e., 5 in.-lb, 10 in.-lb, 20 in.-lb, etc.), and leakage rate is determined at each step to ascertain the maximum load required for each type of seal.

Test operation:

1. Connect the test piece to the pump system.
2. Open the isolation valve to the test piece.
3. Once the chamber pressure is below 10^{-7} torr, turn on the RGA and the helium leak detector.
4. Cover the test piece with a bag and fill with helium.
5. Check the leak rate on the RGA. Cross over to the helium leak detector and record the leakage rate for 15 minutes; then cross over to the RGA and record the leakage rate for 15 minutes.
6. Tighten the flange to the next torque level, and repeat steps 3 and 4.

7. Document the test chamber pressure, leakage rate and helium partial pressure for each torque.

Appendices:

I. Metal Seal parameters and tightening torque references:

Metal C-Ring, External Pressure Face Seal:

1) ECE-007000-09-14-6-SPF — for coupling cavity
   1. Seal material: Alloy 718
   2. Seal diameter: A = 7.00
   3. C seal free height: C = 0.125
   4. Max. radial width: M = 0.100
   5. Material thickness: t = 0.015
   6. Finishing material: Silver with thickness 0.003 – 0.004
   7. Seal OD (= A+2M): D_{so} = 7.2
   8. Seating load: 300 lb/in.
   9. Reference torque applied at each bolt to match a seal seating load starting at 30 in.- lb until metal to metal.
2) ECE-001802-07-14-6-SPF — for beamline
   1. Seal material: Alloy 718
   2. Seal diameter(ID): A = 1.802
   3. C seal free height: C = .094
   4. Max. radial width: M = .075
   5. Material thickness: t = .01
   6. Finishing material: Silver with thickness .003-.004
   7. Seal OD (= A+2M): D_{so} = 1.952
   8. Seating load: 160 lb/in.
   9. Reference torque applied at each bolt to match a seal seating load starting at 20 in.-lb until metal to metal.

Spring Energized Metal C-Ring, External Pressure Face Seal:

1) ESE – 007000 – 09 – 06 – 1 – SPF — for coupling cavity
   1. Seal material: Alloy X - 750
   2. Seal diameter: A = 7.00
   3. C seal free height: C = 0.125 + .004 / - .003
   4. Max. radial width: M = 0.114
   5. Finishing material: Silver with thickness 0.003 – 0.004
   6. Seating load: 950 lb/in.
   7. Reference torque applied at each bolt to match a seal seating load starting at 70 in-lbs. until metal to metal.
2) ESE – 001802 – 07 – 06 – 1 – SPF — for beamline
   1. Seal material: Alloy X - 750
   2. Seal diameter: A = 1.802
   3. C seal free height: C = 0.094
   4. Max. radial width: M = 0.087
   5. Finishing material: Silver with thickness 0.003 – 0.004

6. Seating load: 850 lb/in.
7. Reference torque applied at each bolt to match a seal seating load starting at 40 in. - lb until metal to metal.

Helicoflex delta seal:

1) Type of HNV200, PN – H-306124 Rev NC
   1. Seal material: Copper
   2. Seal diameter: A = 7.330
   3. Delta seal free height: Before Delta – 0.124
After Delta – 0.120
   4. Groove width: M = 0.18
   5. Groove depth: Dp = 0.100
   6. Seating load: 1028 lb/in.
   7. Reference torque applied at each bolt to match a seal seating load starting at 70 in.-lb until metal to metal at 90.5 in.-lb.

2) Type of HNV200, PN – H-306290 Rev NC
   1. Seal material: Aluminum
   2. Seal diameter: A = 2.265
   3. Delta seal free height: Before Delta – 0.134
After Delta – 0.130
   4. Groove width: M = 0.25
   5. Groove depth: Dp = 0.099
   6. Seating load: 800 lb/in.
   7. Reference torque applied at each bolt to match a seal seating load starting at.30 in.-lb. until metal to metal at 40 in-lbs.

3) Type of HNV208, PN – H-306289 Rev NC
   1. Copper delta seal is the same as type 1.
   2. Limiting ring OD: 8.8 inch
   3. Limiting ring thickness: 0.100
   4. Material of ring: SST 304
   5. Seating load: 1050 lb/in.

Special diamond seal:

The prototype special diamond seal was made by Coronado Machine Inc. in Albuquerque, New Mexico.

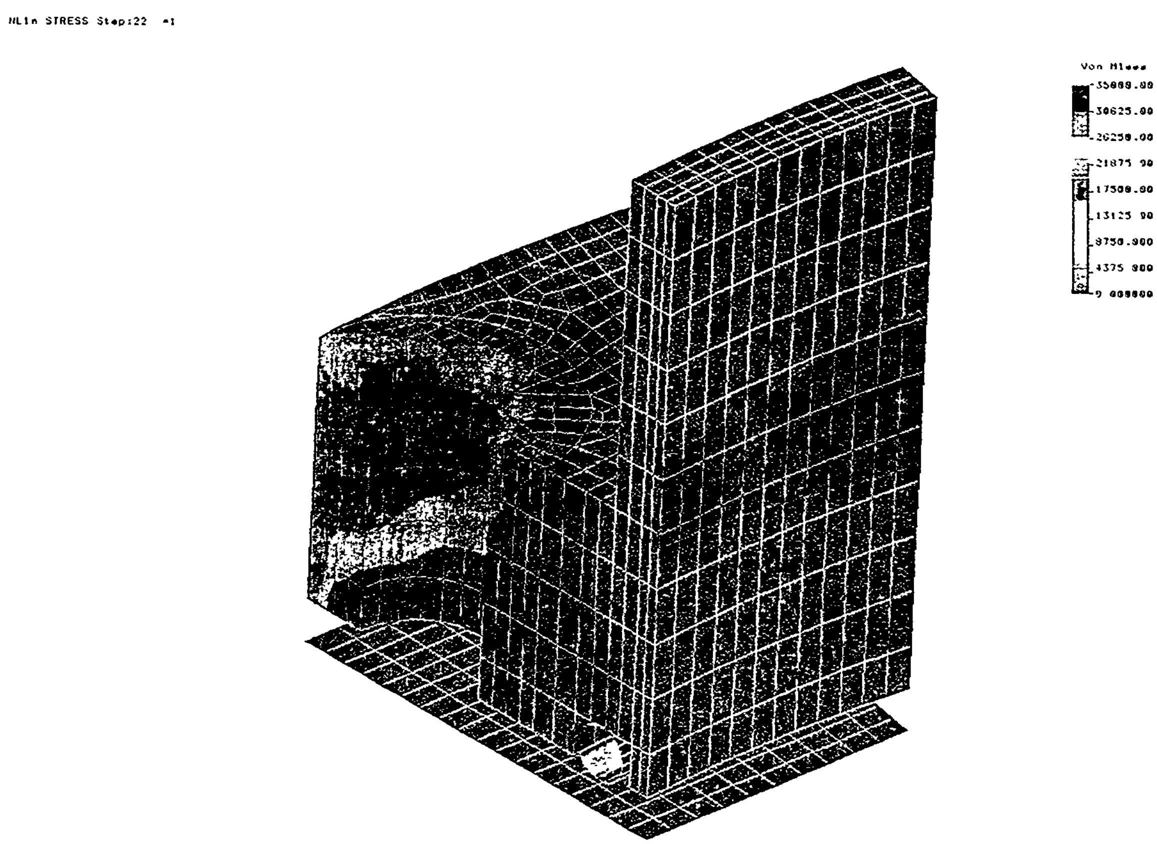
1. Seal material: Copper
2. Seal diameter: $D_{mean} = 7.38$
3. Free height of diamond shape: H = 0.100
4. Seal limited thickness: 0.038
5. Limited plate OD: 8.8 inch
6. Assembly feature: 16 bolt-hole
7. Seating load: 1120 lb/in.
8. Reference torque applied at each bolt to match a seal seating load starting at 80 in.-lb. until 100 in.-lb.

V. STRUCTURAL ANALYSIS OF COUPLING CAVITY FLANGE WITH COPPER DELTA SEAL

The purpose of this structural analysis is to confirm the design of the long coupling cavity flange and the welded area of a cavity body with the flange. It is also to predict a potential deformation of the cavity under a combined force of atmospheric pressure and the seating load of the seal. This is because the deformation will affect the frequency shift. The calculation result will help to determine the thickness of the coupling cavity and flange.

Modeling of this assembly has been achieved using both HKS/Abaqus and COSMOS/M of finite element packages for analysis of coupled, nonlinear problems. Because this design offers many planes of symmetry, the modeling using Abaqus is built to one-sixteenth the size of the flange and tube, while the modeling using COSMOS/M is built to one-thirty-second the size of the assembly. The analysis results of stress and displacement are very close from the analysis on both models. Hereafter, the calculations and results are detailed in the LANL memorandum ESA-EA: 99-242 from F. Hemez.

The following figure shows the result of Von Mises stress from the analysis using COSMOS/M. The copper delta seal is modeled in the real workplace.



Analysis of the SNS Long Coupling Cavity Flange

Summary

This memorandum summarizes the analysis of the SNS long coupling cavity flange. The design features a vacuum joint made out of copper and used at the interface between two flanges to provide sealing. The delta seal joint applies a seating load of 1,028 lbf per inch. which results in a total force of 23,130 lbf around the circumference of the coupling cavity. This, combined with the tightening of 16 bolts used for assembling two flanges together, generates deformations and stresses. Modeling of this system is achieved using HKS/Abaqus, a general-purpose finite element package for analysis of coupled, nonlinear problems. It is concluded that the deformations generated are very small, on the order of 0.048% and well into the linear regime of materials (no plastic deformation is occurring). The maximum engineering stress is estimated to be equal to 13,800 psi in compression and 8,870 psi in traction which remains small for the material considered (SS-304 stainless steel). The assumptions that lead to these results are commented on, and it is explained why they are believed to be conservative. The analysis details results obtained at the interface between two flanges. Regions where the largest stress concentrations occur are also investigated. No particular concern is identified by this analysis which, we believe, validates the current design.

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Analysis of the SNS Long Coupling Cavity Flange

1. INTRODUCTION

The purpose of this memorandum is to validate the design of the long coupling cavity flange for the Spalliation of Neutron Source project.

Deformations and stresses generated when flanges are assembled and bolted together are analyzed. To provide sealing, a copper-made, delta seal joint is inserted between any two flanges of the vacuum tube. Tightening the bolts together has the effect of crushing the joint into its seating groove which provides sealing. Mechanically, two forces tend to oppose each other: the tightening load applied by each bolt and the reaction force of the seal being crushed. In addition, contact at the interface between the two flanges must be accounted for to obtain an accurate description of the assembly. Modeling of this system is achieved using HKS/Abaqus, a general-purpose finite element package for analysis of coupled, nonlinear problems. The explicit module of Abaqus is used as the primary solver, meaning that the equations of motion are integrated in time using an explicit algorithm. Although this problem is essentially static (forces applied do not vary in time), time integration is convenient for handling the contact condition at the interface between the two flanges. The system is simulated over a long enough time period to guarantee convergence to the steady state.

The main conclusion is that no issue of concern seems to be identified by the analysis. This relies on the following observations:

1) Deformations generated are very small, on the order of 0.048%.

2) The static response remains well into the linear regime of materials, and no significant plastic deformation is observed.

3) The maximum engineering stress is estimated to be equal to 13,800 psi in compression and 8,900 psi in traction which remains small for the material considered (SS-304 stainless steel).

4) Finally, pressure applied by the seal does not produce any significant opening between the two flanges and, therefore, the integrity of sealing is retained.

The memorandum is organized as follows. In Section 2, the most important modeling assumptions are reviewed. We believe that these yield conservative results, meaning that the deformations and stresses obtained constitute reasonable upper bounds. The results of the analysis are commented on in Section 3. Of particular interest are deformations generated at the interface between the two flanges and stresses around the bolts. A final conclusion is given in Section 4.

2. MODELING AND ANALYSIS

The system analyzed is the assembly of the long coupling cavity. The main dimensions of the tube are provided in Table 1 for a quick reference. The material considered is a standard, stainless steel (SS-304) whose characteristics are listed in Table 2. A plasticity model is also defined for this material and the corresponding uniaxial, stress-strain data are given in Table 3. Our purpose in introducing an elastic-plastic constitutive law is to evaluate whether or not the response of this system remains linear.

A 22.5 degree segment of the coupling cavity is illustrated in Figure 1. Because this system offers many planes of symmetry, it was decided to restrict the analysis to one sixteenth the size of the tube. Constraints are applied along the planes of symmetry to account for this simplification. The flange shown in Figure 1 comes into contact with a second, identical component. This defines a contact surface between the two flanges. One important aspect of the modeling is the dynamics of this contact. To capture this effect, an explicit time integration solver is adopted, as mentioned previously. To keep the size of this problem as small as possible, the second half of the coupling cavity is replaced with a rigid surface. We believe that this simplification contributes to render the analysis more conservative because only half of the flexibility introduced by the contact condition is represented in the computational model. In other words, deformations obtained during this simulation should constitute an upper bound of the response.

The starting point of the analysis is the seal's seating load of 1,028 lbf per inch. This value is defined by the seal's characteristics (Helicoflex delta seal made out of copper). Combined with a seating groove 0.18 in. wide and with an overall area of 4.05 $in.^2$, it results in a total force of 23,130 lbf. This is the total net force applied by the seal joint on each component of the coupling cavity assembly. The seal is simulated by applying this force on the bottom surface of the seating groove. Equation (1) summarizes this calculation

$$\mathbf{P_{seal} = F_{seating\ load}/d_{groove},} \qquad \mathbf{F_{net} = P_{seal}\ A_{seal}} \tag{1}$$

where

$\mathbf{F_{seating\ load}}$, Seating load (lbf per inch);
$\mathbf{d_{groove}}$, Groove depth (in.);
$\mathbf{P_{seal}}$, Pressure of the seal (psi);
$\mathbf{A_{seal}}$, Area of the groove ($in.^2$); and
$\mathbf{F_{net}}$, Total, net force (lbf).

The tightening pressure applied around each bolt is calculated to produce the same net force in such a way that the system remains in equilibrium. Because a total of 16 bolts/washers are used and each one involves an area of 0.17 $in.^2$ approximately, the resulting pressure is equal to 8,504 psi. This is the pressure applied around each bolt over an area equivalent to the area of a washer. Equation (2) summarizes this calculation

$$\mathbf{P_{bolt} = F_{net}/(16\ A_{bolt})} \tag{2}$$

where

$\mathbf{P_{bolt}}$, Pressure of one bolt (psi); and
$\mathbf{A_{bolt}}$, Area of one bolt/washer ($in.^2$).

The one-sixteenth segment of the coupling cavity is discretized with a small spatial resolution to ensure that the area around each bolt matches the theoretical value as closely as possible. Hence, the component shown in Figure 1 is partitioned into 11,946 nodes and 9,263 finite elements. Nevertheless, a small discrepancy of about 10% is observed between the area used for the calculation and its baseline, 0.17 $in.^2$ value. (The discretized area is 10% smaller.) This also contributes to render the analysis conservative because the load is applied over a smaller area which generally results in higher stress levels. Because the response of the system remains in the linear regime, it can be concluded that the stress values obtained are 10% over-estimated.

The computational procedure determines the response of the system due to these two opposite loads. Gravity is also added in the Z-direction, and the atmospheric pressure (14.7 psi) is applied normal to the surface of all external walls. This simulates the vacuum inside the coupling cavity even though the influence of the atmospheric pressure is negligible compared to the tightening forces. Potential issues of concern are the occurrence of residual, plastic deformations; high stresses; and openings between the flanges that deteriorate the sealing capability.

3. RESULTS

Results of the analysis are presented by first discussing the overall response of the system (Section 3.1). Then, the analysis of displacements on the contact surface is detailed in Section 3.2. This addresses the concern of potential openings between two sections of the coupling cavity. Finally, Section 3.3 offers a summary of the stress analysis in the flange. It shows that the loading applied raises no particular concern.

3.1 *Analysis of the Overall Response*

The displacement response is pictured in Figures 2, 3 and 4 for variables U_1, U_2 and U_3, respectively. These are the displacements at each nodal joint of the mesh aligned with the global coordinate system (X;Y;Z). The first axis (X) is oriented in the radial direction, the second one (Y) is normal to the coupling cavity and the third one (Z) is the longitudinal axis of the coupling cavity. Analyzing the displacement response is important to make sure that deformations remain both small and in the elastic domain. The displacement fields shown in Figures 2, 3 and 4 correspond to the end of the simulation, once the steady-state, static solution has converged. It can be seen that very little deformations are obtained in the X and Y directions. This is expected because the most important load is applied in the Z-direction, perpendicular to the contact surface. Figure 4 shows that the structure deforms almost as a rigid body along the Z-axis because of its uniform coloring. The maximum displacements obtained in each direction are summarized below:

1) X-axis: $\max(U_1) = 0.0006$ in.;
2) Y-axis: $\max(U_2) = 0.0012$ in.; and
3) Z-axis: $\max(U_3) = 0.1330$ in.

The maximum displacement in the direction normal to the coupling cavity occurs on the wall of the vacuum tube. It may be important for the alignment of the beam inside to account for this parameter. However, we emphasize that the deflection obtained (0.0012 in. or, equivalently, a strain equal to 0.94%) is on the order of magnitude of the meshing precision. Furthermore, only two rows of elements are used through the thickness of the coupling cavity wall, which may be insufficient to capture its bending with good accuracy. The problem would have to be re-analyzed with a much finer spatial resolution to confirm this result.

When the three displacement fields are combined, the total deformation of the system is obtained. This is represented in Figure 5 with a magnification factor of 200. (The deformations seen in Figure 5 are amplified 200 times.) It can be observed that the coupling cavity wall tends to be pushed outwards due to a coupling with the deformation of the flange. The flange is somewhat twisted because the bolts apply a force in one direction close to the external edge while the seal applies a force in the opposite direction in the vicinity of the coupling cavity wall. Highly distorted elements near the edges are the result of "edge" effects (application of the contact condition perturbs the symmetry constraints), and they must be disregarded. The maximum deformation generated in the axial direction (Z) is equal to 0.048%. This means that the flange is compressed of 0.048% in the direction of the bolt preload, relative to its original thickness (0.625 in.). This seems too small to be a concern and, more importantly, such deformation remains well within the linear regime of the material. It can be verified in Figure 6 that no significant plastic deformation is occurring. (The only plastic strain obtained involves a set of eight, highly deformed elements. This is due to the mesh/edge effect mentioned previously.) Therefore, the analysis predicts that no residual, plastic deformation appears that could jeopardize the precision of alignment required for the beam traveling inside the coupling cavity.

The stress distribution is shown in Figures 7 to 12. These six figures represent the engineering stresses in units of psi, not the equivalent, Von Mises stress. Principal stresses σ_{11} , σ_{22} and σ_{33} are illustrated in Figures 7, 8 and 9 and shear stresses σ_{12} , σ_{13} and σ_{33} are illustrated in Figures 10, 11 and 12, respectively. They all correspond to the static deformation field obtained after the steady-state has converged. We have verified that the largest stress values obtained (values over 20,000 psi) apply to highly distorted elements. This is caused by a poor resolution in space in specific areas of the mesh, and it is not physically significant. If these singularities are disregarded, only the stress σ_{33} obtained in the direction of bolt preload (Z-axis) matters. Stress values range from -13,800 psi (compression is usually represented with a negative sign) to 8,870 psi in traction. Again, given the material considered, these introduce no particular concern regarding the design. For comparison, it is only after reaching 43,500 psi that plastic deformations start to occur.

3.2 *Analysis of the Contact Surface*

Previously, the overall response was characterized. We now focus on what happens on the contact surface. In particular, we would like to determine whether or not an opening between the two flanges may occur due to the reaction force applied by the delta seal. This would typically be assessed by comparing displacements at coincident nodes on either part of the assembly and determining the maximum distance between them. A significantly non zero gap would then indicate an opening in that area. Here, one of the contact surfaces is rigid and no displacements are produced. In the remainder, displacements obtained on the bottom surface of the flange are analyzed.

Figures 13, 14 and 15 illustrate the displacements U_1, U_2 and U_3 calculated during the simulation for all nodes at the bottom of the flange that would be in contact with the other segment of the coupling cavity. Because an explicit time integration solver is implemented to resolve the contact, these displacements are shown as a function of time. The figures show that the solution converges to a steady-state, that is, displacements remain constant after the contact has been resolved because the load applied is static. Rather than showing the displacement history at the 527 nodal joints on the interface, mean values mean(U_1), mean(U_2) and mean(U_3) are calculated and represented in Figures 13 to 15 with solid lines. Also represented with dashed lines are the curves (mean(U_i) - $2\sigma_i$) and (mean(U_i) + $2\sigma_i$) versus time where σ_i represents the standard deviation for displacement U_i. If the displacements were normally distributed, these curves would represent the 98% confidence interval. To verify to which extent this normality assumption applies to the data, the histograms of displacements U_1, U_2 and U_3, are provided in Figure 16. First, it can be observed from Figures 13 and 14 that displacements U_1 and U_2 in the X and Y directions, respectively, are very small. This indicates no tendency of the contact surfaces to slide relative to each other. Mean displacements calculated are summarized below:

1) X-axis: mean(U_1) = 0.00002 in.;
2) Y-axis: mean(U_2) = 0.00095 in.; and
3) Z-axis: mean(U_3) = 0.13950 in.

together with their standard deviations (values between parentheses represent the percentage of standard deviation relative to the mean):

1) X-axis: σ_1 = 0.00007 in. (277%);
2) Y-axis: σ_2 = 0.00017 in. (17%); and
3) Z-axis: σ_3 = 0.00077 in. (0.6%).

These mean displacements and standard deviations correspond to the steady-state solution at the time equal to 8 milliseconds in Figures 13 to 15.

Clearly, only the displacement U_3 normal to the contact surface provides relevant information regarding potential openings. Figure 15 indicates that, for all practical purpose, nodes on the interface are all translated equally. This is consistent with the fact that bolts compress the interface when two segments of the coupling cavity are assembled and that the resulting deformation is essentially a rigid-body translation. We can estimate the maximum amount of opening to be equal to two standard deviations, that is, $2\sigma_3$ = 0.00154 in. Again, this gap can be considered to be zero because it falls below the precision of the discretization. If it were believed that this gap may introduce a concern, a more detailed analysis would be required to confirm this result and reduce its level of uncertainty.

3.3 *Stress Analysis of the Flange*

In this section, stresses produced around the bolts in the coupling cavity flange are analyzed. This may be useful to determine if the flange thickness could be reduced without deteriorating the expected performance.

The analysis presented here is similar to that of Section 3.2. Figures 17, 18 and 19 illustrate the stresses σ_{11}, σ_{22} and σ_{33} calculated during the simulation for all finite elements located in a radius of 0.4 in. around the bolt centerlines and throughout the thickness of the flange. As before, convergence to the steady-state can be observed. Rather than showing the stress history at the 2,301 elements considered in the flange, mean values mean(σ_{11}), mean(σ_{22}) and mean(σ_{33}) are calculated and represented in Figures 17 to 19 with solid lines. Also represented with dashed lines are the curves (mean(σ_{ii}) - $2\sigma_i$) and mean(σ_{ii}) + $2\sigma_i$) versus time where σ_i represents the standard deviation for stress σ_{ii}. If stresses were normally distributed, these curves would represent the 98% confidence interval. To verify to which extent this normality assumption applies to the data, the histograms of stresses σ_{11}, σ_{22} and σ_{33}, are provided in Figure 20. Clearly, stresses in the X-direction and Y-direction are very small, and they can be ignored for this analysis. The mean stress obtained in the Z-direction is equal to -1,623 psi with a standard deviation of -1,997 psi (123%). This mean stress and standard deviation correspond to the steady-state solution at the time equal to 8 milliseconds in Figure 19. Negative signs indicate compression. Even if two standard deviations are added to the mean to estimate the maximum compression stress obtained, it only provides a value of 5,617 psi that is very small compared to the steel's limit of elasticity at 43,500 psi. In addition, the histograms shown in Figure 20 indicate that very few finite elements record stresses greater than 5,000 psi. These higher stress levels can therefore be attributed to insufficient discretization in particular areas of the mesh.

We conclude from this analysis that the loading in the flange around each bolt introduces no particular concern. Because the response remains well within the linear domain, the 0.625 in. thickness of the flange could be reduced if this provides other advantages for the design.

4. CONCLUSION

The purpose of this memorandum is to validate the design of the long coupling cavity flange for the Spalliation of Neutron Source (SNS) project. Deformations and stresses generated when flanges are assembled and bolted together are analyzed. To provide sealing, a copper-made, delta seal is inserted between any two flanges of the vacuum tube. Tightening the bolts together has the effect of crushing the joint into its seating groove, which provides sealing. The delta seal applies a seating load of 1,028 lbf per inch that results in a total force of 23,130 lbf around the circumference of the coupling cavity. A total of 16 bolts are tightened to assemble two segments together.

Deformations generated are very small, on the order of 0.048% and well into the linear regime of materials (no plastic deformation is occurring). The maximum engineering stress is estimated to be equal to 13,800 psi in compression and 8,870 psi in traction which remains small for the material considered (SS-304 stainless steel). It is therefore concluded that the current design is validated. Other conclusions are:

1) Walls of the coupling cavity seem to be witnessing a small bending due to the twisting of the flange.

2) The maximum opening between two segments of the coupling cavity is estimated to be equal to 0.00154 in. Note that this gap currently falls below the precision of the discretization. This seems to indicate that the number of bolts used to tighten segments together could be reduced from 16 down to a smaller number.

3) Small stresses are calculated in the vicinity of the bolts, and the response of the material remains linear. We can assess with 98% confidence that these stresses are less than 5,617 psi. As a result, the thickness of the flange could be reduced if needed.

A more detailed analysis is required to refine these three conclusions if doing so is important for the design. (In particular, a finer discretization would have to be employed to confirm some of the small displacement response obtained.) Nevertheless, we believe that our modeling and analysis are somewhat conservative, therefore, leading to the "worst case" scenarios discussed here.

5. REFERENCES

Abaqus/Explicit, User's Manual, Version 5.8, Hibbitt, Karlsson & Sorensen, Inc., Pawtucket, Rhode Island, 1998.

Appendix A. Tables

Table 1. Geometry of the Coupling Cavity.

Parameter	Value
Coupling cavity flange, material	SS-304
Coupling cavity flange, outer diameter	8.800 in.
Coupling cavity flange, inner diameter	6.870 in.
Coupling cavity flange, thickness	0.625 in.
Coupling cavity, wall thickness	0.127 in.
Number of bolts	16
Fastener	5/16-24
Bolt circle	8.165 in.
Seal, type	Helicoflex delta seal
Seal, material	Copper
Seal, Seating load	1,028 lbf per inch
Seal seating groove, inner diameter	6.990 in.
Seal seating groove, depth	0.100 in.
Seal seating groove, width	0.180 in.

Table 2. Material Data.

Parameter	Value
Coupling cavity, material	SS-304
Modulus of elasticity	28,700,000 psi
Poisson's ratio	0.264
Density	0.000741 lbf sec.^{2}/in.^{4}
Data for stress-strain curve, stress in first column and corresponding plastic strain in second column: 43,511 psi	0.0000
50,169 psi	0.0208
59,436 psi	0.0582
97,755 psi	0.2448
137,700 psi	0.4568
187,390 psi	0.7503
226,404 psi	1.0170
256,500 psi	1.3340

Appendix B. Figures

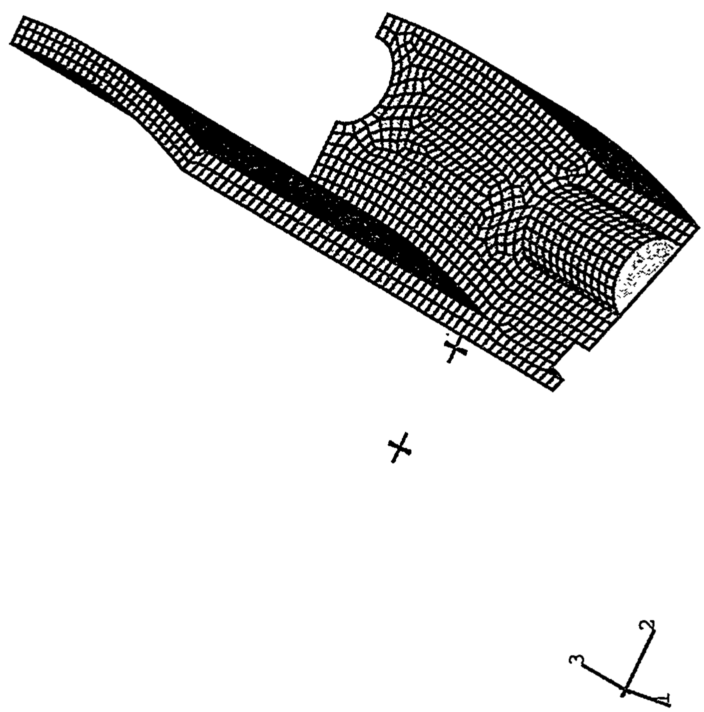


Figure 1. Illustration of the undeformed mesh developed for computational purposes. (A 22.5 degree segment of the coupling cavity flange is shown.)

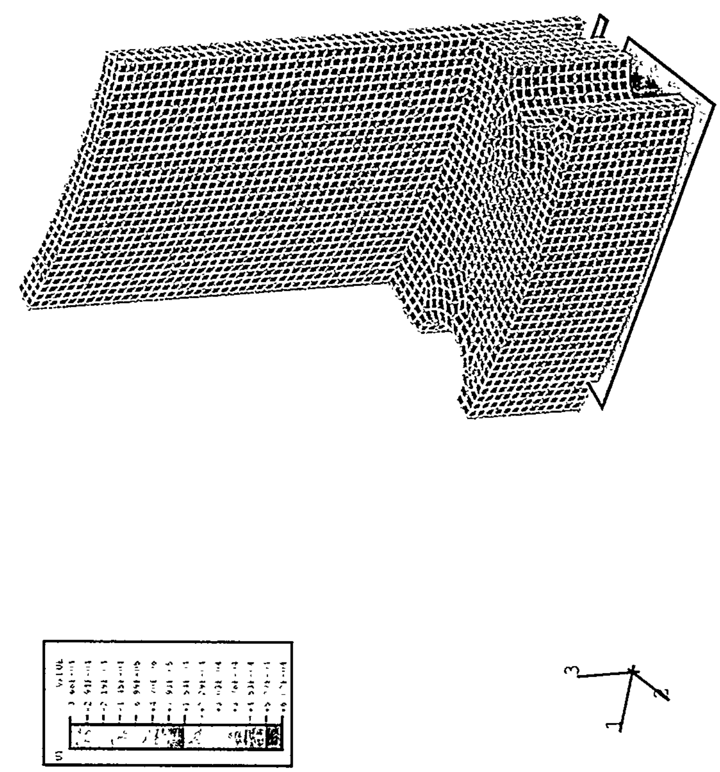


Figure 2. Distribution of static displacements U_1 in the X-direction.

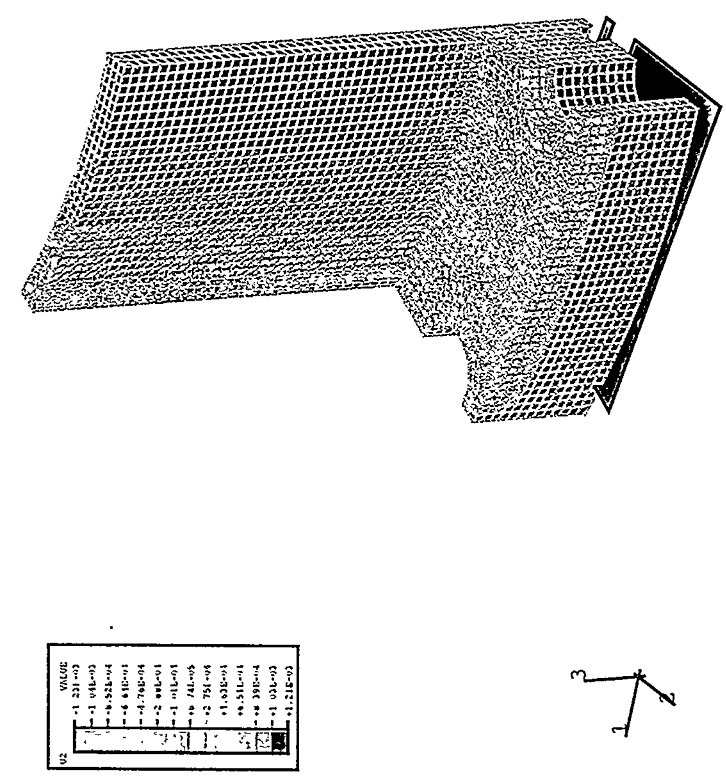


Figure 3. Distribution of static displacements U_2 in the Y-direction.

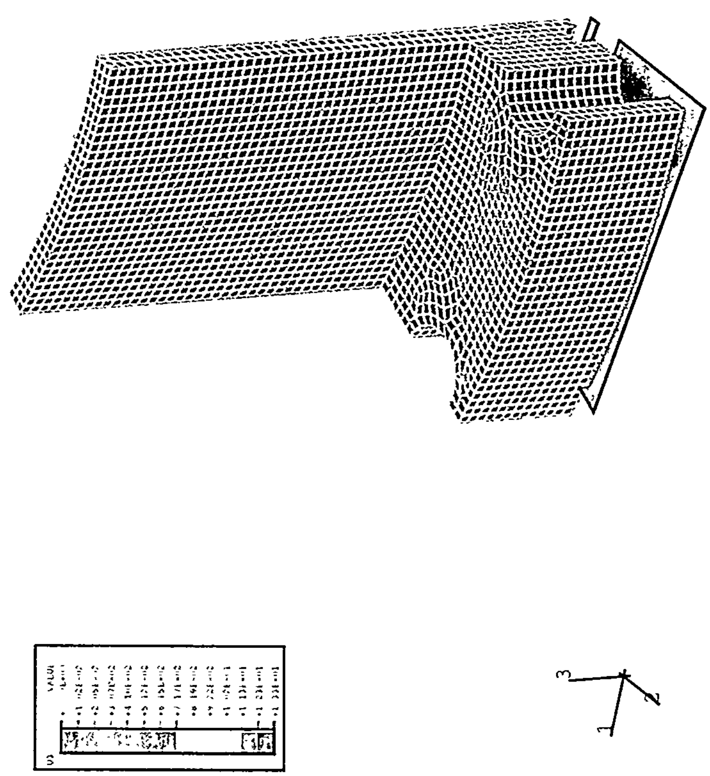


Figure 4. Distribution of static displacements U_3 in the Z-direction.

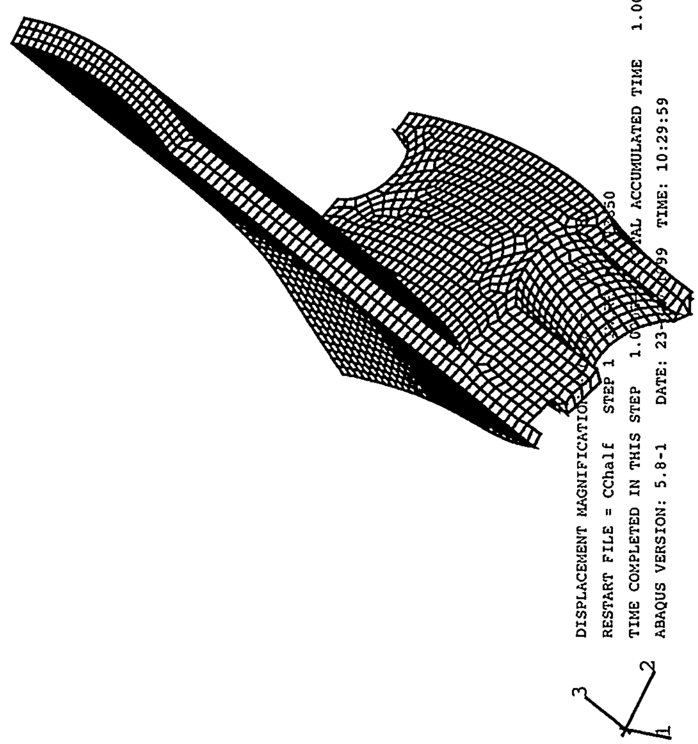


Figure 5. Illustration of the deformed mesh.
(Deformations are amplified 200 times.)

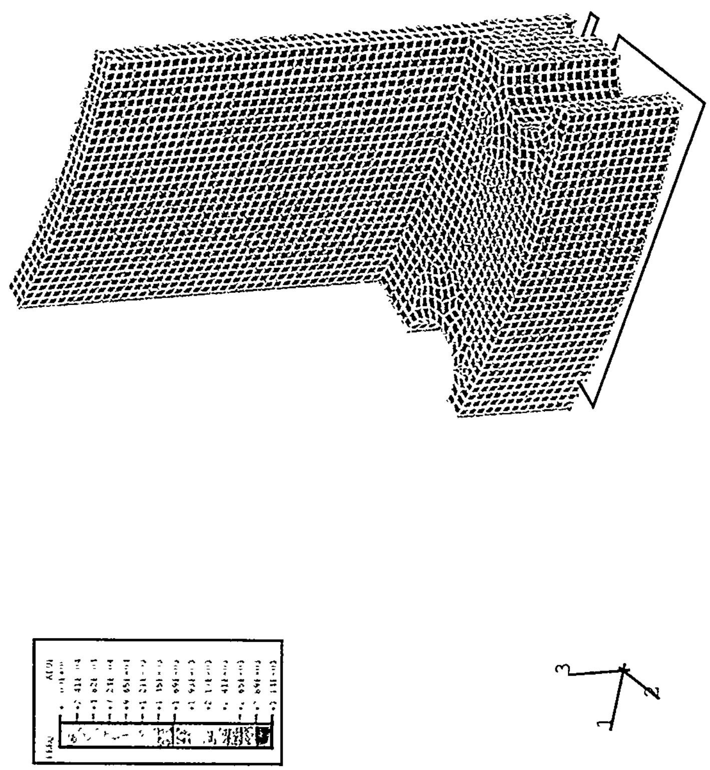


Figure 6. Distribution of plastic strain at steady-state.

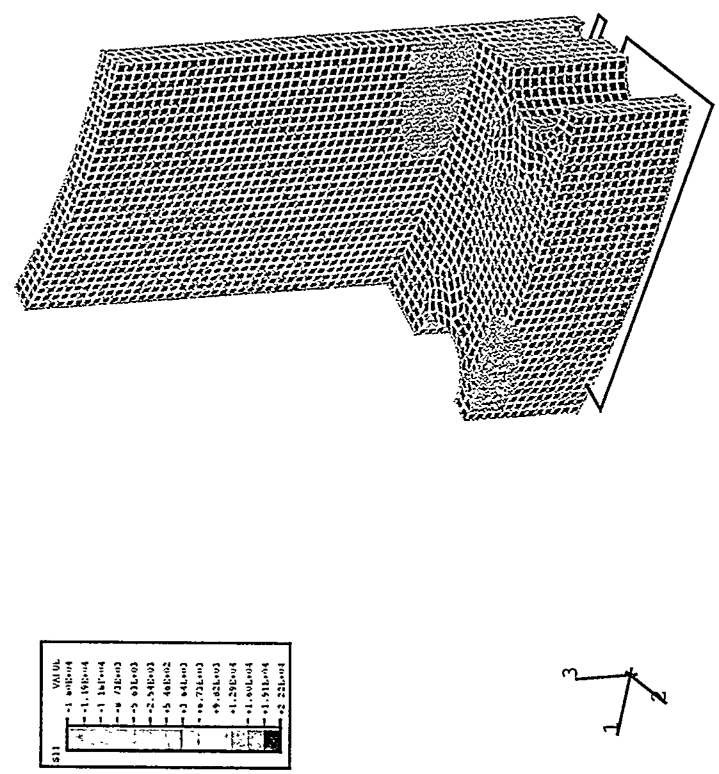


Figure 7. Distribution of engineering stress σ_{11} in the X-direction.

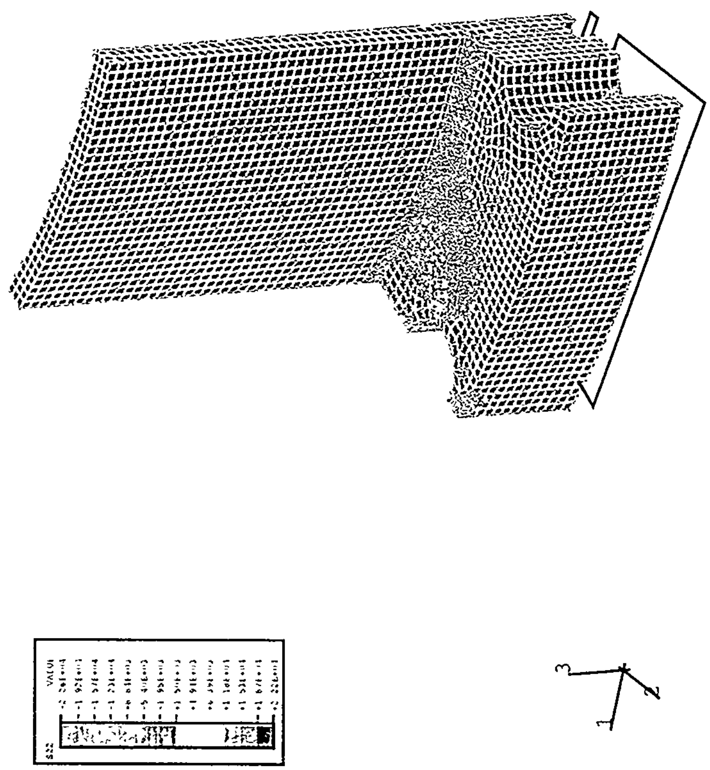


Figure 8. Distribution of engineering stress σ_{22} in the Y-direction.

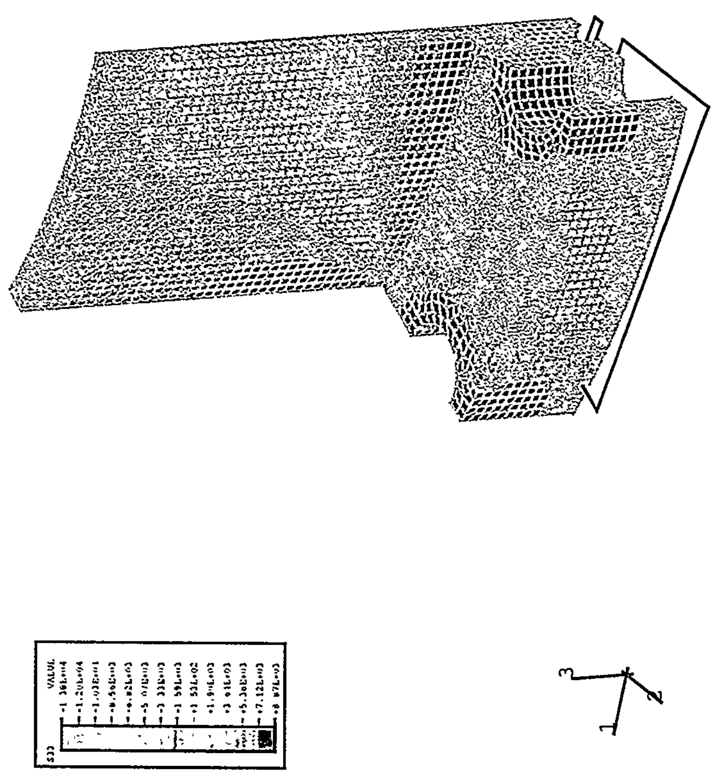


Figure 9. Distribution of engineering stress σ_{33} in the Z-direction.

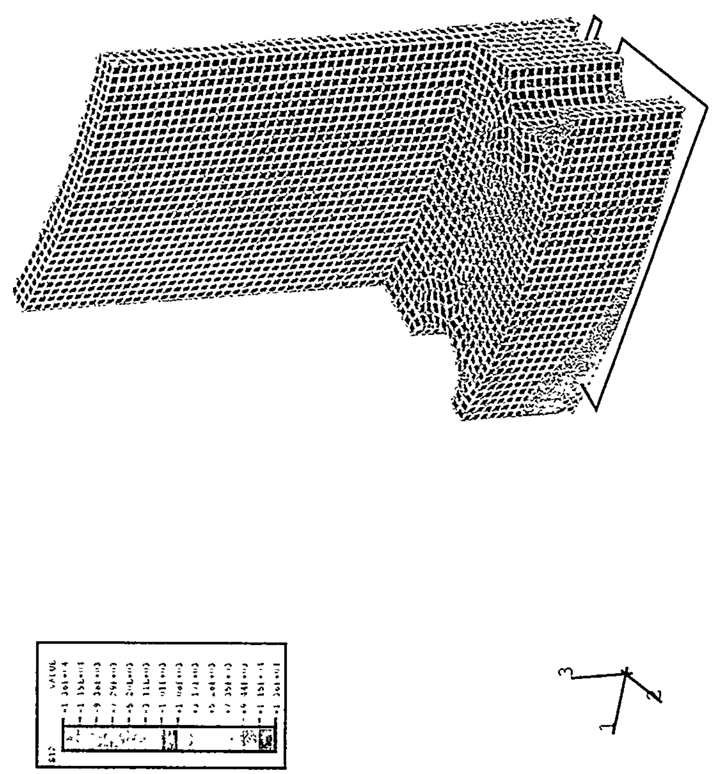


Figure 10. Distribution of engineering stress σ_{12} (shear stress in the (X;Y) plane).

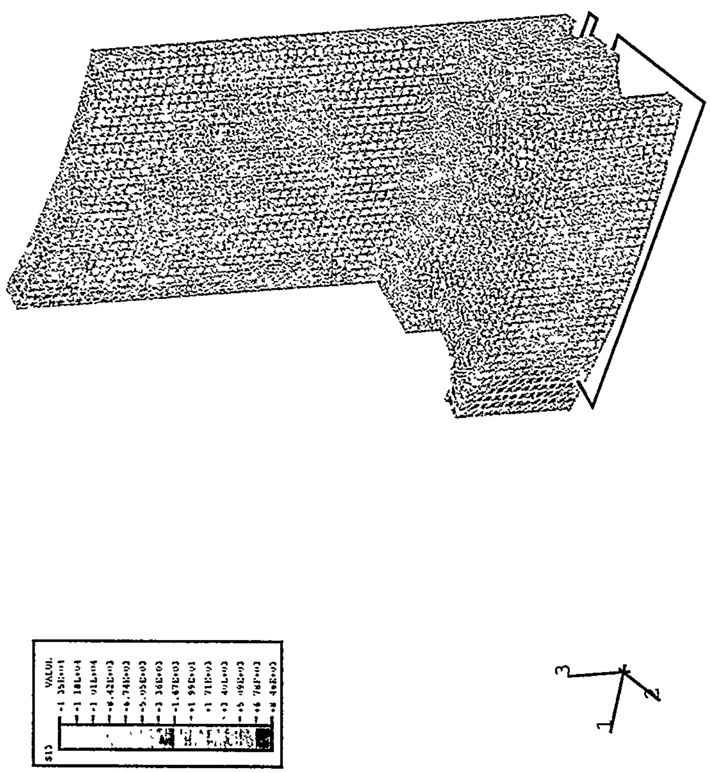


Figure 11. Distribution of engineering stress σ_{13} (shear stress in the (X;Z) plane).

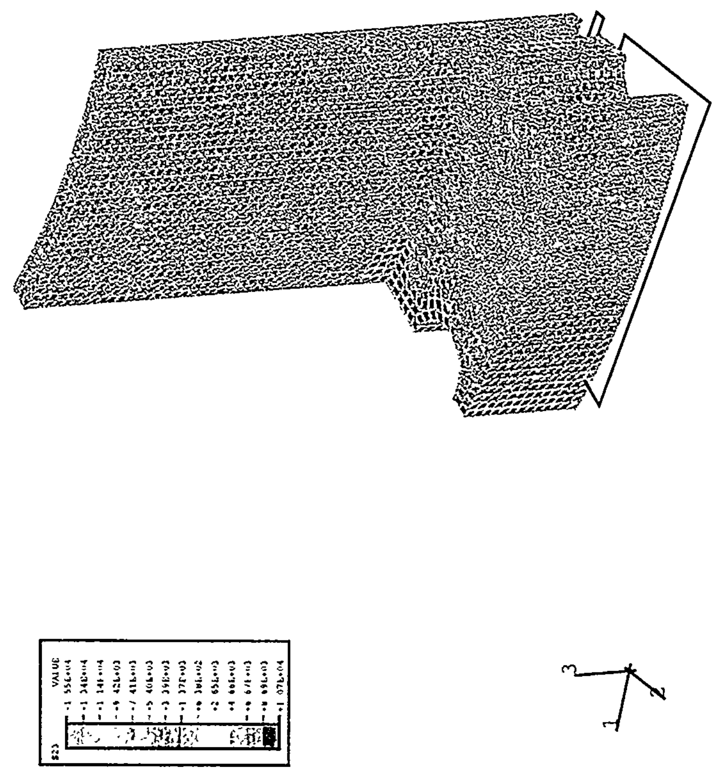


Figure 12. Distribution of engineering stress σ_{23} (shear stress in the (Y;Z) plane).

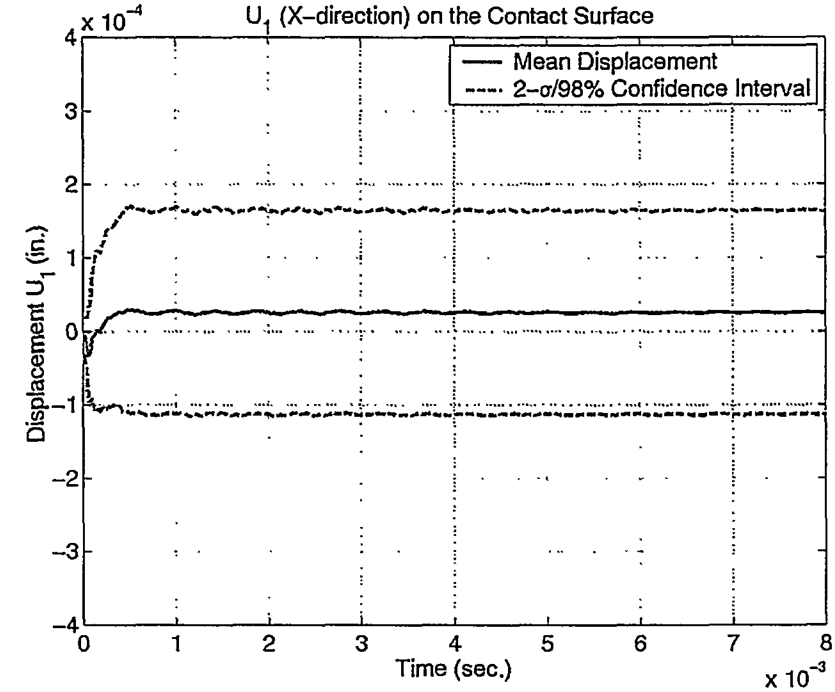


Figure 13. Displacement U_1 on the contact surface versus time. (Solid line: mean displacement; dashed line: 2-σ, 98% confidence interval.)

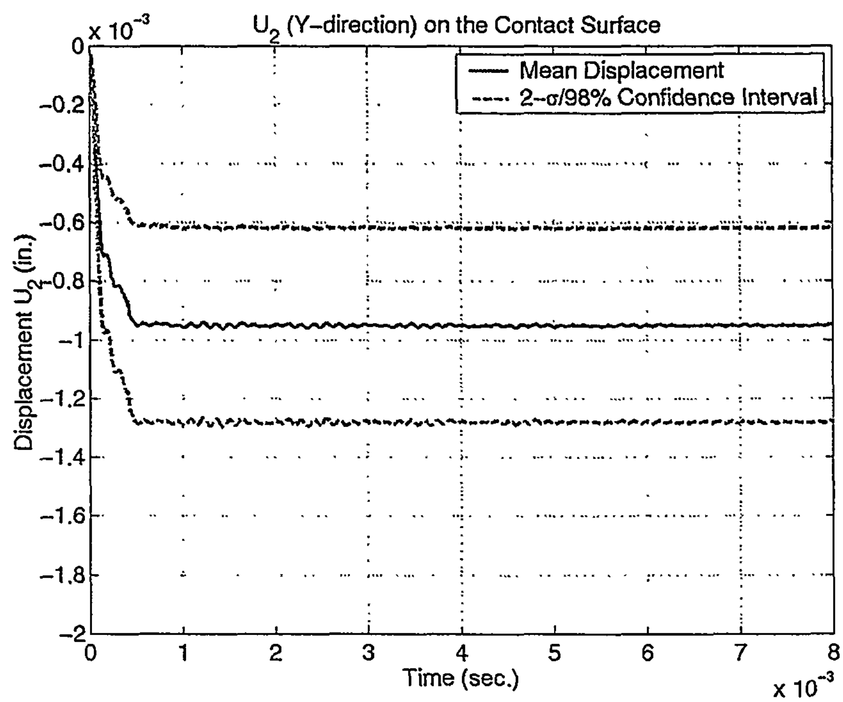


Figure 14. Displacement U_2 on the contact surface versus time. (Solid line: mean displacement; dashed line: 2-σ, 98% confidence interval.)

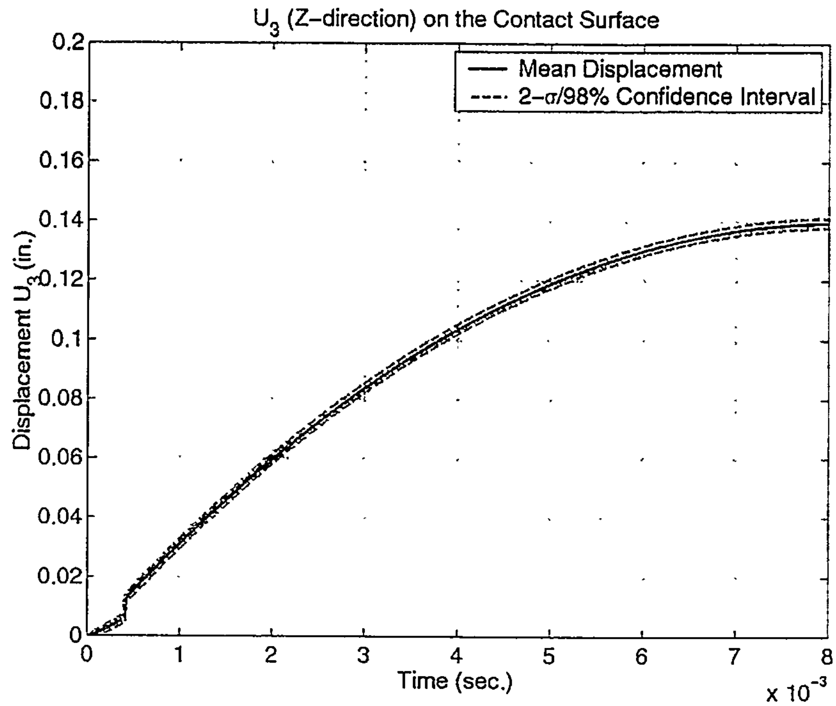


Figure 15. Displacement U_3 on the contact surface versus time. (Solid line: mean displacement; dashed line: 2-σ, 98% confidence interval.)

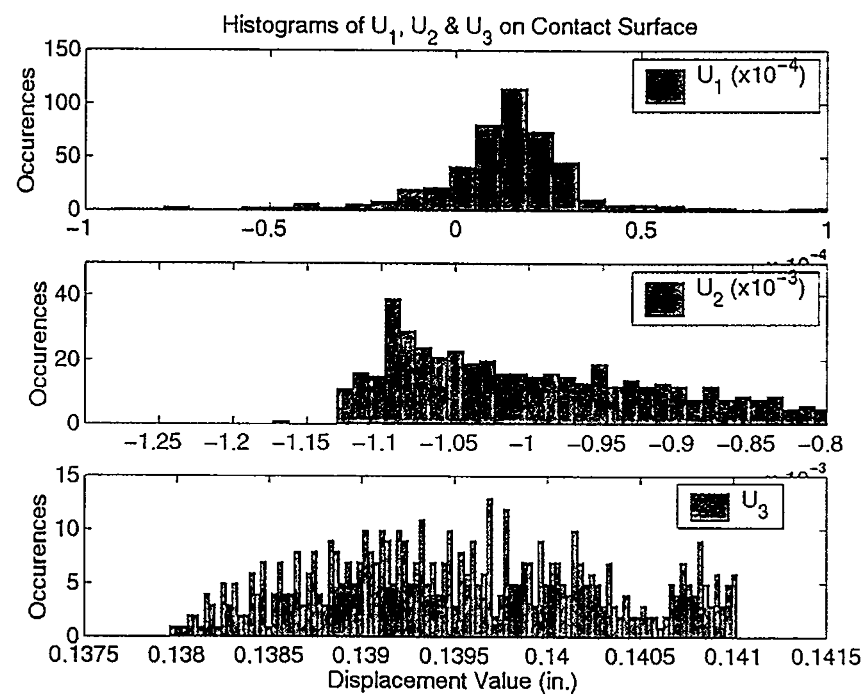


Figure 16. Histograms of displacements U_1, U_2, and U_3 on the contact surface. (Values are shown at steady-state.)

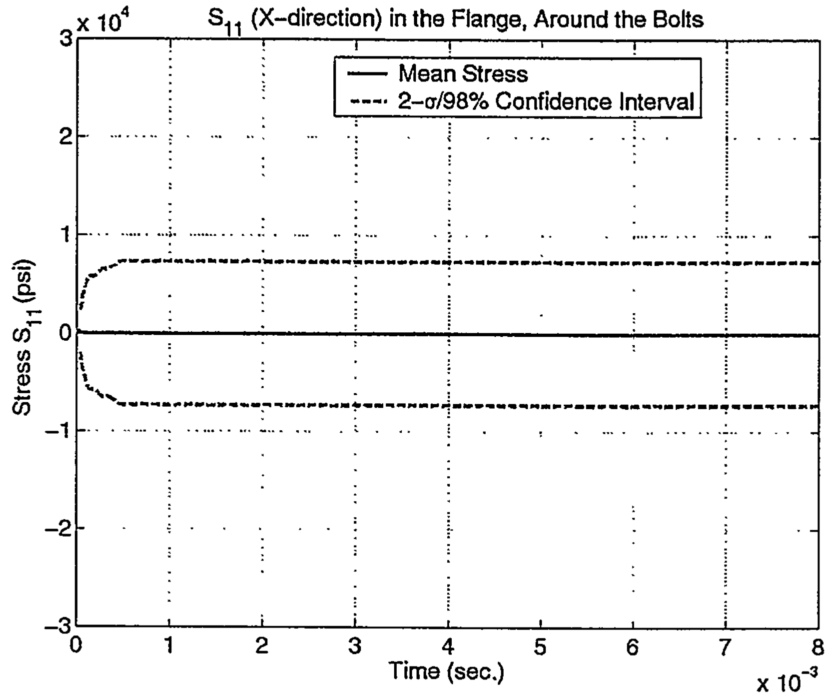


Figure 17. Engineering stress σ_{11} in the flange versus time. (Solid line: mean stress; dashed line: 2-σ, 98% confidence interval.)

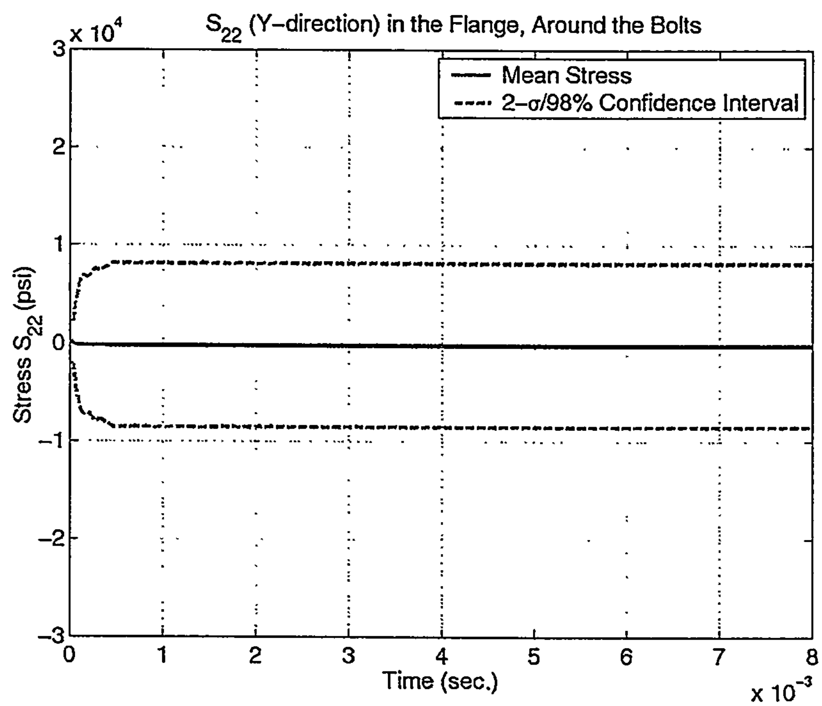


Figure 18. Engineering stress σ_{22} in the flange versus time. (Solid line: mean stress; dashed line: 2-σ, 98% confidence interval.)

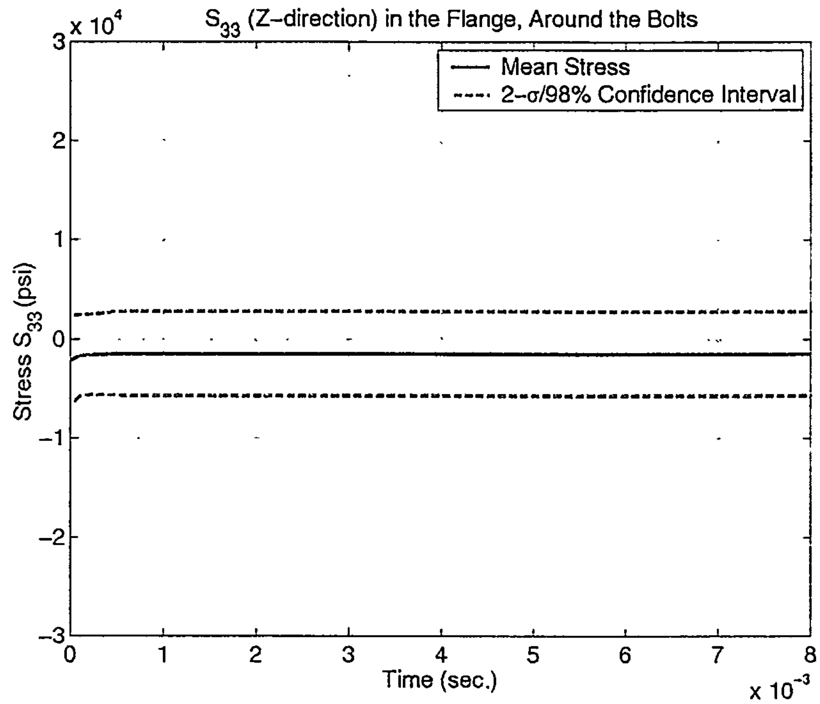


Figure 19. Engineering stress σ_{33} in the flange versus time. (Solid line: mean stress; dashed line: 2-σ, 98% confidence interval.)

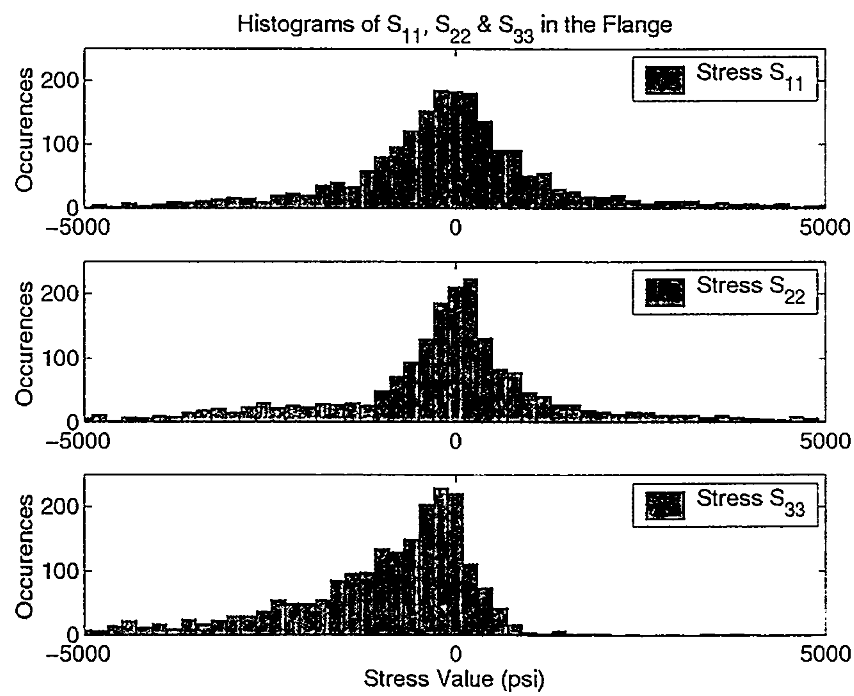


Figure 20. Histograms of stresses σ_{11}, σ_{22}, and σ_{33} in the flange. (Values are shown at steady-state.)

VI. VACUUM TEST HARDWARE PACKAGE LIST

(Unit: inch_pound_second)

	Metal C-Seal Test Package:	
Test #1	C-Seal_1	Material: Inconel 718, Silver plated Part # **ECE-007000-09-14-6-SPF** **Seating Load: 300 lb/in.**
	Flange group	Material: SST 304
	Coupling Cavity Flange_1	**8.8 OD THK = .5**
	CCFlange_1	Drawing # 153Y643813A
	Flange assembly:	Drawing # 153Y643810A
	Vaccum connection:	Drawing # 153Y643811A
Test #2	Coupling Cavity Flange_2	**8.8 OD THK = .625**
	CCFlange_2	Drawing # 153Y643848A
	Flange assembly:	Drawing # 153Y643850A
	Fasteners	Bolts: (16) 5/16 - 24UNF x 1.5LG HEX Washer: 5/16 narrow washer Nut: 5/16 UNF HEX nut
Test #3	C-Seal_2	Part # **ECE-001802-07-14-6-SPF** **Seating Load: 160 lb/in.**
	Beamline Flange 1_NR	**3.38 OD THK = .312 (NR)**
	Flange_NR	Drawing # 153Y643880A
	Flange Assembly_1	Drawing # 153Y643879A
	Adapter Assembly_1	Drawing # 153Y643881A
	Fasteners	Bolts: (8) 5/16 - 24UNF x 1.5LG HEX Washer: 5/16 narrow washer Nut: 5/16 UNF HEX nut
Test #4	Beamline Flange 2_ROT	**3.38 OD THK = .375 (ROT)**
	Flange_ROT	Drawing # 153Y643922A
	Flange Assembly_2	Drawing # 153Y643883A
	Adapter Assembly_2	Drawing # 153Y643881A
	Fasteners	Bolts: (8) 5/16 - 24UNF x 1.5LG HEX Washer: 5/16 narrow washer Nut: 5/16 UNF HEX nut
	Spring Energized Metal C-Ring Test Package:	
Test #5	Spring C-Ring_1	Material: Inconel X-750, Silver plated Part # **ESE-007000-09-06-1-SPF** **Seating Load: 950 lb/in.**
	Flange group	Material: SST 304L
	Coupling Cavity Flange	**8.8 OD THK = .625**

Test #5 Cont.	CCFlange Flange assembly: Adapter assembly: Fastener	Drawing # 153Y643869A Drawing # 153Y643868A Drawing # 153Y643811B bolts: (16) 5/16 - 24 Washer: 5/16 narrow washer Nut: 5/16 UNF HEX nut
Test #6	Spring C-Ring_2 Beamline Flange Flange_ROT Flange Assembly_1 Adapter Assembly_1	Part # **ESE-001802-07-06-1-SPF** **Seating Load: 850 lb/in.** **3.38 OD THK = .375 (ROT)** Drawing # 153Y643880A Drawing # 153Y643879A Drawing # 153Y643881A
	Helicoflex Delta Seal Test Package	
Test #7	Delta Seal HNV200 Coupling Cavity Flange CCFlange Flange assembly: Adapter assembly: Fasteners	Material: **Copper** Part # H-306124 Rev Nc **Seating Load: 1028 lb/in.** Hardness: 120 Vikers **8.8 OD THK = .625** Material SST 304 Drawing # 153Y643877A Drawing # 153Y643878A Drawing # 153Y643811B As same as ones in test# 5.
Test #8	Delta Seal HNV200 Beamline Flange _NR Flange_NR Flange Assembly_1 Adapter Assembly_1	Material: **Aluminum** Part # H-306 290 Rev Nc **Seating Load: 800 lb/in.** Hardness: 65 Vikers **3.38 OD THK = .312 (NR)** Drawing # 153Y644067 Drawing # same as the assembly drawing Drawing # 153Y643881A
	Special Copper Diamond Seal	
Test #9	Prototype Made by Coronado Machine, Inc., in Albuquerque Coupling Cavity Flange Fasteners	Material: **Copper** Drawing # 153Y644014 **Seating Load: 1120 lb/in.** Hardness: 80 Vikers **8.8 OD THK = .625.** Material SST 304 Drawing # 153Y644069 Bolts: (16) 5/16 - 24UNF x 1.5LG HEX Washer: 5/16 narrow washer Nut: 5/16 UNF HEX nut

	Copper Plated CC Flange with Copper Delta Seal	
Test #10	Copper plated SST flange:	Without groove **8.8 OD THK = .625** Copper Plate thickness: 0.002 Drawing # 153Y644068

VII. VACUUM TEST RESULTS ON LEAK RATE AND DETERMINATION OF APPLIED TORQUE

- **Seals tested for long coupling cavity vacuum joints using 8.8-in. OD flanges.** There are four types of metal seals, including metal C-seal, spring C-ring, copper delta seal and copper diamond seal. The detailed test record is listed in Table 1. Figure 2 shows the leak rate of two prototypes of the diamond seal, and Figure 1 shows the leak rate of others.

Table 1. Test Data Records of the Seals for Coupling Cavity

Leak rate unit: mbar-ℓ/s

Torque (in.-lb)	Metal C-seal	Energized Spring C-ring	Copper Delta seal	Copper Diamond seal 1	Copper Diamond seal 1
30	3E-04				
40	5E-06				
50	4E-07			1E-01	
60	2E-09			6E-02	
70	2E-09	4E-09	3E-10	2E-02	
80		2E-10	1E-10	8E-04	3E-10
90		1E-10	5E-11	2E-10	2E-10
100				5E-12	5E-12

- **Seal tested for beam line vacuum joints using 3.38 in. OD flanges.** Some small sized seals of metal C and spring C-ring were purchased for testing the beam line joints leak rate. Compared with the copper delta seal in the coupling cavity, we use an aluminum delta seal for the beam line flanges, because it does not require any electric conductivity, while it is very important for coupling cavity connections. The test results and the final torque level are shown in Table 2. The leak rates are plotted in Figure 3.

Table 2. Test Data Records of the Seals for Beam Line Joints

Leak rate unit: mbar-ℓ/s

Torque (in.-lb)	Metal C-seal	Energized Spring C-ring	Aluminum Delta seal
20	3.00E-07		
30	1.00E-08		2.00E-09
40	2.00E-09	4.00E-07	1.00E-10
50	1.00E-09	5.00E-09	
60		2.00E-09	
70		1.00E-10	

- **Vacuum test on copper plated flange with copper delta seals.** We have two sets to complete this test. After the first seal tested, a clear footprint of the delta seal occurred at the copper plated surface. The photo is shown in Appendix A. The footprint did not change much after the second seal was tested. The vacuum leak rate results from two seals are very close. Table 3 shows the test results and torque applied. A comparison chart of the leak rate test of the copper delta seal with and without a copper plated flange shown in Figure 4.

Table 3. Vacuum Seal Test Records on Coupling Cavity for Copper Plated Flange Using Copper Delta Seal

Leak rate unit: mbar-ℓ/s

Torque (in.-lb)	Coupling Cavity Copper Plated Flange	
	First Copper Delta Seal	Second Copper Delta Seal
40	8.00E-08	
50	3.00E-08	
60	2.00E-08	2.00E-09
70	1.00E-08	
80	1.00E-09	1.00E-09
90	8.00E-10	3.00E-10

- **Vacuum leak rates plots:**

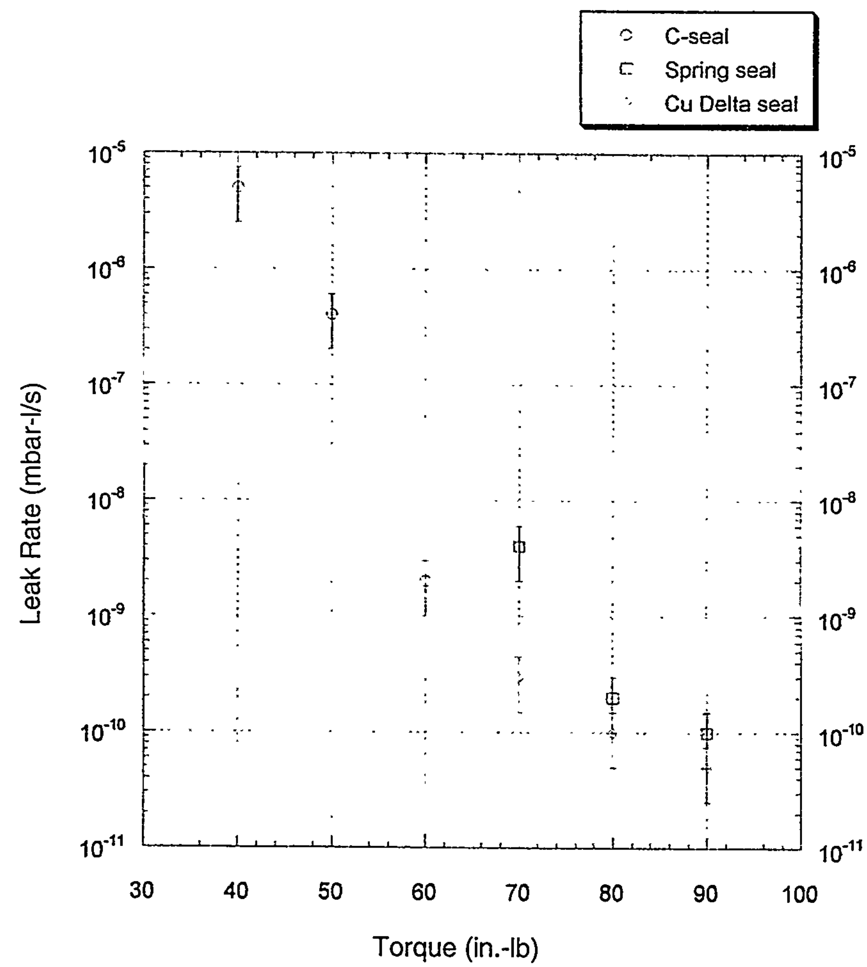


Figure 1. Vacuum Test Results on 8.8 in. OD Coupling Cavity Flange

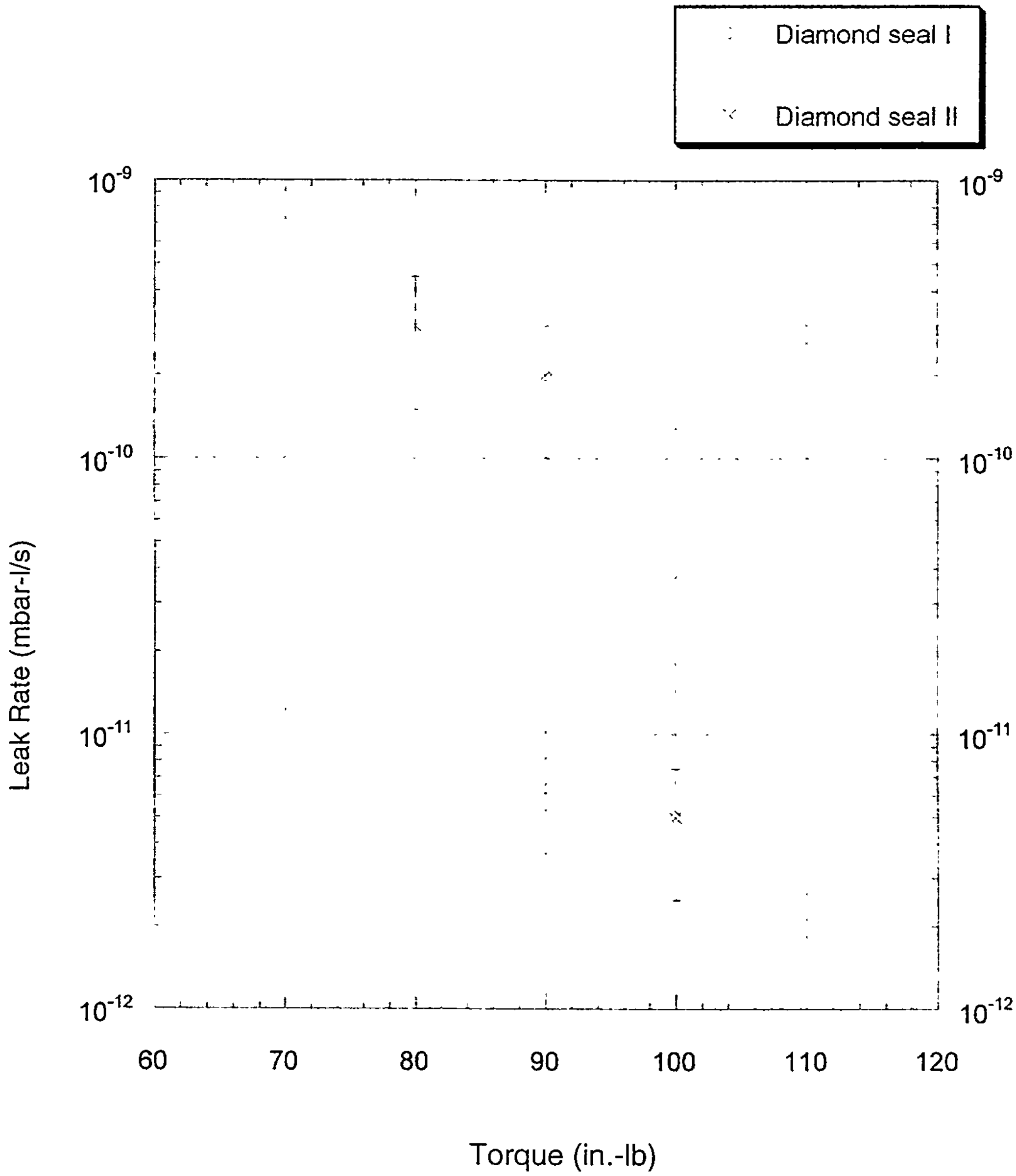


Figure 2. **Copper Diamond Seal Vacuum Test Results on 8.8 in. OD Coupling Cavity Flange.**

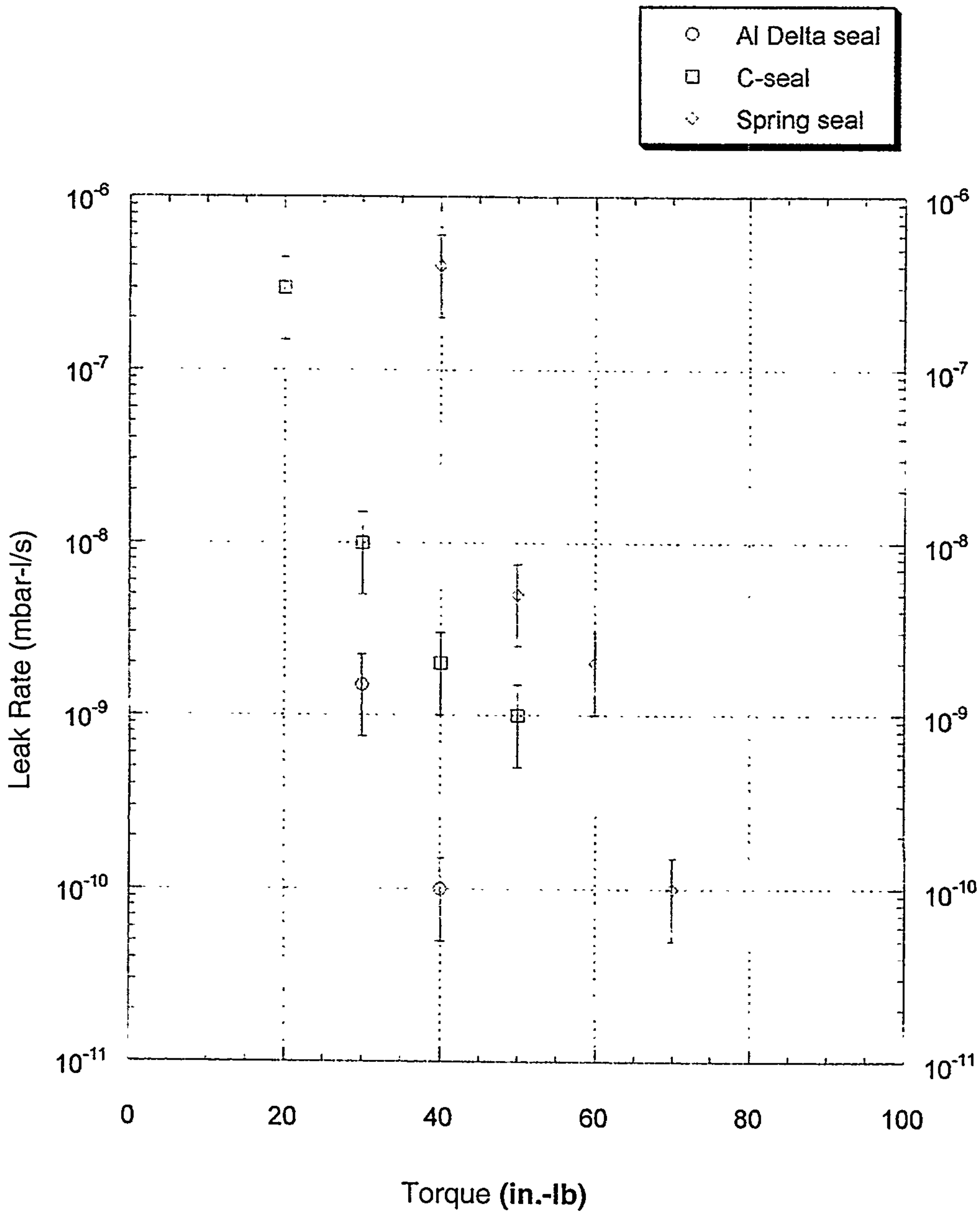


Figure 3. Vacuum Test Results on 3.38 in. OD Beam line Flanges.

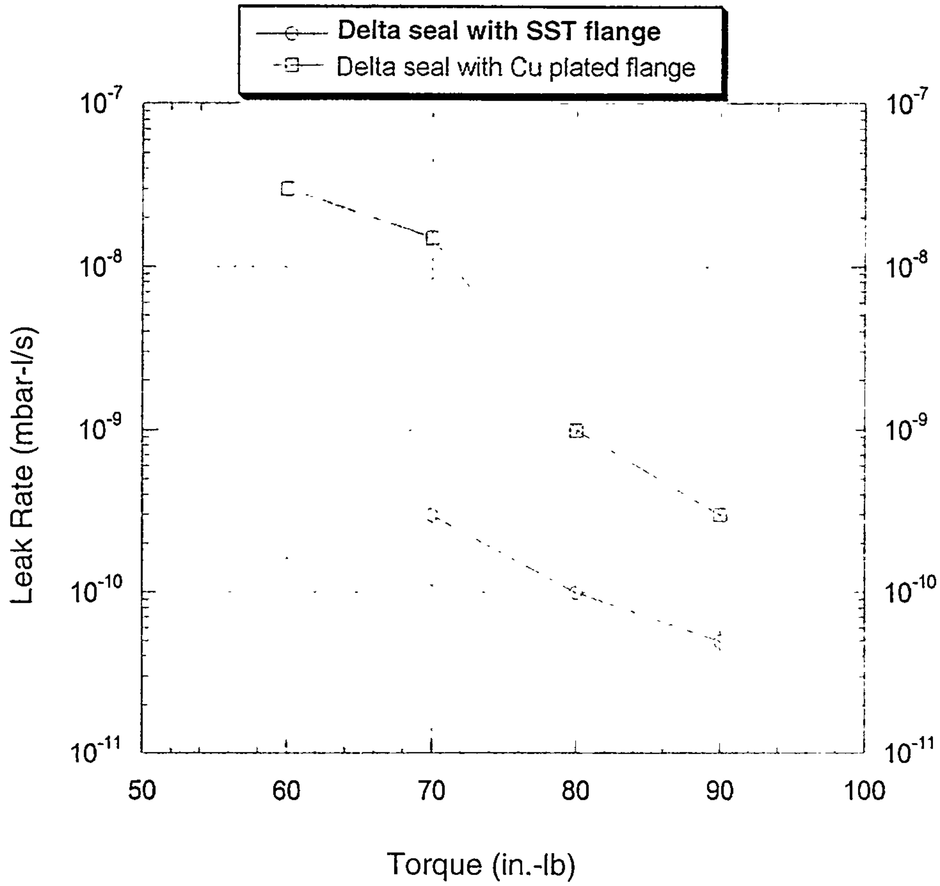


Figure 4. Comparison chart of leak rate test on copper delta seal with and without copper plated flange.

- **Summary:**

A vacuum leak rate test on several types of metal seals has been completed at Los Alamos Laboratory. Testing was performed using a Balzers QualyTest™ Helium Leak Detector. A standardized condition of 1 atmosphere differential pressure at room temperature was used in all cases. The test results of leak rates on the purchased seals have matched the manufacturers' published values. Most of these seals have the capability of achieving the required accelerator vacuum level of less than 5E-8 torr, except the metal C-seal. The leak rate of metal C-seals is marginal. The lowest leak rate of 5E-12 mbar-ℓ/s was achieved by two prototypes of the copper diamond seal.

Considering cost, seating load and risk assessment, Helicoflex delta seals are most suitable to use for the vacuum joints at the beam line and long coupling cavities in the SNS linac. A leak rate of the aluminum delta seals for beam line joints is 1E-10 mbar-ℓ/s under a torque of 40 in.-lb, and a leak rate of the copper delta seals for the long coupling cavity is 5E-11 mbar-ℓ/s under 90 in.-lb. This design needs to add a groove on the coupling cavity flange, which will complicate maintenance. To remove the groove from the flange, a delta seal with a pressurized limited ring may be the appropriate choice, which is reliable for SNS long coupling cavities vacuum joints. It also simplifies the procedure of installation and maintenance.

We have also tested the copper plated coupling cavity flange using the same type of delta seal that was used for testing with a stainless steel flange. The results of the leak rate for both cases are shown in Figure 4. A clear footprint of the delta seal on the flange copper plated surface occurred after the first seal was tested. With the seal footprint, we tested the second delta seal. The results from both seal tests were very close in the level of 5E-10 mbar-ℓ/s that was one order higher than the result from the delta seal test without a copper plated flange. Even though the softer copper plated layer has increased the leak rate, it still matches the requirement that a leak rate be less than 8E-11 torr-ℓ/s/mm with a seal perimeter of over 1,000 mm.

The lowest leak rate reached with various seals and the terminated torque applied at the leak rate have been listed here in Table 4.

Table 4. The Lowest Leak Rate Reached with the Test Seals and the Final Torque Applied

Torque (in.-lb)	Seals for 3.38 in. OD beam line flange, leak rate (mbar-ℓ/s)			Seals for 8.8 in. coupling cavity flange Leak rate (mbar-ℓ/s)			
	C-seal	Spring	Al Delta	C-seal	Spring	Cu Delta	Cu Diamond
40			1E-10				
50	1E-09						
60				2E-09			
70		1E-10					
80							
90					1E-10	5E-11	
100							5E-12

⇩ ⇩

90	Copper plated 8.8 in. OD coupling cavity flange/leak rate	5E-10	

VIII. REFERENCE OF COST FOR VACUUM TEST SEALS

We have purchased several types of the metal seals for vacuum leak rate tests, practice on the assembly performance, and study of the seal repeatability.
The following product price listed is higher than the one ordered in batches.
These are based on the ordered quantity of five. We also obtained the price for ordering 500 pieces, or even 1000 pieces.

- Vacuum Seals for Intersegment Long Coupling Cavity Flange with an 8.80 in. OD:

Type of seal	Unit price based on order quantity		Note on flange design
	5 pieces for test	500 pieces	
Metal C-seal	$167.50/ea	$42.65/ea	Groove on
Energized spring C-ring	$195.00/ea	$49.25/ea	Groove on
Helicoflex copper delta seal	$130.71/ea	$95.00/ea	Groove on
Copper diamond seal (prototype)	$1200.00/ea		No groove
Copper delta seal with limiting ring	$275.00/ea	$200.00/ea	No groove

- Vacuum Seals for an Intersegment Beam line Flange of 3.38 in. OD with a groove:

Type of seal	Unit price with Order quantity	
	5 piece for test	500 piece
Metal C-seal	$150.00/ea	$15.84/ea
Energized spring C-ring	$150.00/ea	$20.73/ea
Helicoflex aluminum delta seal	$90.70/ea	$42.15/ea

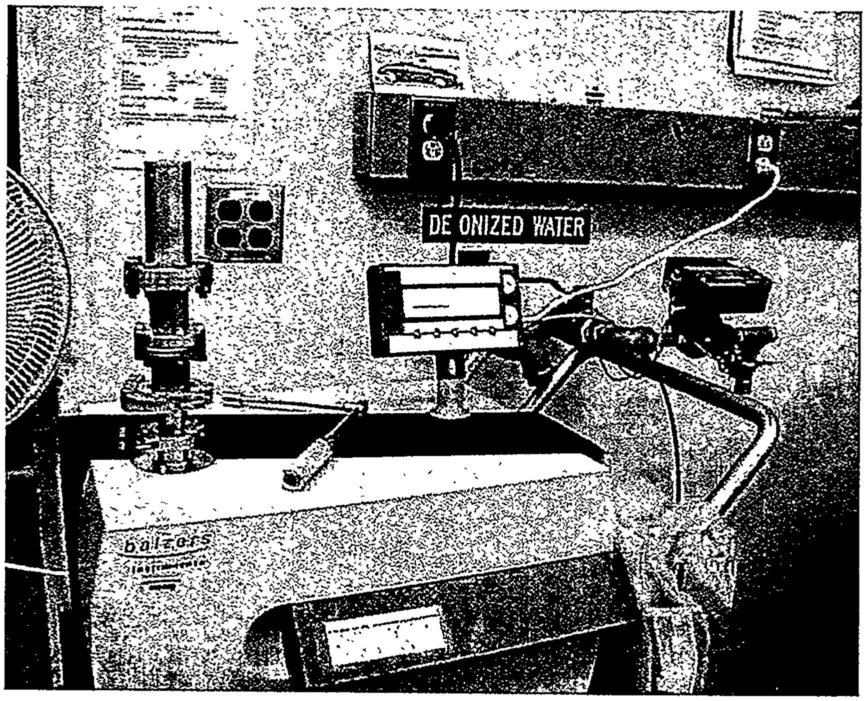
- The total seal cost for vacuum tests is $8.32K, including the smallest seals for the beam line vacuum joints. The smallest seals are not tested, because they were designed to be used for a 1-cm bore radius beam tube that had been removed from the physics design.

  Note: Metal C-seals and spring C-rings are silver plated. They are quoted as Class one seals, which are spin polished to provide the optimum surface finish, specially handed to prevent damage from other seals, and specially cleaned to be compatible with a vacuum environment.

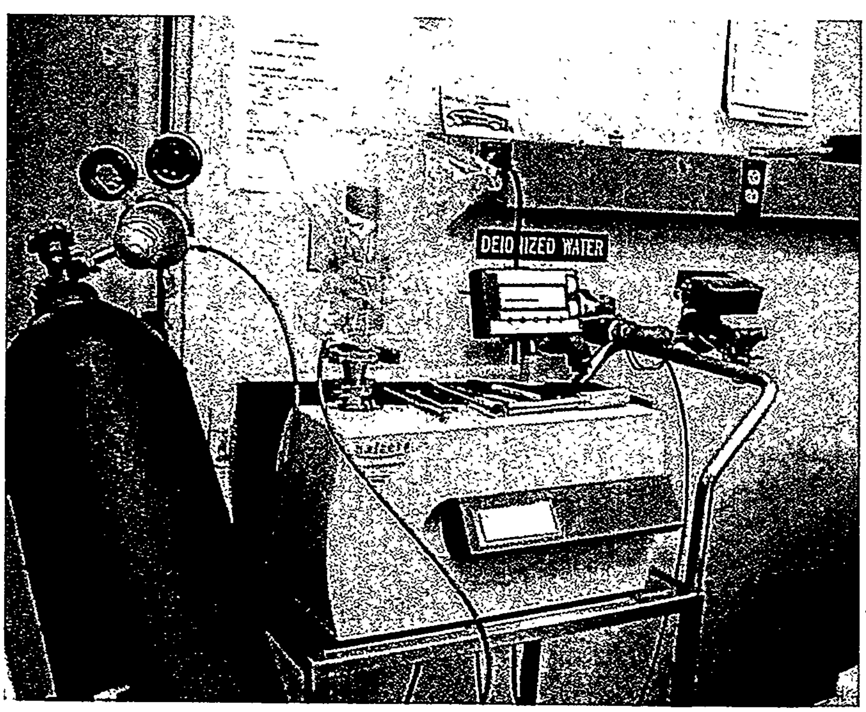
APPENDIX A

VACUUM SEAL TEST SETUP AND PERFORMANCE

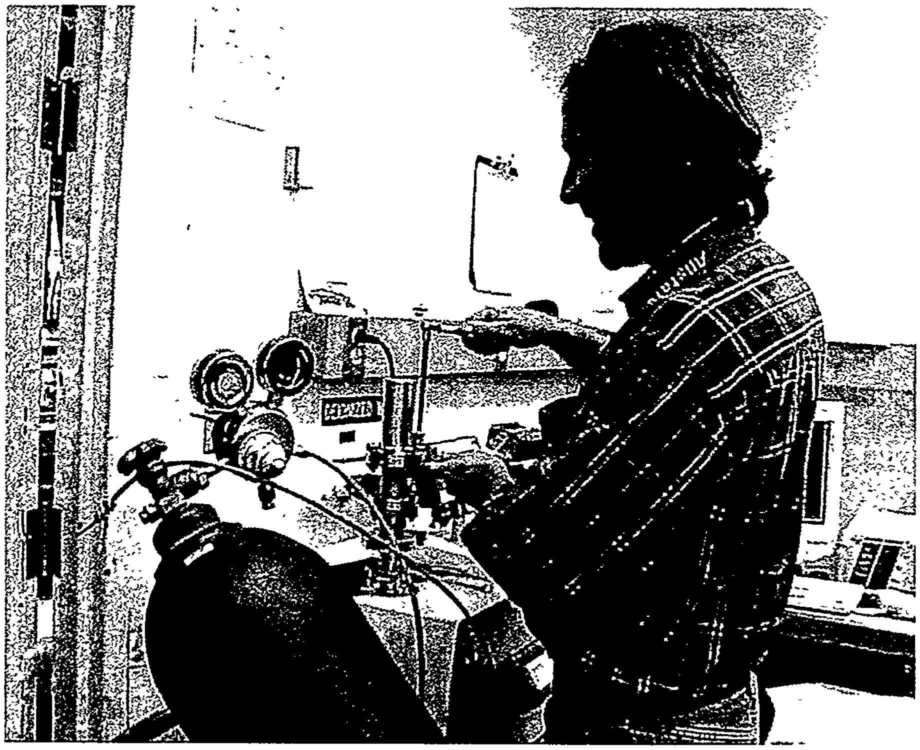
1. Vacuum test setups for metal C-Seal and spring C-ring at the beam line using 3-3/8 in. OD flanges. Because the grooves of two types of seal are different, two setups were needed.



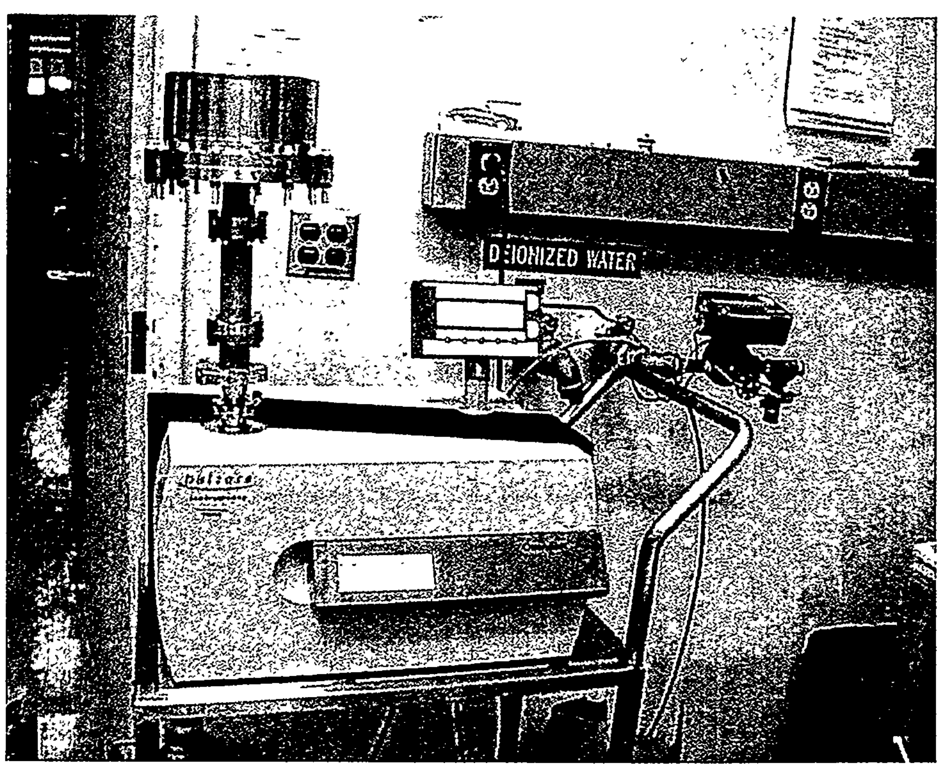
2. Vacuum leak check with helium-filled bag is in process.



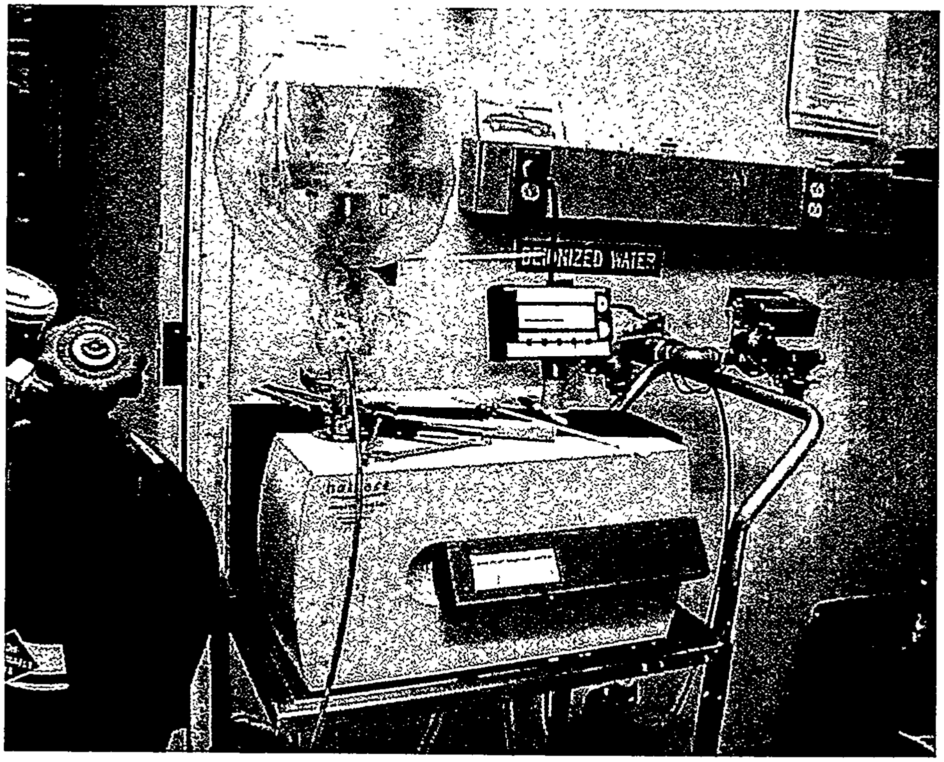
3 Mr Cort Gautier is assembling the spring C-ring and 3-3/8 in OD flanges



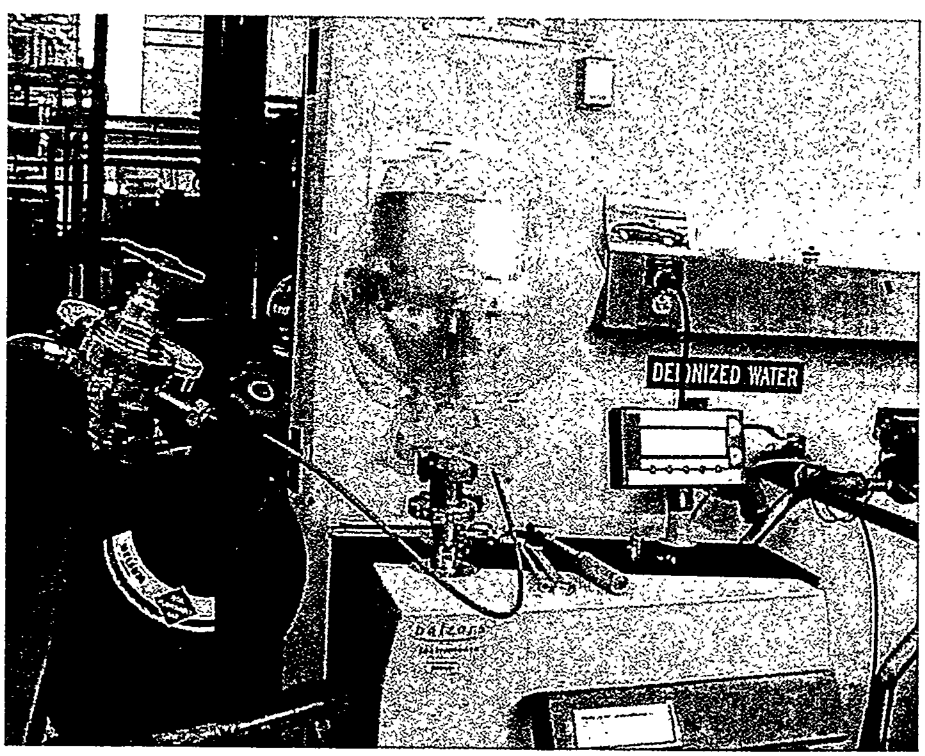
4. Vacuum test setup for metal C–Seal and for spring C-ring using 8.8 in. OD flanges for long coupling cavities. Because the grooves of the two types of seal are different, two setups were needed.



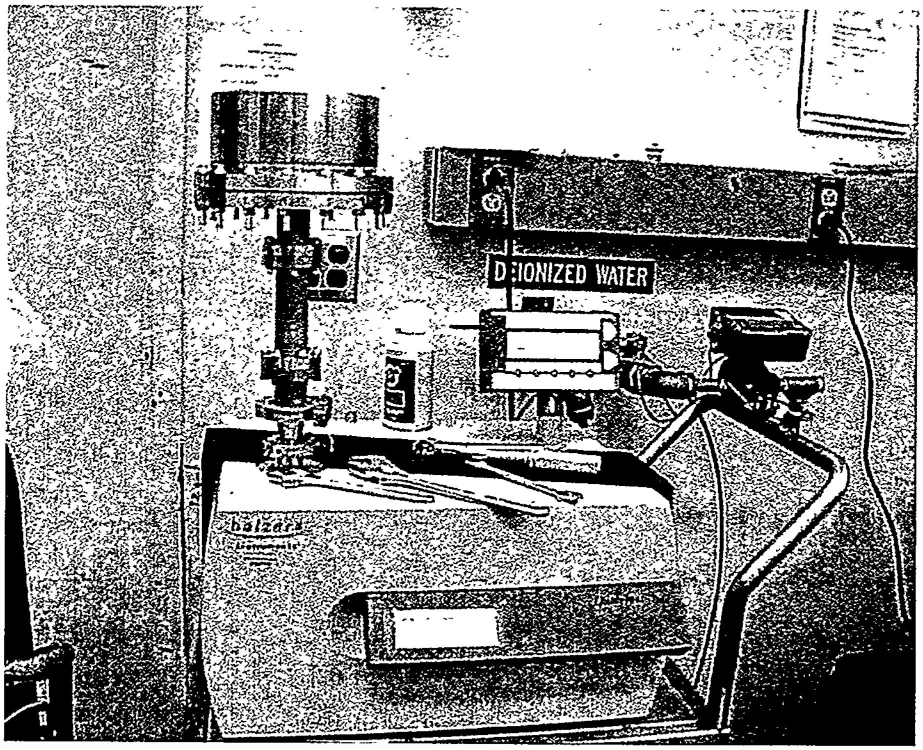
5. Vacuum leak check coupling cavity seals (C-seal and spring C-ring) with the bag being filled with helium.



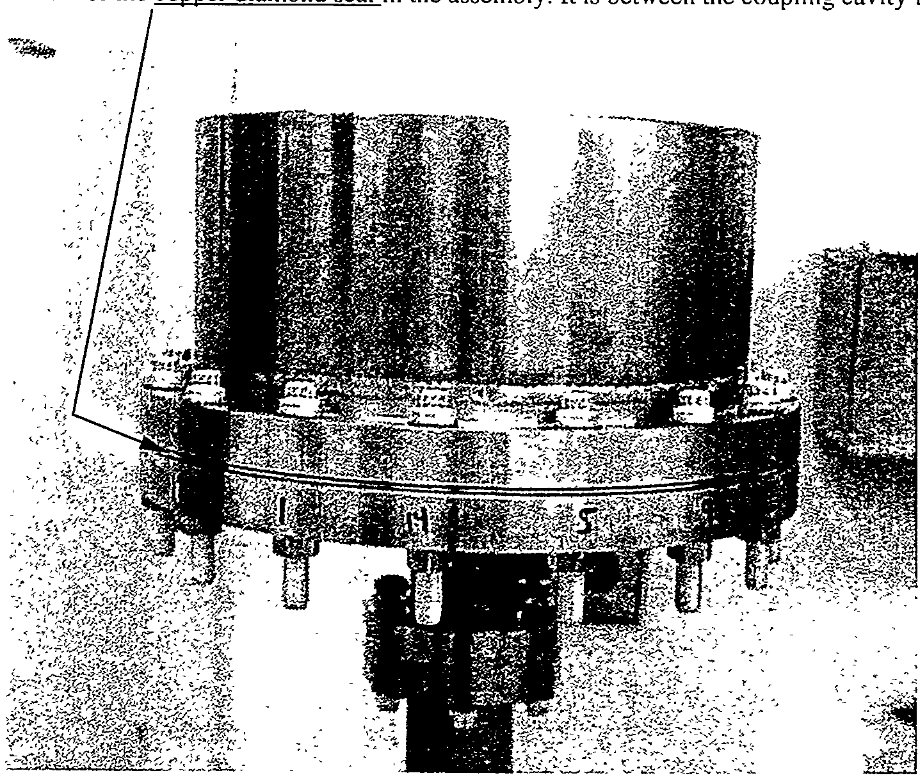
6. Vacuum test setup for <u>copper delta seal</u> using 8.8 in. OD flanges for long coupling cavities and the leak check is in process.



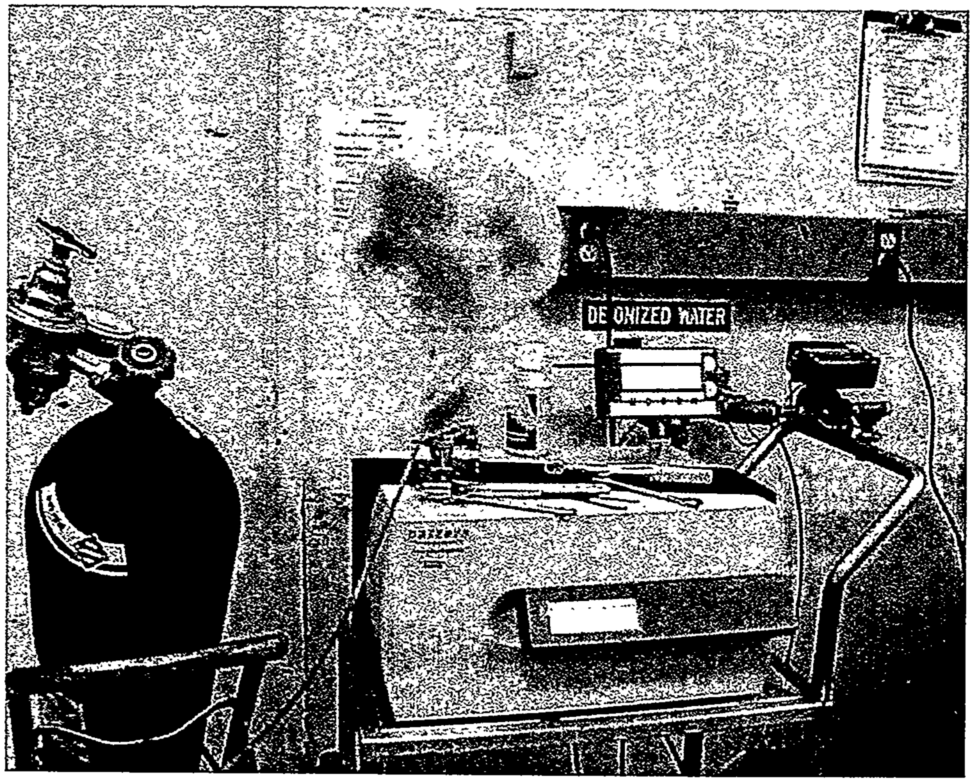
7 Special <u>copper diamond seal</u> prototype is set up and ready for a leak check.



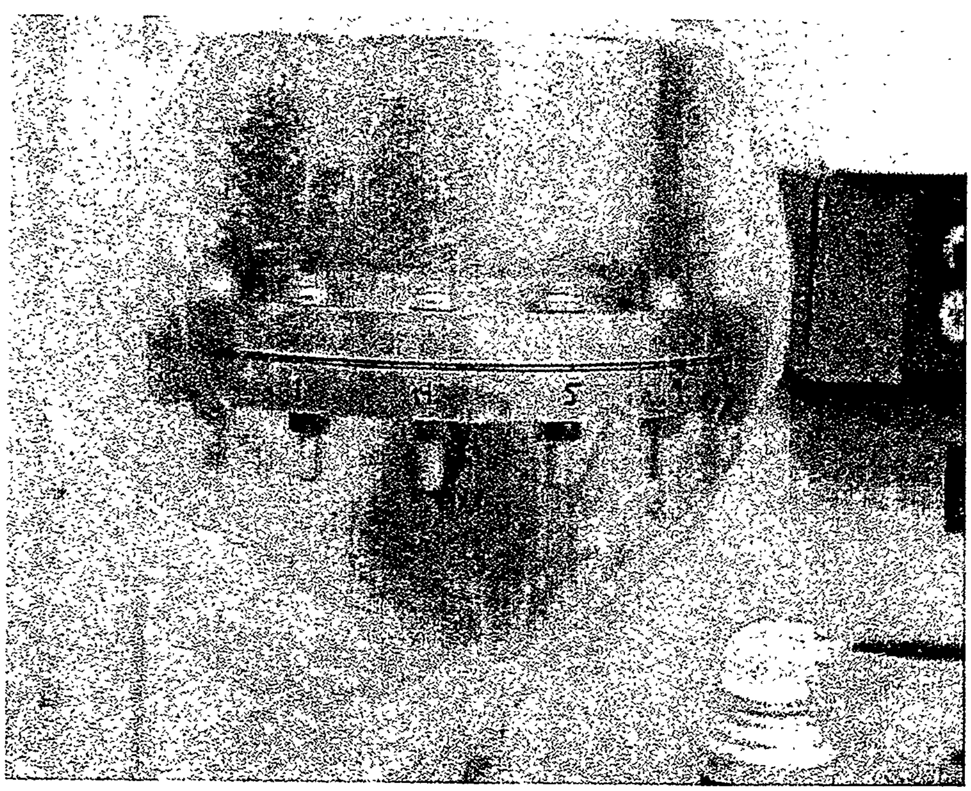
8. Close view of the copper diamond seal in the assembly. It is between the coupling cavity flanges.



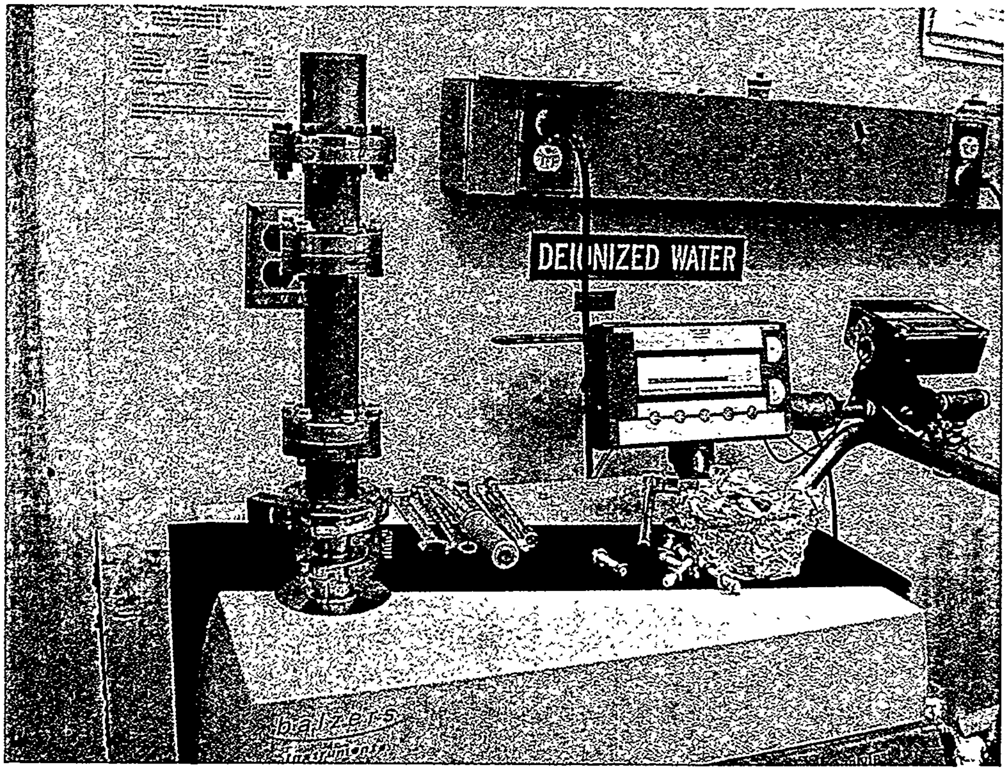
9. A vacuum leak check for using the <u>copper diamond seal</u> at the coupling cavity joint is in process.



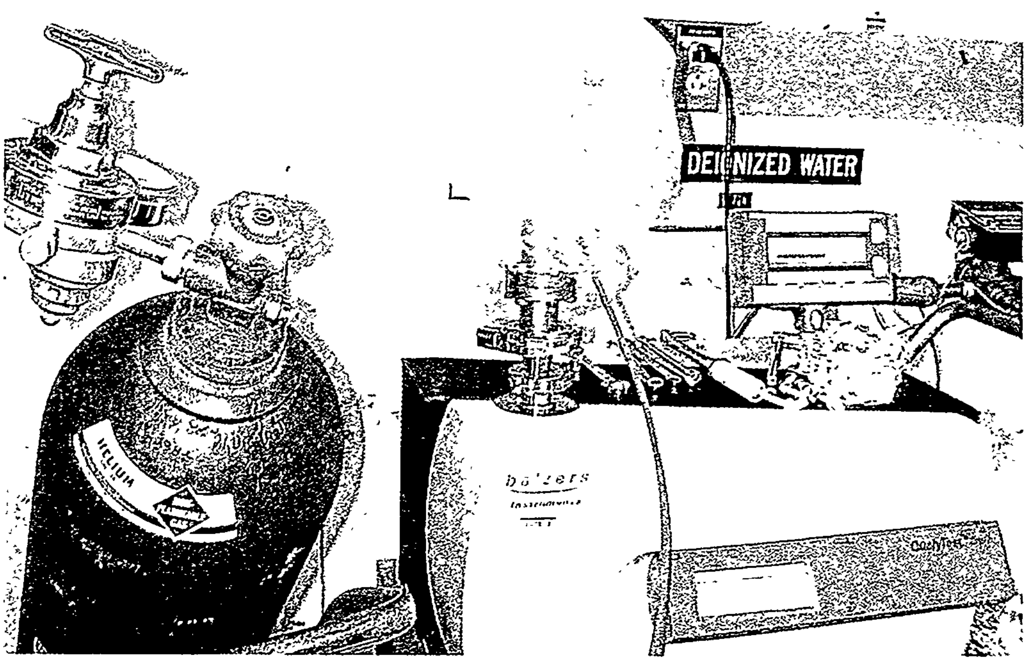
10. Looking close at the test portion when helium is filling the bag.



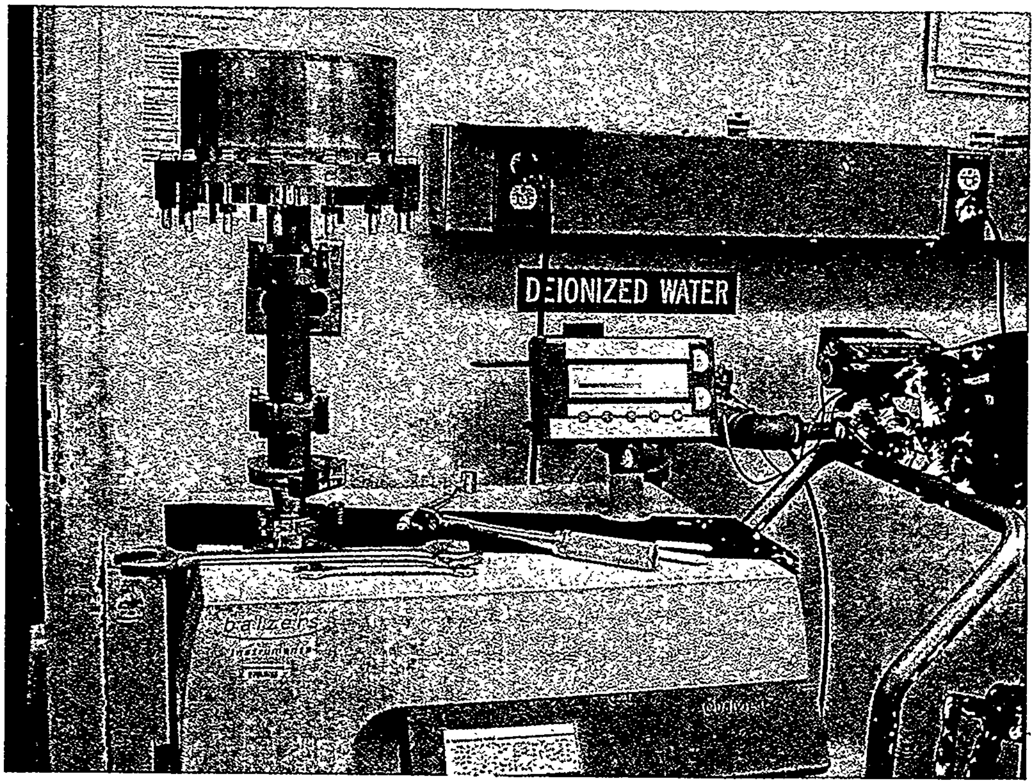
11 A vacuum leak rate check for the aluminum delta seal using a 3-3/8 in. OD flange for the beam line is being set up.



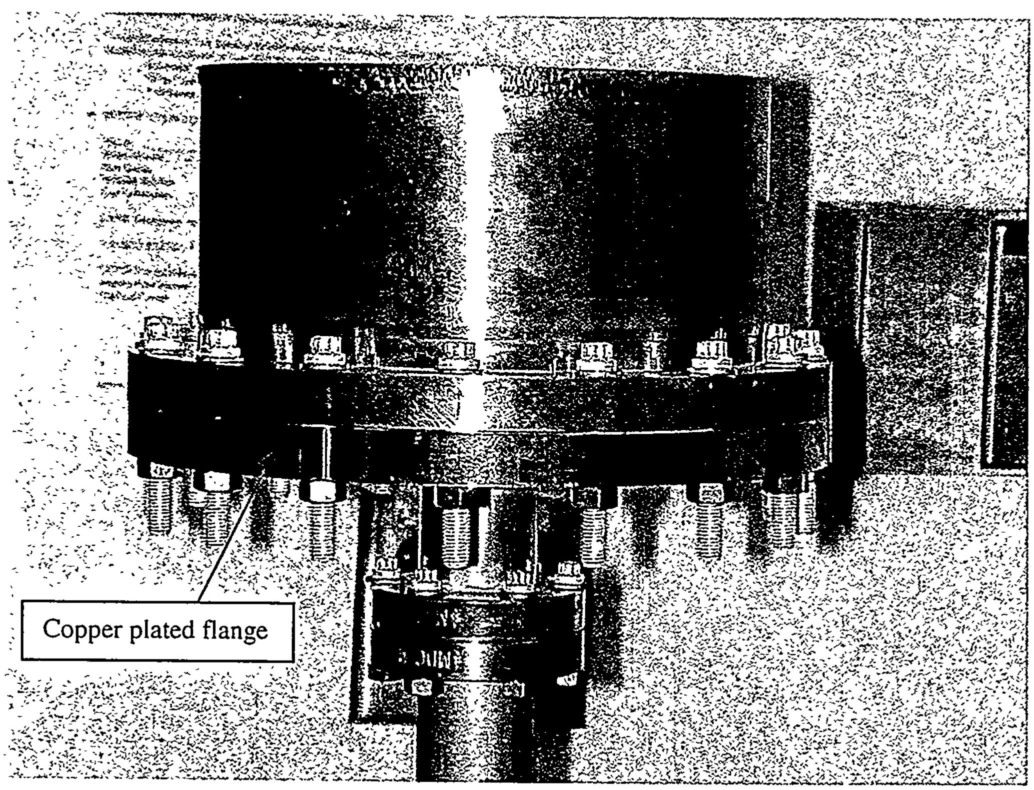
12. A vacuum test of the aluminum delta seal with a helium-filled bag being processed



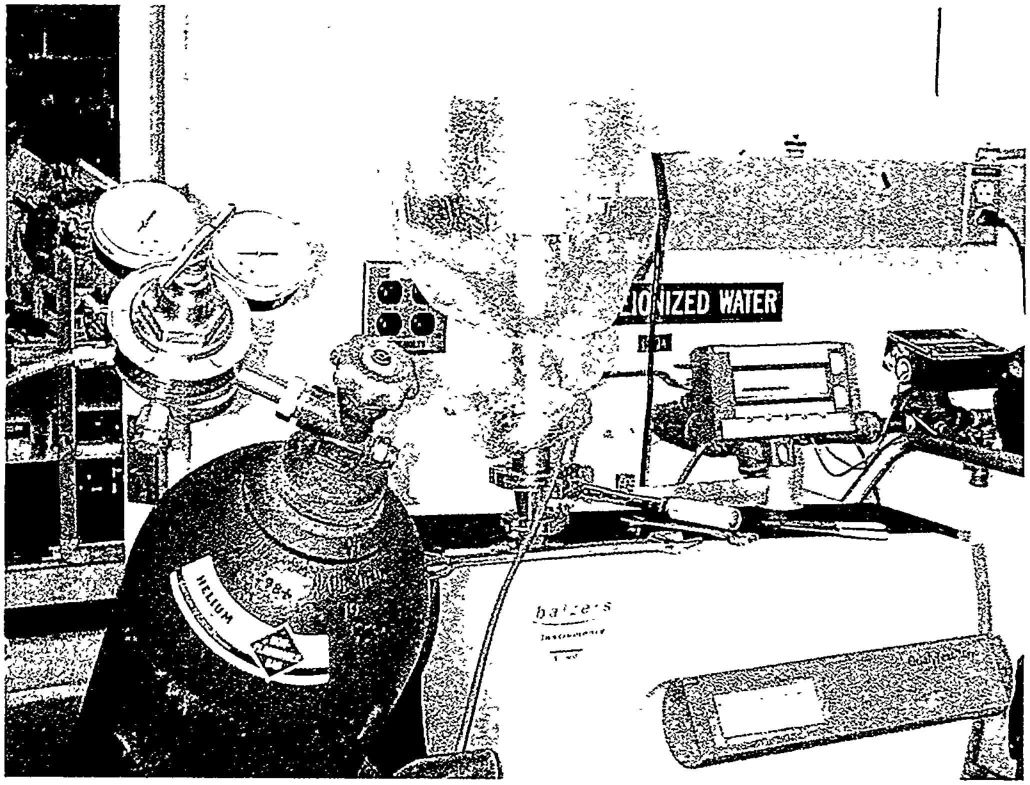
13. A vacuum leak test on a copper plated coupling cavity flange using a copper delta seal is being set up.



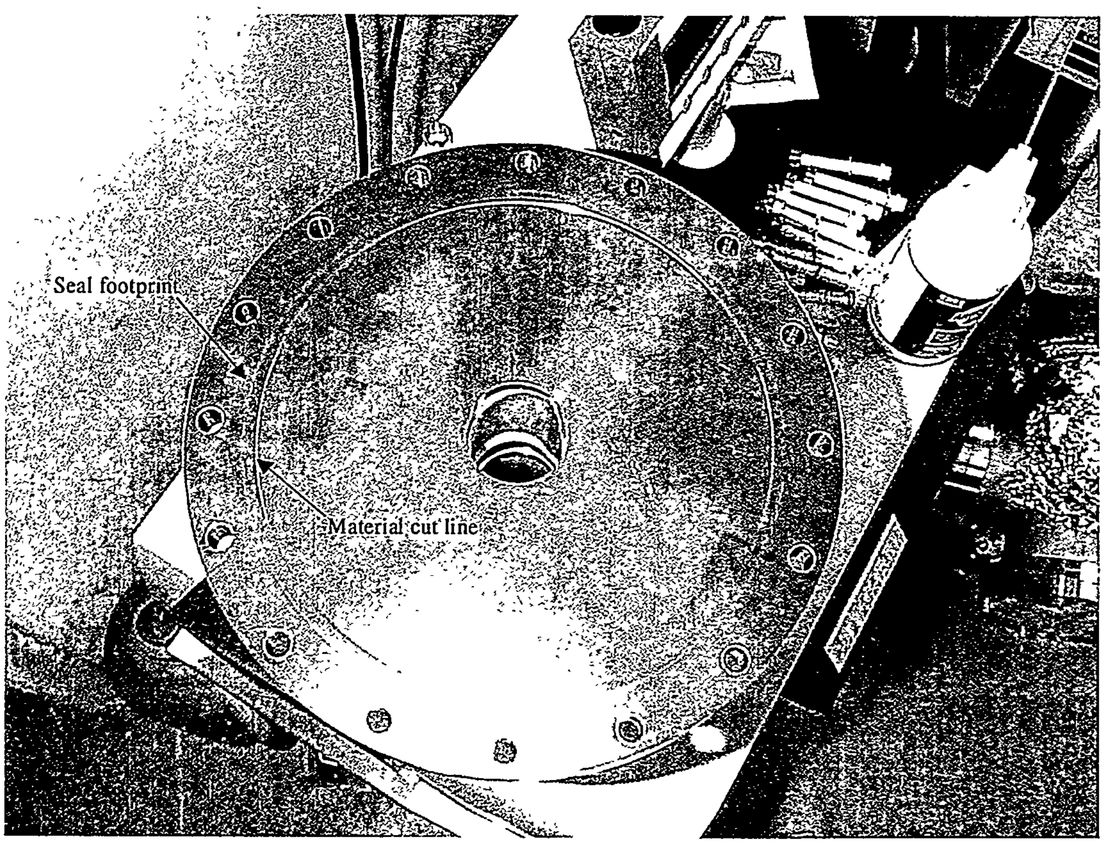
14. A close look at the copper-plated flange assembly.



15. A vacuum joint of copper-plated coupling cavity flanges with copper delta seal is being tested.



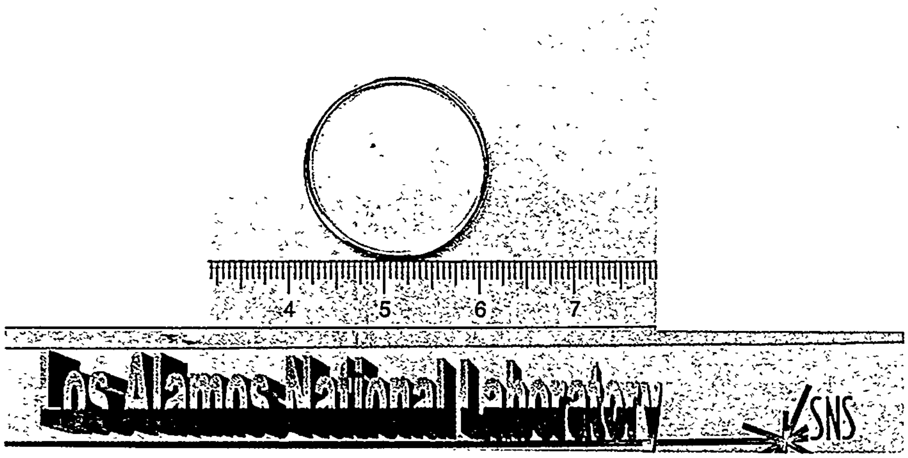
16. A copper-plated coupling cavity flange (stainless steel flange has 0.002-in. copper coat).
The photo was taken after the first seal leak rate test. On the flange surface, the seal footprint is clear



APPENDIX B

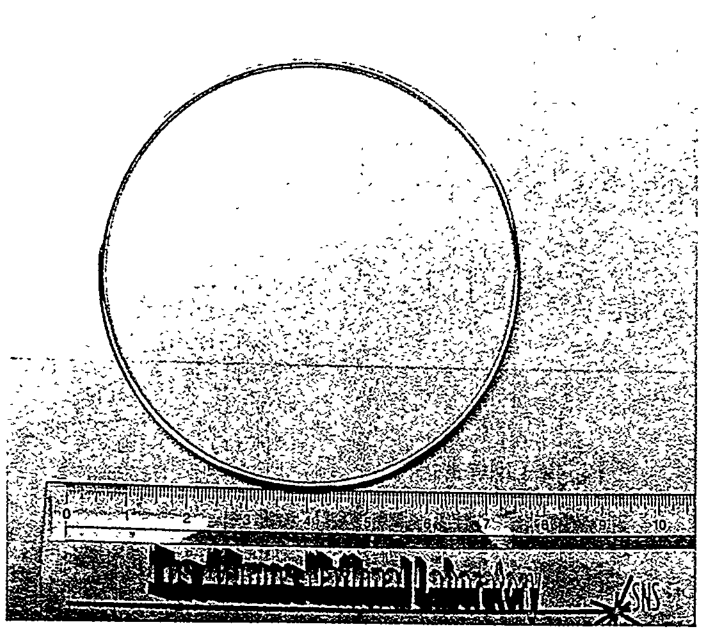
METAL SEALS OF SNS LINAC VACUUM SYSTEM

1. Metal C–seal (ECE-001802-07-14-6-SPF) and energized spring C–ring (ESE-001802-07-06- 1-SPF) for SNS LINAC beam-line vacuum joints.

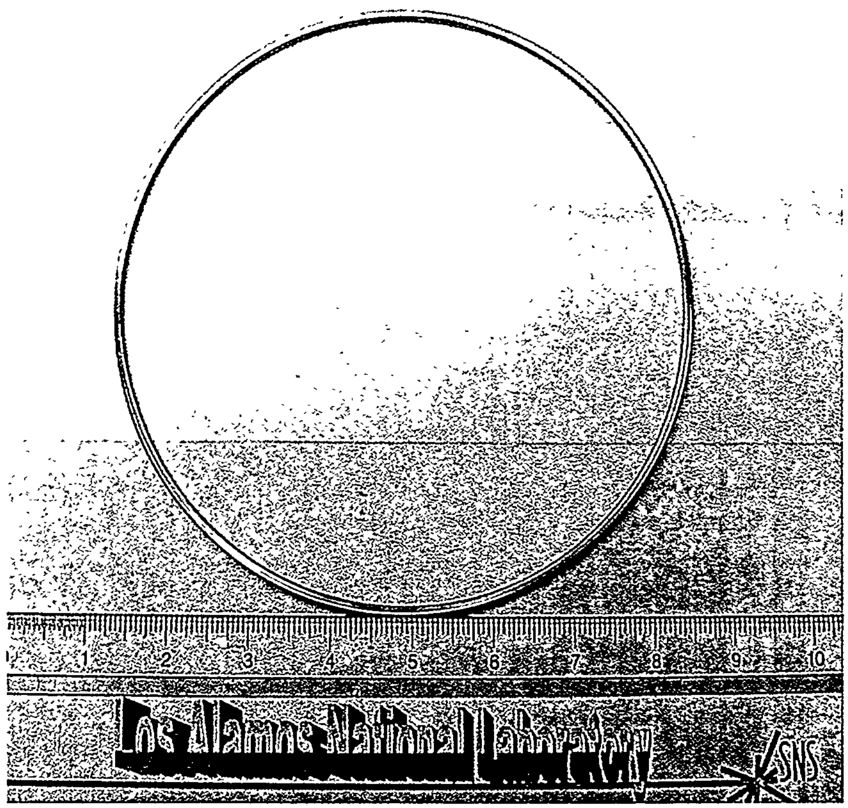


Note: The outside features of the C-seal and spring seal look similar.
The difference is that the spring seal has a spring that is covered by the C-sea

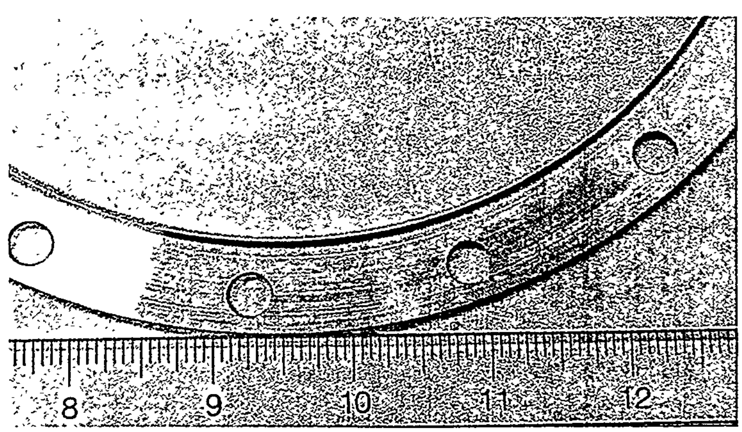
2. Long Coupling Cavities Seals: Metal C – seal (ECE-007000-09-14-6-SPF) and energized spring C – ring (ESE-007000-09-06-1-SPF).



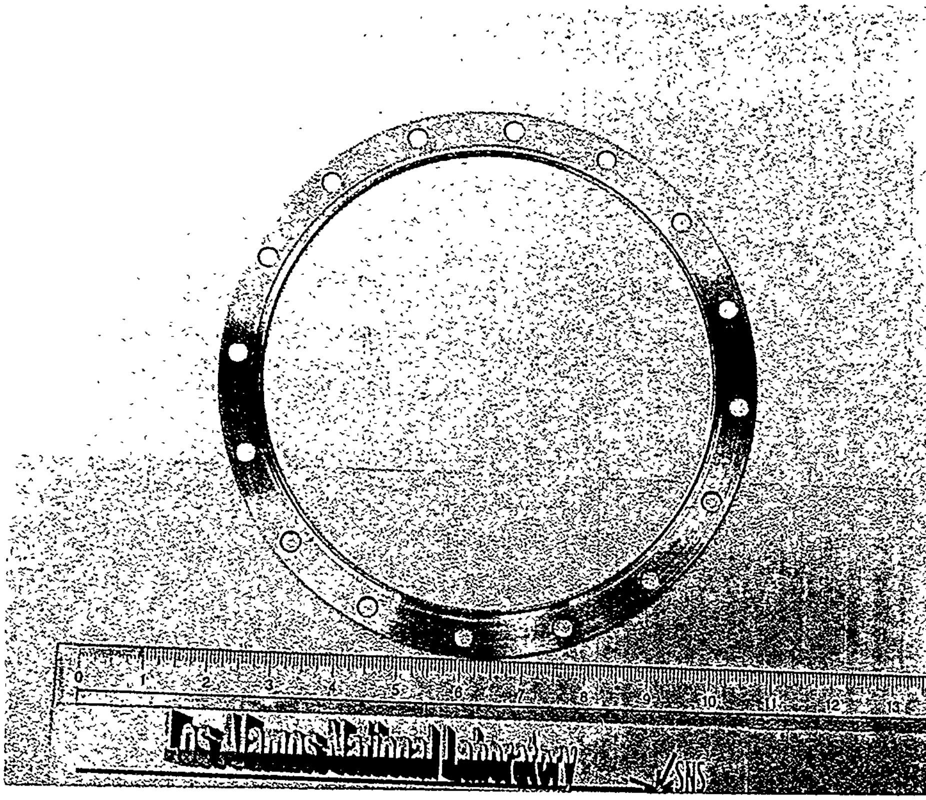
3. Long Coupling Cavities Seal: Helicoflex copper delta seal (HN200 – H-306124 Rev NC).



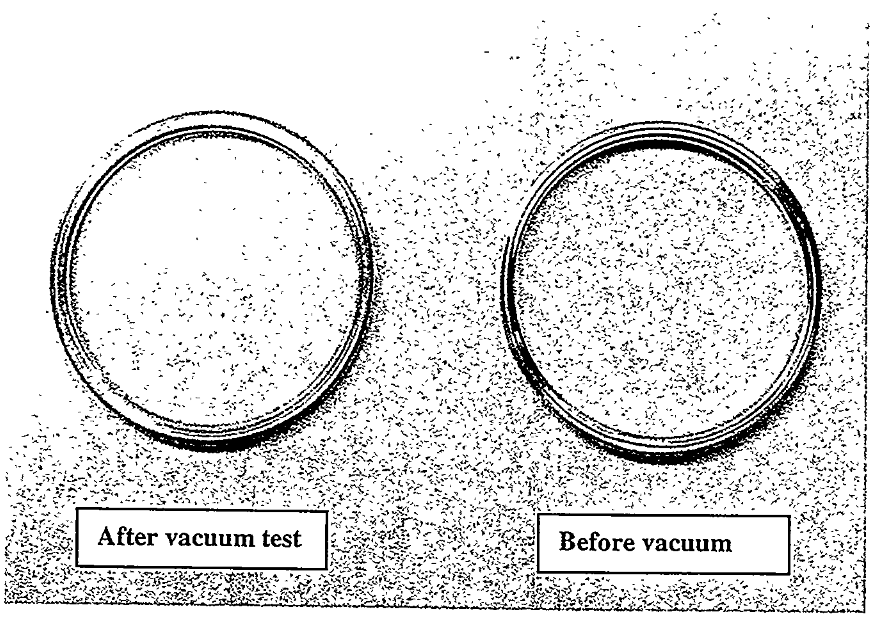
4. Long Coupling Cavities Seal: copper diamond seal—edge detailing view.



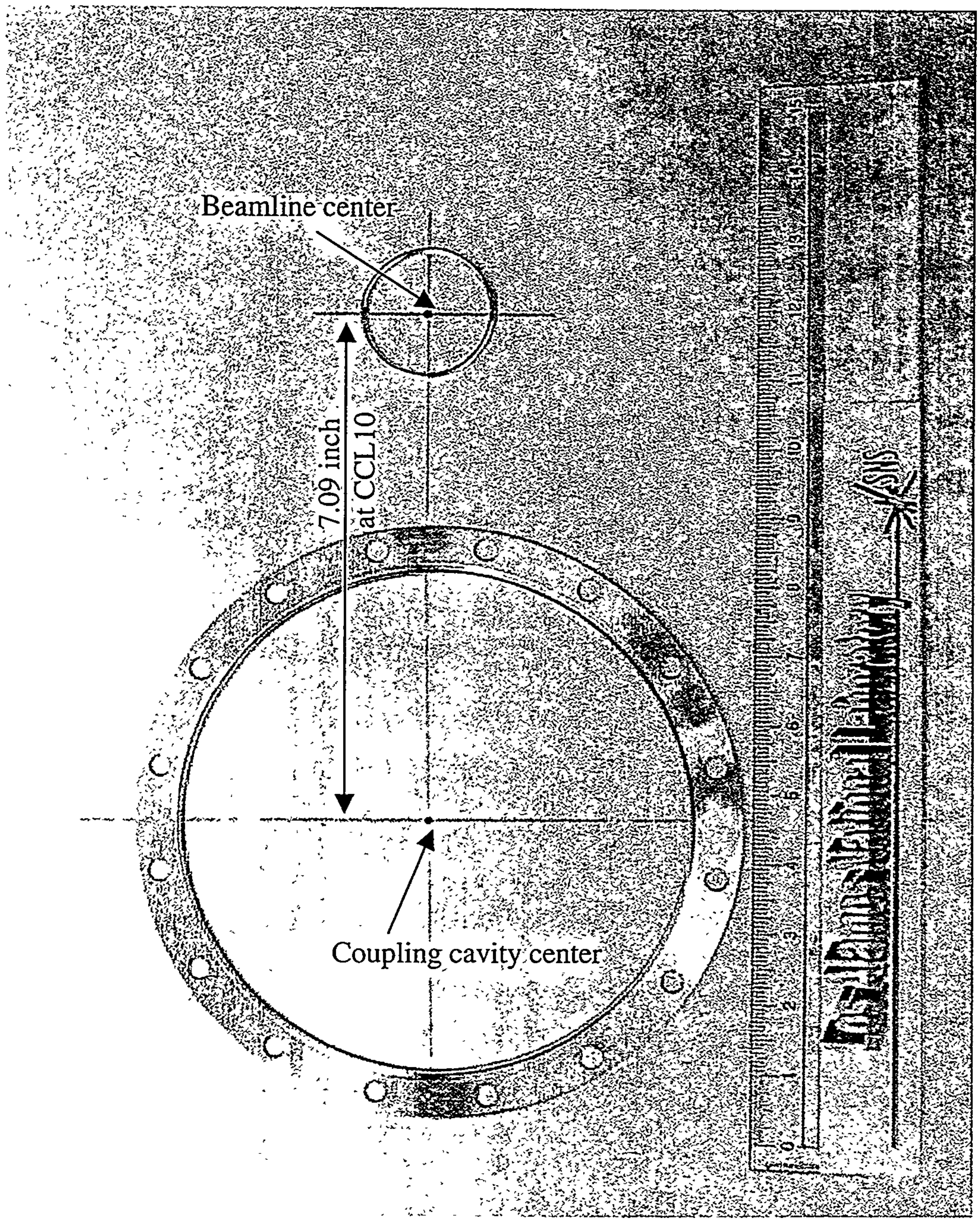
5. Copper diamond seal prototype for long coupling cavity vacuum joints.



6. Helicoflex aluminum delta seal (HNV 200 – H 306 290 Rev NC) for SNS Linac beam-line vacuum joints.



7. Relevant position of vacuum seals for the beamline and coupling cavity in the SNS Linac is shown below.



APPENDIX C

Thin ConFlat Flange Sealing Information

ConFlat Flange OD Diam	No.	Assembly Description	Flange & Gasket Thickness	Applied Torque Inch Pounds	Measurement/Distance Between Flange Faces unit: in.	Estimated Sealing Load Pounds Per Inch of Seal Circumference
2.75 in.	1	# 3 - Half Nipple with 2.75 in. Non-Rot CFF # 4 - 2.75 in. Rot Blank CFF Tapped 1/4-28 Copper gasket, coined 1/4 Hard	NR CF = .312 in. Rot Rec = .375 in. .0787 in. +/- .0043 in.	75 100 115 125	.010/.014 .003/.006 .000/.001 .000/.000	1736 2314 2662 2893
2.75 in.	2	# 1 - Half Nipple with 2.75 in. Rot CFF # 2 - 2.75 in. Non-Rot Blank CFF Tapped 1/4-28 Copper gasket, coined 1/4 Hard	Rot Rec = .375 in. NR CF = .312 in. .0787 in. +/- .0043 in.	75 125	.010/.014 .000/.000	1736 2893
3.38 in.	3	# 5 - Half Nipple with 3.38 in. Non-Rot CFF # 6 - 3.38 in. Rot Blank CFF Tapped 5/16-24 Copper gasket, coined 1/4 Hard	NR CF = .312 in. Rot Rec = .375 in. .0787 in. +/- . 0043 in.	75 100 125 150 175 200 225	012/.016 .010/.015 .006/.015 .002/.013 .015/.009 .000/.004 .000/.000	1391 1854 2318 2782 3246 3709 4173
3.38 in.	4	# 7 - Half Nipple with 3.38 in. Rot CFF # 8 - 3.38 in. Non-Rot Blank CFF Tapped 5/16-24 Copper gasket, coined 1/4 Hard	Rot Rec = .375 in. NR CF = .312 in. .0787 in. +/- .0043 in.	75 150 200 225	.012/.016 .0015/.006 .000/.0015 .000/.000	1391 2782 3709 4173

Note: Joints screws and tapped holes were dry (no lubricant)
Gaskets hardness: 1/4 hard
Leak Check Data:
960 Helium Leak Detector - calibrated to 6.2×10^{-10} torr-l/s
All flanges were checked for all torques to 2×10^{-10} torr-l/s
All flanges were checked at the final tightness (face-to-face) at 1×10^{-10} torr-l/s

APPENDIX D

VENDORS AND MANUFACTURERS

- Metal C-seal and Energized Spring C-ring

Advanced Products Company Inc.
33 Defco Park Road – P.O. Box 296
North Haven, CT 06473 USA
Tel. (203) 239-3341; Fax (203) 234-7233
Representative: Dan Lanman

- Copper Diamond seal

Coronado Machining Inc.
Albuquerque, NM 87102
Tel. (505) 243-1944; Fax (505) 243-1314
Representative: Dan Richards

- Test parts machining

Hand Precision Machining Inc.
127 Eastgate Dr.
Los Alamos, NM 87544 Tel: (505) 662-9001

- Copper Delta, Aluminum Delta seal and Delta seal with limiting ring

Helicoflax Company
P.O. Box 9889
Columbia, SC 29290-9889 USA
Tel. (803) 783-1880 or (800) 233-1722; Fax (803) 783-4279
Representative: Jay Dhillon

- Thin ConFlat flange prototype and test

VARIAN Vacuum Product
121 Hartwell Avenue,
Lexington. MA 02173
Tel. (781) 860-9249
Representative: Tench Forbes

APPENDIX E

HARDWARE DRAWINGS

Not all hardware drawings for the vacuum tests are included in this document. They are to be found in the SNS project Files and the ESA-DE Vault.