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D. R. Harries, M. Dalle Donne
Institut für Neutronenphysik und Reaktortechnik
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D.R. Harries* and M. Dalle Donne
Institut für Neutronenphysik und Reaktortechnik
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*PKF consultant

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Forschungszentrum Karlsruhe GmbH
Postfach 3640, 76021 Karlsruhe

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Abstract

The report presents the specification, manufacture and qualification of the beryllium specimens to be irradiated in the BR2 reactor in Mol to investigate the effect of the neutron irradiation on the embrittlement as a function of temperature and beryllium oxide content.

This work was been performed in the framework of the Nuclear Fusion Project of the Forschungszentrum Karlsruhe and is supported by the European Union within the Europen Fusion Technology Program.

Versuchsprogramm Beryllium Versprödung unter Bestrahlung
Material und Proben Spezifikation, Fabrikation und Qualifizierung

Zusammenfassung

Der Bericht dokumentiert die Spezifizierung, Fabrikation und Qualifizierung der Berylliumproben, die im BR2 Reaktor Mol bestrahlt werden sollen, um die Wirkung einer Neutronenbestrahlung auf die Versprödung in Abhängigkeit von Temperatur und Berylliumoxidgehalt zu untersuchen.

Die vorliegende Arbeit wurde im Rahmen des Projekts Kernfusion des Forschungszentrums Karlsruhe durchgeführt und ist ein von der Europäischen Union geförderter Beitrag im Rahmen des Fusionstechnologieprogramms.

Contents

1. Introduction

An investigation of the irradiation embrittlement characteristics of the more ductile and isotropic grades of beryllium currently manufactured by Brush Wellman using modern powder production and consolidation techniques is being undertaken as part of the European Long Term Fusion Technology Programme. This study is made in support of the development and evaluation of beryllium as a neutron multiplier for the solid breeder blanket design concepts proposed for a DEMO fusion power reactor [1][2].

Several meetings and discussions to plan and agree the beryllium irradiation embrittlement/ test programme were held in the period December 1989 to December 1991and are listed in Annex A; the background and technical specification of the programme, together with the number of specimens required, are summarised in Annex B. A Task Sheet (BSBE) [3] was prepared and agreed in principle by the FTSC(I) at its meeting held in Garching on January 30th. 1991. The programme was finally approved by the FTSC(I) in Brussels on July 3rd. 1991, subject to resolution and agreement on the responsibilities and costs of the various parts of the programme; the latter were subsequently resolved as follows:

Detailed specification and coordination of the programme by KfK, Germany:	0.13 MECU
Irradiations in the BR-2 reactor and testing and examinations of the specimens at the SCK/CEN Laboratory, Mol, Belgium (and including the cost of 0.080 MECU for the KfK Resident Engineer at Mol):	1.26 MECU

The following costs for the supply of the materials and specimens and for preliminary tests by Brush Wellman were borne by KfK:

Manufacture and qualification of materials and machining of specimens: [KfK Order No. 722/03755800/0104, 13:02:92; Brush Wellman Ref. EMC 957 and 958].	94,480 $
Supply of material, machining and preliminary fracture toughness tests on 2 Compact Tension (C-T) specimens (Material 2,000 $; Tests 3,000 $): [KfK Order No. 722/03757110/0104, 20:02:92; Brush Wellman Ref. EMC 959-001].	5,000 $

It was originally anticipated that the irradiation and testing programme could be completed in 3.25 years after receipt of the specimens from Brush Wellman.

The manufacture, qualification and certification of the beryllium and specimens supplied for the programme are described in this report.

2. Material Manufacture

The compositions and properties of the various grades of beryllium produced by Brush Wellman have been publicised [4[. The specifications of the axial vacuum hot pressed (VHP) S-220-F and S-65 and direct hot isostatic pressed (HIP) S-200-FH and S-65-H structural grades selected for the present programme have also been documented [5 - 8] and are summarised in Table I.

The beryllium was manufactured by the following powder production and consolidation processes [9][10]:

(i) Powder Production

The production of high quality beryllium powder entails the machining of chips from a vacuum melted and cast ingot followed by impact grinding. The chips and oversize powder particles are blasted by a high velocity stream of air onto a solid beryllium target; the chips break up on impact into small particles which are removed from the blast chamber by vacuum conveying and then screened. The blocky particles produced in this way have a less textured micro-structure and more uniform properties in all directions than powder made by other techniques such as attrition grinding.

(ii) Powder Consolidation

The defect free impact ground beryllium powders were blended and consolidated as follows:

(a) VHP

The powder is poured into a vertical cylindrical graphite or metal die and the powder column and the surrounding furnace interior thoroughly outgassed by gradually increasing the vacuum. Pressure is then applied axially from top and bottom rams and the temperature increased until the sintering temperature (typically, ~ 1030 C) is reached and a final density of > 99% of theoretical achieved. The beryllium powder is thus converted into cylindrical billets which are machined to remove the surface layers which have a high content of carbon or iron picked up from the dies.

The product has a dense, fine - grained microstructure, thereby promoting high strength, and good machineability. However, the mechanical properties are generally anisotropic with those measured parallel to the pressing direction (longitudinal) being slightly inferior to those measured perpendicular to the pressing direction (transverse).

(b) HIP

The loose powder is vibratory loaded to a tap density of approximately 50 % of theoretical in a mild steel can and degassed under vacuum at a maximum temperature of 650 C. The container is sealed by welding and then simultaneously heated up to the sintering temperature of 1000 C and isostatically pressed using argon gas at a pressure of 103 MPa (15,000 psi) for about 3 hours in a pressure vessel; the mild steel can is finally removed in dilute nitric acid. Simple, fully sintered compact shapes made by this technique are almost 100 % uniformly dense and have minimal anisotropy in mechanical properties.

(iii) Material Qualification and Certification

The billets are machined and any surface defects revealed by dye penetrant tests are also skimmed off. The final dimensions of the beryllium billets supplied for the this programme are given in Table II. These materials were qualified by chemical analysis, immersion density determination, tensile testing and X-ray radiography according to the specifications in Table I; the Brush Wellman test certificates are reproduced in Annex C whilst the analyses and densities, grain sizes and ambient temperature tensile properties of the four beryllium grades are summarised in Tables III and IV respectively.

The materials met the quoted specifications except for the S-200-FH beryllium whose BeO content of 0.9% was not in accord with the 1% min. originally specified. However, this material was accepted for the programme in view of the long lead time required for its replacement.

3. Specimen Manufacture and Qualification

The SCK/CEN, Mol drawings of the tensile (F 1670B) and compact tension (C-T) fracture toughness (F 1669G) specimens finally adopted for this study are shown in Figs. 1 and 2 respectively; the tensile specimen is a slightly shorter version of that advocated by Brush Wellman for testing of beryllium whilst the disc C-T specimen is based on the ASTM standard for plane strain fracture toughness testing [11]. The samples for electron microcopy were in the form of 3 mm (0.118 ±0.001 in.) diameter and 0.15 mm (0.0059 ±0.0011 in.) thick discs.

The blanks from which the specimens were subsequently machined were extracted from the billets by first sawing and then machining. The identifications of the individual tensile and C-T samples were maintained by vibro - etching a letter/number code (3 mm high for the tensile and 4 mm high for the C-T) on the flat ends of the machined blanks. The numbers and identification of the tensile and C-T specimens are recorded in Table V; the EM discs were not individually identified but were designated as indicated in this table. The locations and orientations of the specimen blanks in the respective billets are shown in the Brush Wellman drawings reproduced in Annexes D, E, F and G.*

The tensile specimens were machined from the VHP cylindrical bars in the L orientation; it was also stipulated that the C-T specimens were to be machined in the L-R orientation [that is, with the diameter (D = 21.6 mm) parallel to the axial direction of pressing (L) and the crack propagation in the radial (R) direction] from the VHP billets as previous work by Brush Wellman had shown that this represented the worst case [12]. It was considered that the orientation of the specimens was not critical in the case of the more isotropic HIP billets. Nevertheless, for reproducibility, it was recommended that the tensile specimens should be machined with their lengths parallel to the long directions of the billets (L) and the C-T samples in the L(D)-T orientation [where T is the thickness (minor dimension)] from the HIP rectangular billets; however, it is not clear if this procedure was adhered to in all cases.

The Brush Wellman recommended procedure for machining the beryllium tensile specimens has been documented [13]; the EM disc samples were produced by electrical discharge machining. The tensile and C-T specimens were etched by immersion in an agitated solution of

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* The rods designated PR0 and PR1 in the drawings were supplied for a companion programme to investigate the swelling of beryllium following irradiation in the PHENIX reactor and were provided at no extra charge by Brush Wellman.

(by volume) 2% nitric acid, 2% sulphuric acid, 2% hydrofluoric acid and 94% deionised water at 25 - 38 C [14]; this resulted in the removal of, typically, 0.2 mm (0.008 in.) from the surface and, thereby, eliminated any damage and residual stresses resulting from the machining.

The minimum thickness (B) of a plain sided specimen required to satisfy plane strain conditions is given by:

$$B = 2.5\ [K_{1c}/\sigma_y]^2$$

where K_{1c} is the fracture toughness and σ_y is the tensile yield (0.2 % proof) stress.

Taking K_{1c} = 11 MPa $\sqrt{m}$ (10 ksi $\sqrt{in}$) and σ_y = 207 MPa (30 ksi) for vacuum hot pressed beryllium [15] gives B = 7 mm.

This result led to the original choice of 8 mm thick C-T specimens for this programme. Nevertheless, a minimum specimen thickness of 13 mm has been stipulated to avoid excessive non - linearity in the elastic portion of the load - displacement curve and for valid Linear Elastic Fracture Mechanics (LEFM) testing of VHP beryllium [16]. However, disc C-T specimens with thicknesses in excess of 8 mm could not be irradiated in the numbers required in the BR-2 reactor without significant reductions in the neutron fluence of the samples located at the ends of the rig.

The final machining of the disc C-T samples was consequently delayed pending the completion of preliminary tests aimed at demonstrating that valid fracture mechanics data could be obtained with the 8 mm thick beryllium specimens. Two, plain sided 8 mm thick disc C-T specimens (SCK/CEN Drawing F 1669F) of unirradiated beryllium (S-200-FH. HIP, Lot No. H0685, Specimens SN-1 and SN-2) were machined and tested. The tests were performed at the Materials & Mechanics Department, Southwest Research Institute (SwRI), San Antonio, Texas under sub - contract from Brush Wellman. The SwRI Report entitled: "Fracture Toughness Testing - KfK (Round) Specimens", (SwRI Project No. 06-4522-161; KfK Order No. 722/03757110/ 0104; Brush Wellman Ref. EMC 959-001) is reproduced in Annex H. The fracture toughness K_{1c} results from specimens SN-1 and SN-2 [9.90 and 9.89 MPa $\sqrt{m}$ (9.00 and 8.99 ksi $\sqrt{in}$) respectively were very consistent and the tests met the ASTM validity requirements [16].

The results of the X-ray examinations, carried out to ensure that the machined blanks, bars and/or specimens were free from internal cracks and defects, showed that all the components complied fully with the respective radiographic specifications (Table I).

The tensile, C-T and EM specimens were despatched from Brush Wellman to SCK/CEN, Mol on 30:10:92.

4. References

1. M. Dalle Donne et al, J. Nucl. Mater., 212-215 (1994) 69.
2. M. Dalle Donne et al, "European DEMO BOT Solid Breeder Blanket", KfK Report 5429, November 1994.

3. H. Sebening, "Beryllium Embrittlement Irradiation Test Program", Task Action Sheet No: BSBE, Association KfK, August 7, 1990.
4. "Designing With Beryllium", Brush Wellman Engineered Materials Brochure.
5. "S-200-F Standard Grade Beryllium Block, Revision A", April 1, 1987, Brush Wellman Engineered Materials.
6. "S-65 Structural Grade Beryllium Block, Revision C", July 1, 1987, Brush Wellman Engineered Materials.
7. "S-200-FH Grade Beryllium, Revision B", December 12, 1990, Brush Wellman Engineered Materials.
8. "Preliminary Material Specification for S-65-H Structural Grade Beryllium Block", May 22, 1992, Brush Wellman Engineered Materials.
9. "Producing Defect - Free Beryllium and Beryllium Oxide", Brush Wellman Engineered Materials Brochure, May 1985.
10. D.H. Hashiguchi, T.P. Clement and J.M. Marder, Modern Developments in Powder Metallurgy, 18-21 (1988) 627.
11. ASTM E399 - 91, Appendix A6 - "Special Requirements for the Testing of the Disc - Shaped Compact Specimen".
12. Private Communication from Brush Wellman, October 1991.
13. "1/8 in. Diameter Microbar Tensile Specimen Preparation", Brush Wellman Engineered Materials, Procedure BW/E - 0161 - MA, August 20, 1987.
14. "Etching of Beryllium Test Specimens", Brush Wellman Engineered Materials, Procedure BW/E - 0155 - MT, January 8, 1988.
15. M.H. Jones, R.T. Bubsey and W.F. Brown, J. Testing and Evaluation, 1 (1973) 100.
16. ASTM E399 - 91, Appendix A8 - "Special Requirements for Testing of Beryllium".

Table I

Specifications of Beryllium Grades

Material	S-200-F (Rev.A) VHP	S-200-FH (Rev.B) HIP	S-65 (Rev.C) VHP	S-65-H HIP
Composition (wt.%)				
Be (min.) (1)	98.5	98.5	99.0	99.0
BeO (max.) (2)	1.5	1.5	1.0	1.0
Fe .. (3)	0.13	0.13	0.08	0.08
C .. (4)	0.15	0.15	0.10	0.10
Al .. (3)	0.10	0.10	0.06	0.06
Mg .. (3)	0.08	0.08	0.06	0.06
Si .. (3)	0.06	0.06	0.06	0.06
Other metallic elements (max.) (3)	0.04	0.04	0.04	0.04
Bulk Density (5)(6) % Theoretical (min.)	99.0	99.7	99.0	99.7
Average Grain Size (7) (μm)	< 20	< 12	< 20	< 15
Ambient Temp. Tensile Properties (8)				
Yield Stress (min.) (MPa)	241	297	207	207
U.T.S.	324	414	290	345
Elongation .. (%)	2.0	3.0	3.0	2.0
Penetrant Inspection (9)				
Cracks not permissable.	/	/	/	/
Pores:				
Individual pore on surface (mm).	< 1.27	< 1.27	< 1.27	< 1.27
Max. number of pores 0.08-1.27 mm per 650 mm of surface.	3	3	3	3
Radiographic Inspection (10)				
Voids and/or inclusions shall conform to the following requirements:				
Max. dimension (mm)				
Type 1.	0.76	1.27	0.76	0.76
Type 2.	0.76	0.76		
Max. av. dimension (mm)				
Type 1.	0.51	0.76	0.51	0.51
Type 2.	0.51	0.51		
Total combined vol./mm. = sphere diameter (mm)				
Type 1.	1.27	1.27	1.27	1.27
Type 2.	0.81	0.81		

Table I (continued)

Material	S-200-F (Rev.A) VHP	S-200-FH (Rev.B) HIP	S-65 (Rev. C) VHP	S-65-H HIP
Standard Machined Surface Finish (11) (m rms) (max.)	3.175	3.175	3.175	3.175
Thermal Induced Porosity (TIP) Resistance (12) Max. reduction in density in TIP resistance test (%)	-	0.20	-	0.20

(1) Difference (i.e. 100% - all other elements).
(2) Leco Inert Gas Fusion.
(3) DC Plasma Emission Spectrometry.
(4) Leco Combustion.
(5) Density determined using the water displacement method.
(6) Theoretical density (TD) calculated using the formula:

$$TD\ (g.cm^{-3}) = \frac{100}{\left[\frac{100 - \%\ BeO}{1.8477} + \frac{\%\ BeO}{3.009}\right]}$$

(7) Determined in accordance with ASTM E-112 using the intercept method at a magnification of 500x.
(8) Determined as per ASTM E-8 and MAB - 205M.
(9) Penetrant inspection performed as per MIL - STD - 6866 Type 1, Method B using penetrants and dry developer conforming to MIL - I - 25135 Type 1, Level 2, Method B, Form A.
(10) Radiographic inspection to a penetrameter sensitivity of 2 % performed in accordance with MIL - STD - 453. [Sensitivity of the inspection method decreases with increasing material thickness].
(11) Employing ANSI / ASME B 46.1.
(12) TIP test involves a heat treatment in a predominantly inert atmosphere at 788 C.

Table II

Billet Sizes

Material	Lot No.	Diameter mm. (in.)	Width mm. (in.)	Thickness mm. (in.)	Length mm. (in.)
S-200-F. VHP	4787	916 (36.063)	-	-	1,117.6 (44.0)
S-200-FH. HIP	H0685	-	504.8 (19.875)	266.7 (10.5)	528.6 (20.813)
S-65. VHP	4784	927.1 (36.5)	-	-	1,152.5 (45.375)
S-65-H. HIP	H0349	-	279.4 (11.0)	266.7 (10.5)	368.3 (14.5)

Table III

Material Certification - Analyses of Beryllium (wt.%)

Material	Items	Lot No.	Be	BeO	Fe	C	Al	Mg	Si	Other Metallic Elements
S-200-F. VHP	1 & 5	4787	98.9	1.2	0.10	0.12	0.05	0.02	0.03	<0.04 each
S-200-FH. HIP	2 & 6	H0685	99.1	0.9	0.10	0.08	0.04	0.02	0.03	"
S-65. VHP	3 & 7	4784	99.4	0.6	0.06	0.03	0.02	<0.01	0.03	"
S-65-H. HIP	4 & 8	H0349	99.5	0.5	0.06	0.03	0.02	<0.01	0.02	"

Table IV

Material Certification - Density, Grain Size and Tensile Properties

Material	Items	Lot No.	Density % Theoretical	Average Grain Size m	Direction	Yield Stress MPa	U.T.S. MPa	Total Elong. %
S-200-F. VHP	1 & 5	4787	99.9	8.2	Long. Trans.	261.3 258.6	377.1 407.5	2.1 4.4
S-200-FH. HIP	2 & 6	H0685	99.9	7.1	z	351.6	441.3	5.0
S-65. VHP	3 & 7	4784	99.9	8.4	Long. Trans.	242.0 242.0	377.1 398.5	3.7 5.9
S-65-H. HIP	4 & 8	H0349	99.8	6.6	x z	342.0 339.9	509.5 492.3	4.8 3.6

Table V

Specimen Details

Material	Brush Wellman Order No.	Item	Lot No.	Specimen Type	Number of Specimens	Specimen Identification
S-200-F. VHP	EMC 958	1	4787	EM disc (1)	16	O0 - O9; R0 - R5
		5	..	Rod (2)	2	PR0; PR1
	EMC 957	1	..	Tensile (3)	40	O0-O9; R0-R9; S0-S9; T0-T9
		5	..	Compact tension (4)	40	O0-O9; R0-R9; S0-S9; T0-T9
S-200-FH. HIP	EMC 958	2	H0685	EM disc (1)	16	U0-U9; W0-W5
		6	..	Rod (2)	2	PR0; PR1
	EMC 957	2	..	Tensile (3)	40	U0-U9; W0-W9; Y0-Y9; Z0-Z9
		6	..	Compact tension (4)	40	U0-U9; W0-W9; Y0-Y9; Z0-Z9
S-65. VHP	EMC 958	3	4784	EM disc (1)	16	A0-A9; B0-B5
		7	..	Rod (2)	2	PR0; PR1
	EMC 957	3	..	Tensile (3)	40	A0-A9; B0-B9; E0-E9; H0-H9
		7	..	Compact tension (4)	40	A0-A9; B0-B9; E0-E9; H0-H9
S-65-H. HIP	EMC 958	4	H0349	EM disc (1)	16	I0-I9; K0-K5
		8	..	Rod (2)	2	PR0; PR1
	EMC 957	4	..	Tensile (3)	40	I0-I9; K0-K9; L0-L9; M0-M9
		8	..	Compact tension (4)	40	I0-I9; K0-K9; L0-L9; M0-M9

(1) 3 mm diameter by 0.15 mm thick.
(2) Supplied for PHENIX irradiation - swelling programme.
(3) see Fig. 1.
(4) see Fig. 2.

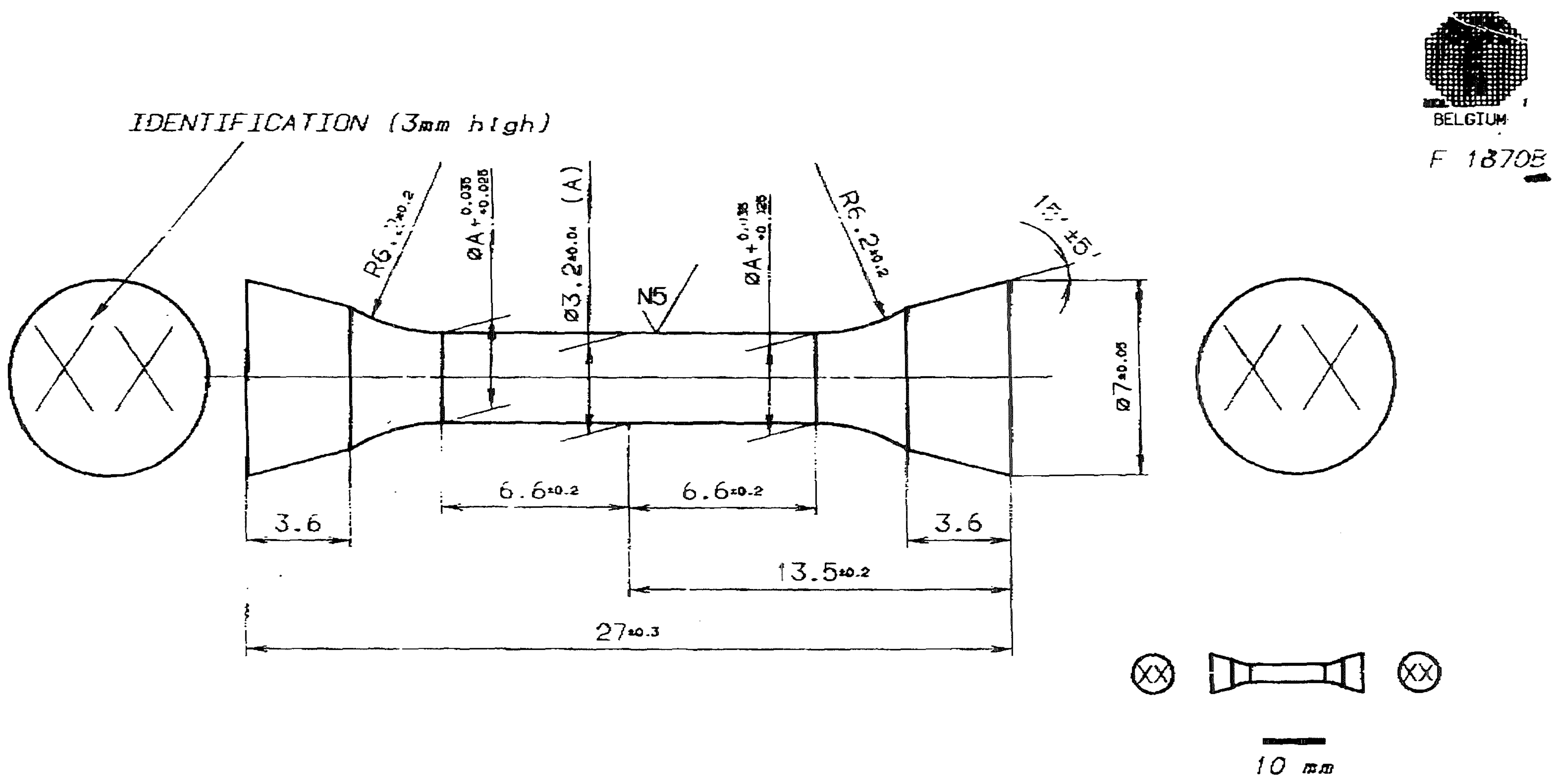
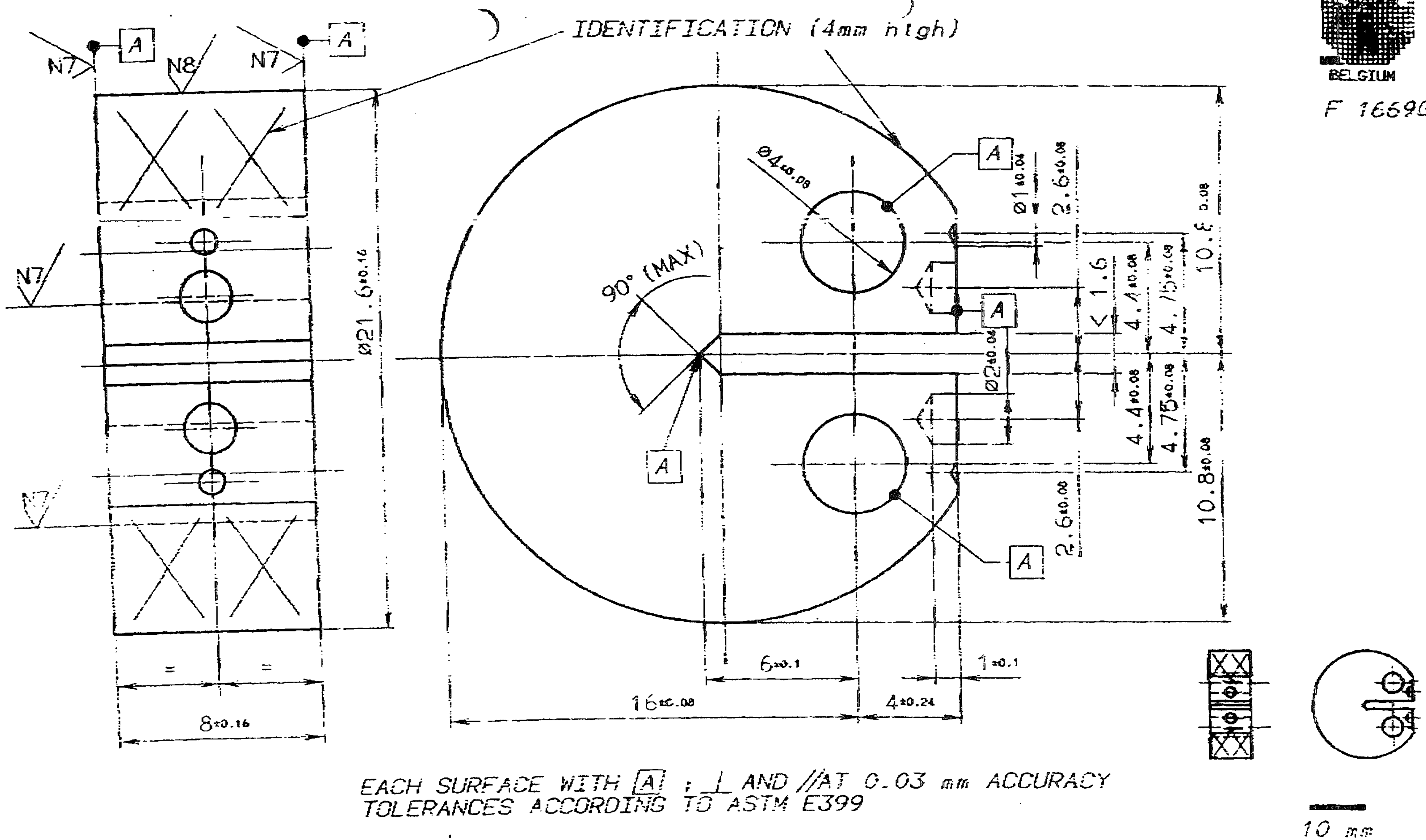


FIG.1 BERYLLIUM TENSILE SPECIMEN

BELGIUM
F 1669G



EACH SURFACE WITH [A] ; ⊥ AND // AT 0.03 mm ACCURACY
TOLERANCES ACCORDING TO ASTM E399

FIG.2 BERYLLIUM COMPACT TENSION SPECIMEN

Annex A

Preparatory Meetings / Discussions

Number	Date	Location	Notes Issued*
1	06:12:89	Brush Wellman Ltd., Reading, U.K.	December 1989
2	24:04:90	.. ..	April 1990
3	14:05:90	Kernforschungszentrum Karlsruhe, Germany	May 1990
4	25:05:90	Brush Wellman Ltd., Reading, U.K.	May 1990
5	13:12:90	The NET Team, Garching, Germany	December 1990
6	14:03:91	Kernforschungszentrum Karlsruhe, Germany	April 1991
7	27:03:91	SCK/CEN, Mol, Belgium	April 1991
8	23:04:91	SBBEG, ENEA, Frascati, Italy	May 1991
9	10:09:91	SCK/CEN, Mol, Belgium	September 1991
10	09:10:91	Kernforschungszentrum Karlsruhe, Germany	October 1991
11	22:10:91	Telephone Link with Dr J.M. Marder, Brush Wellman Engineered Materials, U.S.A.	October 1991
12	20:11:91	Clearwater, Florida, U.S.A.	November 1991
13	05:12:91	Kernforschungszentrum Karlsruhe, Germany	January 1992

* The Notes of the Meetings are archived at the Forschungszentrum Karlsruhe.

Annex B

Technical Specification of a Programme on the Irradiation - Induced Embrittlement of Beryllium

1. Background

Beryllium will be required as a neutron multiplier in the solid ceramic tritium breeding blanket designs being developed for a DEMO fusion power reactor if a breeding ratio in excess of unity is to be attained [B1][B2]. During service, the beryllium will be exposed to energetic neutron bombardment resulting in the production of displacement damage ($\geq$ 70 dpa) and the formation of helium (~ 1.6 x 10^4 appm) and tritium (~ 200 appm) by (n,2n) and secondary reactions respectively at temperatures up to about 600 C.

In addition to being compatible with the breeding and structural materials in the blanket sectors, the beryllium will also have to be dimensionally stable (that is, resistant to irradiation - induced helium gas driven and, possibly, void swelling), to retain the required degree of mechanical integrity and not suffer significant reduction in its initially high thermal conductivity under the stresses imposed during normal operation and transients if the target fluence is to be achieved in DEMO. Furthermore, cracking may occur if the embrittlement induced by irradiation is excessive, producing a dramatic decrease in the thermal conductivity and resulting in enhanced helium gas swelling and, possibly, disintegration of the material.

A fairly extensive data base on the irradiation - induced swelling and embrittlement of beryllium was generated during the 1950s and subsequent years; the data were obtained in programmes carried out in support of its use as a reflector and moderator in material test reactors operating at temperatures of around 100 C and to evaluate its potential for application as fuel element cladding in high temperature gas cooled nuclear power reactors. Most of the experiments were made on hot pressed blocks of relatively impure beryllium which had low ductility and anisotropic properties; furthermore, the data were mainly obtained following irradiation at reactor ambient temperature and annealing or testing at higher temperatures and showed variable and extensive embrittlement and swelling.

In the interim, significant improvements in the ductility and isotropy of beryllium have been made as a result of the development of new powder production and consolidation processes and metal refining techniques. It is essential to determine the pre- and post-irradiation properties and behaviour of the various grades of beryllium now produced so as to isolate the effects of the BeO content and other impurities, porosity, degree of anisotropy and processing parameters on the embrittlement and thereby enable the choice of beryllium grade for the DEMO breeding blanket sectors to be optimised. In addition, it is necessary to perform the irradiations and tests at high temperatures as the dimensional stability, mechanical properties and fracture behaviour are likely to be significantly different to those produced by annealing or testing at higher temperatures after exposure at (lower) reactor ambient temperatures.

Studies of the swelling of beryllium following irradiation in the SILOE and PHENIX reactors have been implemented or are planned. This task description provides the technical specification for a programme aimed primarily at investigating the high temperature irradiation - induced embrittlement of various grades of beryllium currently produced and marketed.

References

B1. M. Dalle Donne et al, J. Nucl. Mater., 212 - 215 (1994) 69.
B2. M. Dalle Donne et al, "European DEMO BOT Solid Breeder Blanket", KfK Report 5429, November 1994.

2. Irradiation Embrittlement / Test Programme Specification

The investigation of the irradiation hardening and embrittlement of beryllium will cover the items and conditions listed in Table B1.

Table B1

Proposed Material, Irradiation and Test Programme Specification

Materials	Brush Wellman Structural Grades: S-65 (BeO = 0.7% max.) S-200-F (BeO = 1.5% max.)
Powder Production	Impact grinding.
Powder Consolidation	(i) Axial vacuum hot pressing (VHP). (ii) Direct hot isostatic pressing (HIP).
Irradiation	In a mixed spectrum MTR at temperatures of 200, 400 and 600 C to a target neutron fluence of 1.5 x 10 n. m (> 1 MeV).
Testing	Pre - irradiation, thermal control and post - irradiation immersion density at ambient temperature, tensile and fracture toughness tests at the irradiation and "stand-by" (coolant) temperatures; helium and tritium analyses of irradiated samples.
Examinations	Optical and electron microscopy (SEM and TEM) of the initial and post - test structures, deformation and fracture characteristics of the unirradiated, thermal control and irradiated samples.

3. Specimens

The numbers of tensile, fracture toughness (compact tension) and electron microscope (TEM) disc specimens of each grade of beryllium required for the unirradiated, thermal control and irradiated tests are given in Table B2.

Table B2

Numbers of Specimens

Specimens		S-200-F. VHP	S-200-FH. HIP	S-65. VHP	S-65-H. HIP
Tensile	Unirradiated	8	8	8	8
	Thermal Control	12	12	12	12
	Irradiation	12	12	12	12
	Spares	8	8	8	8
		--	--	--	--
	Total	40	40	40	40
Fracture Toughness	Unirradiated	8	8	8	8
	Thermal Control	12	12	12	12
	Irradiated	12	12	12	12
	Spares	8	8	8	8
		--	--	--	--
	Total	40	40	40	40
TEM	Unirradiated	4	4	4	4
	Thermal Control	6	6	6	6
	Irradiated	6	6	6	6
		--	--	--	--
	Total	16	16	16	16

Annex C

Brush Wellman Material Test Certificates

BRUSH WELLMAN

ENGINEERED MATERIALS

MATERIAL CERTIFICATION

Customer: Kernforschungszentrum, Karlsruhe GMBH
Postfach 3640
W-7500 Karlsruhe 1
Germany

Date: October 30, 1992
S.O.#: EMC958
P.O.#: 722/03755800/0104
Specification: S-200-F Rev. A, Type I

Material Description:

Item 1 - Lot No. 4787, Sixteen (16) pcs. Beryllium Rod, .118 ±.001" dia. x .0059 +.0011" long, S/N 00-09, R0-R5.
Item 5 - Lot No. 4787, Two (2) pcs. Beryllium Rod .222" dia. x 5.512" long, S/N PR0, PR1.

QUALITY ASSURED PRODUCT

CHEMICAL COMPOSITION: (WT. %)

Element	4787			
Be	98.9			
BeO	1.2			
Fe	.10			
C	.12			
Al	.05			
Mg	.02			
Si	.03			
Batch No.				
(Metallic) Other Elem. ea.	<.04			
Others Total				

MECHANICAL PROPERTIES

DIR.	FTU (Ksi)	FTY (Ksi)	% EL	
Long.	54.7	37.4	2.1	
Trans.	59.1	37.5	4.4	

DENSITY gm/cc: 99.9% Theoretical

AVG GRAIN SIZE: (Microns) 8.2

RADIOGRAPHIC INSP. PER MIL-STD-453

PENETRANT INSP. PER MIL-STD-6866

ADDITIONAL INFORMATION:

X-ray No. H-5710, H-5716.

This is to certify that the above material satisfies the requirements of Specification see above
Drawing see above Purchase Order see above and was removed from Pressing No. 4787

R P Garner

BRUSH WELLMAN INC.
QUALITY CONTROL
R. P. Garner

W-115 1/91

cc:
Shipping (3) Sales (1) File (1)

BRUSH WELLMAN
ENGINEERED MATERIALS

MATERIAL CERTIFICATION

Customer: Kernforschungszentrum, Karlsruhe GMBH
Postfach 3640
W-7500 Karlsruhe 1
Germany

Date: October 30, 1992
S.O.#: EMC957
P.O.#: 722/03755800/0104
Specification: S-200-F Rev. A, Type I.

Material Description:

Item 1 - Lot No. 4787, Forty (40) pcs. Beryllium Finish-Machined Blank per drawing F1670B, S/N 00-09, R0-R9, S0-S9, T0-T9.
Item 5 - Lot No. 4787, Forty (40) pcs. Beryllium Finish-Machined Blank per drawing F1669F, S/N 00-09, R0-R9, S0-S9, T0-T9.

QUALITY ASSURED PRODUCT

CHEMICAL COMPOSITION: (WT. %)

Element	4787			
Be	98.9			
BeO	1.2			
Fe	.10			
C	.12			
Al	.05			
Mg	.02			
Si	.03			
Batch No.				
(Metallic) Other Elem. ea.	<.04			
Others Total				

MECHANICAL PROPERTIES

DIR.	FTU (Ksi)	FTY (Ksi)	% EL	
Long.	54.7	37.9	2.1	
Trans.	59.1	37.5	4.4	

DENSITY g/cc: 99.9% Theoretical

AVG GRAIN SIZE (Microns): 8.2

RADIOGRAPHIC INSP PER: MIL-STD-453

PENETRANT INSP. PER: MIL-STD-6866

ADDITIONAL INFORMATION:

X-ray No. H-5897, H-5900, H-5720.

This is to certify that the above material satisfies the requirements of Specification see above
Drawing see above Purchase Order see above and was removed from Pressing No. 4787

BRUSH WELLMAN INC.
QUALITY CONTROL
R. P. Garner

BW—115 1/91

cc:
Shipping (3) Sales (1) File (1)

BRUSHWELLMAN

ENGINEERED MATERIALS

MATERIAL CERTIFICATION

Customer: Kernforschungszentrum, Karlsruhe GMBH
Postfach 3640, W-7500 Karlsruhe 1
Germany

Date: October 30, 1992
S.O.#: EHC958
P.O.#: 722/03755800/0104
Specification: S-200-F H
Rev. B, Type I.

Material Description:
Item 2 - Lot No. H0685, Sixteen (16) pcs. Beryllium Hot Isostatic Pressed Rod, .118 ±.001" dia. x .0059 +.0011" long, S/N U0-U9, W0-W5.
Item 6 - Lot No. H0685, Two (2) pcs. Beryllium Hot Isostatic Pressed Rod .222" dia. x 5.512" long, S/N PR0, PR1.

CHEMICAL COMPOSITION: (WT. %)

Element	H0685			
Be	99.1			
BeO	.9			
Fe	.10			
C	.08			
Al	.04			
Mg	.02			
Si	.03			
Batch No.				
(Metallic) Other Elem. ea.	<.04			
Others Total				

MECHANICAL PROPERTIES

DIR.	FTU (Ksi)	FTY (Ksi)	% EL		
Z	64.0	51.0	5.0		

DENSITY g/cc: 99.9% Theoretical

AVG GRAIN SIZE: (Microns) 7.1

RADIOGRAPHIC INSP. PER MIL-STD-453

PENETRANT INSP. PER MIL-STD-6866

ADDITIONAL INFORMATION:
X-ray No. H-5704, H-5709.

QUALITY ASSURED PRODUCT

This is to certify that the above material satisfies the requirements of Specification see above,
Drawing see above Purchase Order see above and was removed from Pressing No. H0685.

R P Garner

BRUSH WELLMAN INC. R. P. Garner
QUALITY CONTROL

IW—115 1/91

cc:
Shipping (3) Sales (1) File (1)

NOV-09-1992 11:55 FROM BRUSH WELLMAN INC. TO Pat Murphy P.09

BRUSH WELLMAN

ENGINEERED MATERIALS

MATERIAL CERTIFICATION

Customer: Kernforschungszentrum, Karlsruhe GMBH
Postfach 3640, W-7500 Karlsruhe 1
Germany

Date: October 30, 1992
S.O.#: EHC957
P.O.#: 722/03755800/0104
Specification: S-200-F H Rev. B, Type I.

Material Description:
Item 2 - Lot No. H0685, Forty (40) pcs. Beryllium HIP'D Finish Machined Blank, per drawing F16708, S/N Z0-Z9, Y0-Y9, W0-W9, U0-U9.
Item 6 - Lot No. H0685, Forty (40) pcs. Beryllium HIP'D Finish Machined Blank per drawing F1669F, S/N U0-U9, W0-W9, Y0-Y9, Z0-Z9.

QUALITY ASSURED PRODUCT

CHEMICAL COMPOSITION: (WT. %)

Element	H0685			
Be	99.1			
BeO	.9			
Fe	.10			
C	.08			
Al	.04			
Mg	.02			
Si	.03			
Batch No.				
(Metallic) Other Elem. ea.	<.04			
Others Total				

MECHANICAL PROPERTIES

DIR.	FTU (Ksi)	FTY (Ksi)	% EL		
Z	64.0	51.0	5.0		

DENSITY g/cc: 99.9% Theoretical

AVG GRAIN SIZE: (Microns) 7.1

RADIOGRAPHIC INSP. PER MIL-STD-453

PENETRANT INSP. PER MIL-STD-6866

ADDITIONAL INFORMATION:

X-ray No. H-5898, H-5707, H-5942.

This is to certify that the above material satisfies the requirements of Specification see above.
Drawing see above Purchase Order see above and was removed from Pressing No. H0685.

R. P. Garner
BRUSH WELLMAN INC.
QUALITY CONTROL

IW-115 1/91

cc:
Shipping
File (1)

BRUSH WELLMAN
ENGINEERED MATERIALS

MATERIAL CERTIFICATION

Customer: Kernforschungszentrum, Karlsruhe GMBH
Postfach 3640
W-7500 Karlsruhe
Germany

Date: October 30, 1992
S.O.#: EMC958
P.O.#: 722/03755800/0104
Specification: S-65 Rev. C.

Material Description:
Item 3 - Lot No. 4784, Sixteen (16) pcs. Beryllium Rod .118 ±.001" dia. x .0059 +.0011" long, S/N A0-A9, 80-85.
Item 7 - Lot No. 4784, Two (2) pcs. Beryllium Rod .222" dia. x 5.512" long, S/N PR0, PR1.

CHEMICAL COMPOSITION: (WT. %)

Element	4784			
Be	99.4			
BeO	.5			
Fe	.06			
C	.03			
Al	.02			
Mg	<.01			
Si	.03			
Batch No.				
(Metallic) Other Elem. ea.	<.04			
Others Total				

MECHANICAL PROPERTIES

DIR.	FTU (Ksi)	FTY (Ksi)	% EL		
Long.	54.7	35.1	3.7		
Trans.	57.8	35	5.9		

DENSITY g/cc: 99.9% Theoretical

AVG GRAIN SIZE: (Microns) 8.4

RADIOGRAPHIC INSP. PER MIL-STD-453

PENETRANT INSP. PER MIL-STD-6866

ADDITIONAL INFORMATION:
X-ray No. H-5699, H-5711.

QUALITY APPROVED PRODUCT

This is to certify that the above material satisfies the requirements of Specification see above
Drawing see above Purchase Order see above and was removed from Pressing No. 4784.

R.F. Garner
BRUSH WELLMAN INC.
QUALITY CONTROL

BW—115 1/91

cc:
Shipping (3) Sales (1) File (1)

BRUSH WELLMAN

ENGINEERED MATERIALS

MATERIAL CERTIFICATION

Customer: Kernforschungszentrum, Karlsruhe GMBH
Postfach 3640
W-7500 Karlsruhe
Germany

Date: October 30, 1992
S.O.#: EMC957
P.O.#: 722/03755800/0104
Specification: S-65 Rev. C.

Material Description:
Item 3 - Lot No. 4784, Forty (40) pcs. Beryllium Finish-Machined Blank per drawing F1670B, S/N H0-H9, E0-E9, B0-B9, A0-A9.
Item 7 - Lot No. 4784, Forty (40) pcs. Beryllium Finish-Machined Blank per drawing F1669F, S/N A0-A9, B0-B9, E0-E9, H0-H9.

CHEMICAL COMPOSITION: (WT. %)

Element	4784			
Be	99.4			
BeO	.6			
Fe	.06			
C	.03			
Al	.02			
Mg	<.01			
Si	.03			
Batch No.				
(Metallic) Other Elem. ea.	<.04			
Others Total				

MECHANICAL PROPERTIES

DIR.	FTU (Ksi)	FTY (Ksi)	% EL		
Long.	54.7	35.1	3.7		
Trans.	57.8	35.	5.9		

DENSITY g/cc: 99.9% Theoretical

AVG GRAIN SIZE: (Microns) 8.4

RADIOGRAPHIC INSP. PER MIL-STD-453

PENETRANT INSP. PER MIL-STD-6866

ADDITIONAL INFORMATION:
X-ray No. H-5901, H-5923, H-5687.

This is to certify that the above material satisfies the requirements of Specification see above 4784 . Drawing see above Purchase Order see above and was removed from Pressing No. ______.

R.P. Garner

BRUSH WELLMAN INC.
QUALITY CONTROL

BW—115 1/91

cc:
Shipping (3) Sales (1) File (1)

BRUSH WELLMAN
ENGINEERED MATERIALS

MATERIAL CERTIFICATION

Customer: Kernforschungszentrum, Karlsruhe GMBH
Postfach 3640
W-7500 Karlsruhe 1
Germany

Date: October 30, 1992
S.O.#: EMC958
P.O.#: 722/03755800/0104
Specification: S-65, Rev. C
(S-65-H material)

Material Description:
Item 4 - Lot No. H0349, Sixteen (16) pcs. Beryllium Hot Isostatic Pressed Rod .118 ±.001" dia. x .0059 +.0011" long, S/N I0-I9, K0-K5.
Item 6 - Lot No. H0349, Two (20) pcs. Beryllium Hot Isostatic Pressed Rod, .222" dia. x 5.512" long, S/N PR0, PR1.

CHEMICAL COMPOSITION: (WT. %)				
Element	H0349			
Be	99.5			
BeO	.5			
Fe	.06			
C	.03			
Al	.02			
Mg	<.01			
Si	.02			
Batch No.				
(Metallic) Other Elem. ea.	<.04			
Others Total				

MECHANICAL PROPERTIES					
DIR.	FTU (Ksi)	FTY (Ksi)	% EL		
X	73.9	4[illegible].6	4.8		
Z	71.4	49.8	3.6		

DENSITY gm/cc: 99.8% Theoretical

AVG GRAIN SIZE: (Microns) 6.6

RADIOGRAPHIC INSP. PER MIL-STD-453

PENETRANT INSP. PER MIL-STD-6866

ADDITIONAL INFORMATION:
X-ray No. H-5708, H-5705.

QUALITY ASSURED PRODUCT

This is to certify that the above material satisfies the requirements of Specification see above
Drawing see above Purchase Order see above and was removed from Pressing No. H0349.

BRUSH WELLMAN INC.
QUALITY CONTROL
R. P. Garner

IW-115 1/91

cc:
Shipping (3) Sales (1) File (1)

BRUSH WELLMAN
ENGINEERED MATERIALS

MATERIAL CERTIFICATION

Customer: *Kernforschungszentrum, Karlsruhe GMBH
Postfach 3640
W-7500 Karlsruhe 1
Germany

Date: October 30, 1992
S.O.#: EMC957
P.O.#: 722/03755800/0104
Specification: S-65, Rev. C
(S-65-H material)

Material Description:
Item 4 - Lot No. H0349, Forty (40) pcs. Beryllium HIP'D Finished Machined Blank, per drawing F1670B, S/N I0-I9, K0-K9, L0-L9, M0-M9.
Item 8 - Lot No. H0349, Forty (40) pcs. Beryllium HIP'D Finished Machined Blank, per drawing F1669F, S/N I0-I9, K0-K9, L0-L9, M0-M9.

QUALITY ASSURED PRODUCT

CHEMICAL COMPOSITION: (WT. %)				
Element	H0349			
Be	99.5			
BeO	.5			
Fe	.06			
C	.03			
Al	.02			
Mg	<.01			
Si	.02			
Batch No.				
(Metallic) Other Elem. ea.	<.04			
Others Total				

MECHANICAL PROPERTIES			
DIR.	FTU (Ksi)	FTY (Ksi)	% EL
X	73.9	[illegible]	4.8
Z	71.4	[illegible]	3.6

DENSITY: [illegible] Theoretical	AVG GRAIN SIZE: (Microns) 6.6
RADIOGRAPHIC INSP. PER MIL-STD-453	PENETRANT INSP. PER MIL-STD-6866

ADDITIONAL INFORMATION:
X-ray No. M-5882, M-5909, M-5712.

This is to certify that the above material satisfies the requirements of Specification see above
Drawing see above Purchase Order see above and was removed from Pressing No. H0349

BRUSH WELLMAN INC. R. P. Garner
QUALITY CONTROL

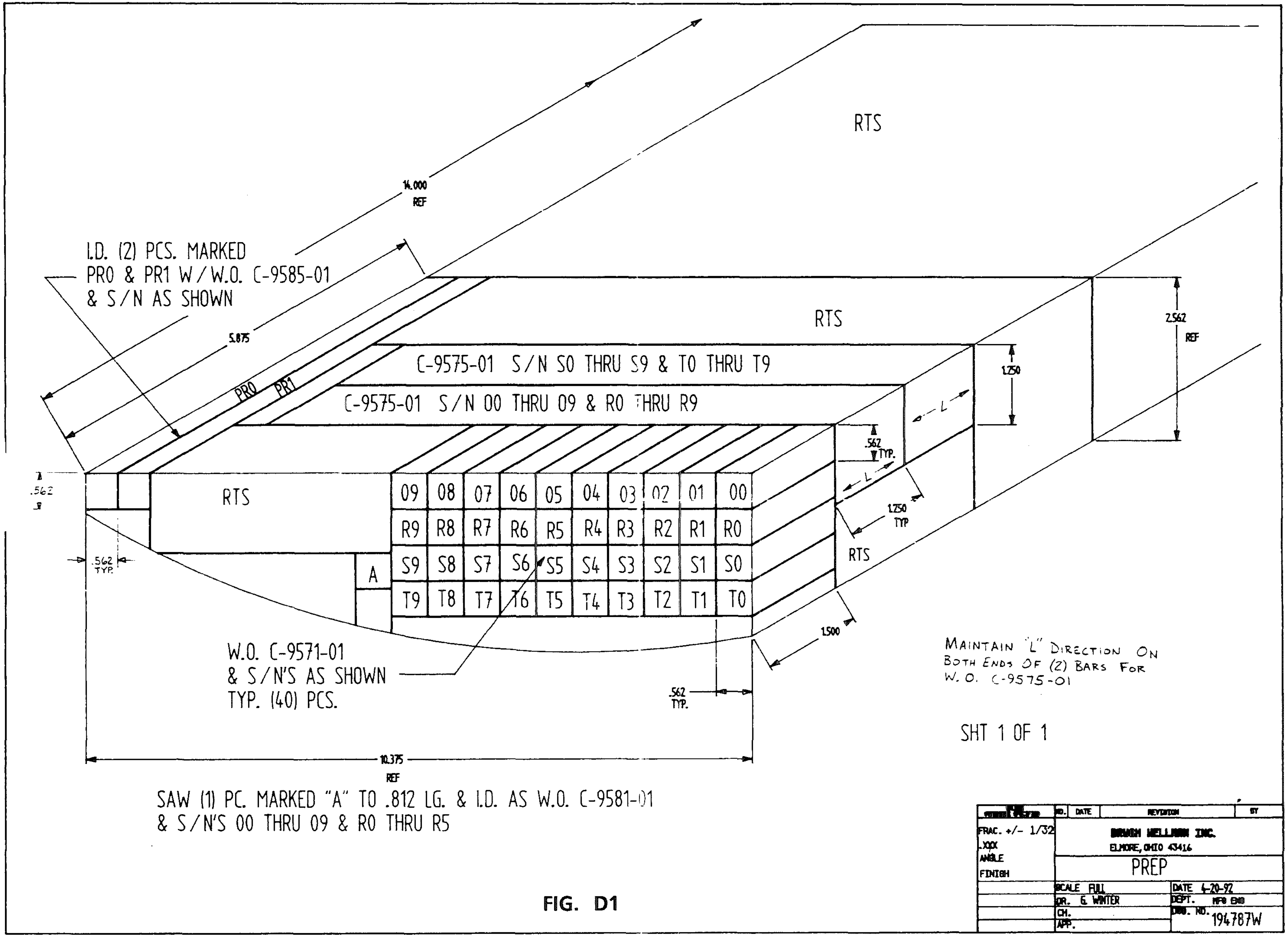
BW-115 1/91

cc:
Shipping (3) Sales (1) File (1)

Annex D

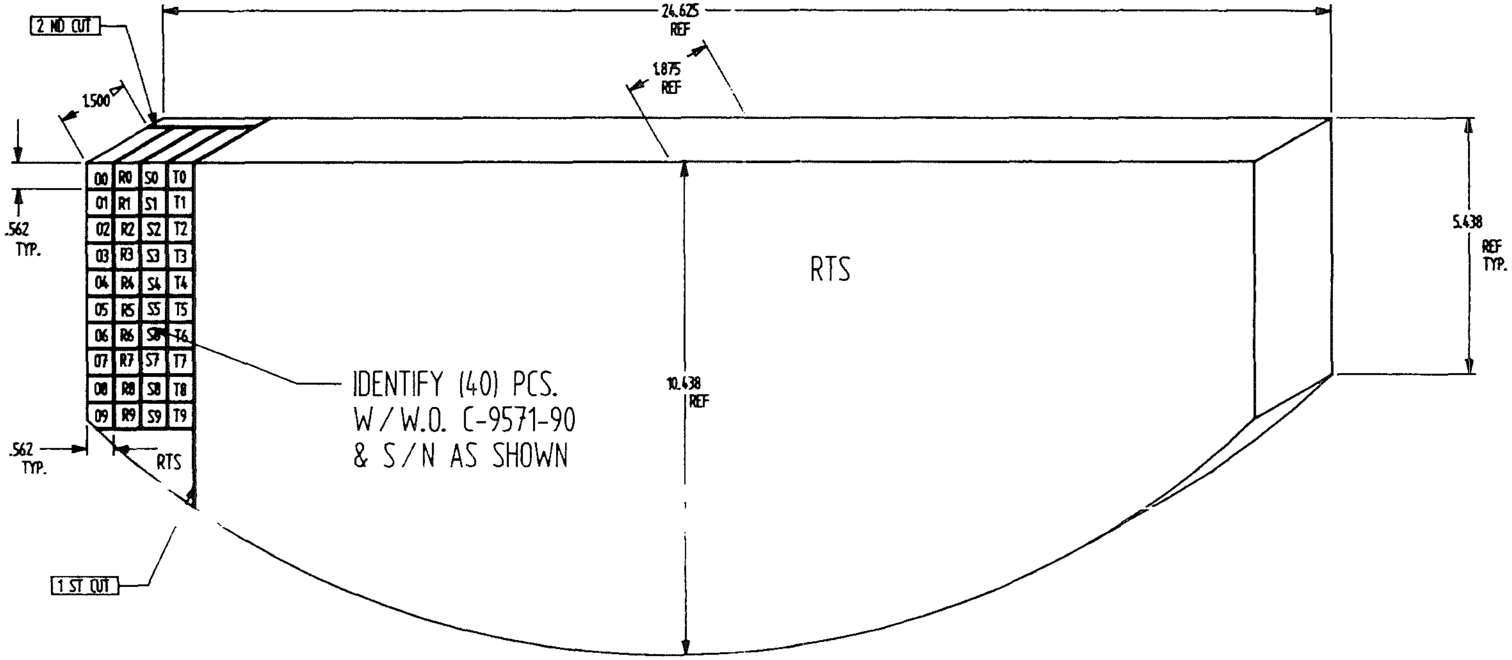
Layout of Machined Specimen Blanks in S-200-F VHP Billet - Lot No. 4787

Fig. No.	Brush Wellman Drawing No.	Date	Brush Wellman Ref. No.	Item	Specimens and Identification	Comments
D1	194787W	20:04:92	EMC 958	1	EM Discs (A) O0-O9; R0-R5	
				5	PR0; PR1	
			EMC 957	1	Tensile O0-O9; R0-R9; S0-S9; T0-T9	Discarded
				5	C-T O0-O9; R0-R9; S0-S9; T0-T9	
D2	194787A	06:07:92	EMC 957	1	Tensile O0-O9; R0-R9; S0-S9; T0-T9	Replacements



RTS
14.000 REF
I.D. (2) PCS. MARKED PR0 & PR1 W/W.O. C-9585-01 & S/N AS SHOWN
5.875
PR0
PR1
RTS
C-9575-01 S/N S0 THRU S9 & T0 THRU T9
C-9575-01 S/N 00 THRU 09 & R0 THRU R9
2.562 REF
1.250
.562 TYP.
.562
RTS
09 08 07 06 05 04 03 02 01 00
R9 R8 R7 R6 R5 R4 R3 R2 R1 R0
S9 S8 S7 S6 S5 S4 S3 S2 S1 S0
T9 T8 T7 T6 T5 T4 T3 T2 T1 T0
A
.562 TYP.
1.250 TYP
RTS
1.500
W.O. C-9571-01 & S/N'S AS SHOWN TYP. (40) PCS.
.562 TYP.
MAINTAIN "L" DIRECTION ON BOTH ENDS OF (2) BARS FOR W.O. C-9575-01
SHT 1 OF 1
10.375 REF
SAW (1) PC. MARKED "A" TO .812 LG. & I.D. AS W.O. C-9581-01 & S/N'S 00 THRU 09 & R0 THRU R5
FRAC. +/- 1/32
ELMORE, OHIO 43416
PREP
SCALE FULL
DR. G. WINTER
194787W

FIG. D1



SHT 1 OF 1

FRAC. +/- 1/32
.XXX +/- .030
ANGLE +/- 0-30'
FINISH

NO. | DATE | REVISION | BY

BRUSH WELLMAN INC.
ELMORE, OHIO 43416

PREP

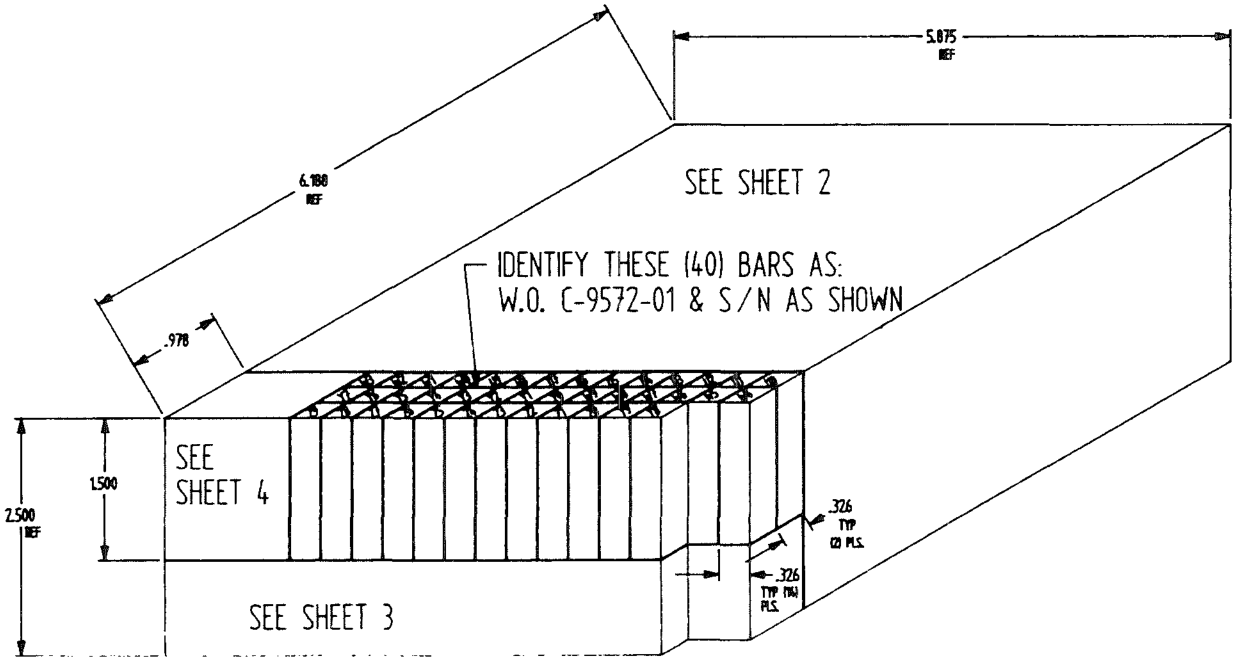
SCALE .5 | DATE 7-6-92
DR. G. WINTER | DEPT. MFG ENG
CH. | DWG. NO. 194787A
APP.

FIG. D2

Annex E

Layout of Machined Specimen Blanks in S-200-FH HIP Billet - Lot No. H0685

Fig. No.	Brush Wellman Drawing No.	Date	Brush Wellman Ref. No.	Item	Specimens and Identification	Comments
E1	19H06856(1/4)	16:04:92	EMC 957	2	Tensile U0-U9;W0-W9; Y0-Y9; Z0-Z9	Discarded
	19H06856(2/4)	16:04:92	EMC 957	6	C-T U0-U9;W0-W9; Y0-Y9; Z0-Z9	
	19H06856(3/4)	16:04:92	EMC 958	6	PR0; PR1	
	19H06856(4/4)	16:04:92	EMC 958	2	EM Discs (A) U0-U9; W0-W5	
			EMC 959-001		C-T SN-1; SN-2	Preliminary Fracture Toughness Tests
E2	19H06857	15:05:92	EMC 957	2	Tensile U9; Y3, Y5, Y6, Y9	Discarded
E3	19H06858	20:05:92	EMC 957	2	Tensile Y5	Discarded
E4	19H06859	06:07:92	EMC 957	2	Tensile U0-U9;W0-W9; Y0-Y9; Z0-Z9	Replacements
E5	19H0685A	01:10:92	EMC 957	6	C-T	Partial Replacements



SHT 1 OF 4

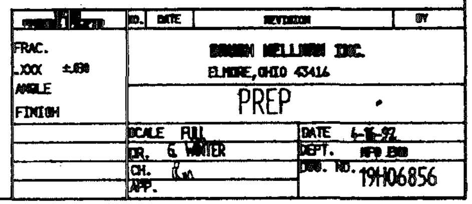
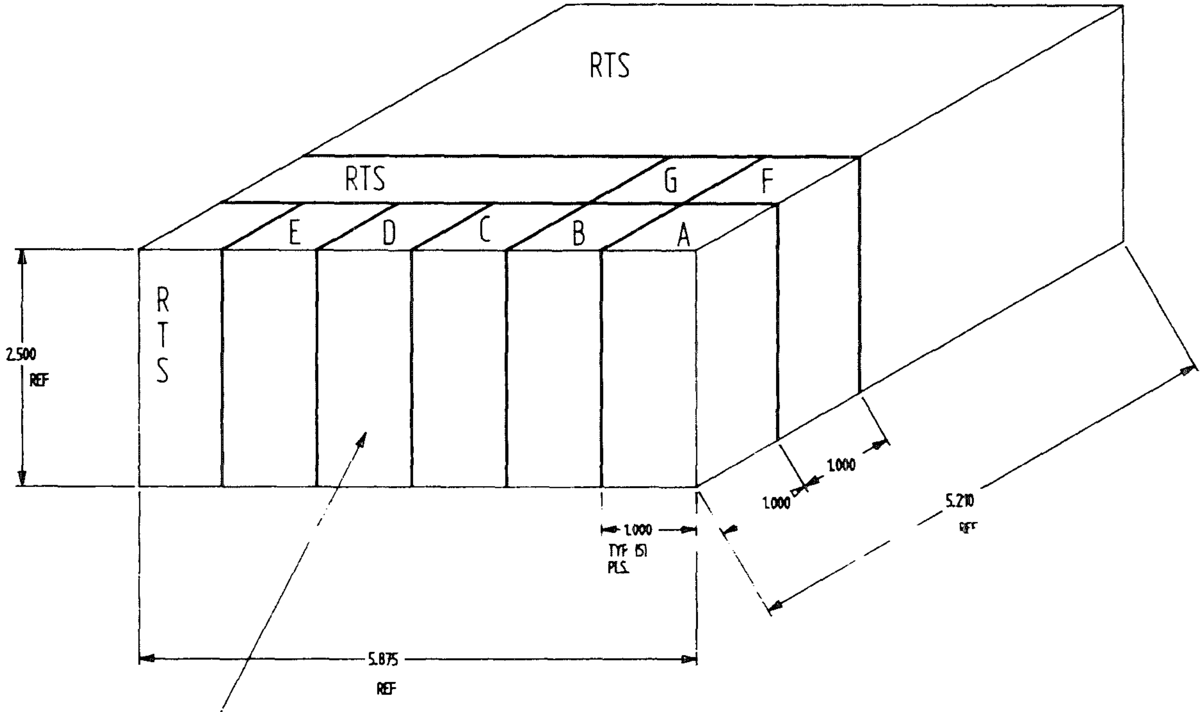


FIG. E1 (i)

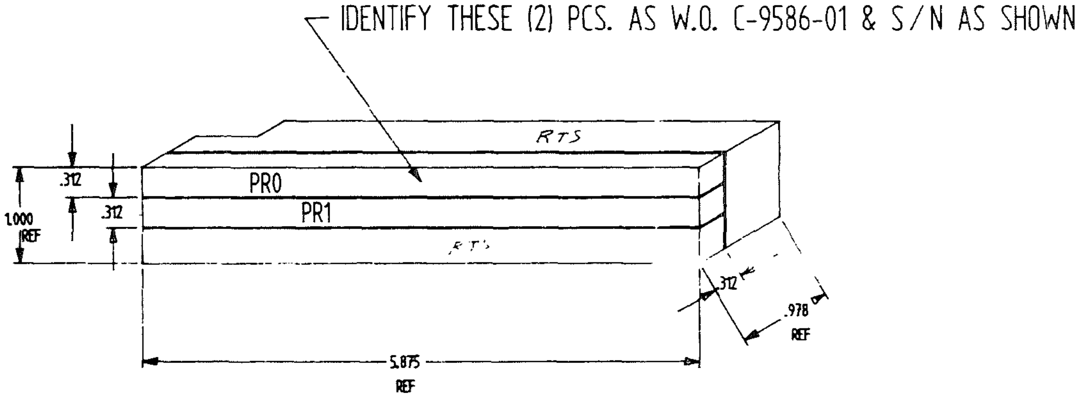


IDENTIFY THESE (7) PCS. AS W.O. C-9576-01 &
A= U0 THRU U5
B= U6 THRU U9 & W0 & W1
C= W2 THRU W7
D= W8 & W9 & Y0 THRU Y3
E= Y4 THRU Y9
F= Z0 THRU Z5
G= Z6 THRU Z9

SHT 2 OF 4

	NO.	DATE	REVISION	BY
FRAC. .XXX ±.030 ANGLE FINISH	ELMORE, OHIO 43416 PREP			
	SCALE FULL		DATE 6-16-92	
	DR. G. WINTER		DEPT. MFG ENG	
	CH. fm		DWG. NO. 19H06856	
	APP.			

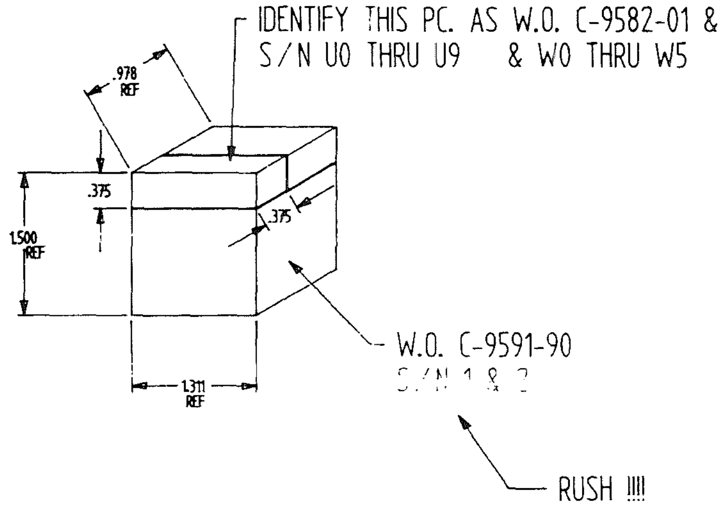
FIG. E1 (ii)



SHT 3 OF 4

	NO.	DATE	REVISION	BY
FRAC. .XXX ±.030 ANGLE FINISH	BRUSH WELLMAN INC. ELMORE, OHIO 43416			
	PREP			
	SCALE FULL		DATE 4-16-92	
	DR. G. WINTER		DEPT. MFG ENG	
	CH.		DWG. NO. 19H06856	
	APP.			

FIG. E1 (iii)



SHT 4 OF 4

A	4-27-92	ADD W.O. C-9591-90	GW
NO.	DATE	REVISION	BY

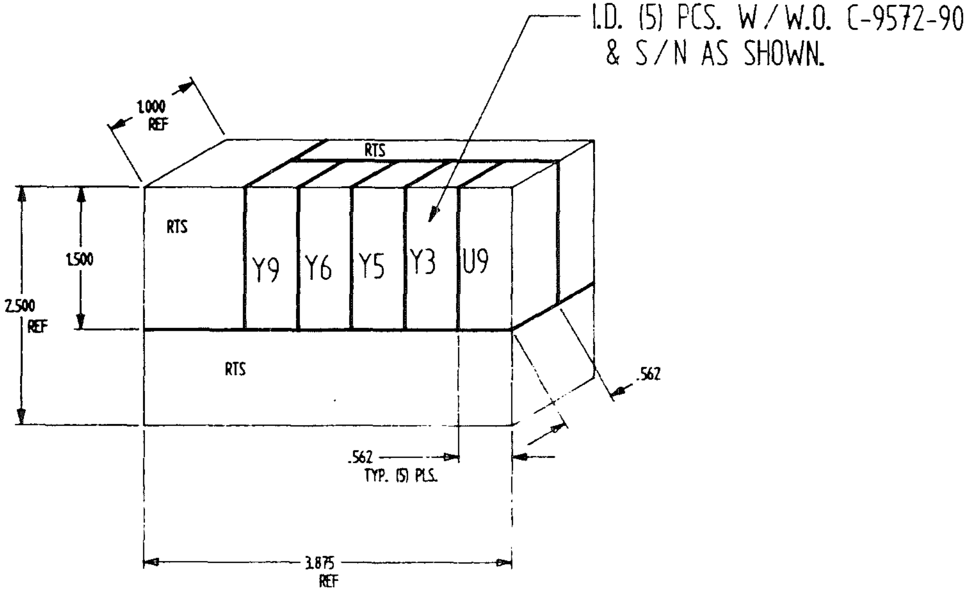
FRAC.
.XXX ±.030
ANGLE
FINISH

BRUSH WELLMAN INC.
ELMORE, OHIO 43416

PREP

SCALE FULL	DATE 4-16-92
DR. G. WINTER	DEPT. MFG ENG
CH.	DWG. NO. 19H06856
APP.	

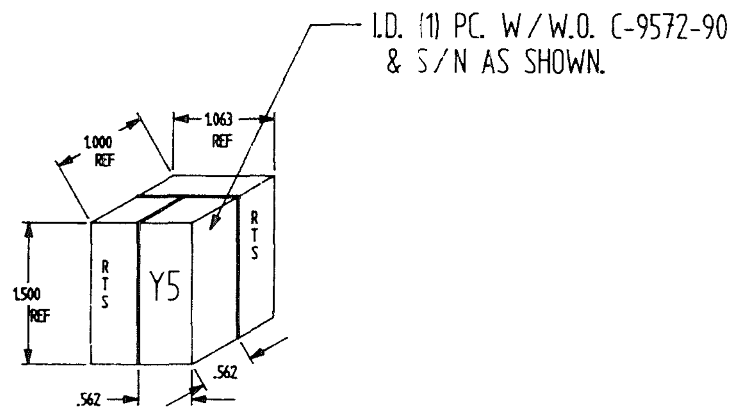
FIG. E1 (iv)



SHT 1 OF 1

	NO.	DATE	REVISION	BY
FRAC. .XXX ±.030 ANGLE FINISH	BRUSH WELLMAN INC. ELMORE, OHIO 43416 PREP			
	SCALE FULL		DATE 5-15-92	
	DR. G. WINTER		DEPT. MFG ENG	
	CH.		DWG. NO. 19H06857	
	APP.			

FIG. E2



SHT 1 OF 1

FIG. E3

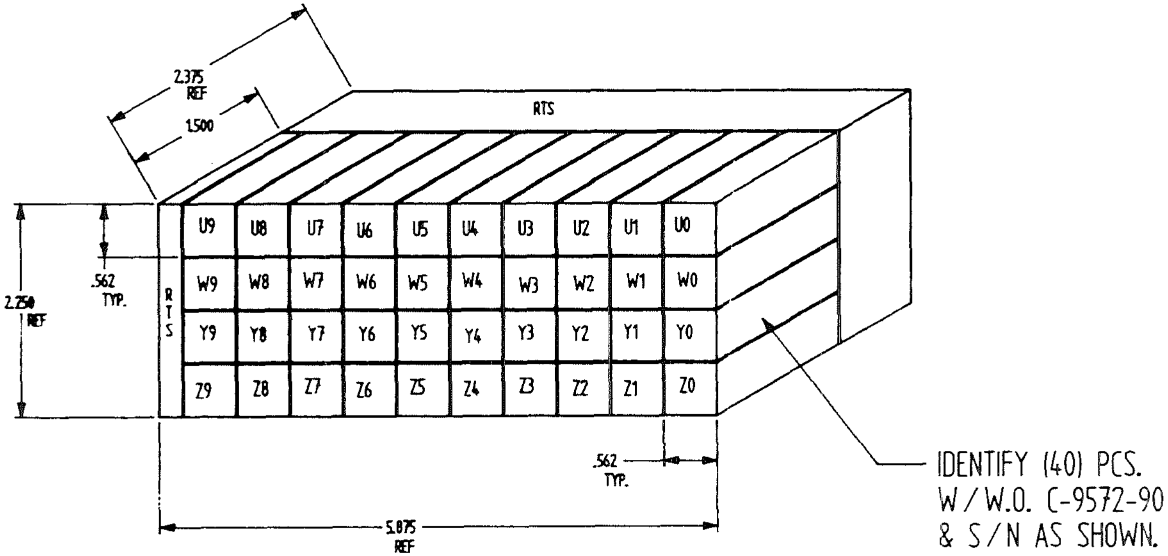
FRAC.
.XXX ±.030
ANGLE
FINISH

NO. DATE REVISION BY

BRUSH WELLMAN INC.
ELMORE, OHIO 43416

PREP

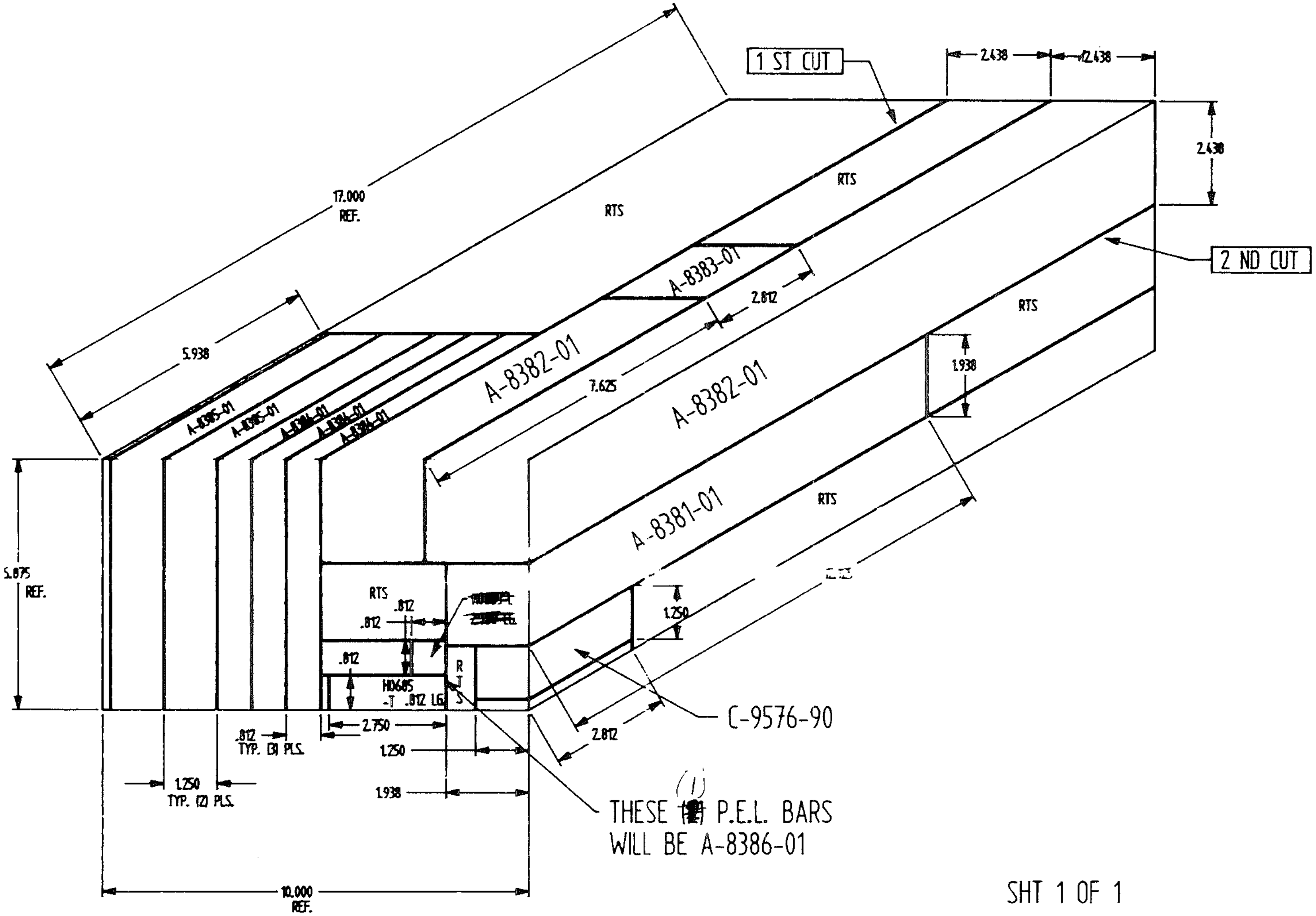
SCALE FULL
DR. G. WINTER
CH.
APP.
DATE 5-20-92
DEPT. MFG ENG
DWG. NO. 19H06858



SHT 1 OF 1

FIG. E4

	NO.	DATE	REVISION	BY
FRAC. +/- 1/32 .XXX +/- .030 ANGLE +/- 0-30' FINISH	BRUSH WELLMAN INC. ELMORE, OHIO 43416			
	PREP			
	SCALE FULL		DATE 7-6-92	
	DR. G. WINTER		DEPT. MFG ENG	
	CH.		DWG. NO. 19H06859	
	APP.			



SHT 1 OF 1

FRAC. +/- 1/32 .XXX +/- .030 ANGLE +/- 0-30' FINISH	BRUSH WELLMAN INC. ELMORE, OHIO 43416		
	PREP		
	SCALE .5	DATE 10-1-92	
	DR. G. WINTER	DEPT. MFG ENG	
	CH.	DWG. NO. 19H0685A	
	APP.		

FIG. E5

Annex F

Layout of Machined Specimen Blanks in S-65 VHP Billet - Lot No. 4784

Fig. No.	Brush Wellman Drawing No.	Date	Brush Wellman Ref. No.	Item	Specimens and Identification	Comments
F1	1947842	22:04:92	EMC 958	3	EM Discs (A) A0-A9; B0-B5	
				7	PR0; PR1	
			EMC 957	3	Tensile A0-A9; B0-B9; E0-E9; H0-H9	Discarded
				7	C-T A0-A9; B0-B9; E0-E9; H0-H9	
F2	1947848	06:07:92	EMC 957	3	Tensile A0-A9; B0-B9; E0-E9; H0-H9	Replacements. E6 and H8 Discarded
F3	194784C	24:09:92	EMC 957	3	Tensile E6;H8	Replacements

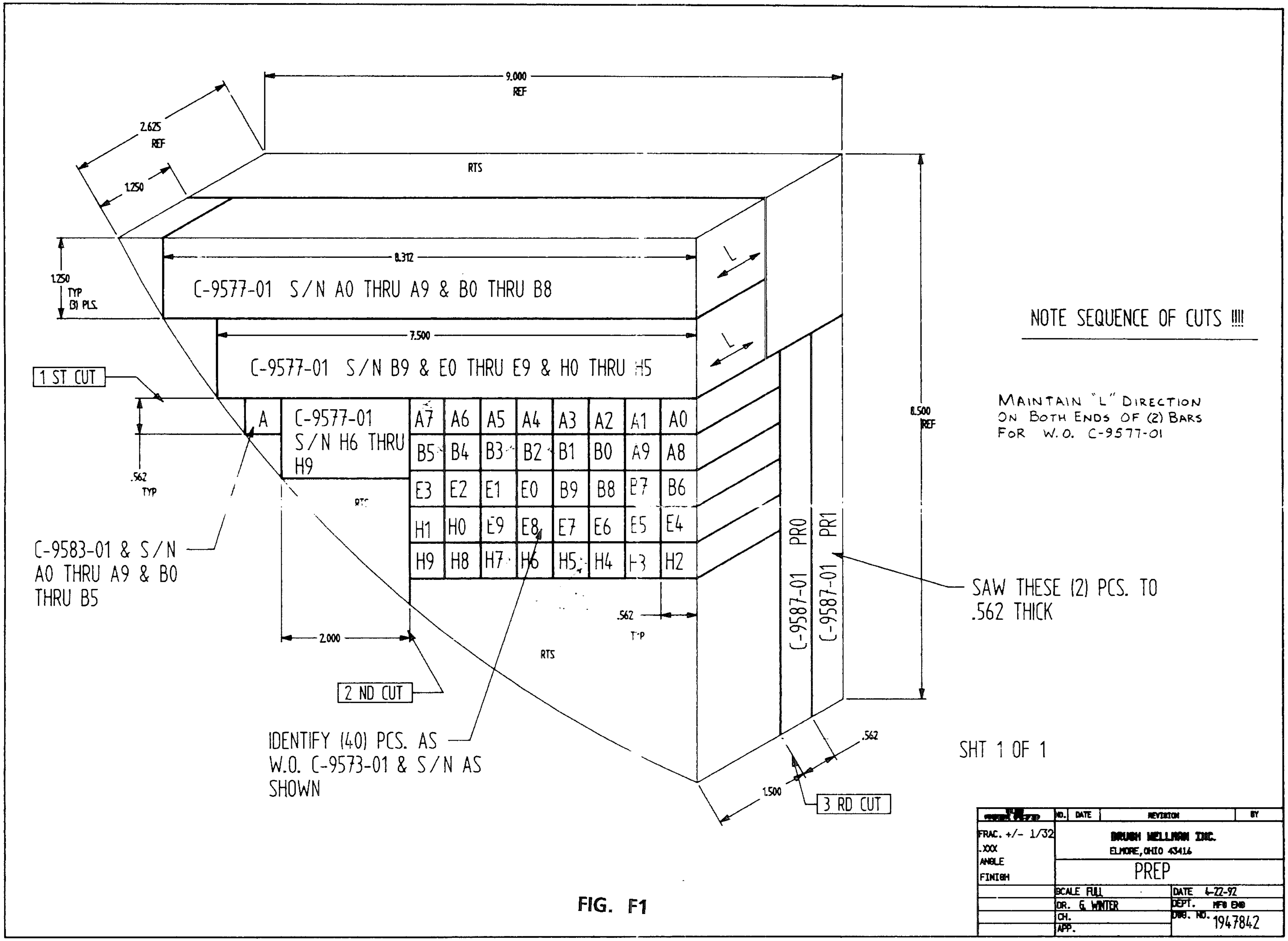
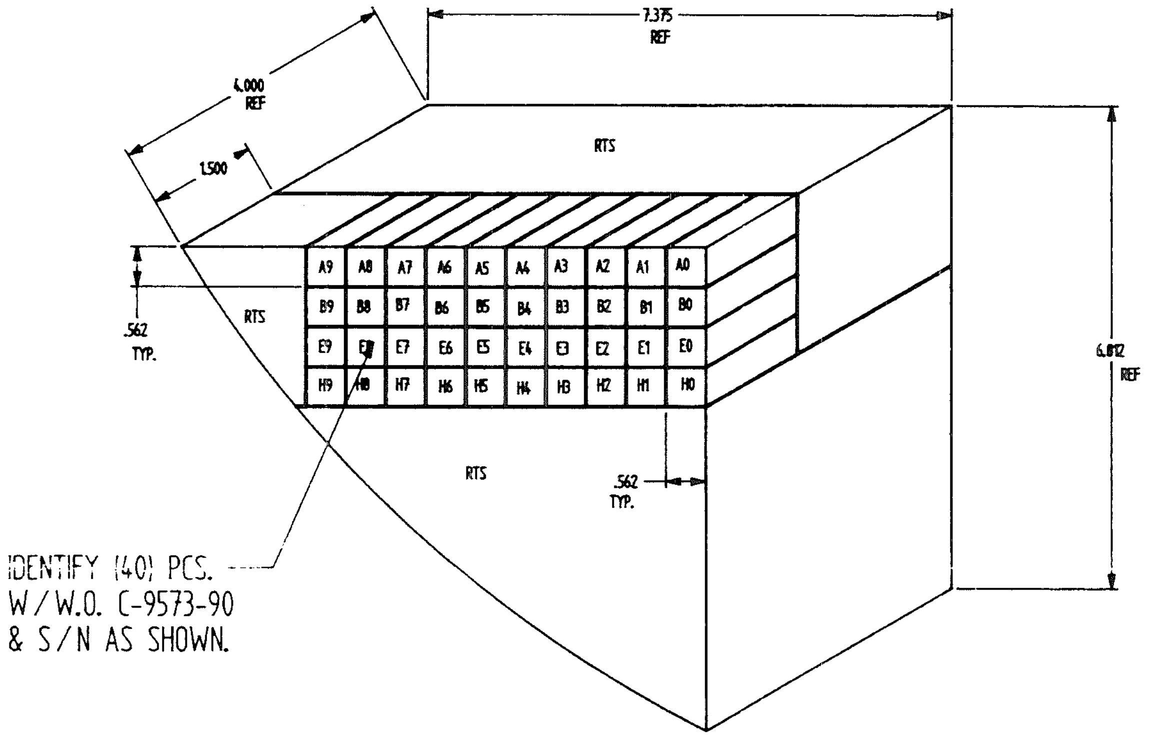

9.000 REF
2.625 REF
1.250
RTS
1.250 TYP (3) PLS.
8.312
C-9577-01 S/N A0 THRU A9 & B0 THRU B8
7.500
C-9577-01 S/N B9 & E0 THRU E9 & H0 THRU H5
1 ST CUT
.562 TYP
A
C-9577-01 S/N H6 THRU H9
A7 A6 A5 A4 A3 A2 A1 A0
B5 B4 B3 B2 B1 B0 A9 A8
E3 E2 E1 E0 B9 B8 E7 B6
H1 H0 E9 E8 E7 E6 E5 E4
H9 H8 H7 H6 H5 H4 H3 H2
C-9583-01 & S/N A0 THRU A9 & B0 THRU B5
2.000
2 ND CUT
.562 TYP
RTS
IDENTIFY (40) PCS. AS W.O. C-9573-01 & S/N AS SHOWN
C-9587-01 PR0
C-9587-01 PR1
8.500 REF
NOTE SEQUENCE OF CUTS !!!!
MAINTAIN "L" DIRECTION ON BOTH ENDS OF (2) BARS FOR W.O. C-9577-01
SAW THESE (2) PCS. TO .562 THICK
.562
1.500
3 RD CUT
SHT 1 OF 1
NO. DATE REVISION BY
FRAC. +/- 1/32
.XXX
ANGLE
FINISH
BRUSH WELLMAN INC.
ELMORE, OHIO 43416
PREP
SCALE FULL
DATE 4-22-92
DR. G. WINTER
DEPT. MFG ENG
CH.
DWG. NO. 1947842
APP.

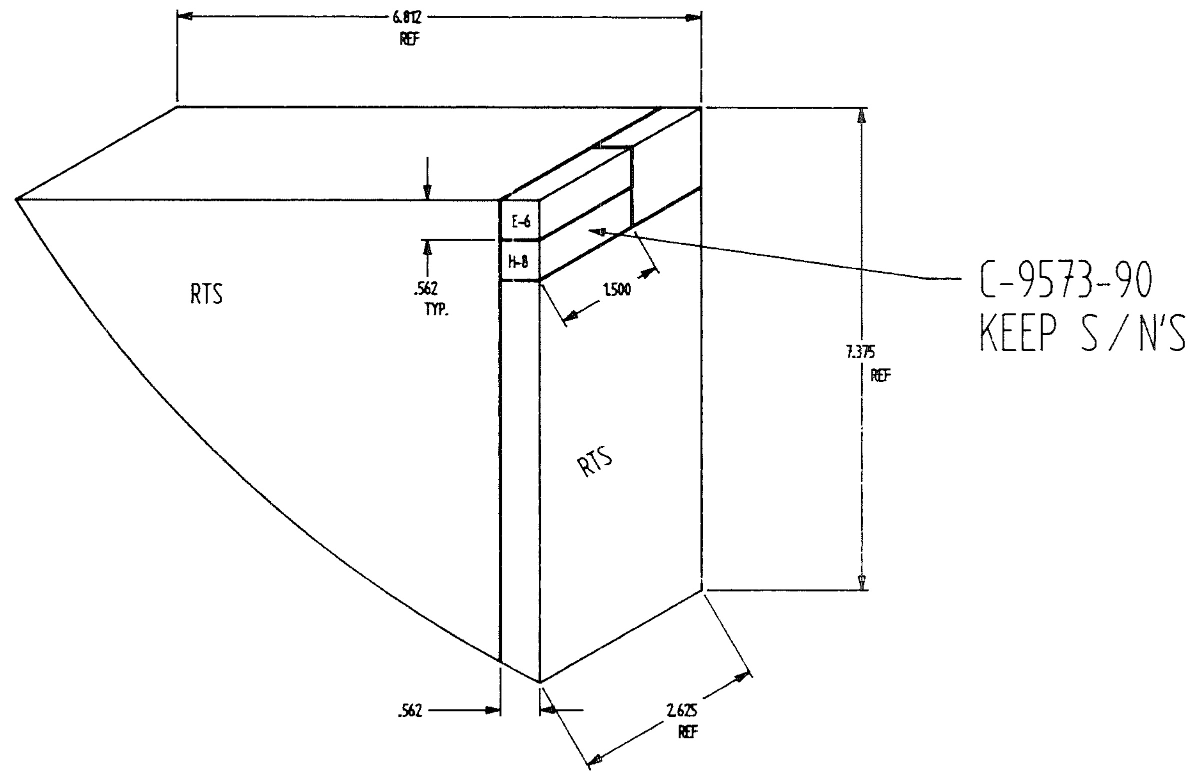
FIG. F1



SHT 1 OF 1

FIG. F2

NO. DATE REVISION BY
FRAC. +/- 1/32
.XXX +/-
ANGLE +/-
FINISH
ELMORE, OHIO 43416
PREP
SCALE .75
DATE 7-6-92
DR. G. WINTER
DEPT.
CH.
APP.
DWG. NO. 1947848



SHT 1 OF 1

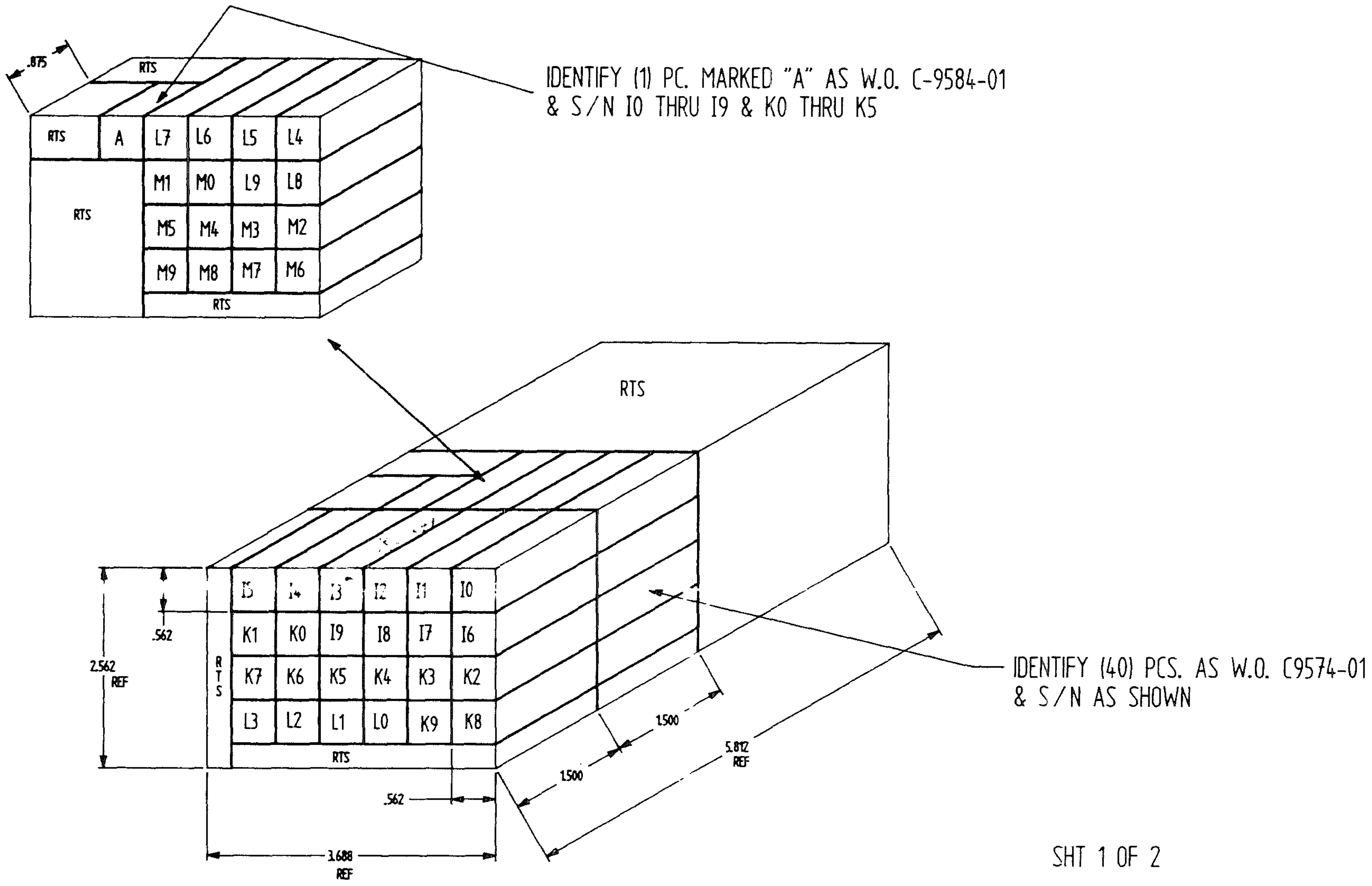
	NO.	DATE	REVISION	BY
FRAC. +/- 1/32 .XXX +/- .030 ANGLE +/- 0-30' FINISH	BRUSH WELLMAN INC. ELMORE, OHIO 43416 PREP			
	SCALE .75		DATE 9-26-92	
	DR. G. WINTER		DEPT: MFG ENG	
	CH.		DWG. NO. 194784C	
	APP.			

FIG. F3

Annex G

Layout of Machined Specimen Blanks in S-65-H HIP Billet - Lot No. H0349

Fig. No.	Brush Wellman Drawing No.	Date	Brush Wellman Ref. No.	Item	Specimens and Identification	Comments
G1	19H0349A(1/2)	21:04:92	EMC 958	4	EM Discs (A) I0-I9; K0-K5	
			EMC 957	4	Tensile I0-I9; K0-K9; L0-L9; M0-M9	Discarded
G2	19H0349A(2/2)	21:04:92	EMC 958	8	PR0; PR1	
			EMC 957	8	C-T I0-I9; K0-K9; L0-L9; M0-M9	
G3	19H0349C	13:05:92	EMC 957	4	Tensile L8	Replacement. Discarded
G4	19H0349D	06:07:92	EMC 957	4	Tensile I0-I9; K0-K9; L0-L9; M0-M9	Replacements. I3 and M3 Discarded
G5	19H0349E	10:09:92	EMC 957	4	Tensile I3	Replacement
G6	19H0349F	22:09:92	EMC 957	4	Tensile M3	Replacement



SHT 1 OF 2

FIG. G1

FRAC. +/- 1/32
.XXX
ANGLE
FINISH
NO. DATE REVISION BY
BRUSH WELLMAN INC.
ELMORE, OHIO 43414
PREP
SCALE FULL
DR. G. WINTER
CH.
APP.
DATE 4-21-92
DEPT. MFG ENG
DWG. NO. 19H0349A

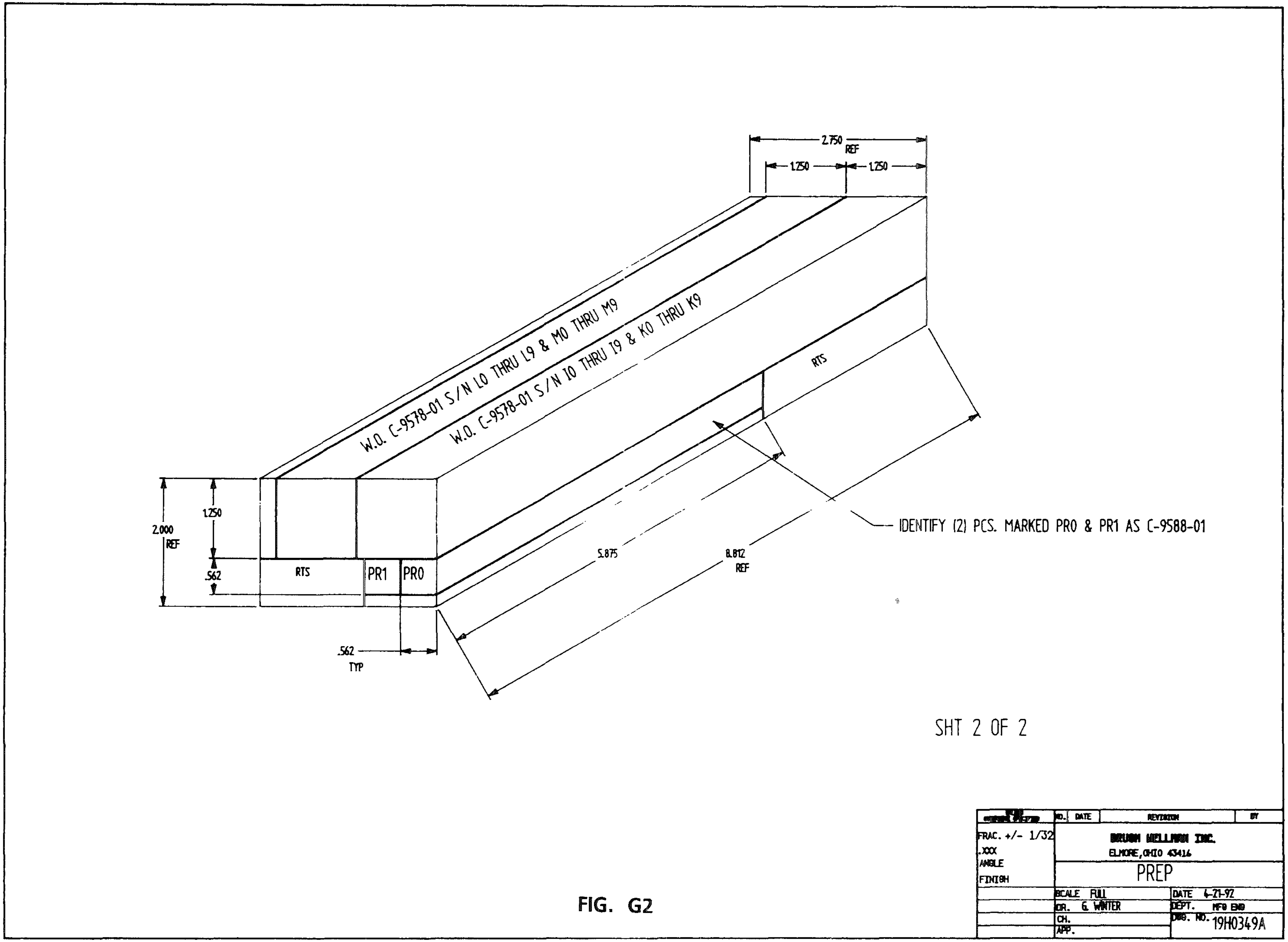
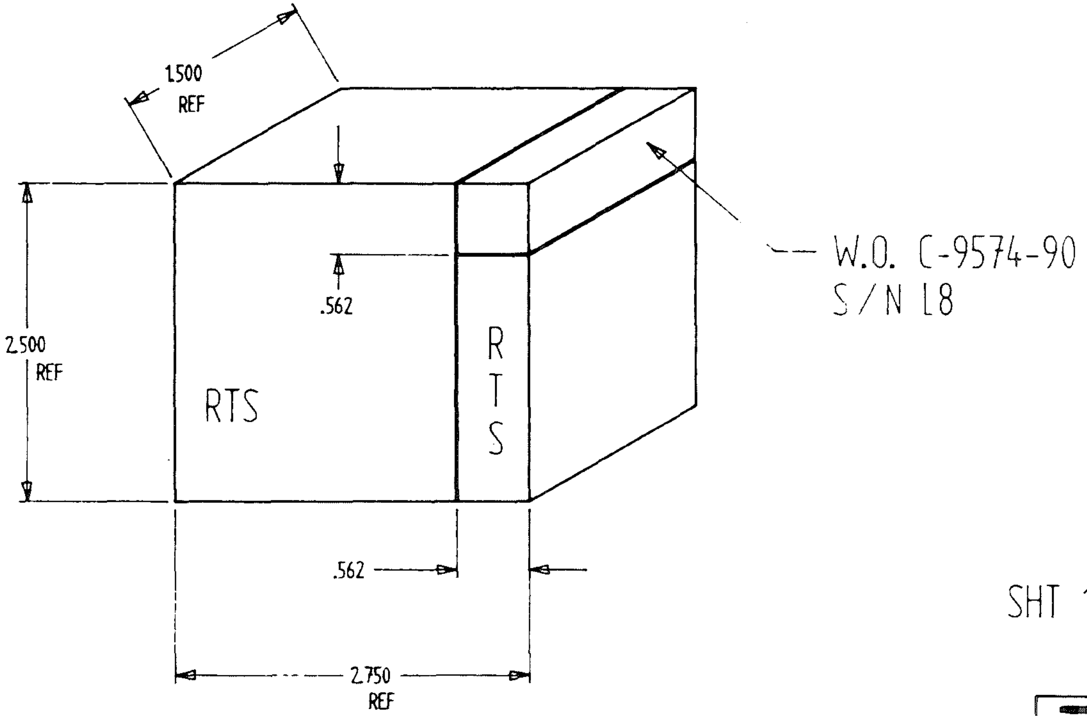

2.750 REF
1.250
1.250
W.O. C-9578-01 S/N L0 THRU L9 & M0 THRU M9
W.O. C-9578-01 S/N I0 THRU I9 & K0 THRU K9
RTS
2.000 REF
1.250
.562
RTS
PR1
PR0
.562 TYP
5.875
8.812 REF
IDENTIFY (2) PCS. MARKED PR0 & PR1 AS C-9588-01
SHT 2 OF 2
NO.
DATE
REVISION
BY
FRAC. +/- 1/32
.XXX
ANGLE
FINISH
ELMORE,OHIO 43416
PREP
SCALE FULL
DR. G. WINTER
CH.
APP.
DATE 4-21-92
DEPT. MFG ENG
DWG. NO. 19H0349A

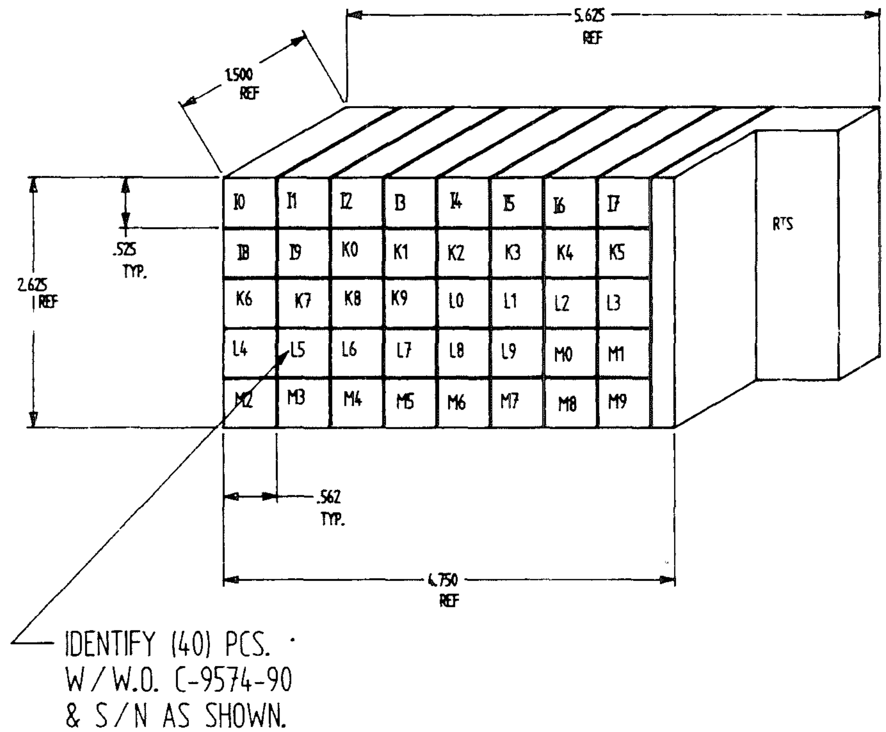
FIG. G2



SHT 1 OF 1

[illegible]	NO.	DATE	REVISION	BY
FRAC. ± 1/32 .XXX ± .030 ANGLE ± 0° 30' FINISH	BRUSH WELLMAN INC. ELMORE, OHIO 43416			
	PREP			
	SCALE FULL		DATE 5-13-92	
	DR. G. WINTER		DEPT. MFG. ENG.	
	CH.		DWG. NO. 19H0349C	
	APP.			

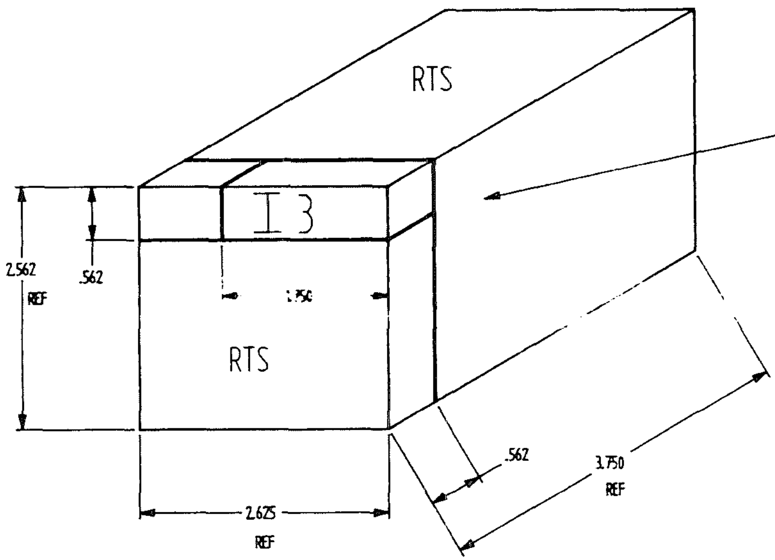
FIG. G3



SHT 1 OF 1

FIG. G4

FRAC. +/- 1/32	ELMORE, OHIO 43416	
.XXX +/- .030	PREP	
ANGLE +/- 0-30'		
FINISH		
	SCALE FULL	DATE 7-6-92
	DR. G. WINTER	DEPT. MFG ENG
	CH.	DWG. NO. 19H0349D
	APP.	



THIS IS A REPLACEMENT PART
FOR W.O. C-9574-90

MAINTAIN S/N

SHT 1 OF 1

[illegible]	NO.	DATE	REVISION	BY
FRAC. +/- 1/32 .XXX +/- .[illegible] ANGLE +/- [illegible] FINISH	BRUSH WELLMAN INC. ELMORE, OHIO 43414			
	PREP			
	SCALE FULL		DATE 9-10-92	
	DR. G. WINTER		DEPT. MFG ENG	
	CH. [signature]		DWG. NO. 19H0349E	
	APP.			

FIG. G5

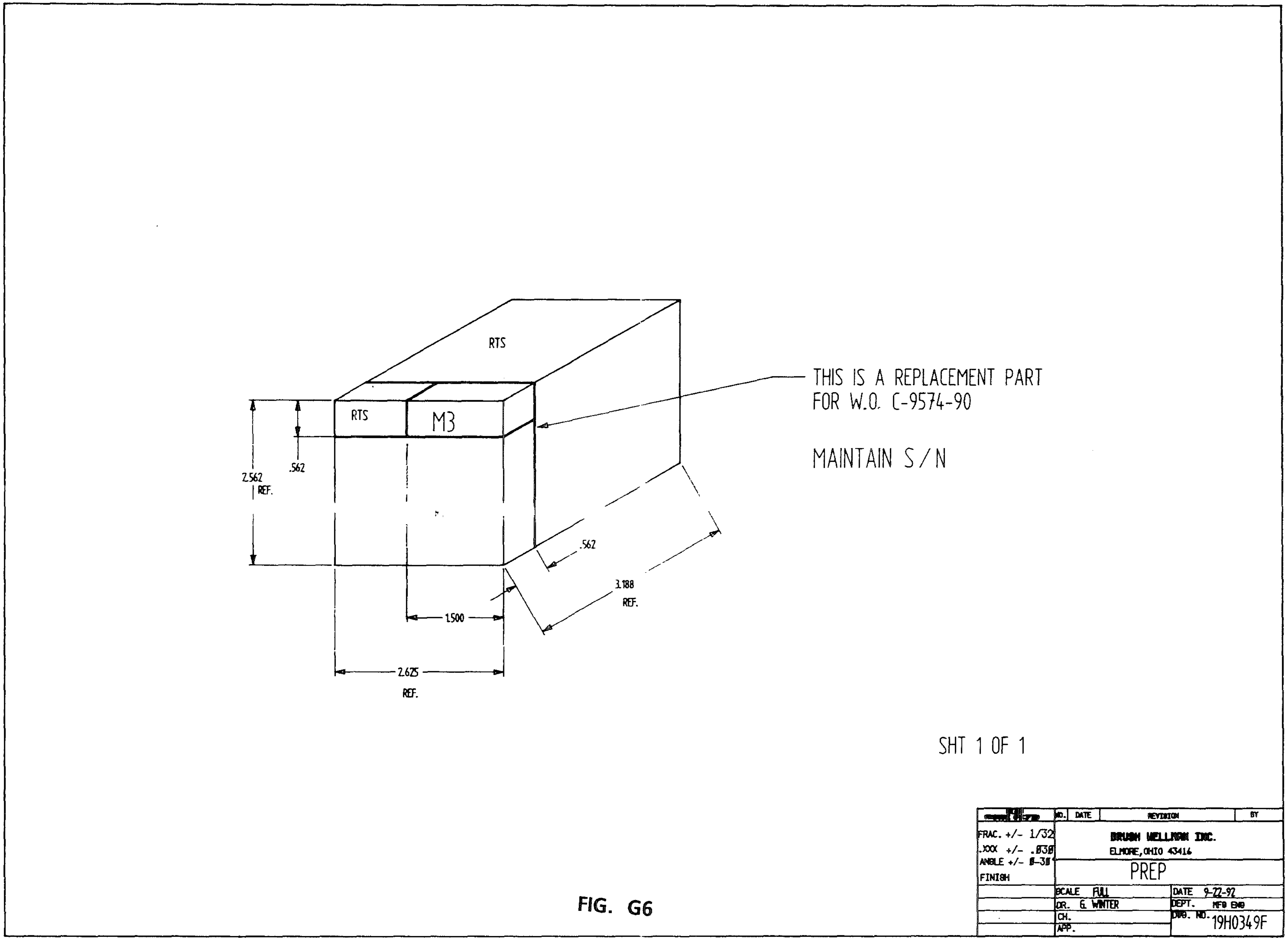

RTS
RTS
M3
THIS IS A REPLACEMENT PART
FOR W.O. C-9574-90
MAINTAIN S/N
2.562
REF.
.562
.562
3.188
REF.
1.500
2.625
REF.
SHT 1 OF 1
NO.
DATE
REVISION
BY
FRAC. +/- 1/32
.XXX +/- .030
ANGLE +/- 0-30'
FINISH
ELMORE, OHIO 43416
PREP
SCALE FULL
DR. G. WINTER
CH.
APP.
DATE 9-22-92
DEPT. MFG ENG
DWG. NO. 19H0349F

FIG. G6

Annex H

Southwest Research Institute Report (SwRI Project No. 06-4522-161)

"Fracture Toughness Testing of KfK (Round) Specimens".

BRUSHWELLMAN
ENGINEERED MATERIALS

MATERIAL CERTIFICATION

Customer: Kernforschungszentrum
Karlsruhe GMBH
Postfach 3640
W-7500 Karlsruhe 1, Germany

Date: 8/3/92
S.O.#: EMC959
P.O.#: 722/03757110/0104
Specification:

Material Description: Item 1: Lot No. H0685, Two (2) pcs. per DWG: F1669E, S/N 1-2.

CHEMICAL COMPOSITION: (WT. %)				
Element				
Be				
BeO				
Fe				
C				
Al				
Mg				
Si				
Batch No.				
(Metallic) Other Elem. ea.				
Others Total				

MECHANICAL PROPERTIES

DIR.	FTU (Ksi)	FTY (Ksi)	% EL		

DENSITY gm/cc

AVG GRAIN SIZE (Microns)

RADIOGRAPHIC INSP PER

PENETRANT INSP PER

ADDITIONAL INFORMATION:

Fracture Toughness Test Results:

S/N	ksi√in
1	9.00
2	8.99

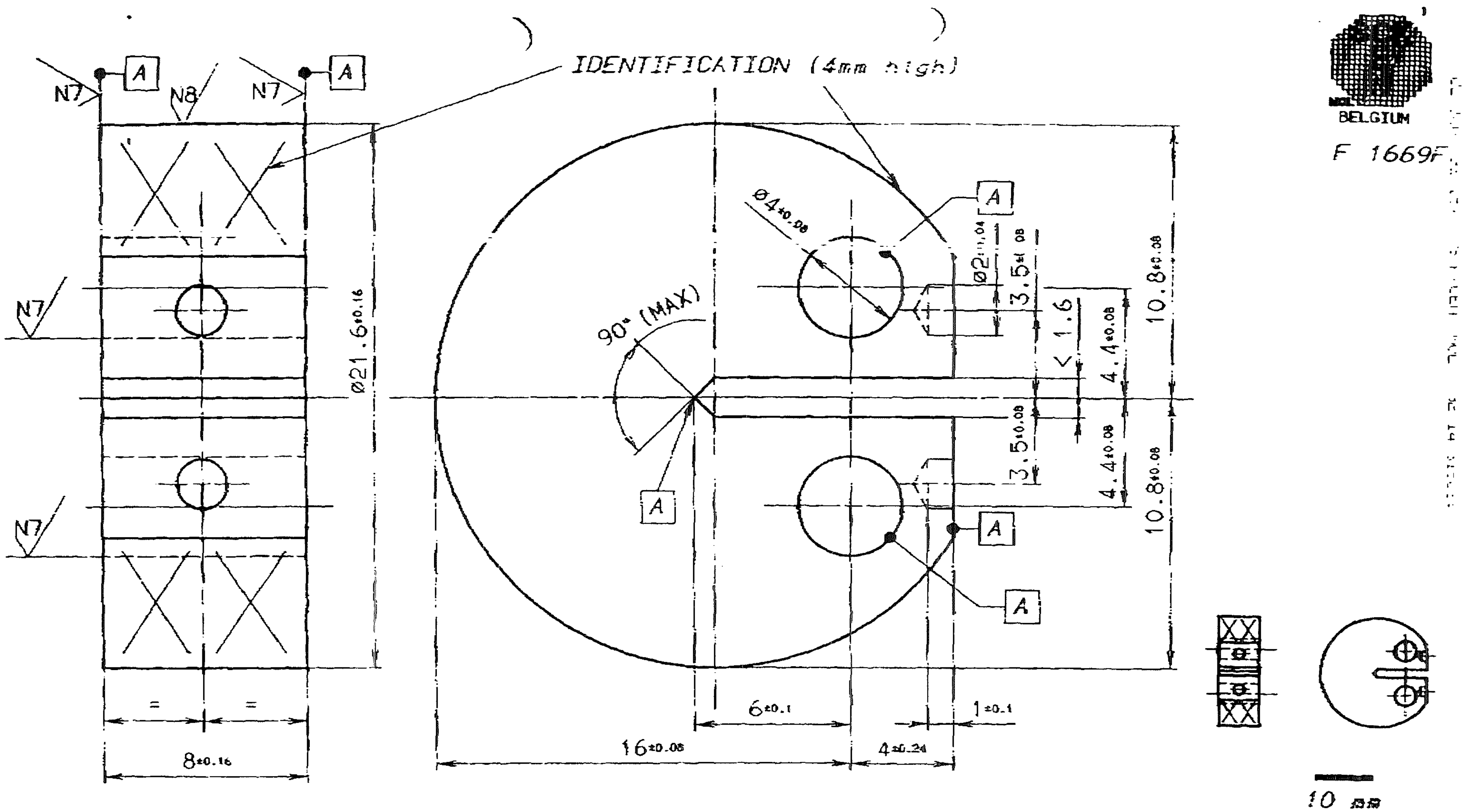
This is to certify that the above material satisfies the requirements of Specification ________,
Drawing see above Purchase Order see above and was removed from Pressing No. H0685.

[signature]

BRUSH WELLMAN INC. R.P. Garner
QUALITY CONTROL

BW—115 1/91

cc:
Shipping (3) Sales (1) File (1)



EACH SURFACE WITH [A] ; ⊥ AND // AT 0.03 mm ACCURACY
TOLERANCES ACCORDING TO ASTM E399

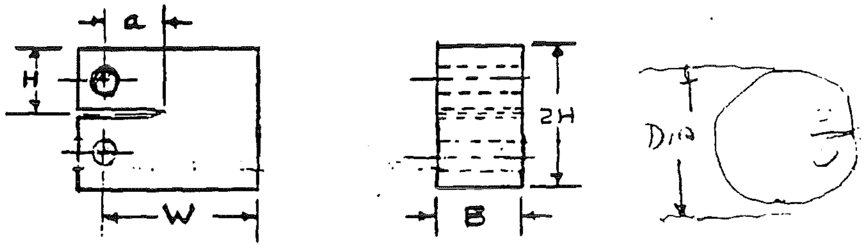
BERYLLIUM COMPACT TENSION SPECIMEN

FRACTURE TOUGHNESS TEST REPORT

GENERAL TEST INFORMATION			
MATERIAL	Be (Brush Wellman)	PROGRAM	06-4522-161
TEMP(°F) 76 SN-2 / 78 SN-1	R.H.(%) 48 SN-2 / 46 SN-1	DATE 7/17/92 / 7/21/92	BY DH, JF / DH, JF
NOTES: P/N F1669E	HL # H0685	DISK-SHAPED COMPACT	

SUMMARY OF TEST REPORT						
SPEC. I.D. NO.	SN-1	SN-2				
ORIENTATION CODE						
KQ (KSI $\sqrt{IN}$)	9.00	8.99				
K_{IC} (KSI $\sqrt{IN}$)	9.00	8.99				
Rsc (IF REQ'D)	—	—				
COMMENTS						

INITIAL SPECIMEN DIMENSIONS



SPECIMEN I.D. NO.	SN-1	SN-2				
B	.315	.3145				
W	.6327	.630				
~~H~~ Diameter/2	.4261	.4264				
2H Diameter	.8522	.8528				

page 1 of 4

-1.34

FATIGUE PRE-CRACK SUMMARY — From Notch

STAGE	SPECIMEN I.D.	MAX LOAD (KIPS)	CYCLES ~~(X1000)~~	CRACK LENGTHS SIDE 1	CRACK LENGTHS SIDE 2	
I	SN 1	+.12 −.24	100,000	0	0	
		.15 −.3	250,000	.013	.002	Reversed
		.15 −.375	84211	.017	.007	
		+.17 −.375	200,000	.032	.013	
		+.2 −.40	59362	.043	.022	Reversed
		+.2 +.02	180,000	.043	.023	
II		+.22 +.022	200,000	.043	.023	
		.225 +.024	200,000	.0[illegible]	.023	
	SN-2	+.2 −.50	218,000	.072	.061	
III	SN-1 (cont)	+.2 −.5	30749	.052	.035	
			142000	.052	.055	
			180,000	.054	.067	
			236,832	.070	.075	

FINAL CRACK LENGTH MEASUREMENTS

SPECIMEN I.D.	SN-1	SN-2				
SIDE 1 (S-1)	.302	.305				
SIDE 2 (S-2)	.2165	.295				
a-QP-1	.304	.3026				
a-CENTER	.305	.3025				
a-QP-2	.3122	.302				
a AVG FROM (QP-1+C+QP-2)/3	.3023	.3024				

7/17/92

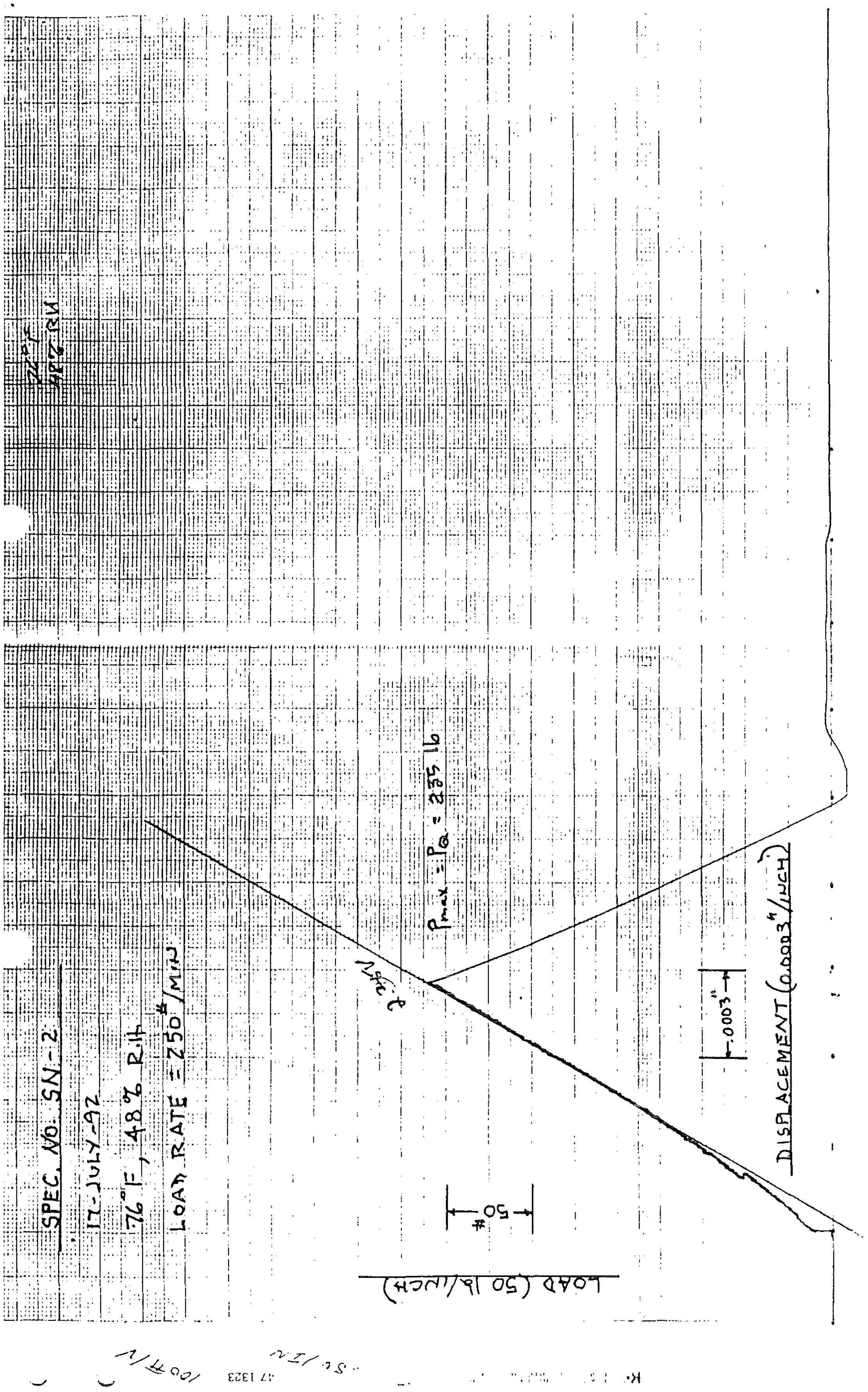
K_{IC} TEST INFORMATION

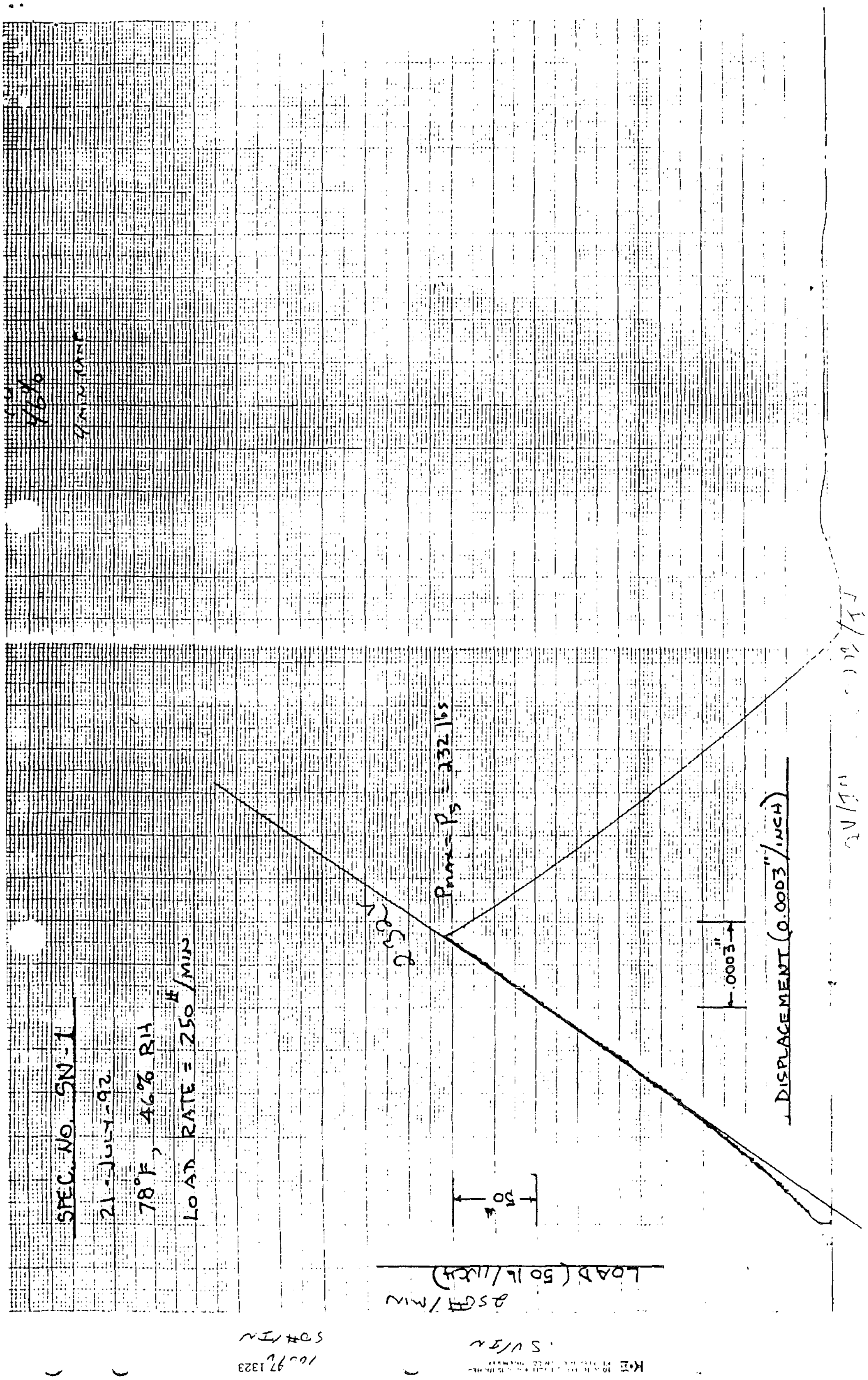
SPECIMEN I.D.	SN-1	SN-2				
AVG a/w	.4856	.480				
f (a/w)	9.7164	9.5466				
PQ (kips)	.232	.235				
Pmax (kips)	.232	.235				
$\frac{Y}{B\sqrt{w}}$ =	38.779	38.244				

Page 2 of 4

K_{IC} VALIDITY CHECK LIST							
ITEM	SPECIMEN I.D.	SN-1	SN-2				
A	Kmax FAT. < 0.6 KQ	NOT	APPLIC	ABLE TO	Beryllium		
	Kmax FATIGUE		ASTM	E399-90	Annex	on Be	
	0.6 KQ						
	VALID ?						
B	Kmax FAT/E < .002 in.$^{1/2}$						
	Kmax FAT/E	.00018	.00017				
	VALID ?	Y	Y				
C	AVG a/w BETWEEN 0.45 & 0.55						
	AVG. a/w	.486	.480				
	VALID ?	Y	Y				
D	S-1 & S-2 > 0.85 a AVG						
	a SIDE 1	.302	.305				
	a SIDE 2	.317	.295				
	85% of a AVG	.261	.257				
	VALID ?	Y	Y				
E	MAX DIFF. OF ANY 2 OF QP-1, CENTER OR QP-2 MEAS < 0.10 a AVG						
	MAXIMUM DIFFERANCE	.007	.001				
	10% OF a AVG	.026	.026				
	VALID ?	Y	Y				
F	LOAD RATE BETWEEN 30 & 150 KSI$\sqrt{\text{IN}}$/MIN	ASTM suggests	E399-90 ~10	Annex ksi$\sqrt{\text{in}}$	on Be /min		
	LOAD RATE (KSI$\sqrt{\text{IN}}$/MIN)	9.7	9.6				
	VALID ?	Y	Y				

K_{IC} VALIDITY CHECK LIST (CONT.)							
ITEM	SPECIMEN I.D.	SN-1	SN-2				
G	a & B > 2.5 $(KQ/Y.S.)^2$						
	a AVG	.307	.302				
	B	.315	.315				
	YIELD STRESS (KSI)	51.5	51.5				
	2.5 $(KQ/Y.S.)^2$	.076	.076				
	VALID ?	Y	Y				
H	Pmax/PQ < 1.1						
	Pmax/PQ	1.00	1.00				
	VALID ?	Y	Y				
I	Kmax FAT_{T1} ∠ 0.6 $(Y.S._{T1}/Y.S._{T2})$ KQ_{T2}	NA	NA				
	VALID ?						
CALC. VALUE OF KQ (KSI$\sqrt{IN}$)		9.00	8.99				
DOES KQ = K_{IC} ?		Y	Y				
IF NO - WHAT ITEM(S) ARE CAUSE FOR INVALID K_{IC}		—	—				
GENERAL COMMENTS							


SPEC. NO. SN-2
17-JULY-92
76°F, 48% R.H.
LOAD RATE = 250#/MIN
Pmax = PQ = 235 lb
.0003"
DISPLACEMENT (0.0003"/INCH)
50#
LOAD (50 lb/INCH)


SPEC. NO. SN-1
21-JULY-92
78°F, 46% RH
LOAD RATE = 250 #/MIN
Pmax = P5 = 232 lbs
.0003"
DISPLACEMENT (0.0003"/INCH)
50
LOAD (50 lb/INCH)