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RECOMMENDATIONS FOR A CONTROLLED ENVIRONMENT ENCLOSURE FOR INSTRUMENTATION PACKAGES

SEPTEMBER 1976

by

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SECTION 1.

SYNOPSIS

An enclosure to protect instrumentation packages from the severe pressure and temperature environment presented by downhole conditions at the LASL Q-12 Division Fenton Hill Geothermal Research site is specified. Due to a general lack of interest by prospective vendors in handling all phases of the design and fabrication, a pressure vessel housing was designed and specified for their use in establishing the thermal insulation and heat sink requirements.

Appendix B is a specification recommended for use in purchasing the pressure vessel material; Appendix C for use in specifying the important thermal parameters and size limitations.

SECTION 2.

INTRODUCTION AND GENERAL SPECIFICATIONS

In July 1976, EG&G, LAO was contracted by the Q-12 Division of the Los Alamos Scientific Laboratory (LASL) to provide our technical support in several areas of their Geothermal Research and Development projects (in process at their Fenton Hill site in the Jemez Mountains). One of those tasks undertaken by EG&G involved writing a specification for an enclosure to protect an electronics Multiplex System (in particular) and other instrumentation packages (in general) from the severe downhole environment.

A number of enclosure design criteria, constraints, and desirable features were established by LASL:

- 1) Maximum continuous time of enclosure in the hostile environment is 12 hours.
- 2) Minimum time between enclosure emersions in the hostile environment is 24 hours; during this time the dewar will be placed in an air ambience at -30°C to $+30^{\circ}\text{C}$ temperature.
- 3) Maximum hostile environment pressure is 10,000 psi (including static and pump heads).
- 4) Maximum hostile environmental temperature is 275°C .
- 5) Enclosure is to be lowered to a maximum depth of 15,000 feet.
- 6) Maximum O.D. of enclosure is 6.000 inches.
- 7) There will be no significant mechanical dynamic loads applied to the enclosure (e.g., shock due to "bottoming-out" in the hole).
- 8) This enclosure will be one of a string of instrumentation packages to be joined end-to-end and all suspended from a logging cable; the sequential order of packages is subject to change for each experiment.
- 9) The volume required to house the Multiplex System electronics and its power source (preferably batteries) was to be determined by EG&G.

SECTION 3.

DISCUSSION

3.1 GENERAL

Potential vendors of a suitable enclosure (dewar or other type) were contacted in an effort to secure an "off-the-shelf" or custom designed unit to meet the stringent environmental conditions of combined high temperature and high pressure. No "off-the-shelf" models were located and only sparse interest found in custom designed and fabricated units (ref. Appendix page A-1). In general, those seemingly qualified to conduct a thorough thermal analysis and design were not interested in designing the pressure vessel housing.

Furthermore, the mechanical interface between this enclosure and other LASL packages in the string to be lowered downhole had not been designed; a task that would have to be completed before a specification could be finalized. Obviously, a significant savings in design and fabrication time and material costs could be realized if all packages in the string were fabricated from the same mechanical tubing and employed the same mechanical interface.

In view of these factors, discussions with LASL personnel resulted in a desire for EG&G to design the enclosure housing (pressure vessel), write a material specification for it and the other LASL packages, write a specification for the enclosure interior thermal shroud, and to work closely with them in developing a mechanical interface for joining the packages. Also, it was decided that the vendors invited to bid the thermal analysis, design, and fabrication would be given the option to bid the pressure vessel fabrication as well.

3.2 MECHANICAL INTERFACE OF ADJACENT PACKAGES

Several methods of joining and sealing the packages end-to-end were submitted to LASL for their scrutiny. Among the first was a technique proposed by Mr. Sheldon Reynolds, U.S. Steel metallurgist who works closely with the petroleum industry. He suggested that standard American Petroleum Institute (API) threads be used with a copper plating to both the male and female threads to insure sealing without galling.

Figure 1 illustrates the API Extreme-Line thread, (one of four standard

HALF SECTION

FIGURE NO.1

API types); it has the advantage of not requiring a coupling and the disadvantage of complicated machining due to the slope of the thread changing several times in its length. A better alternative might be to use an internal (male-threaded) coupling employing API Buttress threads to join two packages together (see Figure 2); it has the advantage of simpler thread machining and the disadvantage of requiring an extra piece (the coupling). Either method would require the use of high temperature API thread compound. However, LASL felt that their equipment was not powerful enough to make up this type of joint and suggested that sealing with elastomer or metallic O-rings in combination with Acme (free-running) threads be investigated.

A method of accomplishing a metallic O-ring seal is depicted in Figure 3. The coupling acts as a turnbuckle, pulling the package ends together to cause the necessary local buckling of the O-ring; optional restraining pins insure that the O-ring plating will not be damaged by relative circumferential movement of the packages. This mechanical interface offers the advantage of easily machined Acme threads and low-torque joint makeup; the disadvantages include an increase in wall thickness to accommodate an O-ring sealing groove and a requirement for a more careful handling of the fragile component parts.

The restraining pins and their associated close tolerance machining and press-fitting could be eliminated by fabricating a simple joint makeup fixture (e.g., two sets of pipe vises and V-blocks mounted to slide on longitudinal tracks); a recommended method.

3.3 PRESSURE VESSEL MATERIAL CONSIDERATIONS

3.3.1 General Considerations

Choosing an appropriate pressure vessel material involved trade-off studies of various desirable features including:

- 1) Instrumentation payload volume vs wall thickness
- 2) Sealing method vs wall thickness
- 3) Temperature vs material strength
- 4) Material cost vs material strength
- 5) Material hardness vs material strength

HALF SECTION
(SCALE: NONE)

FIGURE NO. 2

HALF SECTION

FIGURE NO. 3

- 6) Material hardness vs machinability
- 7) Material availability vs fabrication methods
- 8) Material cost vs material quality

In an effort to determine strength requirements for a pressure vessel with a nominal outside diameter of 6.0 inches and under an external pressure of 10,000 psi, various wall thicknesses were considered in the range of 0.25 through 0.75 inches. This resulted in maximum stresses in the range of 125,000 to 46,000 psi, respectively (ref. Appendix page A-2). Alternatively, the external pressure required to cause yielding of a cylindrical pressure vessel vs its yield strength was calculated for wall thicknesses of 0.500, 0.625, and 0.750 inches for yield strengths in the range of 60,000 through 160,000 psi. At 150,000 psi the yield pressures were determined to be 22,300, 28,000, and 32,800 psi (respectively) for the three wall thicknesses (ref. Appendix page A-3).

The minimum required wall thickness for employing the presently preferred O-ring sealing technique was determined in Section 3.2 to be in the neighborhood of 0.750 inches; the resulting wall in the area of the threaded ends is reduced but still should withstand approximately 20,000 psi external pressure for materials having 145,000 psi minimum yield strength. This should equate to an adequate factor of safety since the maximum design pressure of 10,000 psi is realized only at maximum downhole depths; away from human observers (actually, the maximum pressure at 15,000 feet due to the static head and the specified maximum pump head (2500 psi) should be approximately 9000 psi).

3.3.2 Low Alloy Steels, SAE 4140 & 4340

Some of the higher carbon content low alloy steels are readily heat-treatable (via oil quench and temper) to 145,000 psi minimum yield strength. Grades SAE-4135, -4140, and -4340 can easily be heat-treated to tensile strengths in excess of 200,000 psi in the proper cross-sections. For these high strengths 4340 is limited to cross-sections of approximately 3.5 inches; 4140 to approximately 0.5 inches. However, the cross-sections can be increased if lower strength heat treatment is acceptable. Hence, 4340 is satisfactory for heat-treating 0.750 inch wall tubing to the desired yield strength of 145,000-175,000 psi; 4140 becomes somewhat marginal.

This yield strength range (145,000 - 175,000 psi) corresponds to a Brinell Hardness range of approximately 312-383 (BHN) for both the 4140 and 4340 steel. The convenience of having this material heat treated to its desired final strength before shipment vs the better machinability of the material as supplied to meet the applicable AMS specification (max. BHN = 255) must be considered; for the moderate amount of machining required for the pressure vessel (enclosure housing), heat treatment before machining seems the better choice.

These low alloy steels are generally supplied in "commercial" grades and, on occasion, are sometimes available in the "aircraft quality" (magna-flux quality) grade. The basic difference is that the commercial grade meets only very loose quality standards while the aircraft quality grade is continuously monitored throughout the steel-making process to insure that the end mill product meets high quality standards. Certified quality control documentation is supplied to the buyer of aircraft quality products; none is available for commercial grade.

For example: aircraft quality low alloy steel tubing purchased to SAE AMS Specification No. 6415H (Aircraft quality SAE 4340) is certified to meet the following:

- 1) Tolerances per AMS 2253
- 2) Chemical analysis per AMS 2259
- 3) Steel cleanliness per AMS 2301
- 4) Quality assurance sampling per AMS 2370
- 5) Other standards controlling the hardenability, maximum hardness, grain size, macrostructure, decarburization depth, and frequency - severity rating.

Fabrication of a cylindrical pressure vessel is obviously simplified if tubing of the proper size and material can be located. Approximately fifteen potential vendors (manufacturers and warehouses) were contacted in an effort to locate 6" nominal O.D. x .75" wall thickness aircraft quality 4140 or 4340 seamless mechanical tubing; the results are tabulated on Appendix page A-4. In summary, only one vendor has the material in stock; two others are willing

to manufacture it in the relatively small quantities that LASL requires (40-140 lineal feet).

Since the AMS tubing standards are rather liberal (6.000 ± 0.060 Dia. $\times 0.750 \pm 0.056$ wall) and industry can easily work to closer tolerances ($6.000 \pm 0.025 \times 0.750 \pm 0.045$ wall), the tubing size tolerances were chosen to be: 6.030 ± 0.030 Dia. $\times 0.750 \pm 0.050$ wall. This should allow for a more predictable coupling cross-section stress area (the coupling is proposed to be fabricated from the purchased tubing) and allow for decarburization removal while retaining an O.D. of approximately 6.000 inches.

A concern in using heat-treated low alloy steels in this application is that they are affected by extended exposures to temperatures near or above their tempering temperature. The limit to which each alloy may be exposed for no longer than one hour per inch of thickness without loss of strength is given in *MIL-HDBK-5* as 725°F for 4140 and 800°F for 4340 (when they have been heat treated to 180,000 psi ultimate tensile strength); these temperatures are approximately 100°F below the typical tempering temperatures employed in this strength range. Since our worst case operating characteristics are specified to be 527°F (275°C) for 12 hours, some strength deterioration from room temperature values are expected. In fact, *ASTM Special Technical Publication No. 199*¹ shows the variation of strength vs temperature for some alloy steels. From an analysis of the 4340 data it can be concluded that the curve for "oil quench from 1650°F plus 6-hour temper at 1000°F " is very suitable for our application; the Brinell Hardness is listed at 352. This hardness is slightly in excess of the hardness range (286-325 BHN) recommended by *ARP No. 1110*² to reduce the possibility of stress corrosion. Analysis of the 4140 data (from the same source) eliminates it from further consideration due to its marginal strength at the specified operating temperature.

3.3.3 Other Steels

There are a number of other steels with substantially better high-temperature strength and (in some cases) better corrosion resistance than the previously discussed low alloy steels (4140 and 4340). The problem in selecting one of

¹ *Report on Elevated-Temperature Properties of Wrought Medium-Carbon Alloy Steels*, American Society for Testing Materials, 1957.

² Published by the Society of Automotive Engineers (1969).

these better types is their lack of availability in the proper size of tubing.

A few of these steels will be discussed:

3.3.3.1 Five Percent Chromium Steels with Molybdenum and Vanadium

This family of steels most salient characteristic is their retention of 70 to 80% of their room temperature strength up to 1000°F; approximately 90% strength is retained at 500°F for exposures exceeding 1,000 hours.¹ These are available in aircraft quality grades (e.g., per AMS 6485).

3.3.3.2 Precipitation-Hardening Stainless Steels

This group of steels exhibit good corrosion resistance and high mechanical properties at temperatures to 800°F. As an example of their mechanical properties: 17-7 PH, Condition TH1050, has a tensile yield strength of 138,000 psi at 800°F.

3.3.3.3 Inconel Alloy No. 718

This age-hardenable alloy is readily welded with joint efficiencies very close to 100%; its resistance to postweld cracking are outstanding. It exhibits room temperature yield strengths of 150,000 psi; dropping only to approximately 125,000 psi at 1200°F.

Corrosion resistance of this nickel-chromium alloy is excellent to many media.

It is available in a range of standard mill forms including rod, bar, plate, forging stock, sheet, and tube; all available in aircraft quality material per AMS specifications. However, the seamless tubing is not readily available in larger sizes (i.e., the needed 6" O.D.); larger-sized tubes are generally rolled from sheet or plate and welded.

The applicable AMS standards are listed for reference:

- 1) Seamless Tubing; AMS-5589, -5590
- 2) Sheet, Strip, & Plate; AMS-5596, -5597
- 3) Bars, Forgings, & Rings; AMS-5662, -5663, -5664
- 4) Welding Wire; AMS-5832

¹ Reference: *Metals Handbook*, 8th Edition, American Society of Metals.

3.4 ENCLOSURE THERMAL CONSIDERATIONS

From a heat-transfer viewpoint, the surface area must be minimized in order to minimize the heat flow from the high-temperature environment to the lower temperature electronics canister (or other instrumentation package). Preliminary analysis of the Multiplexing System electronics and its power source (batteries) indicated that a volume of greater than 160 cubic inches would be adequate for packaging. Determination of the minimum cylindrical surface area yields a cylinder of 5.88 inches diameter x 5.88 inches length. Since this diameter is approximately equal to the pressure vessel (pv) outside diameter, a smaller canister diameter must be chosen to allow for wall thickness, insulation, and heat sink. A canister receptacle with 2.8 inches diameter x 26.00 inches length was chosen; allowing for the maximum diameter (2.6 inches), commercially available, mercuric-oxide button-cells (high-temperature batteries).

Insulation manufacturers were contacted (see Appendix page A-5) to survey the types of insulation available; both flexible and rigid types were considered. One of the most promising is "MIN-K" manufactured by Johns Manville; available in the rigid and flexible forms (rigid types are favored due to ease of replacement), both in variable densities and associated thermal conductivities ("K-factor"). For a mean temperature of 400°F, the "MIN-K" molded type No. 1301 with a density of 20 pcf has a $K = 0.22 \text{ BTU-IN/FT}^2 - \text{HR} - ^\circ\text{F}$ (better than "still air").

Most of the vendors interested in solving the thermal problem have indicated that they would use a latent heat of fusion phase change of material as a heat sink to remove the heat from the electronics canister; in addition, they plan to have insulation interposed between the pressure vessel steel walls and the heat sink. This method is very attractive for several reasons:

- 1) The heat sink would be self regenerating; the material changing back to a solid as the pressure vessel cools after being removed from the hole.
- 2) As compared to the common ice-packed dewars, the fusion heat sink does not have to be dismantled at the test site for charging nor does it have to be recharged if the experiment is delayed.
- 3) Since the heat sink will be either a solid or a hermetically sealed

liquid, the electronics cannot be damaged by its vapors (such as steam damage in ice-packed dewars).

4) Electronic component drift should be significantly reduced due to limiting the maximum ambient temperature within the canister to approximately that of the constant heat-of-fusion temperature of the heat sink material (e.g., if FM multiplexing is used, the FM center-frequencies should be more stable due to less temperature drift of the input resistor biasing network to the individual VCO's).

A control drawing of the proposed instrumentation enclosure appears in Appendix C.

SECTION 4.

CONCLUSIONS

4.1 PRESSURE VESSEL MATERIAL SELECTION

The harsh downhole environment created by a concurrence of high pressure and high temperature lead to direct consideration of materials with high strength retention at elevated temperatures. A graphical representation of some families of materials' strength vs temperature is depicted in the *Metals Handbook*.¹ As depicted, steel "H11" has not only the highest room temperature strength but a better strength retention at elevated temperatures (depicted by less slope of its curves) than most of the other listed materials; not shown, but of significant importance, is its general susceptibility to corrosion.

Aircraft quality seamless² tubing manufactured in accordance with the appropriate AMS specification is definitely recommended for procurement. In consideration of only the technical aspects of the enclosure pressure vessel housing, I believe Inconel Alloy 718 to be the most suitable material; it exhibits excellent corrosion resistance, excellent weldability (up to 100% joint efficiency), and very good strength retention at elevated temperatures.

However, realizing that consideration of time alone (availability) often dictates an alternate choice in matters and in view of the recent location of an "off-the-shelf" stock of suitably-sized AMS-6415 steel (aircraft quality 4340), I would recommend the purchase of this alternate material. Hence, the specification for its purchase is inserted as Appendix B.

Toward the end of this investigation approximately 150 lineal feet of AMS-6415 seamless, cold-drawn, tubing was located in stock at the Channing-Hamilton Corporation warehouse (ref. Appendix page No. A4). Although this 6" nominal O.D. x 0.750 nominal wall thickness material could have been outside the 6.030 ± 0.030 O.D. x 0.750 ± 0.050 wall sought after, they assure me that it conforms to the specified closer tolerances. Furthermore, the mandatory AMS certification papers are on file and will be provided; arrangements can be made for heat treatment and subsequent tensile testing before shipment (if desired).

¹ *Metals Handbook*, 8th Edition, American Society of Metals.

² Inconel Alloy 718 can be considered in a welded tube configuration as well as in the seamless configuration.

4.2 ENCLOSURE THERMAL ANALYSIS AND FABRICATION

Thermal analysis of the enclosure is complicated in that the heat flow is not a steady-state conduction; at least until the latent heat-of-fusion temperature of the heat sink material is reached, internally (if a phase change heat sink is employed). Several insulation manufacturers have run an analysis with widely varying results; caution should be employed when selecting a vendor to do the analysis and subsequent fabrication. I would suggest that the prospective vendors plant be visited, that they convincingly demonstrate their competence to accomplish the task, and (depending upon their size and reputation) the possibility of their signing a Performance Bond be considered.

The specification outlined in Appendix C is for employment of reputable firms; additions may be necessary to control others.

A P P E N D I X A

POTENTIAL PROTECTIVE-ENCLOSURE VENDORS

DATE OF INITIAL CONTACT	POTENTIAL VENDOR	PERSON CONTACTED	RESPONSE	COMMENTS
01 July '76	Noren Products, Inc. (415) 365-0632	Mr. Don Noren	Very interested in the thermal aspects (has forwarded a preliminary sketch); not interested in the pressure vessel design.	Apparently well qualified. Rec- ommended by Jermyn Mfg. Co. as the designer of their heat-pipe product line.
19 July '76	Cryogenic Technology, Inc. (617) 890-9400	Mr. Harry Nicoll	Not too interested, but very helpful. Recommended I con- tact the Arthur D. Little Co.	Apparently well qualified. Rec- ommended "MIN-K" Insulation and Inconel 718.
19 July '76	Arthur D. Little Co. (617) 864-5770	Mr. Peter O'Farrell	Very interested, but would like to have funding for a feasibility study.	Apparently well qualified -- but expensive; men- tioned \$50,000 for a feasibility study.
19 July '76	Cryofab, Inc. (201) 925-2916	Mr. George Grillo	Not interested in custom work.	
19 July '76	Minnesota Valley Engineering, Inc. (612) 758-4484	Mr. Mike Lumpkin	Not interested; said that they were "too busy".	Apparently qualified.

STRESSES CAUSED BY APPLICATION OF
UNIFORM EXTERNAL PRESSURE, ENDS CAPPED¹

t (in.)	r = (in.)	σ_1 (KSi)	σ_2 (KSi)	σ_3 (KSi)	
0.3	a	-52.63	-95.26	10.00	
	b	-52.63	-105.3	0.00	
0.4	a	-40.18	-70.36	10.00	
	b	-40.18	-80.36	0.00	
0.5	a	-32.73	-55.45	10.00	
	b	-32.73	-65.45	0.00	
0.6	a	-27.78	-45.56	10.00	
	b	-27.78	-55.56	0.00	
0.75	a	-22.86	-35.71	10.00	
	b	-22.86	-45.71	0.00	
0.25	a	-62.61	-115.2	10.00	.25 = t is slightly less than the minimum allowed with this formula
	b	-62.61	-125.2	0.00	

q $\equiv$ external pressure = -10,000 psi

t $\equiv$ wall thickness

a $\equiv$ outside R = 3.000"

b $\equiv$ inside R = a - t

Formula is invalid for

$$t < \frac{a}{10} = \frac{3.00}{10} = 0.30"$$

σ_1 , σ_2 , and σ_3 are normal stresses in the longitudinal, circumferential, and radial directions, respectively (positive with tensile).

$$\sigma_1 = \frac{qa^2}{a^2 - b^2} ; \quad \sigma_2 = \frac{qa^2(b^2 + r^2)}{r^2(a^2 - b^2)} ; \quad \sigma_3 = \frac{-qa^2(r^2 - b^2)}{r^2(a^2 - b^2)}$$

¹ Formulas for Stress and Strain, Roark & Young, McGraw-Hill, 1975.

YIELD PRESSURES VS STRENGTH FOR THICK-WALLED
CYLINDRICAL TUBES UNDER UNIFORM EXTERNAL PRESSURE¹

t	D/t	FORMULA			YIELD PRESSURE (KSi)	GIVEN MATERIAL YIELD STRENGTH (psi)
		P _{YP}	P _P	P _T		
0.5	12.00	X			9.167	60,000
0.625	9.6	X			11.20	60,000
0.750	8.00	X			13.13	60,000
0.5	12.00	X			10.69	70,000
0.625	9.6	X			13.06	70,000
0.750	8.00	X			15.31	70,000
0.5	12.00	X			12.22	80,000
0.625	9.6	X			14.93	80,000
0.750	8.00	X			17.50	80,000
0.5	12.00	X			13.75	90,000
0.625	9.60	X			16.80	90,000
0.750	8.00	X			19.69	90,000
0.5	12.00	X			15.28	100,000
0.625	9.60	X			18.66	100,000
0.750	8.00	X			21.88	100,000
0.5	12.00	X			16.81	110,000
0.625	9.60	X			20.53	110,000
0.750	8.00	X			24.06	110,000
0.5	12.00	X			18.33	120,000
0.625	9.60	X			22.40	120,000
0.750	8.00	X			26.25	120,000
0.5	12.00	X			19.86	130,000
0.625	9.60	X			24.26	130,000
0.750	8.00	X			28.44	130,000
0.5	12.00		X			140,000
0.625	9.60	X			26.13	140,000
0.750	8.00	X			30.36	
0.5	12.00		X		22.33	150,000
0.625	9.60	X			27.99	150,000
0.750	8.00	X			32.81	150,000
0.5	12.00		X		23.49	160,000
0.625	9.60	X			29.86	160,000
0.750	8.00	X			35.00	160,000

t = wall thickness; D = outside diameter; P_{YP} = yield point formula; P_T = transition formula; P_P = plastic range formula

¹ Formulas and their applicable ranges are taken from API Bulletin No. 5C3, 2nd Edition, November 1974.

POTENTIAL VENDORS OF AIRCRAFT QUALITY
4140 OR 4340 STEEL TUBING

<u>DATE (INI. CONTACT)</u>	<u>VENDOR</u>	<u>AVAILABILITY</u>	<u>COST \$/FT. FOR FT.</u>	<u>COMMENTS</u>
Aug. 11	Jorgensen Steel Co. (213)567-1122 Jim Miller	Do not stock	\$57.87/ft for 6" round	\$45.83/ft to bore out to 4.8 in. I.D. Total=\$103.70/ft.
Aug. 11	Tubing Spec- alties, Div. of U.S. Steel Mr. Fred Call (800)348-8900	Not in stock, 6-8 weeks to manufacture	\$25.89/ft for stress reliev- ed; \$34.30/ft for heat treated	Must order 40- 140 ft. @ their option.
Aug. 16	Kilsby Tube Supply, "Cris" (303)371-7600	Not in stock		
Aug. 16	C. A. Russell, Inc., "Patty" (214)641-1222	Not in stock		
Aug. 23	Whitaker Metals (913)869-8661	Not in stock		
Aug. 23	Ducummin Metals, "Rodney" (713)675-4301	Not in stock		
Aug. 31	Channing- Hamilton Corp. Tron Carter (213)889-6791	140 ft. of 4340 in stock per AMS 6415	\$43.14/ft for 140 ft. \$57.36/ft for 40 ft.	\$2.00/ft for Staitening; \$4.95/ft for heat treating
Aug. 31	IML Metals, Inc. (516)981-1300	Do not stock		
Sept. 01	Babcox & Wilcox, Mr. Carne (412)846-0100	Not in stock; 6-8 weeks to manufacture	\$49.98/ft for 60-110 ft. (quantity at their option)	Contact via their inquiry #4138
Sept. 01	Wheeling- Pittsburg (412)288-3600	Not in stock		
Aug. 11 through Sept. 01	Other Steel Vendors and Manufacturers Contacted		Minimum buy of 5-12 tons	

POTENTIAL INSULATION VENDORS

DATE OF INITIAL CONTACT	VENDOR	PERSON CONTACTED	INSULATION TYPE		COMMENTS
			RIGID	FLEXIBLE	
30 July 1976	Johns-Manville R&D Center (303) 770-1000	Mr. Tony Silva	X	X	Their "MIN-K" rigid insulation is the best yet found.
"	Babcock & Wilcox (404) 798-8000	Mr. Ted Cook		X	
"	Pittsburgh- Corning (412) 327-6100	Mr. Chester Smolenski	X	X	
"	SONO-THERM, Inc. (716) 875-6625	Mr. Ernest Feine	X	X	Recommended Carborrundum brand rigid "FIBER-FRAX"
"	E. J. Davis Co. (203) 239-5391	Mr. Bill Major			Did not follow-up with literature as promised.
"	Permali, Inc. (412) 547-4581	Ms. Ruth Klingensmith	X		

APPENDIX B

MATERIAL SPECIFICATION,
PRESSURE VESSEL

1.0 INTRODUCTION

- 1.1 Scope: This specification sets forth controls for the procurement of aircraft quality low-alloy steel cold-drawn seamless mechanical tubing manufactured in accordance with AMS-6415H¹ and then subsequently heat-treated to a yield strength (0.2% offset) = 145,000 to 175,000 psi.
- 1.2 Purpose: The specified tubing will be used in fabricating a sealed cylindrical pressure vessel housing to protect an electronics canister package from a hostile environment. The pressure vessel will be subjected to an external pressure of 10,000 psi while emersed in water at 527° F for a 12-hour duration.

2.0 SPECIFICATIONS AND REQUIREMENTS

- 2.1 Vendor shall certify in writing to customer that the material supplied to customer per this specification is new material.
- 2.2 Material is to conform to the following before heat-treatment: 6.030 ± 0.030 inches outside diameter x 0.750 ± 0.050 inch wall thickness aircraft quality low-alloy steel cold-drawn seamless mechanical tubing manufactured in accordance with AMS-6415H with the exception that the diameter and wall thickness tolerances shall be as specified herein.
- Vendor shall furnish customer the certification stipulated in AMS-6415H.

2.3 Preparation for Heat-Treatment

- 2.3.1 Prior to heat-treatment, vendor shall engrave, impact-stamp, or otherwise permanently mark within 6" of one end of each piece of tubing the information required per paragraph No. 5.1.1.1 of AMS-6415H (this information already exists in ink). Permanent marking is defined as being easily read under normal room-ambient lighting conditions after the tubing is subjected to heat-treatment.

¹ Material manufactured to earlier revisions of AMS-6415 will be considered upon written request from vendor; approval for substitutions must be given in writing by customer.

2.3.2 Since, technically, the tubing will no longer conform to AMS-6415H after heat-treatment (due to an increase in hardness beyond the allowed maximum), the vendor shall have the option of placing any other additional markings within the 6" limited area specified in the previous paragraph (e.g., "Special", "Additional H.T.", etc.).

2.3.3 The markings and protective coating required per AMS-6415H shall not be removed except just prior to heat-treatment at the heat-treatment facility.

2.4 Heat-Treatment

2.4.1 The material shall be oil-quench and temper heat-treated to obtain the properties specified in paragraph 2.5.

2.4.2 The minimum allowable tempering temperature is 800° F.

2.5 Post Heat-Treatment Testing and Certification

2.5.1 Room-temperature yield strength (0.2% offset), tensile strength, elongation, and reduction of area tests shall be run on material samples in accordance with ASTM Specification No. A370. Samples are to be selected for these tests per the requirements of AMS-2370.

2.5.2 The allowable limits of acceptance are as follows:

- a) Yield strength (0.2% offset): 145,000-175,000 psi
- b) Elongation: 8.0% minimum
- c) Reduction of area: 45-70%

2.5.3 Vendor shall provide customer with written and certified documentation of testing conditions and results and the heat-treatment procedure.

2.6 Dimensions After Heat-Treatment: Tubing straightness shall conform to AMS-6415H limits. If straightening operations are required they shall be performed before the tensile yield specimens are taken.

Tubing diameter and wall dimensions shall conform to those specified in paragraph No. 2.2 after heat-treatment and after straightening operations (if they are used).

2.7 Protective Treatment: Subsequent to heat-treatment and prior to shipping, the tubing shall be coated with a suitable corrosion-preventive compound.

2.8 Packaging: The product shall be prepared for shipment in accordance with paragraph No. 5.3 of AMS-6415H.

3.0 REJECTIONS

Material not conforming to this specification or to authorized modifications will be subject to rejection.

POTENTIAL VENDORS OF AIRCRAFT QUALITY

4140 OR 4340 STEEL TUBING

<u>DATE</u> <u>(INI.CONTACT)</u>	<u>VENDOR</u>	<u>AVAILABILITY</u>	<u>COST</u> <u>\$/FT. FOR FT.</u>	<u>COMMENTS</u>
Aug. 11	Jorgensen Steel Co. (213)567-1122 Jim Miller	Do not stock	\$57.87/ft for 6" round	\$45.83/ft to bore out to 4.8 in. I.D. Total=\$103.70/ft.
Aug. 11	Tubing Spec- alties, Div. of U.S. Steel Mr. Fred Call (800)348-8900	Not in stock, 6-8 weeks to manufacture	\$25.89/ft for stress reliev- ed; \$34.30/ft for heat treated	Must order 40- 140 ft. @ their option.
Aug. 16	Kilsby Tube Supply, "Cris" (303)371-7600	Not in stock		
Aug. 16	C. A. Russell, Inc., "Patty" (214)641-1222	Not in stock		
Aug. 23	Whitaker Metals (913)869-8661	Not in stock		
Aug. 23	Ducummin Metals, "Rodney" (713)675-4301	Not in stock		
Aug. 31	Channing- Hamilton Corp. Tron Carter (213)889-6791	140 ft. of 4340 in stock per AMS 6415	\$43.14/ft for 140 ft. \$57.36/ft for 40 ft.	\$2.00/ft for Staitening; \$4.95/ft for heat treating
Aug. 31	IML Metals, Inc. (516)981-1300	Do not stock		
Sept. 01	Babcox & Wilcox, Mr. Carne (412)846-0100	Not in stock; 6-8 weeks to manufacture	\$49.98/ft for 60-110 ft. (quantity at their option)	Contact via their inquiry #4138
Sept. 01	Wheeling- Pittsburg (412)288-3600	Not in stock		
Aug. 11 through Sept. 01	Other Steel Vendors and Manufacturers Contacted		Minimum buy of 5-12 tons	

APPENDIX C

ENCLOSURE THERMAL SPECIFICATION

1.0 INTRODUCTION

1.1 Scope

This specification defines physical constraints, external environment, maximum operating time, and other parameters necessary to accomplish an analysis, design, and fabrication of a thermal-protective shroud for an instrumentation package.

1.2 Purpose

An enclosure consisting of a previously designed pressure vessel and a thermal shroud designed to this specification is to be employed to protect instrumentation used in surveying natural faults and hydraulically-induced fractures occurring in subterranean hot granite rock formations.

2.0 SPECIFICATIONS

- (a) Maximum hostile environment pressure is 10,000 psi.
Maximum hostile environment temperature is 275°C (527°F).
- (b) The medium of the hostile environment is water.
- (c) Maximum continuous time of enclosure in the hostile environment is 12 hours.
- (d) Minimum time between enclosure emersions in the hostile environment is 24 hours; during this cooling period, the enclosure will be placed in an air ambience at -30°C to +30°C temperature.
- (e) Before the enclosure is placed in the hostile environment the interior will be evacuated of air and then filled with dry nitrogen gas to a pressure of 11.1 ± 2.0 psia (absolute pressure).
- (f) The instrumentation package (e.g., Multiplex System electronics canister) will be placed within the "electronics package cavity" depicted in Figure C1 and vented to the dry nitrogen atmosphere.
- (g) Power dissipation of the instrumentation package will be limited to a maximum of 15-watts.
- (h) A thread gage will be furnished if vendor chooses to fabricate the

pressure vessel as well as the thermal fabrication (ref. paragraph 5.0).

- (i) Figure C1 is subject to minor changes and is to be used for bidding purposes only; finalized drawings will be furnished to vendor for firm design and fabrication at a later date.
- (j) The longitudinal axis of the enclosure will be limited to 15° maximum deviation from vertical when emersed in the hostile environment.

3.0 REQUIREMENTS

- (a) Figure C1 and its "Notes" are to be considered a part of this specification. In the event of conflicting requirements, this specification should take precedence over Figure C1.
- (b) A copy of Figure C1 shall be annotated in red ink to show pertinent interface dimensions, signed, and returned to customer at time of bid submitted.
- (c) Insulation materials, if used, shall not support fungus growth.
- (d) If a vacuum chamber is employed in lieu of insulation: the chamber must withstand the application of 0-20 psia absolute external pressure at a temperature of 275°C without damage or distortion beyond the tolerance limits shown in Figure C1. Also, the vacuum must be permanent; no maintenance shall be required.
- (e) Heat sink, if used, must be encased and hermetically sealed if it would be in the liquid phase under an absolute external pressure of 9.0 psia at a temperature of 280°C. Furthermore, it must be able to withstand the application of 0-20 psia absolute external pressure at a temperature of 275°C without damage or distortion beyond the tolerance limits shown in Figure C1.
- (f) The enclosure thermal shroud shall not require the addition of any "charging" material (such as cryogenic materials or ice).
- (g) The thermal shroud shall be designed so that the instrumentation (electronics) canister interior ambient temperature does not exceed 85°C for a period of 12 hours after the enclosure is emersed in the hostile environment; the interior electronics will dissipate a maximum of 15 watts for a period of 10 hours while the enclosure is emersed.

- (h) Vendor shall specify, at time of bid submittal, if the enclosure must be in a certain position during its cooling period; if the enclosure must be disassembled for cooling; if air must be blown through or across the enclosure for cooling; or if any other special cooling methods are required.
- (i) Vendor shall specify, at time of bid submitted, if enclosure must be stored or transported in any particular position.
- (j) If vendor finds it necessary and/or advantageous to employ a thermal-conductive compound in the annulus between the instrumentation (electronics) canister and the heat sink (ref. Figure C1), he shall specify same at time of bid submittal. If this choice is made the compound shall not bond the surfaces together, flow under the specified conditions, or cause corrosion of the mating materials. Also, the tolerances controlling the annulus size (e.g., heat sink I.D.) will be tightened.

4.0 ACCEPTANCE TESTS

It is the intention of customers to monitor, as deemed necessary, tests conducted by the vendor or by an approved laboratory selected by vendor. Reports on tests conducted by laboratories other than the vendor's must be prepared by the laboratory conducting such tests.

Certified test reports depicting the results of all required Acceptance Tests shall be submitted to customer.

4.1 Schedule

Vendor shall schedule the required tests to be accomplished in a maximum of three (3) consecutive working days. The first day of testing shall not be scheduled to begin on Friday, Saturday or Sunday.

4.2 Customer Notification

Vendor shall notify customer's Project Manager (or his designated alternate) via telephone at least seventy-two (72) hours in advance of the beginning of the required tests; Saturdays and Sundays will not be credited toward this time requirement.

4.3 Accuracy of Test Apparatus

Vendor shall supply all test apparatus necessary to accomplish the tests. Measuring instruments must be accurate within $\pm 5\%$ and must have been calibrated within 30 days of the beginning of the tests by an independent calibration laboratory; customer reserves the right to have the instrumentation calibrations verified and/or recalibrated at any time.

4.4 Testing Procedure

The tests are to be run in the following ascending sequential order:

4.4.1 Shock Test

- 1) Assemble the complete enclosure as shown in Figure C1 except:
 - a) Seals are not required.
 - b) A dummy electronics canister (provided by customer) weighing approximately 3 pounds will be placed in the electronic package cavity.
 - c) Rigid end-caps (provided by customer) shall be placed on each end of the enclosure.

2) Vertically suspend the assembly 2.0 ± 0.1 inches above a hardened steel plate (Brinell Hardness of 250 minimum); the electronics cavity toward the bottom. The steel plate is to be backed by other materials of sufficient strength and rigidity to limit deflections of the steel plate, induced by enclosure impact, to less than 0.1 inches.

3) Quick-release (without impeding gravitational acceleration) the enclosure so that it impacts the steel plate.

4) In a similar manner as above, horizontally suspend the enclosure and drop it.

5) Disassemble the enclosure and examine it for damages; the interior parts (parts housed within the pressure vessel) shall show no damages or any deformations beyond their toleranced limits of Figure C1.

4.4.2 Temperature Test

- 1) Assemble the complete enclosure as shown in Figure C1 except:

- a) Install a customer furnished dummy electronics canister with an internal 15-watt source (suspended near its middle) in the electronics package cavity.
 - b) Place two temperature-sensing probes (or devices) within the canister approximately one (1) inch from each end. The probes are to be used to monitor the ambient temperature of the nitrogen gas; hence, they should be suspended so that they do not have a thermal conductive path to the canister walls.
 - c) Seal the enclosure passages approximately as shown in Figure C1 with the logging cable in place.
 - d) A logging cable and cable head (both furnished by customer) will be connected to one end of the enclosure; electrical connections for the 15-watt source and the temperature probes are to be made via this cable (do not energize the 15-watt source at this time).
 - e) Apply an end-cap to the other end of the enclosure.
- 2) Connect a vacuum pump and evacuate the interior. Backfill the interior with dry nitrogen gas to an absolute pressure of 11.1 ± 1.0 psia.
- 3) Begin uniform heating of the pressure vessel exterior surface (via heat-tapes, environmental chamber, or other means). The exterior surface shall reach and maintain a temperature of $275^{\circ}\text{C} \pm 5^{\circ}\text{C}$ within one (1) hour after heating begins. If heat-tapes are used, at least three surface points shall be monitored and the lesser temperature of the three will be used as the controlling temperature.
- 4) One hour after the heating cycle begins, energize the 15-watt internal heat source.
- 5) Disconnect the 15-watt internal heat source ten hours after being energized.
- 6) The ambient temperature within the canister shall not exceed $+85^{\circ}\text{C}$ for a period of twelve (12) hours from the application of the external heat.

7) At the end of the 12-hour period the external heat source shall be removed from around the enclosure. The enclosure shall be cooled at room ambient temperature ($23^{\circ}\text{C} \pm 7^{\circ}\text{C}$) in accordance with vendor's recommended method (at time of bid submittal). While cooling, the canister interior temperature must not rise above 100°C .

8) Promptly, at the end of the 24-hour cooling period,* the Temperature Test will be repeated beginning with step No. 3, above. This second test is run for the purpose of demonstrating the ability of the enclosure heat sink to regenerate itself in the allotted time.

- a) If a Pressure Test is required (ref. paragraph No. 4.4.3), it shall be initiated at the beginning of the eleventh hour of the second temperature test (during step No. 6).
- b) If a Pressure Test is not required, the Temperature Test shall be continued through step No. 7.

After the enclosure has cooled sufficiently, it shall be disassembled and inspected for damages and distortions of the vendor supplied interior parts.

4.4.3 Pressure Test

This test is designed to determine the structural integrity of the hermetically sealed heat sink and/or vacuum chamber under external pressure. If neither of these devices are employed in the thermal shroud, this test is to be omitted from the required Acceptance Tests.

If either one or both of these devices exists the following test sequence shall be run, beginning at the eleventh hour of the second Temperature Test:

- 1) Hold the temperature constant at $275^{\circ}\text{C} \pm 5^{\circ}\text{C}$.
- 2) Pull a vacuum on the interior of the pressure vessel (enclosure housing).
- 3) After 0.5 hours, backfill the pressure vessel with dry nitrogen to 20.0 psia (absolute pressure).

* Vendor may proceed earlier if he determines that the heat sink has regenerated sufficiently.

4) After an additional 0.5 hours, remove the external heat source from around the enclosure and begin the cooling cycle as specified in step No. 7 of the Temperature Test. Also, equalize the internal pressure with that of the room.

5) After the enclosure has cooled sufficiently, it shall be disassembled and inspected for damages and distortions of the vendor supplied interior parts.

4.4.4 Final Acceptance

If the Shock, Temperature, and Pressure (if required) Tests were passed with no apparent damage to the pressure vessel interior components supplied by vendor, the customer's representative shall supply vendor with a signed statement acknowledging Acceptance Test passage.

If any tests are failed or damages are found, vendor shall instigate corrective action. Subsequently, customer may require any or all tests to be re-run.

5.0 BIDDING INSTRUCTIONS

Potential vendors may bid either "Option A", "Option B", or both.

5.1 "Option A"

The bidder (potential vendor) will supply all materials and labor required to accomplish a thermal analysis, thermal design, fabrication and installation of the pressure vessel interior thermal shroud components necessary to conform to the intent of this specification.

Customer will provide a finished pressure vessel (enclosure housing) and set-screw retaining rings ready for vendor's use.

5.2 "Option B"

The same as "Option A" except:

- a) Customer will provide the raw material (steel tubing) necessary for vendor to fabricate the pressure vessel (enclosure housing).
- b) Customer will provide a thread gage for the external pressure vessel threads.

- c) Customer shall provide the material for the set-screw retaining rings.
- d) Vendor will fabricate the pressure vessel and set-screw retaining rings from material supplied by customer to customer's drawings.
- e) Vendor will machine the external pressure vessel threads so that they mate with a thread-gage supplied by customer.

6.0 REJECTIONS

Equipment not conforming to this specification or to authorized modifications will be subject to rejection.

7.0 PACKAGING AND SHIPMENT

Upon successful completion of the acceptance tests, vendor shall package the enclosure in a substantially strong crate (at vendors expense) to insure against its damage. Vendor shall then ship the packaged enclosure to customer; shipping charges prepaid by vendor.

8.0 VENDOR WARRANTY

Vendor shall warrant that he will expediently repair or replace any defect in workmanship and/or material found within one year from the date of delivery. Vendor shall be responsible for all costs incurred to correct any defects in his product including packing and transportation charges.

DISTRIBUTION:

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NOTES (UNLESS OTHERWISE SPECIFIED):

- ① DIMENSION SPECIFIED BY VENDOR WITH TOLERANCE SHOWN AT TIME OF BID.
- ② CONNECTOR RECESS AND MOUNTING DIMENSIONS TO BE DETERMINED BY CUSTOMER AT A LATER DATE.
- ③ VENDOR SHALL PROVIDE FOR EASY REMOVAL OF A FULL SIZE ELECTRONICS CANISTER (PROVIDED BY CUSTOMER) FROM THE ELECTRONICS PACKAGE CAVITY.
- ④ VENDOR SHALL NOT WELD TO, CUT GROOVES IN, DRILL, OR OTHERWISE MAKE CHANGES IN THE MECHANICAL INTEGRITY OF THE PRESSURE VESSEL WITHOUT WRITTEN CONSENT OF CUSTOMER.
- ⑤ RATIO OF INSULATION HEAT SINK AND VACUUM CHAMBER (IF USED) IS OPTIONAL WITH VENDOR WITHIN THE SPECIFIED LIMITS.
- ⑥ CONNECTOR MOUNTING STUDS OR RECESSED TAPPED HOLES TO BE SPECIFIED BY CUSTOMER AT A LATER DATE.
- ⑦ ALL DIMENSIONS ARE IN INCHES.
- ⑧ NON-PRESSURE SEALS WILL EXIST APPROXIMATELY IN THE AREAS SHOWN (ACCOMPLISHED BY CUSTOMER AROUND CABLE HARNESS, ETC.)
- ⑨ THESE ARE TUBING CONTROL DIMENSION USED BY MILL; THE I.D. CAN BE CONTROLLED TO CLOSE TOLERANCE BY MACHINING IF NECESSARY.

FIGURE NO. C1

(SCALE: NONE)

C900023