MASTER

**SUMMARY OF GEOSCIENCE'S DESIGN STUDIES
FOR THE ROD HEAT FLUX TRANSDUCER AND
THE THERMAL CONDUCTIVITY PROBE**

Energy Research and Development Administration

Contract E(04-3)-1318

**A. J. Sellers
D. J. Connelly
H. F. Poppendiek
C. M. Sabin**

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

August 1977

**GEOSCIENCE LTD
410 South Cedros Avenue
Solana Beach, California 92075**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

WDM

TABLE OF CONTENTS

I. INTRODUCTION	1
II. STRUCTURAL STRENGTH CALCULATIONS	2
1. Rod Heat Flux Transducer	2
2. Thermal Conductivity Probe	2
3. Cable and Electrical Connectors	4
III. TEMPERATURE LEVEL AND CORROSION EFFECTS ON MATERIAL INTEGRITY	8
IV. DESIGN DRAWINGS	9
V. CONCLUDING REMARKS	10

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

I. INTRODUCTION

The designs of the heat flux transducer and thermal conductivity probe are based on several factors. First, theoretical considerations dictate the long cylindrical form of the transducers and limit some parameters such as wall thickness. Secondly, the probes must be strong enough to withstand the downhole environment and the handling necessary to lower them into the hole and remove them repeatedly. Further, they must be reasonably easy to fabricate and, if necessary, repair.

The following sections include the results of some of the calculations made and information gathered in meeting these design criteria. The design drawings for the transducers are also presented.

II. STRUCTURAL STRENGTH CALCULATIONS

1. Rod Heat Flux Transducer

The rod heat flux transducer itself (not including cables or electrical connectors which will be discussed in a separate section) presents no structural strength problems in the most severe conditions expected in the downhole environment. The extremely thick walls of this transducer make it very strong.

2. Thermal Conductivity Probe

It is desirable in the case of the thermal conductivity probe to make the wall as thin as possible consistent with the required strength. Therefore, calculations were made to determine the structural strength of various probe designs under expected conditions of temperature and pressure. Three independent strength criteria were considered, namely, the hoop stress, the buckling pressure and the collapsing pressure.

The hoop stress was calculated for the assumed pressure level for each shell configuration. This stress, when compared to the yield strength of 76,500 lb/in² for 316 stainless steel at 500°F, gives an indication of the ability of the shell to withstand the external fluid pressure without material failure.

Calculations were also carried out to determine the pressure at which the cylindrical probe would fail in an elastic, axial buckling mode. In this analysis

it was assumed that the shell ends are closed and held circular by the end plates; the system is exposed to uniform external radial and longitudinal pressure. (1, 2) The pressure at which failure by buckling occurs was found from the following equation:

$$P = \frac{E \left(\frac{t}{r}\right)}{1 + \frac{1}{2} \left(\frac{\pi r}{n l}\right)^2} \left\{ \frac{1}{n^2 \left[1 + \left(\frac{n l}{\pi r}\right)^2\right]^2} + \frac{n^2 t^2}{12 r^2 (1 - \mu^2)} \left[1 + \left(\frac{\pi r}{n l}\right)^2\right]^2 \right\}$$

where

P = external pressure

E = modulus of elasticity

t = wall thickness

r = tube radius

n = number of lobes formed by the tube
in buckling

l = tube length

μ = Poisson's ratio

It has been shown in the literature that tubes under external pressure collapse laterally before the hoop stress exceeds the yield strength of the material.⁽³⁾ A number of empirical relationships have been found for predicting the pressure

¹ Saunders, H.E., Windenberg, D.F., "Strength of Thin Cylindrical Shells Under External Pressure", Trans. Am. Soc. Mech. Eng., Vol. 53, No. 15, p 207, 1931.
² Von Mises, R., "Der kritische Aussendruck Zylindrischer Rohre", Zeits, Vereine deutscher Ing., Vol. 58, p 750, 1914.
³ Love, A.E.H., "Mechanical Engineers' Handbook", L. S. Marks, Ed; p 422, 1951.

at which a tube will collapse under various conditions. Calculations were made using the formula which is most suitable in the present case, namely, a thin-walled steel tube where $t/d > 12$. This experimentally derived formula is:

$$P = 65,720,000 \left(\frac{t}{d}\right)^3$$

d = outside diameter of the tube

Typical results from the thermal conductivity probe shell strength analyses can be seen in Tables 1 and 2. A range of applicable tube diameters, lengths and wall thicknesses have been considered. Table 1 relates to the condition of a 2300 ft. head of water above the probe ($p = 1000$ psi) and Table 2 relates to the condition of a 7000 ft. head ($p = 3000$ psi). In each table, hoop stresses, the buckling failure pressure and the collapsing failure pressure are given.

Although a number of the designs outlined in Tables 1 and 2 have failure pressures that exceed hole pressures, some do not have sufficient safety factors; therefore, some reductions in hole pressure would still have to be made.

3. Cable and Electrical Connectors

The cable tentatively chosen for use with both transducers is a 7/32 inch diameter, four conductor cable with a maximum temperature rating of 500°F manufactured by Rochester Corporation. With the heaviest transducer presently envisioned (750 lbs) at the end of 7000 ft. of this cable, the static load at

TABLE 1

(head = 2300 ft

pressure = 1000 lb/in²)

Outside Diameter (inches)	Wall Thickness (inches)	Length (feet)	Hoop Stress (lb/in ²)	Buckling Failure Pressure (lb/in ²)	Collapsing Failure Pressure (lb/in ²)	Acceptable (In Comparison to the 1000 lb/in ² Fluid Pressure)
5.5	0.100	9	22,500	900	395	No
5.5	0.125	9	18,000	1800	770	No
5.5	0.150	9	15,000	3000	1300	Yes

TABLE 2

(head = 7000 ft

pressure = 3000 lb/in²)

Outside Diameter (inches)	Wall Thickness (inches)	Length (feet)	Hoop Stress (lb/in ²)	Buckling Failure Pressure (lb/in ²)	Collapsing Failure Pressure (lb/in ²)	Acceptable (In Comparison to the 3000 lb/in ² Fluid Pressure)
3.5	0.120	7	42,700	6400	2600	No
3.75	0.120	7	45,900	3100	2100	No
4.0	0.188	7	30,700	10,200	6800	Yes
4.25	0.188	7	32,800	8500	5700	Yes
4.5	0.188	7	34,800	7000	4800	Yes
5.5	0.200	9	33,800	7100	2800	No
5.5	0.250	9	27,000	14,100	3500	Yes

the top of the cable would be about 1400 lbs which is well below the nominal breaking strength of 4400 lbs.

In the transducer designs shown in Section IV of this report, a Gearhart-Owens connector and cable head is used to mate the transducer and cable.

Using the projected thread area for a normal tight joint thread engagement length of 1/2 inch and the weight of the heaviest heat flux transducer, the load on the threads is 770 lb/in^2 which is well within safe limits (approximately 2000 lbs/in^2).

III. TEMPERATURE LEVEL AND CORROSION EFFECTS ON MATERIAL INTEGRITY

All of the materials used in the two types of transducers, including the Teflon insulators are rated for a continuous service temperature of 500°F. Corrosion by hot geothermal brines is not expected to be a problem in the relatively short-time exposures experienced by the transducers.

IV. DESIGN DRAWINGS

The design drawings are attached to this report.

V. CONCLUDING REMARKS

The calculations in this report consider a range of possible transducer configurations. The specific dimensions of the transducers that are finally built will relate to the size of the hole which is chosen for the downhole experiments.

TRANSDUCER MATERIALS LIST

HEAT FLUX TRANSDUCER

<u>Component Description</u>	<u>Material</u>
Rod	steel; aluminum
Plate	steel
Thermopile elements	copper-constantan; chromel-alumel
Cablehead	SS
Bolts	steel
Seal rings	SS
Electrical insulation	silicone
Compression rings	SS
Compression plugs	Teflon

THERMAL CONDUCTIVITY PROBE:

<u>Component Description</u>	<u>Material</u>
Shell tube	SS
Plate	SS
Thermopile elements	copper-constantan; chromel-alumel
Heater strip	SS; nichrome
Insulation sheet	Teflon
Cablehead adaptor	SS
Welding rod	SS
Electrical insulation	silicone
Core insulation	vermiculite
Compression rings	SS

ERDA CONTRACT E(04-3)-1318 RELATES TO THE DEVELOPMENT OF TWO NEW TRANSDUCER SYSTEMS WHICH MEASURE GEOTHERMAL HEAT FLUX AND EARTH THERMAL CONDUCTIVITIES IN BOREHOLES. ONE OF THEM, THE GEOTHERMAL HEAT FLUX TRANSDUCER SYSTEM, CONSISTS OF TWO LONG CYLINDRICAL SECTIONS CONTAINING THERMOPILES TO MEASURE AXIAL HEAT FLOW. THE GEOTHERMAL HEAT FLUX IN THE EARTH IS EXTRACTED FROM THE TWO TRANSDUCER MEASUREMENTS WITH THE AID OF MATHEMATICAL TWO-DIMENSIONAL HEAT FLOW SOLUTIONS FOR THE GEOMETRIES INVOLVED.

3		BOTTOM PLUG		
2		PROBE BODY		
1		G-O MALE BODY & PIN WIRE CONNECTOR		
No.	REV. DATE	DESCRIPTION AND DIMENSIONS	REQ'D PAGE	MATERIAL
SCALE		TITLE	1	
1:10		HEAT FLUX TRANSDUCER	OF	
UNLESS OTHERWISE STATED ALL DIMENSIONS IN		DRAWN BY	DATE	APPROVED
		GEOSCIENCE LTD.		DATE
				CONTRACT
				E(04-3)-1318
				DWG. NO.
				0105

Technical drawing of a mechanical part showing two cross-sectional views. The top view is a half-section with a central vertical line labeled 'E'. The bottom view is a full section with diagonal hatching. Dimensions include 1.530 DIA at the top, 1.0 DIA for a central hole, and 1/2 inch for a side feature. A vertical dimension line on the left is labeled 'L'.

-3		BAR, D" DIA x L" LG	1	STEEL
-2		BAR, D" DIA x L" LG	1	STEEL
-1		BAR, D" DIA x L" LG	1	STEEL
No.	REV. DATE	DESCRIPTION AND DIMENSIONS	REQD PAGE	MATERIAL
SCALE 1:1 EXCEPT AS NOTED	TITLE <u>HEAT FLUX TRANSDUCER</u> <u>BODY</u>		OF	2
UNLESS OTHERWISE STATED ALL DIMEN- SIONS IN INCHES	DRAWN BY	DATE	APPROVED	DATE CONTRACT E(04-3)-1310
GEOSCIENCE LTD.			DWG. NO. 0105

- 2 TOP (BOTTOM) PLATE

- 3 TOP (BOTTOM) PLATE

-3	TOP (BOTTOM) PLATE, 3 1/2 DIA - 5/8 TH	2	STEEL
-2	TOP (BOTTOM) PLATE, 3 1/2 DIA - 5/8 TH	2	STEEL
NO.	REV. DATE	DESCRIPTION AND DIMENSIONS	REC'D
SCALE	1:1	HEAT FLUX TRANSDUCER TOP AND BOTTOM PLATE	PAGE 3
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS IN INCHES			
GEOSCIENCE LTD.			
0105

G-O BLANK MALE BODY, 04-1020-81		1	55
SCALE	1:1	FOUR PIN, MALE CONNECTOR HOUSING	FACE 4
UNIT	INCHES	DATE	0105
E(04-3)-1318		0105

		THERMOPILE WIRE, AWG #30		CONSTANTAN
		THERMOPILE WIRE, AWG #30		COPPER
No.	REV. DATE	DESCRIPTION AND DIMENSIONS	REQ'D	MATERIAL
SCALE	TITLE		PAGE	5
		HEAT FLUX TRANSDUCER	OF	
		THERMOPILE SCHEME		
UNLESS OTHERWISE STATED ALL DIMENSIONS IN INCHES		DRAWN BY	DATE	APPROVED
		GEOSCIENCE LTD.		DATE
				CONTRACT
				E(04-3)-1318
				DWG. NO.
				0105

3	BOTTOM PLUG				
2	PROBE BODY				
1	G-0 MALE BODY & PIN MALE CONNECTOR				
NO.	REV. DATE	DESCRIPTION AND DIMENSIONS		REQ'D	MATERIAL
SCALE		TITLE		PAGE	1
1:10		THERMAL CONDUCTIVITY PROBE		OF	
UNLESS OTHERWISE STATED ALL DIMENSIONS IN INCHES		DRAWN BY	DATE	APPROVED	DATE CONTRACT
					E(04-3)-131B
GEOSCIENCE LTD.				DWG. NO.	0.106

2		TUBE, D'OD - .111" WALL X 1" LG.	1	55
1		TUBE, D'OD - .111" WALL X 1" LG.	1	55
No.	REV. DATE	DESCRIPTION AND DIMENSIONS	REV'D	MATERIAL
SCALE	TITLE		PAGE	2
1:1		THERMAL CONDUCTIVITY PROBE SHELL	OF	
UNLESS OTHERWISE STATED ALL DIMENSIONS IN INCHES	DRAWN BY	DATE	APPROVED	DATE CONTRACT
				8/01/8-1218
		GROSCIENCE LTD.	DWG. NO.	0106

REV. 2	BAR, D" DIA. x 3" LG	2	SS
REV. 1	BAR, D" DIA. x 5/8" LG	2	SS
NO.	DESCRIPTION AND DIMENSIONS	REV. D.	MATERIAL
SCALE	TITLE	PAGE	3
1:1	THERMAL CONDUCTIVITY PROBE TOP AND BOTTOM COVER PLATES	OF	
UNLESS OTHERWISE STATED ALL DIMEN- SIONS IN	DRAWN BY DATE APPROVED DATE	CONTRACT E(043)-1218	DWG. NO. 0106
	GEOSCIENCE LTD.

1	HEATER STRIP, 1/8" x 1/8" x .002"	17	SS
2	HEATER STRIP, 1/8" x 1/8" x .002"	17	SS
3	WIRE, AWG #30		CONSTANTAN
4	WIRE, AWG #30		COPPER
5	SUPPORT PLATE, 1/8" x 1/8" x 1/16"	1	TEFLON
6	REV. DATE	REV. DATE	REV. DATE
7	SCALE	TITLE	PAGE
8	1:1	THERMAL CONDUCTIVITY PROBE	4
9	AS NOTED	OF	
10	AS NOTED	AS NOTED	AS NOTED
11	STUFFED ALUMINUM	DATE	DATE
12	SIGNS IN INCHES		
GLOSCIENCE LTD		E(003)-1318	
		FAC NO.	
		0106

SECTION A-B
-1 ASSEMBLY

SECTION C-D
-2 ASSEMBLY

SECTION E-F
-3 ASSEMBLY

NO.	REV.	DATE	DESCRIPTION AND DIMENSIONS	REQ'D	MATERIAL
SCALE	TITLE			PAGE	6
1:1	HEATFLUX TRANSDUCER ASSEMBLY			OF	
UNLESS OTHERWISE STATED ALL DIMENSIONS IN INCHES		DRAWN BY	DATE	APPROVED	DATE
		GEO SCIENCE LTD.		CONTRACT 604-3-1718	
				DWG. NO. 0106	