JHU/APL
QM-80-190
DECEMBER 1980
Copy No.

*Geothermal Energy Development
in the Eastern United States*

**TECHNICAL ASSISTANCE REPORT NO. 6
GEOTHERMAL SPACE HEATING AND
AIRCONDITIONING — MCGUIRE
AIR FORCE BASE, NEW JERSEY**

F. K. HILL

R. von BRIESEN

This work was supported by the Department
of Energy under Interagency Agreements
EX-76-A-36-1008 and DE-Alo1-79ET27025

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY

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.

JHU/APL

QM-80-190

DECEMBER 1980

*Geothermal Energy Development
in the Eastern United States*

**TECHNICAL ASSISTANCE REPORT NO. 6
GEOTHERMAL SPACE HEATING AND
AIRCONDITIONING — McGUIRE
AIR FORCE BASE, NEW JERSEY**

F. K. HILL

R. von BRIESEN

DECEMBER 30, 1980

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY
Johns Hopkins Road, Laurel, Maryland 20810
Operating under Contract N00024-78-C-5384 with the Department of the Navy

Geothermal Space Heating
McGuire Air Force Base, New Jersey

PREFACE

This is one in a series of reports on technical assistance in the utilization of geothermal energy. The scope of technical assistance is limited to basic technical and economic feasibility analysis to assist in deciding whether detailed engineering is warranted now, or in the future. This effort is supported by the U.S. Department of Energy's Division of Geothermal Energy (Dr. David B. Lombard, Program Manager). The Laboratory's role is limited to the Eastern United States.

The analysis documented in this report was initiated at the request of Col. Franklin W. Myers, Headquarters Military Airlift Command (MAC), Scott AFB, with the concurrence of Mr. Edward Porr, Deputy Base Civil Engineer, McGuire AFB.

Previous technical assistance reports are as follows:

1. "Geothermal Space Heating - Crisfield High School," APL/JHU Technical Assistance Report No. 1.
2. "Geothermal Energy Applied to the Mariculture Industry on the Eastern Shore of Maryland," APL/JHU Technical Assistance Report No. 2.
3. "Geothermal Vaporization of LNG by Geothermal Water," APL/JHU Technical Assistance Report No. 3.
4. "Geothermal Space Heating - Pittsville Middle/Elementary School," APL/JHU Technical Assistance Report No. 4.
5. "Geothermal Space Heating - Naval Air Rework Facility, Norfolk, Virginia," APL/JHU Technical Assistance Report No. 5.

SUMMARY

A method of utilizing the geothermal (66°F) water resource for space heating and cooling of 200 of the 1452 housing units at McGuire AFB is suggested. Using projections of future costs of gas, coal and electricity made by DOD and by industry (Westinghouse), the relative costs of the geothermal-water-plus-heat-pump system and the otherwise-planned central gas heating (to be converted to coal in 1984) and air-conditioning (using individual electric units) system are compared.

For heating with the geothermal/heat-pump system, an outlet temperature of 130°F is selected, requiring a longer running time than the conventional system (at 180°F) but permitting a COP (coefficient of performance) of the heat pump of about 3.4. For cooling (obtained in this study by changing directions of water flow, not refrigerant cycles), the change in temperature is less, and a COP near 4.5 is obtained. The cost of cooling in the summer months would be significantly less than the cost of using individual electric air-conditioners. Thus, by using nonreversible heat pumps, geothermal water is used to heat and to cool a section of the housing compound, minimizing operating expenditures.

It is estimated that, to drill 1000 ft deep production and reinjection wells and to install ten heat pumps, heat exchangers and piping, would require a capital outlay of \$643K. This cost would replace the capital cost of purchasing and installing 200 air-conditioning units and 14% of the cost of the future coal-fired central heating system (which would otherwise serve all 1452 housing units at McGuire). The net additional capital outlay would be \$299K, which could be amortized in 10 years by the lower operating cost of the geothermal system if electricity and coal prices escalate as industry suggests. If the coal and electricity costs rise at the more modest rates that DOD projects, the capital costs would be amortized in a 15 year period.

I. Introduction

An evaluation has been made of the potential use of geothermal energy at McGuire AFB to: a) reduce the use of natural gas (or coal after 1984) for heating water; and b) improve the efficiency of the heating and cooling systems provided for the Base's housing units. An inspection of the heating system on September 25, 1980, as well as drawings and data supplied by Mr. John Bernet at McGuire AFB and recorded in Ref. 1, defined the areas where geothermal energy could be used. It was not immediately obvious that a geothermal application would be practical because the available well water temperature at depth is approximately 66°F, and the cost of heating via burning gas is relatively low at present.* However, a rework program is now in process to refurbish the living quarters, to convert the heating system to use coal by 1984 or 1985, and to add air-conditioning. The refurbishment is only partly completed while the whole system of central heating and transmission of hot water at least two miles to the housing area is wasteful because of leaks and heat losses. The question, then, was whether the use of a geothermal/heat pump system for both heating and cooling of 200 of the 1452 housing units on the Base would be economical.

II. Application of Geothermal Energy

The utilization of geothermal water for heating and cooling was considered for that area of the housing compound where the refurbishment is scheduled but not yet implemented, so that avoidance of the capital expenditure for air-conditioning units would take care of part of the capital costs for the installed geothermal system. The program considered herein uses one geothermal well and ten heat pumps to supply 14% of the total heating and cooling loads in an area. Ten "U"-shaped complexes of 20 units each (200 units total) would be served (see Fig. 1 schematic).

A. Heating

The data supplied indicated a need for 50×10^6 BTU/hr maximum load in the entire housing compound comprising 1452 housing units (Ref. 1), so that the aforementioned 200 units are assumed to have a peak heating requirement of

*\$1.92/10⁶ BTU is cost calc. from EUN for "Industries Nat. Gas to Boilers," in 1980 \$, as shown in Table 1.

Fig. 1 Schematic of heat transfer and loss conditions.

6.9×10^6 BTU/hr. This group size was selected to match the heat produced by one 1000 ft deep well producing 700 gpm at 66°F* (see Appendix E). The plan then suggests that a production and reinjection well be drilled at a convenient location central to the selected group of ten complexes (Fig. 1). The tepid geothermal water would be piped to each of the complexes where a heat pump could raise the temperature of water circulated to each of the 20 housing units in each complex. A schematic of this system is shown in Fig. 2. The pertinent calculations for heat delivery and costs are given in Appendix A and Tables A1 and A2. Since this system will reduce the maximum heat load on the Base main supply by 14%, both the supply temperature and transmission line loss may be reduced. The transmission loss, estimated to be at least 10% of the delivered heat load of the existing system or 5×10^6 BTU/hr, would be reduced to 4.23×10^6 BTU/hr. Calculation of this loss is given in Appendix C.

B. Air-Conditioning

The temperature of the wellhead water at depth (1000 ft) should be 66°F, suitable for use in a heat pump to do space cooling as well as heating. The calculations for cooling performance of the heat pump are given in Appendix B and Tables B1 and B2. It is assumed that the same heat exchanger-convective system can be used for cooling as for heating in each of the housing units. No additional capital equipment has, therefore, been added for air-conditioning.

III. Operating and Capital Costs

The rapidly changing price of fuel oil, natural gas, coal and electricity have a significant effect on the cost of conventional heating and cooling systems and on the projected payback period for amortizing capital costs of a geothermal/heat-pump system. In order to indicate the range of operating costs which may be encountered in the next 10 to 11 years, two sets of escalation figures were selected. These figures for energy fuel rates are shown in Table 1. The first set is based on DOD economics as presented in Refs. 4 and 5. The second set of figures is recommended by industry, in this

* [Four wells, approximately 1000 ft deep at the Base have been drilled and each has produced 700 gpm or more. There is a large aquifer of potable water underlying this area of New Jersey (Ref. 3)].

Fig. 2 Schematic geothermal application for ten housing complexes.

Table 1
Gas, coal and electricity escalation rates.

	DOD economic projections						Industry projections							
	Gas		Coal		Electricity		Gas		Coal		Electricity		Oil	
	Escal. Rate	\$/10 ⁶ BTU	Escal. Rate	\$/10 ⁶ BTU	Escal. Rate	\$/10 ⁶ BTU	7% Infl. +13% Escal. Rate	\$/10 ⁶ BTU	7% Infl. +4% Escal. Rate	\$/10 ⁶ BTU	7% Infl. +3% Escal. Rate	\$/10 ⁶ BTU	7% Infl. +7% Escal. Rate	\$/10 ⁶ BTU
1980	20%	1.92	15%	1.51	16%	10.44	20%	1.92	11%	1.51	10%	10.44	14%	4.70
1981	↓	2.30	↓	1.74	13	11.80	↓	2.30	↓	1.68	↓	11.48	↓	5.30
1982	↓	2.76	↓	2.00	13	13.33	↓	2.76	↓	1.86	↓	12.63	↓	6.11
1983	↓	3.32	↓	2.30	13	15.06	↓	3.32	↓	2.07	↓	13.90	↓	6.96
1984	↓	3.98	↓	2.64	7	16.12	↓	3.98	↓	2.29	↓	15.28	↓	7.94
1985	↓	4.78	↓	3.04	↓	17.25	↓	4.78	↓	2.54	↓	16.81	↓	9.05
1986	↓	5.73	↓	3.49	↓	18.45	↓	5.73	↓	2.82	↓	18.49	↓	10.33
1987	↓	6.88	↓	4.01	↓	19.74	↓	6.88	↓	3.13	↓	20.34	↓	11.76
1988	↓	8.26	↓	4.62	↓	21.13	↓	8.26	↓	3.48	↓	22.38	↓	13.40
1989	↓	9.90	↓	5.31	↓	22.61	↓	9.91	↓	3.86	↓	24.62	↓	15.28
1990	20%	11.89	↓	6.11	↓	24.19	20%	11.89	11%	4.29	↓	27.08	↓	17.42
1991			15%	7.03	7%	25.89					10%	29.79	14%	19.85

1978 price* of oil in 1979 \$ = \$3.60 → 3.60/1.075 = \$3.49 → 3.49 x 1.16 = \$4.05 → 4.05 x 1.16 = \$4.70 /10⁶ BTU.
 1978 price of elec. in 1979 \$ = \$8.34 → 8.34/1.075 = \$7.76 → 7.76 x 1.16 = \$9.00 → 9.00 x 1.16 = \$10.44 /10⁶ BTU.
 1978 price of gas in 1979 \$ = \$1.56 → 1.56/1.075 = \$1.45 → 1.45 x 1.15 = \$1.67 → 1.67 x 1.15 = \$1.92 /10⁶ BTU.
 1978 price of coal in 1979 \$ = \$1.34 → 1.34/1.075 = \$1.25 → 1.25 x 1.10 = \$1.375 → 1.375 x 1.10 = \$1.51 /10⁶ BTU.

*From Energy Users News, August 1980.

case Westinghouse, Ref. 2. The values for electricity in the two sets of figures are similar, but not so for coal. Industry projects coal escalating rapidly until it reaches 50% of the cost of oil by 1988, whereas DOD projects escalation after 1984 only modestly above the inflation rate. Figure 3 shows graphically the industrial costs projected over the next ten years using the same starting values in 1980. The Air Force Base plans to convert from gas-fired boilers to coal-fired in 1983-1984. The effects of the two escalation rates on operating costs are markedly different, primarily because of projected coal costs. Figure 4 shows the calculated operating costs in the 1980-1990 time frame for heating with the existing system less the costs for heating with a modified system using a geothermal well and heat pumps to supply 14% of the heat load. Use of industry projected costs leads to a saving that would amortize \$299K in 11 years (see Table 3) with annual interest at 10%, but use of DOD projections indicates that the geothermal system would not produce a saving until 16 years after the capital outlay. Figure 5 shows the relatively modest but consistent increase in savings from reduced cooling cost with time. Figure 6 is obtained by combining this with the net savings from heating, Table 2. For the industry projection of coal costs, about \$299K could be paid back in a little over 10 years; but for the DOD projections it would require 15 years.

The main capital costs are listed in Table 3, showing the outlay for the geothermal wells and equipment. A credit of \$220K is taken for the air-conditioning units which do not need to be purchased and \$115K for the computed reduction in capacity of the future coal-fired replacement system.

As Table 3 indicates the net capital outlay which should be paid back as quickly as possible is near \$300K. For the industry escalation case shown in Fig. 6 the payback period would be just 10 years. But for escalation rates as given by the more conservative DOD projections, the capital would be amortized in a 50% longer period, nearly 15 years.

IV. Fuel Conservation

With the heat pump operating at a COP of 3.38 in the heating mode and 4.5 in the cooling or air-conditioning cycle the savings to the nation in fuel used would be

$$\left(1 - \frac{3}{3.38}\right) = 11\% \text{ of the heating load supplied by the geothermal}$$

Fig. 3 Cost projections of coal, oil, gas and electricity based on EUN, Aug 1980 prices. Escalation given in Table 1.

Fig. 4 Net operating savings in heating costs.
The growth of \$299 K at 10% is shown to illustrate projected amortization.
Data from Tables A-1 and A-2

Fig. 5 Calculations are given in Tables B-1, B-2. This shows little difference between industrial and DOD electrical escalation, see Table 1.

Fig. 6 Heating and air conditioning savings in energy costs.
Data from Table 2.

Table 2
Net heating and airconditioning costs combined.

Year	DOD cost projections			Industry cost projections		
	(Table A-1) Net heating gain (DOD)	(Table B-1) Net a/c diff. cum.	Heat + a/c	(Table A-2) Heating	(Table B-2) A/C	Heat + a/c
1980	\$ 1.62K	\$ 4.64K	\$ 6.26K	\$ 1.62K	\$ 4.64K	\$ 6.26K
1981	7.17	10.33	17.50	8.72	10.21	18.93
1982	18.41	17.30	35.71	23.73	16.86	40.59
1983	37.64	25.73	63.37	49.18	24.71	73.89
1984	71.71	35.46	107.17	88.50	33.98	122.48
1985	77.92	46.68	124.60	110.59	44.88	155.47
1986	91.22	59.57	151.79	151.61	57.57	209.18
1987	114.07	74.31	188.38	221.80	72.37	294.17
1988	148.85	91.13	239.98	318.21	89.56	407.77
1989	198.78	110.29	309.07	439.07	109.47	548.54
1990	266.89	132.08	398.97	589.30	132.44	721.74
1991	360.81	156.80	517.61	774.74	158.95	933.69
1992	482.99	184.79	667.78	1001.89	189.44	1191.33
1993	619.23	216.44	835.67	1279.47	224.40	1503.87
1994	819.09	252.17	1071.26	1616.53	264.46	1880.99
1995	1078.95	292.47	1371.42	2024.33	310.29	2334.62
1996	1389.16	337.86	1707.02	2515.79	362.63	2878.42

Table 3
Capital Costs

Geothermal installation

1. Wells (production & reinjection) at \$50/ft	\$100 K
2. Piping, valves & installation, 10 complexes	100
3. 10 heat exchangers [$10 \times 0.057 (5.84 \times 10^5)^{0.84}$]	39.8
4. 10-68 hp heat pumps [$10 \times 5.05 (5.84 \times 10^5)^{0.67}$]	368.8
5. 1 production well pump, 35 hp	10
6. 10 circulation pumps; 1-1.5 hp	<u>15</u>
	\$633.6 K

Reduction in gas/coal fired system

1. Replacement of a/c units by heat pump system 200 units at \$1.1 K/unit	\$220 K
2. Reduction in coal fired burner required to provide 13.8% less hot water — @ \$30/1000 BTU, $\frac{1}{2}(55.56 \times 10^6 \times 0.138 \text{ BTU/hr}) \times$ \$30/1000 BTU =	<u>115</u>
	\$335 K

Difference \$298.6 K

system, but only 14% of the total heat load is supplied by burning natural gas (or coal after 1984). Thus, there would be $0.11 \times 14\%$ or 1.5% savings of the input fuel load, or 1.83×10^6 ft³ of gas or 73 tons coal per year. On the other hand for the air-conditioning system the heat pump performs at a COP of 4.5 replacing the conventional refrigeration units which operate near a COP of 2.5. Therefore, the geothermal system would save the nation about 50% of the fuel required to generate the electricity used for air-conditioning.

References

1. R. von Briesen, "McGuire Air Force Base (Technical Assistance) Preliminary Visit," APL/JHU Memo QM-80-158, October 6, 1980.
2. Article reprint - International Solar Energy Society, Atlanta, GA, May 20, 1979, entitled "Reducing Solar Costs with the Solar-Assisted-Templifier," by A. Weinstein and G. J. van Zuiden.
3. R. von Briesen, "Water Wells at McGuire AFB, NJ," APL/JHU Memo QM-80-179, November 14, 1980.
4. NAVFACINST 11010.14M, FAC 051A, December 14, 1978.
5. Economic Analysis Handbook, NAVFAC P-442, July 1980.
6. "Monthly Normals of Temperature, Precipitation and Heating and Cooling Degree Days, 1941 - 1970," NCC/NOAA. Private memorandum by R. W. Henderson, November 12, 1980.
7. Westinghouse Templifier Heat Pump Water Heater, TPB-EM, February 1979.
8. Westinghouse Templifier Heat Pump Model TPB Performance - Air-Conditioning Range Performance Data, TPB-B1, September 1979.

APPENDIX A

Heating Calculations

Calculated heat load for 200 housing units at McGuire AFB which would require the heat output of one-700 gpm well. Costs of capital equipment are indicated (Table 3), and a schematic of the system given in Fig. 1.

1. 1452 housing units. Heat requirement & use =

$$50 \times 10^6 \text{ BTU/hr}$$

$$34,435 \text{ BTU/hr/unit}$$

Most of the housing units are arranged in complexes of 20 units each (U shaped layout).

∴ 1 complex requires max. heating rate = $6.89 \times 10^5 \text{ BTU/hr.}$

10 complexes require max. heating rate = $6.89 \times 10^6 \text{ BTU/hr.}$

2. Well & Heat Exchanger. One geothermal well, 1000' deep, can produce 700 gpm at 66°F. With reinjection at 50°F, and 95% efficient heat exchange, $700 (0.134) \times 62.5 \times 1 \times (66-50) \times 60 \times 0.95 = 5.35 \times 10^6 \text{ BTU/hr.}$ Drawdown ~200', pump needed = 35.5 hp. (Conservative allowance, less than 100' for production well & same for reinjection). [An additional 12 hp may have to be supplied to circulate the heat transfer water.]

Use 1 heat pump/complex.

3. Heat Pumps. Raise water temperature from 65°F to 130°F.

Use Templifier TPB-060A Refs. 7 and 8, 65°F to 130°F.

$584 \times 10^3 \text{ BTU/hr, COP:3.38, 50.6 kw input (68 hp).}$

Note $5.84 \times 10^6 \text{ BTU/hr}$ is less than $6.89 \times 10^6 \text{ BTU/hr}$, the max. heating rate. However, for heating use at 130°F the

blowers will run longer so that not as large a heating rate is required (i.e. for 5.84×10^6 BTU/hr with 1.73×10^6 BTU/hr electrical to the heat pumps, 4.11×10^6 BTU/hr is needed from the well which is 540 gpm).

4. Distribution.

1-540 gpm well to 10 complexes.	4.11×10^6 BTU/hr
10 heat pumps provide, at COP 3.38	$\frac{1.73 \times 10^6}{5.84 \times 10^6}$ BTU/hr
	BTU/hr

to produce 6.89×10^6 BTU/hr, the geothermal system would have to run 18% longer time.

5. Savings on 12 in. hot water supply line to other units.

$$\frac{6.89 \times 10^6}{50 \times 10^6} = 13.8\%. \text{ Proportion of heat supplied by}$$

geothermal system.

The use of one well providing heat for 10 complexes reduces line load by 13.8%. A 10% savings or reduction in heat load provides a 9.14% reduction in the heat loss so that if 50×10^6 BTU/hr are used, the loss normally is 5.56×10^6 BTU/hr. With a 13.8% load reduction, 47.89×10^6 BTU/hr input would be required to provide a 43.1×10^6 BTU/hr to the residences. The loss would be 8.62% of the original full load input or 10% of the reduced load. The reduced loss amounts to 0.77×10^6 BTU/hr; the original full load loss was 5×10^6 BTU/hr.

6. 1980 Costs.

a) Capital.

10-68 hp heat pumps	$[10 \times 5.05 (5.84 \times 10^5)^{0.67}]$	=	\$368.8K
10-heat exchangers	$[10 \times 0.057 (5.84 \times 10^5)^{0.84}]$	=	39.8
Piping, valves (installation/complex) x 10		=	100.0
Well @ \$50/ft x 2 (Production & Reinjection)		=	100.0
Pumps: Circulation & Production, 35 + 15 = 50 hp		=	<u>25.0</u>
			\$633.6K

b) Operation.

1. Time of Operation.

The weather records for Pemberton, N.J. (Fort Dix) indicate an average 4984 deg-days over the 1941-1970 period, Ref. 6. A plot of temperature vs time is given in Fig. A1. The average time at full load is 2065 hrs. A 10% addition for weather colder than average gives an operation time of 2272 hrs. The geothermal system will operate about 18% longer to supply the design heat load or 2681 hrs.

2. Well Pump.

26.5 kw x electrical cost x 2681 hrs.

3. Heat Pump.

10 x 50.7 kw x electrical cost x 2681 hrs.

4. Maintenance.

2% (368.8 + 39.8 + 100)

Fig. A-1 Temperature distribution at Pemberton, N.J., 1941-1970 assumed to be representatives of McGuire AFB.

c) Method of calculating annual heating costs.

1. Annual cost of existing gas-fired system:

no. BTU used annually =

$$55.56 \times 10^6 \text{ BTU/hr} \times 2272 \text{ hrs} = 1.262 \times 10^{11} \text{ BTU/yr}$$

Price of gas \$1.92/10⁶ BTU, 1980

Cost/yr =

$$(\$1.92/10^6 \text{ BTU}) \times (1.262 \times 10^{11} \text{ BTU}) \frac{1}{\text{Eff of gas burners} = \eta}$$

$$= \$346.24K \quad \eta = 0.7$$

annual cost of 100% gas-fired system - 13.8% of
100% system = \$298.5K.

2. Annual cost of geothermal system supplying 13.8%
heat load.

$$533.5 \text{ kw} \times \left(\frac{10.44}{293} \right) \$/\text{kw-hr} \times 2681 \text{ hrs} = \$50.96K$$

3. Cost difference of (100% gas fired system) -

$$[86.2\% \text{ gas-fired system} + \text{geo. system}] = \$346.24K - \\ (\$298.46K + \$50.96K) = -\$3.18K$$

These numbers appear in the first row of Tables A1 and A2. The succeeding years are calculated as above, but the escalated prices for gas, coal and electricity, according to escalation schedules shown in Table 3. The results of the heating costs are shown in Fig. 4.

Table A1
Heating costs using DOD escalation rates for gas at 20% and coal at 15%.

A Operating costs of 100% hot water gas or coal fired boiler system. 55.56 x 10 ⁶ BTU/h \$/10 ⁶ BTU 2272 h (1)			B Operating cost of 86.2% gas or coal fired system \$/10 ⁶ BTU 2272 h		C Geothermal system costs, 2681 h 507 KW for heat pump 26.5 KW for well pump \$/10 ⁶ BTU 2681 h		D Net A-B-C	E Cumula- tion at 10%	F. Reduction in Transmission heat loss	G Cumula- tion at 10%	H Total Accumu- lation E + G (2)
1980	\$1.92 (Gas)	\$ 346.24K	\$1.92 (Gas)	\$ 298.46K	\$10.44 (Elec.)	\$ 50.96K	\$-3.18K	\$ -3.18K	\$ 4.80K	\$ 4.80K	\$ 1.62K
1981	2.30	414.76	2.30	357.53	11.80	57.60	-0.36	-0.36	5.75	11.03	7.17
1982	2.76	497.72	2.76	429.03	13.33	65.07	3.62	-0.62	6.90	19.03	18.41
1983	3.32	598.70	3.32	516.08	15.06	73.52	9.10	8.41	8.29	29.23	37.64
1984	3.98	717.72	3.98	618.67	16.12	78.69	20.35	29.61	9.95	42.10	71.71
1985	3.04 (Coal)	548.21	3.04 (Coal)	472.56	17.25	84.21	-8.56	24.01	7.60	53.91	77.92
1986	3.49	629.36	3.49	542.51	18.45	90.06	-3.21	23.20	8.72	68.02	91.22
1987	4.01	724.93	4.01	624.89	19.74	96.36	3.68	29.20	10.05	84.87	114.07
1988	4.62	833.13	4.62	718.16	21.13	103.15	11.82	43.94	11.55	104.91	148.85
1989	5.31	957.56	5.31	825.42	22.61	110.37	21.77	70.11	13.27	128.67	198.78
1990	6.11	1101.83	6.11	949.78	24.19	118.09	33.96	110.08	15.27	156.81	266.89
1991	7.03	1267.73	7.03	1092.79	25.89	126.38	48.57	170.75	17.57	190.06	360.81
1992	8.08	1457.08	8.08	1256.00	27.70	135.18	65.90	253.73	20.19	229.26	482.99
1993	9.29	1675.28	9.29	1444.09	29.64	144.65	86.54	365.65	23.22	253.58	619.23
1994	10.69	1927.75	10.69	1661.72	31.72	154.80	111.23	513.44	26.72	305.65	819.09
1995	12.29	2216.28	12.29	1910.43	33.94	165.63	140.22	705.01	30.72	366.94	1031.95
1996	14.14	2549.89	14.14	2198.01	36.31	177.20	174.68	950.19	35.34	438.97	1389.16

(1) Operating cost = (No. BTU/hr) x (cost/BTU) x (No. hr) x $\frac{1}{\text{Eff}}$

(2) This column is plotted in Fig. 4

Table A2
Heating costs (industry escalation rates).

	A Operating costs of 100% hot water gas or coal fired boiler system. 55.56 x 10 ⁶ BTU/h \$/10 ⁶ BTU 2272 h		B Operating cost of 86.2% gas or coal fired system \$/10 ⁶ BTU 2272 h		C Geothermal system costs, 2681 h 507 KW for heat pump 26.5 KW for well pump \$/10 ⁶ BTU 2681 h		D Net A-B-C	E Cumula- tion at 10%	F Reduction in Transmission heat loss	G Cumula- tion at 10%	H Total Accum- ulation E + G (1)
1980	\$1.92 (Gas)	\$ 346.24K	\$1.92 (Gas)	\$ 298.46K	\$10.44 (Elec.)	\$ 50.96K	\$ 3.18K	\$ 3.18K	\$ 4.80K	\$ 4.80K	\$ 1.62K
1981	2.30	414.76	2.30	357.53	11.48	56.04	1.19	-2.31	5.75	11.30	8.72
1982	2.76	497.72	2.76	429.03	12.63	61.65	7.24	4.70	6.40	19.03	23.73
1983	3.32	598.70	3.32	516.08	13.90	67.85	14.77	19.94	8.30	29.24	49.18
1984	3.98	717.72	3.98	618.67	15.28	74.59	24.46	46.39	9.95	42.11	88.50
1985	*3.48 (Coal)	627.55	3.48 (Coal)	540.95	16.81	82.06	4.54	55.57	8.70	55.02	110.50
1986	*4.39	791.66	4.39	682.41	18.49	90.26	18.99	80.12	10.97	71.49	151.61
1987	*5.45	987.81	5.45	847.18	20.34	99.29	41.34	129.47	13.69	92.33	221.80
1988	*6.70	1208.22	6.70	1041.49	22.38	109.25	57.48	199.90	16.74	118.31	318.21
1989	*7.64	1377.74	7.64	1187.61	24.67	120.18	69.95	289.84	19.09	149.23	439.07
1990	*8.71	1570.69	8.71	1353.94	27.08	132.19	84.56	403.38	21.77	185.92	589.30
1991	*9.93	1790.69	9.93	1543.58	29.79	145.42	101.69	545.41	24.82	229.33	774.74
1992	11.31	2039.55	11.31	1758.09	32.77	159.92	121.54	721.49	28.26	280.40	1001.89
1993	12.90	2326.28	12.90	2005.25	36.04	175.88	145.15	938.79	32.24	340.68	1279.47
1994	14.70	2650.88	14.70	2285.06	39.64	193.45	172.37	1205.04	36.74	411.49	1616.53
1995	16.76	3022.36	16.76	2605.27	43.61	212.83	204.26	1529.80	41.89	494.53	2024.33
1996	19.11	3446.14	19.11	2970.57	47.97	234.10	241.47	1924.75	47.76	591.74	2515.79

*Coal prices adjusted to reach 1/2 oil price in 1988 - see Table 3 for oil price.

(1) This column plotted in Fig. 4

APPENDIX B

Air-Conditioning Calculations

The geothermal well water temperature is well suited to be used for cooling the housing units through the heat pump (by reversing the direction of heat flow in the heating circuit). In this case the supply of water at 66°F from one 700 gpm well appears adequate to handle the cooling load for the 200 housing units. The design of the water circulation system should incorporate a reversible cooling/heating design so that very little if any additional capital would be required over the heating requirements. See Fig. B-1 and B-2.

1. Housing Cooling Requirement.

a) Each housing unit, avg. $\sim 1275 \text{ ft}^2$, requires 2 ton air-conditioning of about 25,000 BTU/hr or 5 hp (3.73 kw) (COP ~ 2). Each complex of 20 housing units requires $20 \times 5 = 100 \text{ hp}$. Ten complexes of 200 housing units requires 1000 hp or 746 kw. One complex of 20 housing units requires $25,000 \times 20 = 5 \times 10^5 \text{ BTU/hr}$.

b) Time Requirement.

June 1 - September 15 - 6 hrs/day $\times$ 63 days = 378 hrs.

2. Geothermal Requirements.

Westinghouse Templifier Model TPB-060A - Ref. 8,

Reverse flow for cooling from heating mode.

$$\begin{aligned} 45^{\circ}\text{F} - 90^{\circ}\text{F}, & \quad 37.5 \text{ kw}, \quad 6.34 \times 10^5 \text{ BTU/hr, Heat rejected at } 66^{\circ}\text{F} \\ 43.2 \text{ tons} &= 5.18 \times 10^5 \text{ BTU/hr withdrawn from housing units.} \\ \text{COP} &= \frac{5.18 \times 10^5}{1.16 \times 10^5} = 4.47 \end{aligned}$$

Illustration of Water to Water Heat Pump System

Used Alternately for Heating and Cooling

The water to water heat pump has the considerable advantage that it can be used for either cooling or heating by simply redirecting the water which is cooled at the evaporator and heated at the condenser. See Figures B-1 and B-2. This is contrasted to the type of heat pump design where refrigerant flow is reversed.

Fig. B-1 Water to water heat pump used for heating.

Fig. B-2 Water to water heat pump used for cooling.

$$\text{Vol. of flow required} = \frac{6.34 \times 10^5}{500 (90-66)} = 52.83 \text{ gpm/heat pump,}$$

528.3 gpm

1. Well pump cost: 26.5 kw x elect. cost x 378 hrs.
2. Heat pump cost: 10 x 50.6 kw x elect. cost x 378 hrs.
3. Maintenance: 2% capital costs - not more than alternate system.

3. Costs

Capital costs provided by heat pumps and heat exchangers accounted for in heating costs. But costs for conventional air-conditioning units are estimated at \$1100/unit installed or \$220K for 200 units.

Operating Costs:

$$37.5 \times 10 + 26.5 = 401.5 \text{ kw} = \text{power required of 10 heat pumps + well pump.}$$

1980 Operating Costs:

$$401.5 \text{ kw} \times 378 \text{ hrs} \times \text{elect. cost/kw hr}$$

$$401.5 \text{ kw} \times 378 \text{ hrs} \times \frac{\$10.44}{293} = \$5.41\text{K}$$

1980 difference between separate refrigerator units and geothermal cooling

$$= 200 (3.73) \text{ kw} \times \frac{10.44}{293} \times 378 - (10 \times 37.5 + 26.5) \text{ kw} \times$$

$$\frac{10.44}{293} \times 378 = (746 - 401.5) \frac{10.44}{293} \times 378 = \$4.64\text{K}$$

These numbers appear in Tables B1 and B2, the capital costs in Table 3. Results of the air-conditioning costs are shown in Fig. 5.

Table B1
Cost difference between conventional airconditioning and cooling from a geothermal system. Electricity rates from DOD projections.

Year	Electricity \$/10 ⁶ BTU	Conventional a/c (746 KW x 378 h x elec.)	Geothermal system (401.5 KW x 378 h x elec.)	Net diff.	Cumulation
1980	10.44	\$10.05K	\$ 5.41K	\$ 4.64K	\$ 4.64K
1981	11.80	11.36	6.13	5.23	10.33
1982	13.33	12.83	6.90	5.93	17.30
1983	15.06	14.49	7.79	6.70	25.73
1984	16.12	15.51	8.35	7.16	35.46
1985	17.25	16.61	8.94	7.67	46.68
1986	18.45	17.79	9.56	8.23	59.57
1987	19.74	19.00	10.22	8.78	74.31
1988	21.13	20.33	10.94	9.39	91.13
1989	22.61	21.77	11.73	10.04	110.29
1990	24.19	23.29	12.52	10.77	132.08
1991	25.89	24.92	13.41	11.51	156.80
1992	27.70	26.65	14.34	12.31	184.79
1993	29.64	28.52	15.35	13.17	216.44
1994	31.72	30.52	16.43	14.09	252.17
1995	33.94	32.65	17.57	15.08	292.47
1996	36.31	34.94	18.80	16.14	337.86

Table B2
Cost difference between conventional airconditioning and cooling from a geothermal system. Electricity rates from industry projections.

Year	Electricity \$/10 ⁶ BTU	Conventional a/c (746 KW x 378 h x elec.)	Geothermal system (401.5 KW x 378 h x elec.)	Net diff.	Cumulation
1980	10.44	\$10.05K	\$ 5.41K	\$ 4.64K	\$ 4.64K
1981	11.48	11.05	5.94	5.11	10.21
1982	12.63	12.15	6.53	5.62	16.86
1983	13.90	13.37	7.20	6.17	24.71
1984	15.28	14.69	7.89	6.80	33.98
1985	16.81	16.19	8.69	7.50	44.88
1986	18.49	17.79	9.59	8.20	57.57
1987	20.34	19.51	10.52	9.05	72.37
1988	22.38	21.54	11.59	9.95	89.56
1989	24.62	23.69	12.74	10.95	109.47
1990	27.08	26.06	14.03	12.03	132.44
1991	29.79	28.68	15.42	13.26	158.95
1992	32.77	31.53	16.97	14.56	189.44
1993	36.04	34.68	18.66	16.02	224.40
1994	39.65	38.15	20.53	17.62	264.46
1995	43.61	41.96	22.58	19.38	310.29
1996	47.97	46.15	24.84	21.31	362.63

Appendix C
Transmission Loss Conditions

Fig. C-1 Schematic of heat transfer and loss conditions.

Given: 10% loss of heat supplied, when maximum heating is 10% to 15%
for an output of 50 to 60 $\times 10^6$ BTU/h.

$\therefore$ Conservative boundary conditions assume 5×10^6 BTU/h transmission loss.

$$\text{Input} = M_{F_i} \times (390 - T_i) = 55.56 \times 10^6 \text{ BTU/h} \quad (1)$$

where M_{F_i} is mass flow of water in pipe
 T_i is the return water temp.

$$\text{Output, at user end,} = M_{F_i} \times (380 - T_{EX}) = 50 \times 10^6 \text{ BTU/h} \quad (2)$$

where T_{EX} = temp. of water leaving user statem.

The temperature loss from supply to user must equal, very nearly, the loss
from user to the supply reservoir.

$$390 - 380 = T_{EX} - T_i = 10^\circ \text{F} \quad (3)$$

From Eq. (1) and (2),

$$\frac{390 - T_i}{380 - T_{EX}} = \frac{55.56 \times 10^6}{50 \times 10^6} = 1.111 \quad (4)$$

$$\text{from Eq. (3) and Eq. (4), } T_i = 190^\circ \text{F, } T_{EX} = 200^\circ \text{F.} \quad (5)$$

These values are shown in Fig. C-1 for conditions where 13.8% of the heat
is otherwise supplied, we may reduce the load to 43.1×10^6 BTU/h. The
same mass flow rate, M_{F_i} , is retained so that the supply temperature may
be reduced. The reduced maximum load to be supplied to the housing
units is 43.1×10^6 BTU/h.

We keep the same mass flow rate of water to allow the temperature T_1 to be reduced, and expect the same return temperature T_i . $T_i = 190^\circ\text{F}$.

$$(T_0 - T_{EX}) M_F = 43.1 \times 10^6 \quad (6)$$

$$\text{Using Eq. (2) and (5), find } T_0 - T_{EX} = 155.16^\circ\text{F} \quad (6a)$$

since

$$M_F (T_1 - T_i) 0.9 = 43.1 \times 10^6 \text{ and with Eq. (2),}$$

$$T_1 - T_i = 172.4^\circ\text{F}, T_1 = 362.4^\circ\text{F} \quad (7)$$

$$T_1 - T_0 \sim T_{EX} - T_i, T_1 - T_0 = 8.62^\circ\text{F} \quad (8)$$

Eq. (8) indicates the temperature drop in the transmission line is reduced from its previous value of 10°F to 8.62°F .

$$\begin{array}{r} \text{The heat saving is: } 5.556 \times 10^6 \text{ BTU/h-loss with } T_1 = 390^\circ\text{F} \\ - 4.789 \times 10^6 \text{ BTU/h-loss with } T_1 = 362.4^\circ\text{F} \\ \hline 0.767 \times 10^6 \text{ BTU/h-loss} \end{array}$$

net reduction in heat loss: $0.767 \times 10^6 \times \text{no. h heating/yr. BTU}$

$$\frac{0.767 \times 10^6}{5.0 \times 10^6} = 15.34\% \text{ less heat loss}$$

$$\frac{4.789 \times 10^6}{55.56 \times 10^6} = 8.62\% \text{ of orig. output compared to } 10\% \text{ of orig. output}$$

APPENDIX D

Comparative Energy Fuel Costs

Figure 6 indicates graphically costs of electricity, gas and coal, projected by industry (Westinghouse) and by the military services (U.S. Navy). It is seen that within the 1980 to 1990 time frame the figures for each of the energy forms are in relatively close agreement, except for coal after 1985. Estimates have been made of the effect on coal price as the demand accelerates (more coal being shipped abroad as well as increasing demand by utility plants converting to coal), as pollution controls are imposed, transportation costs increase and labor costs escalate as coal itself becomes more difficult to mine. The arguments for escalating coal costs well above the inflation rate made a strong case for the higher projections of industry.

APPENDIX E

Geothermal Supply at McGuire AFB

The groundwater at McGuire Air Force Base is considered potable down to basement (approximately at 1000 ft. depth). Information obtained from the Department of Environmental Protection, Division of Water Resources, Bureau of Water Allocation in Trenton, New Jersey indicates that a standby water well was drilled to 831 ft in 1961 at McGuire and was pump tested at 703 gpm for eight hours with a draw-down of 53 feet (Ref. 3). Using this information, the transmissivity calculates out to $T = 19,000 \text{ GPD/ft}$ or $27.323 \text{ cm}^2/\text{sec}$ and the storage coefficient to $S = 0.01376$. The other water wells drilled at McGuire in 1953 have a capacity of approximately 900 gpm. No information for these wells was available concerning their pump test duration for a given drawdown. The depth of these older wells is similar to the newer standby well (approximately 900 ft), so their transmissivity and the storage coefficient are assumed to be the same. Using these parameters, a computer program was run to find the effects with time of a geothermal production and reinjection well on each other and on an existing water well which was drilled and put into use in 1953. The following table summarizes these effects.

Assumptions:

$T = 27.32 \text{ cm}^2/\text{sec}$, static water level below land surface
 $\approx 120 \text{ ft.}$

$S = 0.01376$, all wells 10 inch diameter at depth.

Wells spaced 1 km apart as shown.

Well No. 1

Well No. 2

Well No. 3

1 km

1 km

Well No. 1

900 gpm existing McGuire water well No. B

Pumping started in 1953

Well No. 2

Geothermal Reinjection Well

700 gpm continuous

Assume reinjection started in 1980

Well No. 3

Geothermal Production Well

700 gpm

Assume pumping started in 1980.

Year	Well No. 1 Drawdown Level (ft)	Well No. 2 Reinjection Level (ft)	Well No. 3 Drawdown Level (ft)
1	-124.41	+43.12	-100.49
2	-124.36	+43.01	-100.76
5	-124.75	+42.53	-101.34
10	-125.49	+41.76	-102.14
20	-126.76	+40.47	-103.44
50	-129.43	+37.80	-106.12
100	-132.14	+35.08	-108.83

INITIAL DISTRIBUTION EXTERNAL TO THE APPLIED PHYSICS LABORATORY*

ORGANIZATION	LOCATION	ATTENTION	No. of Copies
U.S. GOVERNMENT			
DEPARTMENT OF ENERGY			
DOE/DGE	Washington, DC	F. Abel	1
		A. D. Allen	1
		C. Bufo	1
		C. Carwile	1
		D. Clements	1
		R. A. Gray	1
		R. I. Gerson	1
		R. O. Holliday, Jr.	1
		A. J. Jelacic	1
		R. LaSala	1
		D. B. Lombard	1
		C. B. McFarland	1
		R. E. Oliver	1
		E. A. Peterson	1
		R. Reeber	1
		J. W. Salisbury	1
		M. R. Scheve	1
		L. W. Seward	1
		M. Skalka	1
		R. C. Stephens	1
		R. S. H. Toms	1
		F. Hudson	1
		E. Z. Heller	1
		D. Greenwall	1
DOE/EV	Washington, DC		
DOE/IG	Washington, DC		
DOE/Dallas	Dallas, TX		
DOE/Geothermal Programs, San Francisco Operations Office	Oakland, CA		3
Idaho Operations Office	Idaho Falls, ID		5
DOE/Regional Offices			
Region III	Philadelphia, PA		1
Region IV	Atlanta, GA	W. Rankin	1
Region VIII	Lakewood, CO		1
Region IX	San Francisco, CA		1
Region X	Seattle, WA		1
OTHER GOVERNMENT AGENCIES			
U.S.G.S.	Menlo Park, CA	M. Reid	1
		W. Duffield	1
		P. Muffler	1
		D. Klick	1
		I. M. Baill	1
		P. C. Mears	1
		D. Attaway	1
Economic Development Admin.	Reston, VA		
NASA Flight Test Center	Washington, DC		
NOAA/OSG	Wallops Island, VA		
NTIS	Washington, DC		
	Springfield, VA		25
DEPARTMENT OF DEFENSE			
Dir. for Energy Policy, DoD	Washington, DC	W. J. Sharkey	1
U.S. Air Force			
Hq. USAF/PREE Bolling AFB	Washington, DC	Code USAF/PREE	1
Hq. USAF/RDPDT	Washington, DC	A. Eaffy	1
Hq. USAF/DCS	Washington, DC	W. D. Gilbert	1
AFAPL/POE	WPAFB, OH		1
Tyndall AFB	Tyndall AFB, FL	B. McDonald	2
Scott AFB	Scott AFB, IL	A. G. Glover	1
McGuire AFB	McGuire AFB, NJ	E. Porr	4
		J. Burnett	1

INITIAL DISTRIBUTION EXTERNAL TO THE APPLIED PHYSICS LABORATORY*

QM-80-190

ORGANIZATION	LOCATION	ATTENTION	No. of Copies
<u>Department of the Navy</u>			
OASN (R&D)	Washington, DC	R. Leonard, Rm 5E 787	1
NAVFA	Alexandria, VA	W. Adams	1
		T. Ladd	1
NAVPRO	Laurel, MD		1
NWC/China Lake	China Lake, CA	C. Austin	1
NAVMAT	Washington, DC	NMAT 08T3	1
U.S. Naval Academy	Annapolis, MD	D. Edsall	1
Naval Air Rework Facility			
Naval Air Station	Norfolk, VA	W. J. Maxwell, Code 640	3
<u>STATE AND LOCAL AGENCIES</u>			
<u>Alabama</u>			
State Energy Management Board	Montgomery, AL	Director	1
Geological Survey of Alabama			
University of Alabama	University, AL	State Geologist	1
<u>Arkansas</u>			
Arkansas State Energy Office	Little Rock, AR	Director	1
<u>California</u>			
California Energy Commission	Sacramento, CA	S. Willard	1
<u>Colorado</u>			
National Conf. of State Legislatures	Denver, CO	K. Wonstolen	1
<u>Delaware</u>			
State Energy Office	Dover, DE	D. Anstine	1
State Legislature	Dover, DE	H. B. McDowell, III	1
University of Delaware			
Delaware Geological Survey	Newark, DE	State Geologist	1
<u>Florida</u>			
Energy Management Administration	Tallahassee, FL	Director	1
Bureau of Geology, Dept. of Natural Resources	Tallahassee, FL		1
<u>Georgia</u>			
State Energy Office	Atlanta, GA	Director	1
Dept. of Natural Resources		Director and State Geologist	1
Earth and Water Div.	Atlanta, GA		
<u>Illinois</u>			
Energy Resource Commission	Springfield, IL		1
Illinois State Geological Survey	Urbana, IL	Chief	1
<u>Indiana</u>			
Dept. of Commerce			
Energy Group	Indianapolis, IN		1
Dept of Natural Resources, Geological Survey	Bloomington, IN	State Geologist	1
<u>Iowa</u>			
Energy Policy Council	Des Moines, IA	Chairman	1
Iowa Geological Survey	Iowa City, IA	State Geologist	1
<u>Kansas</u>			
Kansas Energy Office	Topeka, KS	Director	1
Kansas Geological Survey			
Univ. of Kansas	Lawrence, KS	Director	1
<u>Kentucky</u>			
Kentucky Energy Council	Frankford, KY	Chairman	1
Kentucky Geological Survey	Lexington, KY	Director and State Geologist	1

INITIAL DISTRIBUTION EXTERNAL TO THE APPLIED PHYSICS LABORATORY*

QM-80-190

ORGANIZATION	LOCATION	ATTENTION	No. of Copies
STATE AND LOCAL AGENCIES (cont'd)			
<u>Maryland</u>			
Energy Policy Office	Baltimore, MD	Director	1
Dept. of Natural Resources	Annapolis, MD	Chief	1
Water Supply Div.			
Dept. of State Planning	Salisbury, MD	E. Phillips	1
Coastal Zone Management			
<u>Michigan</u>			
Michigan Dept. of Natural Resources, Geological Survey Div.	Lansing, MI	State Geologist	1
<u>Mississippi</u>			
Assistant to the Governor	Jackson, MS		1
Mississippi Geological Survey	Jackson, MS	Director and State Geologist	1
<u>Missouri</u>			
Missouri Energy Agency	Jefferson City, MO	Director	1
Missouri Geological Survey, Div. of Geological Survey	Rolla, MO	Director and State Geologist	1
<u>Nebraska</u>			
Office of Energy			
Coordinator and State Tax Commissioner	Lincoln, NE		1
Univ. of Nebraska			
Conservation and Survey Div.	Lincoln, NE	Director and State Geologist	1
<u>New Jersey</u>			
State Energy Office	Newark, NJ		1
Geologic Survey	Trenton, NJ	Commissioner	1
<u>New Mexico</u>			
New Mexico State Univ.			
New Mexico Energy Inst.	Las Cruces, NM	J. Marlin	6
<u>New York</u>			
Cayuga Co. Planning Board	Auburn, NY	V. K. Mital	1
ERDA	Albany, NY	B. Krakow	1
State Energy Office	Albany, NY	T. Maxwell	1
<u>North Carolina</u>			
Dept. of Natural & Econ. Resources	Raleigh, NC	Director	1
Office of Earth Resources	Raleigh, NC	P. Hitchcock, Director	1
Dept. of Military and Vet. Affairs			
Dept. of Commerce	Raleigh, NC	Director	1
Energy Division	Research Triangle Park, NC	J. C. Bresee	1
North Carolina Energy Inst.			
<u>North Dakota</u>			
Geological Survey	Grand Forks, ND		1
Office of Energy Management and Conservation	Bismarck, ND		1
<u>Ohio</u>			
Energy Advisory Council	Columbus, OH		1
Ohio Dept. of Natural Resources	Columbus, OH	Div. Chief and State Geologist	1
Div. of Geological Survey			
<u>Oklahoma</u>			
Governor's Advisory Council on Energy	Oklahoma City, OK		1

INITIAL DISTRIBUTION EXTERNAL TO THE APPLIED PHYSICS LABORATORY*

ORGANIZATION	LOCATION	ATTENTION	No. of Copies
STATE AND LOCAL AGENCIES (cont'd)			
<u>Pennsylvania</u>			
Governor's Energy Council	Harrisburg, PA		1
Dept. of Environmental Resources			
Bureau of Topographic and Geological Survey	Harrisburg, PA	Director & State Geologist	1
<u>South Carolina</u>			
Div. of Geology	Columbia, SC	State Geologist	1
Energy Management Office	Columbia, SC	Director	1
<u>South Dakota</u>			
Geological Survey	Vermillion, SD		1
Office of Energy Policy	Pierre, SD		1
<u>Tennessee</u>			
Tennessee Energy Office	Nashville, TN	Director	1
Dept. of Conservation, Div of Geology	Nashville, TN	State Geologist	1
<u>Virginia</u>			
Div. of Mineral Resources	Charlottesville, VA	State Geologist and Commissioner	1
		R. DeKay	1
Emergency Energy Services			
Virginia State Office	Richmond, VA	J. Johansen	1
Energy Office	Richmond, VA	Director	1
Virginia Industrial Development Authority, Accomack County	Parksley, VA	S. K. Schubart	1
Water Control Board	Richmond, VA	A. Giles	1
<u>West Virginia</u>			
Fuel and Energy Office	Charleston, WV	Director	1
West Virginia Geological and Economic Survey	Morgantown, WV	Director and State Geologist	1
LABORATORIES			
Argonne Nat'l. Lab.	Argonne, IL	P. F. Gustafson	1
Battelle Pacific NW Lab.	Richland, WA	C. H. Bloomster	1
Brookhaven Nat'l. Lab.	Upton, NY	A. Reisman	1
Civil Eng. Lab., NCBC	Port Hueneme, CA	E. H. Early	1
Lawrence Livermore Lab.	Livermore, CA	A. L. Austin	1
Lawrence Berkeley Lab.	Berkeley, CA	N. Goldstein	1
Oak Ridge Nat'l. Lab.	Oak Ridge, TN	W. Barron	1
		R. DeVault	1
COLLEGES AND UNIVERSITIES			
Institute for Energy Analysis	Oak Ridge, TN	N. L. Treat	1
		C. E. Whittle	1
		D. Karr	7
Oregon Inst. of Technology	Klamath Falls, OR		
The Johns Hopkins University			
Center Metro Plan. and Res.	Baltimore, MD	Director	1
		S. Kane	14
University of Maryland	Cambridge, MD	K. A. Vaughn	1

INITIAL DISTRIBUTION EXTERNAL TO THE APPLIED PHYSICS LABORATORY*

ORGANIZATION	LOCATION	ATTENTION	No. of Copies
COLLEGES AND UNIVERSITIES (cont'd)			
University of Maryland	College Park, MD	Library	1
University of Maryland	Princess Anne, MD	Library	1
University of Virginia	Charlottesville, VA	S. F. Singer	1
Virginia Polytechnic Inst. and State University	Blacksburg, VA	J. K. Costain	1
		L. Glover	1
COMPANIES			
A. C. Schultes & Sons, Inc.	Woodbury, NJ		1
Burns and Roe Industrial Services Corp.	Paramus, NJ	R. M. Costello	1
		M. I. Knebel	1
Centrilift, Inc.	Tulsa, OK	J. F. Boutwell	1
CH2M Hill	Reston, VA	R. Dagostaro	1
	Boise, ID	J. C. Austin	1
Columbia LNG Corp.	Wilmington, DE	A. Litchfield	1
Dames and Moore	Cranford, NJ	President	1
D'Appalonia Consulting Engineers	Pittsburgh, PA	C. Schubert	1
Dunn Geoscience Corp.	Latham, NY	J. R. Dunn	1
EBASCO Services, Inc.	New York, NY	R. Cummins	1
EBL Engineers, Inc.	Salisbury, MD	R. H. Stratemeyer	1
EG&G Idaho, Inc.	Idaho Falls, ID	E. DiBello	1
Energy Exploration, Inc.	Research Triangle Park, NC	M. Beam	1
Energy Resources Group	New York, NY	J. Cline	1
Energy Systems, Inc.	Anchorage, AK	W. Ogle	1
Geraghty & Miller, Inc.	Annapolis, MD	J. P. Sgambat	1
Grace Geothermal Co.	New York, NY	A. W. Rutherford	1
Gruy Federal, Inc.	Arlington, VA	J. Renner	1
Kidde Consultants, Inc.	Newark, DE	R. R. Ruggis	1
Salisbury Wicomico Economic Development Corp.	Salisbury, MD	R. L. Kiley	1
Standard Brands Inc.	Wilton, CT	W. B. Sharp	1
Shore Engineering	Melfa, VA	A. Grothous	1
Solar Energetics	Wilmington, DE	B. Weber	1
The Mitre Corp.	McLean, VA	D. Entingh	1
Westinghouse Elec. Corp.	Staunton, VA	R. C. Neiss	1