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EQR/79-4

Quarterly Report

ENERGY PROGRAMS

at The Johns Hopkins University Applied Physics Laboratory

OCTOBER—DECEMBER 1979

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY

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FOREWORD

The Applied Physics Laboratory issues the Quarterly Report series to provide the defense establishment and the scientific community with current awareness of selected APL activities. At present, the Quarterly consists of the following volumes:

<u>Programs</u>	<u>Report Designators</u>
<u>Department of Defense Programs</u>	
Research and Development	RQR
Exploratory Development for Missile Propulsion	DQR
<u>Civil Programs</u>	
Energy	EQR
Biomedical Research, Development, and Engineering (Annual Report)	MQR

The nomenclature for the APL Quarterly Report is as follows. The designation for Quarterly Report, "QR," is preceded in each case by a letter that indicates the volume's program area. After the "QR," a virgule is followed by a year indicator (e.g., "77-") and a number from 1 to 4 to specify the calendar quarter.

The format is flexibly designed so that most technical articles can be presented on a single sheet of paper. Each article is given a section number (e.g., §24), which applies to the current Quarterly only. Each article is keyed to its major program area (e.g., Research and Exploratory Development), its technical instruction (e.g., Amorphous Semiconductors), its budget code (e.g., A3), the Laboratory Group or Groups that performed the work (e.g., BBE), and the agency that supported it (e.g., SEA-62R).

Certain Laboratory programs, including some that report a portion of their activities through the Quarterly Report, use document series other than the QR to report the bulk of their activities. Those series are available only to individuals and organizations that are directly concerned with the specific programs involved.

Requests for Quarterly Reports should be directed to: Supervisor, Technical Publications Group, Applied Physics Laboratory, Johns Hopkins Road, Laurel, Maryland 20810.

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PREFACE

The Johns Hopkins University Applied Physics Laboratory, under contracts with several agencies of the federal government and an agency of the State of Maryland, is engaged in developing energy resources, utilization concepts, and storage methods. This Quarterly Report summarizes the work on the various tasks as of 31 December 1979.

The Energy Quarterly Report is divided into five sections. The first, Geothermal Energy Development Planning and Technical Assistance, supported by the Department of Energy/Resource Applications (DOE/RA), contains reports on the progress of those geothermal-related tasks where effort was concentrated during the quarter.

The second section, Operational Research, Hydroelectric Power Development, also supported by DOE/RA, contains reports on small-scale hydroelectric investigations in the southeastern states.

The third section, Seismotectonic Studies, supported by the Reactor Safety Research Division of the Nuclear Regulatory Commission, reports on neotectonic investigations in Connecticut.

The fourth section, Energy Conversion and Storage Techniques, contains two articles, the first on OTEC core unit testing supported by the Department of Energy, Division of Central Solar Technology (DOE/CST), and the second on recovery of landfill methane, supported by the Argonne National Laboratory.

The fifth section, New Energy Technologies, reports on Laboratory studies of an unconventional gas source - Eastern Devonian shales.

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GEOHERMAL ENERGY DEVELOPMENT PLANNING AND TECHNICAL ASSISTANCE § 13

Development of Geothermal Energy in the
Eastern U. S. ZJ7CQO

Support: DOE/RA

W. J. Toth (APL) and W. F. Barron and H. Shukla
(Metro Center) October-December 1979

ECONOMIC MODELING — COST OF GEOHERMAL ENERGY

In order to estimate costs of geothermal energy for various applications and for various resource, market, and financial conditions, a computer model called GRITS (Geothermal Resource Interactive Temporal Simulation) was developed to estimate the discounted revenue and the cost streams, both of which are needed to determine the net present value of the system (Ref. 1).

GRITS is now being used to estimate costs and to determine areas and conditions where geothermal energy is economically viable. It is being compared with other economic estimates to assess its credibility.

SUMMARY

As part of the evaluation of the potential contribution of low to moderate temperature geothermal resources in the eastern United States, Metro Center and APL have used GRITS to determine the minimum size and population density required for a geothermal community heating system. Twenty towns and cities on the Delmarva Peninsula, each with at least 130 single-family residences, appear to be candidates for conversion to geothermal energy, provided that they are co-located with a resource. Cost estimates produced by GRITS have been compared to estimates published by the French (Ref. 2) for planned systems and agree remarkably well (Ref. 3). Since the French estimates are based on first-hand experience in building such systems, the agreement indicates that GRITS produces realistic estimates of the major cost components in a geothermal district heating system.

DISCUSSION

Because of the characteristics of resources found in the eastern U.S., residential applications of geothermal energy will require community ("district") heating systems to distribute the energy to a number of users in order to be economically competitive with conventional energy sources. So that the portion of the residential

Table 1

Comparison of GRITS estimates with French estimates.

Resource	French	GRITS
Temperature	65°C (149°F)	149°F*
Production well depth	1800 m (5905 ft)	5900 ft*
Reinjection well depth	1800 m	5900 ft*
Output	200 m ³ /h (880 gal/min)	880 gal/min*
Users		
Number of apartments	2500	2159
Design temperature	6°C (43°F)	41°F*
Energy, total supplied	146 × 10 ⁶ MJ (138 × 10 ⁹ Btu)	116 × 10 ⁹ Btu
Percentage geothermal	75%	88%
System costs		
Total capital	10 MF (\$2.2 million)	\$2.0 million
Cost per user	4000 F (\$880)	\$908
Fuel oil for peaking system (cost per unit)	0.014 F/MJ (\$3.25/10 ⁶ Btu)	\$4.50/10 ⁶ Btu*
Electricity costs (pumping)	0.160 MF (\$35 200)	\$43 960
Maintenance	0.100 MF (\$22 000)	\$19 600
System energy cost	0.0135 F/MJ (\$3.14/10 ⁶ Btu)	\$3.23/10 ⁶ Btu

* Input condition

sector on the Delmarva Peninsula that can be served economically by such systems can be determined, GRITS was run with the parameter values (resource conditions and housing densities) likely to be encountered in that area. Assuming the maximum acceptable cost of delivered energy to be \$8.00 per million Btu, the GRITS results indicate that the minimum residential market requirements are 130 single-family housing units that house about 400 people on lots no larger than 5300 ft².

With these criteria, the population distribution on the Delmarva Peninsula south of the Chesapeake and Delaware Canal was examined to determine the areas that can economically use district heating. Because the Delmarva Peninsula is principally an agricultural area, only 20 towns and cities were large enough for district heating. The total population of these towns and cities is about 50 000. While the number of towns suitable for district heating might change somewhat under different assumptions, the total population involved will not change substantially. The total energy required for space and water heating for these towns and cities is about 1×10^{12} Btu/year. If the systems that would serve this population were also used to supply agricultural or industrial markets (cascading uses whenever possible), the energy supplied could substantially exceed 1×10^{12} Btu/year.

The French have had considerable experience in using geothermal resources similar to those expected in the eastern U.S. (Ref. 2). In order to test GRITS, runs were made for the three sets of conditions given in Ref. 2. Table 1 shows that the estimates are quite similar, especially in the system capital costs per customer and in the delivered costs. Thus, it appears that GRITS produces credible estimates of the major cost components of a geothermal district heating system.

FUTURE PLANS

Efforts will continue in exploring the conditions necessary for the economic viability of geothermal energy. Documentation of GRITS as well as a summary of current price projections of conventional fuels will be published.

REFERENCES

1. Section 2, Quarterly Report, APR-Jun 1979, APL/JHU EQR/79-2.
2. M. Boschetti, "Geothermal Energy in France," *Rev. Gen. Therm.*, Nos. 200-201, Aug-Sep 1978.
3. W. J. Toth, "Comments on 'Geothermal Energy in France'," JHU/APL QM-79-282, Dec 1979.

GEOHERMAL ENERGY DEVELOPMENT PLANNING AND TECHNICAL ASSISTANCE

§ 14

Development of Geothermal Energy in the Eastern U.S.
ZJ7CQO

Support: DOE/RA

A. Goodman and R. Dubin (Metro Center) and W. J.
Toth (APL)

October-December 1979

GEOHERMAL ENERGY MARKETS ON THE ATLANTIC COASTAL PLAIN - MARKET PENETRATION

The U.S. Department of Energy (DOE) is assessing the potential impact of geothermal energy and is developing plans to ensure its maximum use. DOE has asked APL to develop a methodology to estimate energy market penetration by moderate-temperature geothermal resources in the Atlantic Coastal Plain.

SUMMARY

The market penetration model described previously (Ref. 1) has been published (Ref. 2). The model has shown that market penetration of geothermal energy for space heating is slow because people do not want to replace their existing conventional furnaces before they are worn out. More favorable prospects for market penetration exist in new housing developments, some of which - in Anne Arundel County, Md. - have been studied in detail.

DISCUSSION

A model (Ref. 2) has been developed for estimating market penetration by geothermal energy in residential space heating. This model has shown that such penetration depends on (a) the rate of conversion of existing housing and (b) the rate of use in new housing. The rate of conversion of existing housing depends on the failure rate of current furnaces and heating systems and on the proportion of homeowners (β_e in Refs. 1 and 2) who will then switch to geothermal energy. Reference 3 discusses incentives that might be offered to maximize β_e .

The rate of use in new housing will depend on (a) the current housing growth rate and (b) the proportion of new housing (β_N in Refs. 1 and 2) in which geothermal heating systems are installed. New housing occurs both in a random fashion (custom building) and in a high density fashion (housing developments). In the first case, geothermal energy will probably not be a viable option unless a distribution system is currently in place. However, the larger new developments are attractive markets for geothermal energy for space heating because no incentives or conversion costs need be paid by the geothermal provider, the buildings in the development are often located in a geographically compact area, and a single person (the developer) makes the decision concerning the use of geothermal energy in the entire development. Thus, in the case of a sizable new development, a large number of houses may be brought onto the system at one time.

The specific characteristics of interest to the geothermal provider are the number of dwelling units contained in the development and the density of the development. In this study, all development types are categorized as to general density. The resulting classifications are as follows:

Class I

- a. Single-family detached
- b. Clustered houses

Class II

- a. Duplex
- b. Semidetached
- c. Townhouse

Class III

- a. Multifamily
- b. Condominium

For Class I developments, the procedure is to categorize the developments by lot size and number of units. For Classes II and III, classifications are based on the number of dwelling units in the development. The following is an analysis of Class I developments.

RESULTS

Data from Anne Arundel County were used to test this procedure because the information was readily available, whereas similar information from the Delmarva Peninsula was not. Although this county contains no geothermal resource, the population distribution mirrors that of the Eastern Shore of Maryland, where known resources are located.

The distribution of the number of dwelling units in Class I developments is shown in Fig. 1. It can be seen that the distribution is highly skewed. The mean development size is 45.5 houses, the median development size is 28, and upper and lower quartiles equal 56 and 14, respectively. However, it should be noted that,

Fig. 1 Single family detached housing units, Anne Arundel County, 1977-1979. (79-4/39)

Table 1

Classification of single family detached units, Anne Arundel County;
number of dwelling units by lot size.

Number of dwelling units	Average lot size (acres)					Total acreage
	<0.25	0.26-0.75	0.76-1.25	1.26-1.75	>1.76	
<25	5	7	4	3	18	37
26-50	0	6	0	3	10	19
51-100	2	7	1	0	1	11
>100	1	8	0	0	0	9
Total	8	28	5	6	29	76

while most of the developments are small, 45% of all new dwelling units that are built in housing developments are in developments of 100 units or more.

Class I dwelling units are further classified by lot size and number of dwelling units as shown in Table 1. Geothermal providers are interested in large, dense developments, which are shown in the shaded portion of the table. Lot size is computed by dividing the total area of the development, minus 1000 ft² per lot, by the number of dwelling units. One thousand square feet per lot is subtracted because county zoning laws require this area to be devoted to open space. No allowance was made for roads. Thus, the total acreage of these lots represents the acreage that a geothermal distribution system would have to encompass.

Table 1 highlights two important aspects of new developments with regard to geothermal market penetration. First, although the shaded area contains only a small fraction of all developments, it contains a large fraction of all new houses. Second, there is a strong tendency for large developments (greater than 50 dwelling units) to be built with small lot sizes. Eight-

teen of the twenty largest developments in Anne Arundel County fall into the dense category.

FUTURE PLANS

In light of the preliminary results, the developers of large, dense developments will be interviewed for further information on the types of heating systems installed, the types of insulation used, the factors that influence their choice of heating systems, and their attitudes toward geothermal energy.

The analysis will be repeated for Classes II and III developments, which potentially are more attractive to the geothermal provider because of their dense construction.

REFERENCES

1. Section 3, Quarterly Report, Apr-Jun 1979, APL/JHU EQR/79-2.
2. A. Goodman, "Geothermal Energy Market Penetration: Development of a Model for the Residential Sector," JHU/APL GEMS-006/MCGER-79-003, Sep 1979.
3. Section 15, Quarterly Report, Jul-Sep 1979, JHU/APL EQR/79-3.

GEOHERMAL ENERGY DEVELOPMENT PLANNING AND TECHNICAL ASSISTANCE

§ 15

Development of Geothermal Energy in the
Eastern U. S. ZJ7CQO

Support: DOE/RA

W. J. Toth

October-December 1979

GEOHERMAL ENERGY MARKETS ON THE ATLANTIC COASTAL PLAIN – MARKET DEFINITION

A Geothermal Energy Market Study (GEMS) is being performed for DOE/DGRM by APL in six areas of the Atlantic Coastal Plain that offer promise of geothermal resources. The purposes of the study are: (a) to identify existing energy requirements for space and water heating and for process heat at temperatures below 250°F, (b) to determine the technical feasibility of supplying these energy requirements with the geothermal resources expected, (c) to estimate the cost of geothermal energy for potential applications, and (d) to estimate the penetration of geothermal energy into energy markets that are technically and economically attractive. The Metro Center is assisting in the last two efforts, which are reported in Sections 13 and 14.

SUMMARY

A final review has been completed of the thermal energy requirements below 250°F for over 600 industries involved in the energy survey of the four resource areas shown in Fig. 1. Some of the results are given here. A comprehensive market definition report will be published soon.

Market Survey. Industrial markets for process heat from geothermal energy were surveyed to provide a more accurate picture of the total markets in a particular resource area. As noted in Ref. 1, preliminary results have indicated accurately the markets for the companies contacted. However, where survey activities were abbreviated, markets for geothermal energy in

Fig. 1 The four areas of interest in the Atlantic Coastal Plain. (79-4/40)

companies not involved in the survey were not properly represented. A review of the data has been performed to include those additional industrial markets and also to differentiate the very small from the medium-sized companies. Figure 2 shows the results for the resource area on the Delmarva Peninsula. Comparing this figure to Fig. 9 of Ref. 2 reveals 67 more companies that are potential markets for geothermal energy. Similar results were obtained in each resource area.

Table 1

Current potential markets for geothermal energy.
(10¹¹ Btu/yr)

Resource area	Residential and commercial	Military	Agricultural	Industrial
Southeast New Jersey	290	25	0.2	9.3
Delmarva	125	8	14.5	23.2
Norfolk area	200	97	0.5	9.1
East North Carolina	78	15	9.5	13.7
Coastal South Carolina	131	30	7.6†	~18†
Southeast Georgia	125	1*	12.0†	~44†

* No data on planned submarine base at King's Bay

† Extrapolated estimates

Fig. 2 Industrial markets for geothermal energy on the Delmarva Peninsula. (79-4/41)

With this analysis, the magnitude of each market for geothermal energy below 250°F can be listed, as is shown in Table 1. In addition to the four resource areas shown in Fig. 1, extrapolated estimates are listed for resource areas in South Carolina and Georgia (Ref. 3).

FUTURE PLANS

The detailed market definition report will be published soon. Market surveys should then begin in South Carolina and Georgia.

REFERENCES

1. Section 1, Quarterly Report, Apr-Jun 1979, APL/JHU EQR/79-2.
2. W. J. Toth, "Geothermal Energy Markets on the Atlantic Coastal Plain," Proc. of a Symposium of Geothermal Energy and Its Direct Uses in the Eastern United States, Geothermal Resources Council, Special Report No. 5, Apr 1979, pp. 87-93.
3. W. J. Toth, "DOE/DGE Request for Geothermal Energy Market Estimates," APL/JHU QM-79-193, 9 Aug 1979.

GEOHERMAL ENERGY DEVELOPMENT PLANNING AND TECHNICAL ASSISTANCE § 16

Development of Geothermal Energy in the Eastern U. S.
ZJ7CQO

Support: DOE/RA

C. S. Leffel, Jr.

October-December 1979

WRITING OF PROSPECTUSES FOR GEOHERMAL DEVELOPMENT IN THE DELMARVA PENINSULA

APL is assisting Maryland, Virginia, and Delaware in preparing the geothermal prospectuses for the Delmarva Peninsula. The prospectuses are tutorial narratives designed to provide local interests and agencies with information to assist them in planning and developing a geothermal energy resource. Preliminary drafts of the prospectuses that were prepared by APL discuss the technical, environmental, legal, economic, and institutional factors that affect that development. Since initiatives must originate at the local level, the drafts were written with inputs from state and local authorities. APL has contended that the prospectuses should be completed, state-specific, by the concerned state agencies and has attempted to negotiate an arrangement whereby state teams would be organized to complete them. Funds for these efforts will be supplied by DOE.

FUTURE PLANS

APL will continue its efforts to encourage the states to organize their teams and submit the necessary proposals to DOE to obtain planning funds for completion of the prospectuses. APL will provide the necessary assistance to the states.

SUMMARY

The preliminary drafts of the Delmarva prospectuses have been distributed to DOE and to Maryland, Delaware, and Virginia. Delaware has submitted a proposal to DOE for the completion of its state prospectus, and DOE has endorsed it at the technical program level. Virginia is in the process of organizing its team and preparing its proposal. Maryland has not yet organized its team.

DISCUSSION

The difficulties that the states encounter in completing the prospectuses are discussed in Ref. 1. However, as stated there, Delaware has prepared and submitted its proposal. It assigns the responsibility for coordinating the state efforts to the State Energy Office. The outline of the prospectus is essentially the same as Ref. 2. To expand the draft prospectus and make it peculiar to the state, Delaware proposes to include geological data and information, site-specific and state-aggregated scenarios, a list-

ing of permits and attendant rules and regulations, estimated costs for prospective users, and an outreach program. The Delaware proposal has been received by DOE and endorsed at the contract officer level of the Division of Resource Applications as a grant to the state. Since the proposal was submitted, APL has maintained contact with the state agencies, the principal contact being a member of the Delaware State Energy Office. As submitted, the proposal involves the Delaware State Energy Office of the Division of Economic Development as the lead state agency, supported by the Department of Natural Resources and Environmental Control, the Office of Management, Budget, and Planning, and the Delaware Geological Survey.

In November 1979, Virginia forwarded a prospectus proposal to APL for suggestions. After slight revisions, APL returned the proposal for forwarding to DOE. It follows the outline of Ref. 2 and is essentially state-specific. Virginia proposes that the Office of Emergency and Energy Services manage the writing of the prospectus. State agencies that will be involved include the State Water Control Board, the Division of Mineral Resources, the Council on the Environment, the Air Pollution Control Board, the Department of Conservation and Economic Development, the Department of Industrial Development, and the Department of Housing and Community Development.

Maryland has not yet submitted a proposal although, within the State Administration, it was decided that if the state does attempt to write a state-specific geothermal prospectus the decision will be made by the Administrator, Energy Administration, of the Department of Natural Resources. APL has sent copies of the Delaware and Virginia proposals to the Energy Administration and has urged the state to review them and submit a similar proposal to DOE (Refs. 3 and 4).

Both the Delaware and Virginia proposals list as an additional objective the promotion of geothermal energy development. As would be expected for proposals in a new area, many state agencies are involved. APL expects that, if the proposals are funded, a small, knowledgeable, and competent state team will emerge to promote the development of geothermal energy. The cognizant state officials have been assured that APL and the Virginia Polytechnic Institute and State University (VPI&SU) will provide technical assistance for the completion of the prospectuses and also will provide the liaison with DOE to organize effective state teams.

REFERENCES

1. Section 18, Quarterly Report, Jul-Sep 1979, APL/JHU EQR/79-3.
2. "A Prospectus for the Development of Geothermal Energy on the Delmarva Peninsula," APL/JHU QM-79-114, 22 May 1979.
3. Letter to Dr. Paul O. Massicot, Administrator, Energy Administration, Maryland Department of Natural Resources, APL/JHU Lett. CQO-2554, 8 Nov 1979.
4. Letter to Dr. Paul O. Massicot, Administrator, Energy Administration, Maryland Department of Natural Resources, APL/JHU Lett. CQO-2774, 12 Dec 1979.

GEOHERMAL ENERGY DEVELOPMENT PLANNING AND TECHNICAL ASSISTANCE § 17 Development of Geothermal Energy in the Eastern U. S. ZJ7CQ0

Support: DOE/RA

K. Yu

October-December 1979

ANALYSIS OF TESTS OF THE CRISFIELD GEOTHERMAL WELL

The geothermal well at Crisfield, Md., was tested and analyzed by Gruy Federal, Inc. (Ref. 1). The well was cased and cemented, and perforations were made through the cement casing layers into the zones of water-bearing sand.

Zone	Depth (ft)	Net sand thickness (ft)	Water temp. (°F)	Salinity (‰)	Perforations per ft
1	4148 to 4223	72	135	67.9	4
2	3901 to 4032	86	133	68.9	4
3	3798 to 3846	44	128	68.4	2

DISCUSSION

APL Analysis (Refs. 2 and 3). After a brief review of the entire test data sequence, it became apparent that the customary methods of analysis based on constant pumping rates are not applicable because of the frequent large rate variations. Therefore APL undertook the data analysis to infer the best possible values of two critical parameters, the transmissivity (or, equivalently, the permeability) and the storage coefficient. Upon further examination, data from the second zone were selected for analysis because that zone was the most productive of the three and the data were the most complete as well as the most reliable (the turbine flow meter readings were inaccurate for the first and third zones).

The development of the second zone consisted of several irregular sequences of pumping and pausing at various pumping rates, a procedure that is typical in oil-well development. Subsequently, while the well was recovering, the pumping phase was reinitiated. This phase continued for about two days, followed by a 48-hour complete recovery period. Throughout the pumping phase, the rate of pumping changed considerably, including a 23-minute shutdown caused by an equipment malfunction. Aside from the numerous perturbations in the pumping rate, the development and the pumping phases (particularly the earlier parts) were both plagued with considerable sand production. The observed pressure-time is shown in Figs. 1 and 2.

Several features merit comment. The pressure drop occurring at 07:55 does not involve pumping head loss. Although there is no notation in the pump-test record, it was inferred that this pressure drop may have been caused by the pressure sensor being pulled up from the initial depth of 3966.5 ft (listed at the beginning of the pump-test record) to its final depth of 3890

Fig. 1 Calculated and actual pump test data from Crisfield geothermal test well, test zone No. 2. (79-4/42)

Fig. 2 Calculated and actual pump test data from Crisfield geothermal test well, test zone No. 2. (79-4/43)

ft (stated at the end of the record). The least-square-fit parameters to the calibration of the pressure sensor, performed at the end of the test, give an apparent pressure drop of 34.28 psi for this depth change. The supposition that the pressure sensor was pulled up by 76.5 ft is further supported by the fact that, with the associated pressure correction, the apparent drop in the pressure disappears and the corrected test data give rise to a continuous derivative of the pressure recovery data.

When the pump-test phase began, the pressure head was still actively recovering. This introduced transients into the early data.

There were numerous perturbations throughout. The three "glitches" seen in Fig. 2 are due to the throttling-down operations during the turbine-meter calibration. The break in the curve covers the 23-minute shutdown and the 30-minute segment following the shutdown when the electronics malfunctioned.

Applicability of Conventional Evaluation Methods. Customarily, three methods are available for the analysis/evaluation of an unsteady (i.e., non-steady-state) flow. They are all based on the assumption of a constant pumping rate and the total absence of extraneous transients.

To determine leakage and/or delayed yield, it is useful to examine the so-called Theis plot, i.e., the log-log plot of drawdown versus pumping time.

For the pressure loss, we may reference the static level of 1732 psi. However, since the pumping was initiated while the head was actively recovering, there is no convenient reference point available for the time axis. We have therefore used the actual pumping time in Fig. 3. The curvature is minimal, eliminating the possibility of reliably determining the transmissivity and the storage coefficient by matching it with the theoretical Theis curve. With the assumption that the changes in the pumping rate can be neglected, Fig. 3 shows that there is no evidence of recharge into the second zone for the duration of the pump test. By the same token, we see no evidence of leakage (or delayed yield) for that zone. In view of the well log, we conclude that the zone may be treated as a confined aquifer. Thus, aside from this qualitative indication, the Theis curve method fails to provide a reliable estimate of the formation parameters.

The second method is to examine pumping time versus drawdown in a semi-log plot (Fig. 4). This involves the same difficulty of not having a true time reference as in the previous case. In any event, it may be seen that the curve does bend at about the sixth minute of pumping. According to an elementary theory, this curve is supposed to be a straight line (provided the pumping rate has been held constant). Since the pressure was actively recovering when the pump-test phase was initiated, the early part of the data cannot be separated from the pre-existing transient effects.

After the bend, we estimate the apparent transmissivity to be approximately $0.70 \text{ cm}^2/\text{s}$ ($\approx 487 \text{ GPD/ft}$, in hydrology units). In view of the pumping rate variations and the unrecovered drawdown condition, this value is uncertain. Further, the time reference uncertainty eliminates the possibility of inferring the storage coefficient.

To avoid the "noise" problem often seen in the pumping phase data, the ratio of the time since the pumping started to the time since the recovery started is studied in a semi-log plot versus pressure (head) recovery (the Horner plot). This, too, is supposed to yield a straight line according to elementary theory. The Horner plot of the recovery data is shown in Fig. 5. The curve bends very noticeably because of transient and real well effects. Therefore, the Horner plot yields an unreliable result.

Thus, the conventional methods of data analysis are not applicable to zone 2 data.

Theoretical Calculations. Zone 2 behaved as a confined aquifer during the pump test. Be-

Fig. 3 Data from Crisfield geothermal well, zone No. 2. (79-4/44)

Fig. 4 Data from pumping phase of Crisfield geothermal test well, zone No. 2. (79-4/45)

cause there were no observation wells, there is no reason to introduce anisotropy. Therefore, we have chosen the model to be an isotropic and homogeneous confined aquifer. We have further assumed that the aquifer parameters remained constant throughout.

The head-loss calculations were made for a fixed set of permeability and storage coefficients using all 85 variations in the pumping rate. The approximate ranges covered are 10 to $10^{-3} \text{ cm}^2/\text{s}$ for the transmissivity (corresponding in perme-

(continued)

Fig. 5 Data from recovery phase of Crisfield geothermal well, zone No. 2. (79-4/46)

ability to approximately 2 darcys to 0.2 mdarcy) and 10^{-5} for the storage coefficient.

The best fit to the pumping data was obtained for a transmissivity of $0.50 \text{ cm}^2/\text{s}$ (near 107 mdarcys), with an effective storage coefficient of 0.20 (for the calculation, the well radius was taken to be equal to the casing radius, i.e., 12.54 cm). Theoretical results are compared with experimental results in Figs. 1 and 2.

The more interesting comparison is in Fig. 2. Note that for the most part, the agreement is better than $\pm 1 \text{ psi}$ (during the pumping phase). However, comparison of the recovery phase shows that the experimental data lagged the theoretical well recovery during the early hours. This difference (approximately 10 psi) can be explained on the basis of the real well effect.

Unlike the "mathematical" well, which is infinitely thin, the real well has a finite radius, within which the water content is 100%, in contrast to a 25% porosity in the theoretical case. This gives rise to an integral equation for which we have obtained an approximate first-

order perturbation solution. Evaluating the first-order correction in the appropriate range, there is about a 10 psi lag in the recovery, which eliminates the apparent disagreement of the theoretical calculations with the recovery data. (The first-order correction term is proportional to T^{-2} . Thus, the real well effect is more pronounced for a well with low transmissivity such as the one under consideration. This causes a noticeable bend in the Horner plot.)

Storage Coefficient. The effective storage coefficient of a confined aquifer is typically about 10^{-6} times the thickness of the aquifer in feet. On the other hand, for an open aquifer, it is typically 0.1 or 0.2. Consequently, an effective storage coefficient as large as 0.2 for a confined aquifer is usually a measure of sand production. From the well log, taking the bulk modulus of the skeleton to be $1.0 \times 10^6 \text{ lb/ft}^2$ and using an isothermal compressibility of $4.44 \times 10^{-11} \text{ dynes/cm}^2$, the storage coefficient of the second zone is estimated to be 3.9×10^{-3} .

For the sand production, the argument of the well function contains a factor $r^2 S$. Hence, from the dimensional analysis we infer that sand production extended the effective radius to nearly seven times the radius used in the calculation.

SUMMARY

Transmissivity: $T = 0.50 \text{ cm}^2/\text{s}$

Storage coefficient: $S = 3.9 \times 10^{-3}$

CONCLUSIONS

Because the method used in the APL analysis deviated from customary methods, meetings were held with Prof. S. Bush, Department of Hydrology, The Johns Hopkins University, with the USGS Water Resources Division (G. Bennett), and with the Lawrence Berkeley Laboratory Earth Sciences Division (R. Schroeder) to discuss methods and results. All concurred that the APL analysis was the only one possible. Evidently the method used in the APL analysis was known to Mr. Schroeder.

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**GEOHERMAL ENERGY DEVELOPMENT PLANNING AND
TECHNICAL ASSISTANCE** § 18
**Development of Geothermal Energy in the Eastern U.S.
ZJ7CQO**

Support: DOE/RA
F. C. Paddison and K. Yu
October-December 1979

ANALYSIS OF THE USE OF GEO- THERMAL ENERGY AT CRISFIELD, MARYLAND

At the request of DOE, APL has analyzed the application and economics of geothermal energy for space heating in the Crisfield, Md., area. The high school was considered first because of the National Energy Act Conversion Grant Program (NEACGP) for schools and hospitals. The economic analysis of payback times for conversion to geothermal energy includes both the federal grant and normal financing.

The initial study (Refs. 1 and 2) assigned estimates for well productivity and extrapolated temperatures to the resource. The deep experimental well at Crisfield produced substantially lower temperatures and less water than was anticipated. This report documents the revised analysis based on the actual temperatures and the productivity of the well (Ref. 3).

DISCUSSION

Resource Characteristics. The deep test well at Crisfield identified two sand sequences useful for the production of geothermal energy:

Zone	Depth (ft)	Sand thickness (net) (ft)	Water temperature (°F)
1	4223-4148	72	135
2	4032-3901	86	133

The water was determined to be similar to ocean water but it contained twice as much salt (Ref. 4).

In the analysis of well drawdown versus time for zone 2, the formation transmissivity was estimated to be 348 gpd/ft, a permeability of about 100 mdarcies (Ref. 5). A less reliable measure of the transmissivity of other zones can only be inferred from the limited test data. To be conservative, the contribution of flow for a given well drawdown will not assume any contribution from the first zone. The other significant parameter of the formation is the storage coefficient. This cannot be determined from the pump test data but can be found for similar formations in Ref. 6.

The well was abandoned at the conclusion of the DOE tests.

Well Productivity. With a properly designed water well with an effective gravel pack diameter of 24 in., a transmissivity of 348 gpd/ft, and a dimensionless storage coefficient of 3.9×10^{-3} , the well drawdown can be calculated as a function of time and as a function of water withdrawal rate. This is an important consideration since the energy required to lift the water or reinject the water from a geothermal well becomes

significant for modest temperature resources such as those at Crisfield. Reference 7 documents the method of calculation, the solution for well drawdown, and the pumping costs associated with space heating applications. The results are applied to heating the Crisfield High School with water from a new well drilled near the school.

In the cases considered here, the withdrawal rate varies with heating degree-days to a maximum of 100 gal/min; cost of pumping and reinjection varies accordingly. Figure 1 shows the assumed heating degree-day cycle. Figure 2 shows pressure drawdown versus time corresponding to the required withdrawal rates from the geothermal source. The annual cost of this pumping energy is \$3500, in toto for both the production and the reinjection wells for the high school, assuming the cost of electrical energy to be 5¢/kWh.

The water-producing sands from the Crisfield well were found to be nonconsolidated and, at withdrawal rates in excess of 100 gal/min, sand was produced. For the pumping rates below, a graduated gravel pack and well screen should minimize the problem.

Table 1 summarizes the results from the test well.

Table 1

Results and conclusions from the Crisfield geothermal test well.

Location

Crisfield Municipal Airport
3+ miles from the high school

Results

Aquiclude between 2500 and 2700 ft
Three potential production zones - unconsolidated sand
3798 - 3846 ft net 44 ft 128°F
3901 - 4032 ft net 86 ft 133°F
4148 - 4223 ft net 72 ft 135°F
Transmissivity - mid-zone - 348 gpd/ft
Permeability - 110 mdarcies
Water chemistry
Similar to seawater - twice as salty

Conclusions

Sand control requires water well completion, i.e., gravel pack, screen
Well drawdown must be minimized
Intermittent use
Moderate withdrawal rates - use with peaking system
Reinjection required
Temperatures adequate for space heating
New wells recommended near user
Cost effective for baseload space heating for a moderate-size building

Geothermal Heating - Retrofit System Design.

Reference 8 documents a visit to Crisfield High School to determine if space were available for additional radiation, so that one could use geothermal energy as baseload heating in parallel with existing fossil-fired boilers and circulating hot water (Fig. 3). Reference 8 concludes that there is sufficient space, and the cost estimates are for such an installation.

Fig. 1 Annual temperature versus duration, typical of Crisfield. (79-4/47)

Fig. 2 Crisfield well drawdown (first year). (79-4/48)

Temperature Where Peaking Begins. The ambient temperature at which the existing boilers begin to add heat was selected to be 30°F for this study. This places the required water withdrawal rate at approximately 100 gal/min maximum during the coldest time of the year and minimizes the well drawdown (see Fig. 2). This choice of temperature results in the geothermal system supplying 97.5% of the annual heat load and the peaking plant supplying 2.5%. Previously, the high school has used 57 600 gal of No. 2 fuel oil. Upon conversion to geothermal, the annual usage would be 1400 gal/yr, a potential savings of 56 200 gal. The cost of this saved oil can be considered as income in subsequent years to amortize the cost of conversion. Table 2 summarizes the parameters.

The Cost of Conversion. New hot water radiators sized to 130°F are estimated to cost \$110 000 installed, including the distribution

Fig. 3 Schematic of geothermal heating system. (79-4/49)

Table 2

Summary of geothermal retrofit at Crisfield High School.

Design heating days	4000
Maximum heating rate	3.6×10^6 Btu/h
Annual heating requirement (Based on 57 600 gal of oil in a 70% efficient furnace)	5×10^9 Btu
Base annual heating, geothermal system	97.5% annual total
Ambient temperature	Begin peaking at 30°F
Peaking system annual heating	2.5% annual total or 1400 gal of no. 2 oil
Fuel oil displaced	56 200 gal

system within the school. Estimates of the cost of insulated piping from a new production well to the high school and an uninsulated line from the school to the reinjection well (each a distance of 1 mi) are \$200 000.

There has been considerable discussion as to what a production (nonresearch and development) geothermal well should cost on the coastal plain. The DOE Crisfield well, which costs approximately \$1 million, cannot be used as any sort of measure, since it attempted to do many things. An analysis has been made of oil and gas wells in the Appalachian Basin drilled in 1977 (Refs. 9 and 10) and was reported in the annual survey of the U.S. oil and gas producing industry published by the American Petroleum Institute (Ref. 11). The costs as a function of depth are shown in Figs. 4 and 5 from Ref. 9. Here a cost of \$20 to 25/ft is reported for depths less than 6000 ft. These costs are consistent with estimates by east coast water-well drillers, one of whom bid on the DOE Crisfield well. Analyses of other geologic areas in the U.S. that should have geology and sedimentary deposits similar to those of the Coastal Plain (e.g., northern Louisiana) are consistent with Figs. 4 and 5. The addition of gravel pack and screen in place of the normal cemented casing and jet perforations through cement and casing is not expected to increase the well costs.

(continued)

Fig. 4 1977 average drilling cost for Appalachian area (1000 to 6000 ft depth). (79-4/50)

Fig. 5 Comparison of well costs in selected areas. (79-4/51)

Fig. 6 Types of pumps used to withdraw geothermal water. (79-4/52)

Production Well Geothermal Water Pump. Because well drawdown was minimized by using a peaking system and the building being heated was of moderate size, it is possible to consider vertical shaft turbine pumps rather than submersible down-hole pumps (Fig. 6). Vertical pumps are preferable since annual maintenance is limited to inspection, and historically their life expectancy is greater than down-hole systems by at least an order of magnitude. Finally, variable speed drives of several designs that are very dependable are commercially available. These water well pumps have been used for irrigation and are applicable almost without modification for geothermal waters with the temperatures expected in the Atlantic Coastal Plain.

The cost of a vertical-shaft turbine pump, located approximately 600 ft deep in the production well, pumping 100 gal/min maximum with enough lift to bring the water to the surface and circulate it through the heat exchanger (700 ft of head), is estimated to be \$22 000. The life expectancy of the pump motor and variable speed drive is estimated to be greater than 20 years. An annual inspection of similar pumps in Klamath Falls, Oregon, and in Iceland for bearing or other wear is estimated to cost \$2500 per year.

In summary, the cost of conversion to geothermal space heating and domestic hot water for the Crisfield High School (Table 3) is \$752 000. The annual operating and maintenance costs are estimated to be \$6000 per year. The geothermal system displaces 56 200 gal of No. 2 fuel oil based on 1979 fuel usage. At a cost of \$0.75/gal, this is \$42 000. When the annual operating cost of the proposed geothermal system is subtracted (i.e., \$6000), a balance of approximately \$36 000 is available to amortize all or part of the conversion costs. Figure 7 and Table 4 show

Table 3

Costs of geothermal retrofit at Crisfield High School.

<u>Capital Costs</u>	<u>Thousands of dollars</u>
Additional radiators	110
New wells - with screen and gravel pack	250
Production (4200 ft)	(125)
Reinjection (3000 ft) (with small diameter extension to 4200 ft)	(100)
Testing and logging	(25)
Pumping wells to school (1 mi)	200
Heat exchanger, pumps, well house, etc.	100
Architects and engineering	70
Subtotal	730
Production well pump, motor, variable speed drive	22
Total Capital Costs	752
<u>Annual Operating Costs</u>	
Electrical pumping energy	3.5
Annual inspection of pumps	2.5
	6.0
<u>Peaking System Oil - 1400 gal/year</u>	
Fuel oil displaced - 56 200 gal/year	
1979-1980 savings at \$0.75 gal	42
First year savings to amortize conversion	36

Fig. 7 Capital recovery time for Crisfield High School. (79-4/53)

Table 4

Payback period, conversion to geothermal energy at Crisfield High School using NEACGP.

Annual escalation of cost of oil and electricity (%)	Payback period (years) NEACGP subsidy		
	None	50%	80%
0		14.5	4.25
5	23.4	10.4	3.9
10	15.5	8.6	3.7
15	12.3	7.5	3.5
20	10.5	6.7	3.3
25	9.2	6.2	3.2
30	8.4	5.7	3.1

how long it will take to amortize this obligation. Figure 7 also shows the payback time versus percent of subsidy under the NEACGP (Ref. 12) with the escalation rate of heating oil as a parameter. It is assumed that the cost of oil and the annual cost of electric power for pumping escalate at the identical rate.

(continued)

CONCLUSIONS

1. The application for converting the Crisfield High School to geothermal space heating under the NEACGP is encouraged since the payback period with the 80% subsidy available to Crisfield is very short. However, even without the subsidy, conversion is attractive and not inconsistent with normal school payback periods with 7% money.
2. The low temperature and poor productivity of the Crisfield well have done considerable damage to the commercialization of geothermal energy in the Eastern U.S. A careful systematic approach to system design as presented here illustrates that geothermal energy application engineering is a systems job and must be so approached.

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5. K. Yu, "Crisfield Well Characteristics Determined Using All Test Data," APL/JHU QM-79-287, 28 Dec 1979.
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7. K. Yu, "Head Loss and Pumping Cost of a Geothermal Well for Space Heating," 31 Oct 1979.
8. R. von Briesen, "Trip to Hospital and High School at Crisfield, MD on 7/17/79," APL/JHU QM-79-169, 18 Jul 1979.
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**GEOHERMAL ENERGY DEVELOPMENT PLANNING AND
TECHNICAL ASSISTANCE** § 19
Development of Geothermal Energy in the Eastern U. S.
ZJ7CQO
Support: DOE/RA
K. Yu, R. von Briesen, J. E. Tillman, and F. C.
Paddison
October-December 1979

GEOHERMAL TECHNICAL ASSISTANCE

APL is designated a center for technical assistance for individuals, groups, or organizations interested in the application of geothermal energy. Normally constrained to 100 hours for each request, Laboratory assistance is in the form of preliminary feasibility, engineering, or economic studies and is not a substitute for detailed design - the province of the consulting engineering community. Laboratory effort can include

1. Counsel on known information concerning geothermal resources in an area and DOE programs that are in process there;
2. Preliminary estimates of the hydrologic properties of geothermal resources as functions of time and usage;
3. Advice on recovering geothermal energy in a specific case - an engineering feasibility study, for example;
4. The estimated life-cycle cost of applying geothermal energy in a specific case;
5. The legal, institutional, and other requirements for the application of geothermal energy; and
6. Advice on available federal geothermal opportunities or other federal programs that bear on the use of geothermal energy.

Limited feasibility and application studies are under way for

1. The conversion of the elementary school at Pittsville, Md., to geothermal heating;
2. The conversion of bathhouses at Hot Springs National Park, Hot Springs, Ark.;
3. The heating of downtown Bellows Falls, Vt., using water-referenced heat pumps;
4. The use of geothermal energy for mariculture on the Eastern Shore of Maryland; and
5. The use of geothermal energy for vaporizing liquefied natural gas at Cove Point, Md.

Other requests for technical assistance are in process.

DISCUSSION

Bellows Falls, Vt. A meeting was held during the summer of 1979 to discuss the anomalously warm water obtained from a city well (Ref. 1). The town manager and planner met with representatives from APL, DOE, and Dunn Geoscience. APL reviewed the town setting and suggested a study of the feasibility of using the water supply from the large glacial terrace on which the town is constructed in conjunction with a heat pump to provide energy to heat the buildings in their

downtown revitalization project. Dunn Geoscience submitted a proposal to evaluate the aquifer and possibly manage it for the town. Plans are being developed on how the heat-pump system could be integrated into a long-term revitalization program and the best method for funding the project.

Hot Springs National Park, Ark. During this quarter, APL has provided assistance to the U.S. Park Service in Hot Springs. The Park Service runs as concessions six large buildings built as bathhouses around 1920 to use the thermal water (140°F) from the hot springs. It would like to convert the heating of these buildings from natural gas to thermal water with minimum cost and using the least amount of thermal water. A feasibility study for this conversion was funded by the Park Service. The study involved both a complete and a partial conversion of the bathhouse heating systems. The Park Service felt that the cost for either conversion was too high for the concessioners to pay.

Personnel from APL visited the bathhouses; their recommendations are documented in Ref. 2. The report concludes that the thermal water that each bathhouse purchases from the Park Service can be used twice, first to heat the bathhouse using a water-to-air heat exchanger, and then to serve as 90°F bath water. Records show that the bathhouses normally purchase enough thermal water for bathing but, if the water is used for heating first, it could provide over 80% of the heating load. Another method of heating mentioned in the APL study was dehumidification (changing latent heat into sensible heat). This method would work well for the very humid bathhouses. Either scheme should be less expensive and should conserve more thermal water than the methods suggested in the original feasibility study.

The Pittsville Elementary School, Wicomico County, Md. In response to Ref. 3, APL is evaluating for the Wicomico County Board of Education the feasibility and economics of converting the Pittsville Elementary School to geothermal energy. The school is being renovated extensively and a new addition is planned. APL is preparing a study to show how the school can be heated with geothermal water from a well drilled on school property. The study will examine the cost of the entire system and point out areas that need further investigation.

Mariculture in the Chesapeake Bay Area. The Ceda Corp. of Annapolis, Md., operates an experimental hatchery on the western shore of Chesapeake Bay at Shadyside, Md. It is engaged in

the mariculture of oysters, clams, and other shellfish. The company has requested our assistance regarding the possible application of geothermal energy to a new production facility on the eastern shore of Chesapeake Bay.

At temperatures of 10°C or below, the growth rate of the oyster larvae becomes very sluggish; it attains a peak at about 25°C and diminishes sharply above 30°C. The mortality rate increases at temperatures below 10°C, and the oysters are essentially destroyed at 33°C. Salinity, too, has a noticeable effect. At less than 10 parts per thousand (ppt) salinity, both growth and survival rates become unacceptably low. In fact, most oyster growth occurs only during the three summer months. Salinity diminishes to about 7 ppt (a baywide average) during the winter, the mean surface temperature is about 0°C, and there is a steady increase in the fresh water runoff to the Bay. Therefore, a reduction to one-fifth

the production rate over the past 100 years can be readily understood.

APL is studying the use of geothermal water to maximize the net weight gain of the oysters. Preliminary calculations indicate that the pumping rate would vary by a factor of seven from summer to winter.

REFERENCES

1. J. E. Tillman, "Geothermal Potential of Bellows Falls, Vermont," APL/JHU QM-79-157, 29 Jun 1979.
2. R. von Briesen, "Visit to the U.S. Park Service and Buckstaff Bathhouse in Hot Springs, Arkansas," APL/JHU QM-79-272, 7 Dec 1979.
3. Letter from Malone and Williams, Architects, re: PSC-22.019.79LP Pittsville School, 14 Nov 1979.

**GEOHERMAL ENERGY DEVELOPMENT PLANNING AND
TECHNICAL ASSISTANCE** § 20
Development of Geothermal Energy in the Eastern U. S.
ZJ7CQO
Support: DOE/RA
W. B. Chapman
October-December 1979

TECHNICAL INTERCHANGE MEET- ING, EASTERN U.S.

The fourth Technical Information Interchange Meeting on eastern geothermal programs was held at Berkeley Springs, W. Va., on 30 and 31 October 1979. The meeting was sponsored by the Division of Resource Management of DOE and arranged by APL.

Descriptions of various aspects of the DOE program and the program plans of the several contractors and laboratories operating under DOE sponsorship were presented on the first day of the meeting. Presentations from the state agencies and private investigations involved in the study of resource potential and application were

made on the second day. APL will collect and publish the minutes of this meeting. This report is now in preparation and will be released the first week of January 1980 (Ref. 1).

REFERENCE

1. W. B. Chapman (Ed.), "Geothermal Energy and the Eastern U.S. Technical Information Interchange Meeting, Minutes," JHU/APL QM-79-261, Dec 1979.

THE UNITED STATES OF AMERICA
DO hereby certify that
the following is a true and correct copy
of the original as the same appears in the
files of the Department of the Interior.

WITNESSETH my hand and seal
this 1st day of January, 1901.

JOHN W. FOSTER,
Secretary of the Interior.

IN WITNESS WHEREOF, I have hereunto set my hand
and the seal of the Department of the Interior
at Washington, D. C., this 1st day of January, 1901.

THE UNITED STATES OF AMERICA
DO hereby certify that
the following is a true and correct copy
of the original as the same appears in the
files of the Department of the Interior.

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WITNESSETH my hand and seal
this 1st day of January, 1901.
JOHN W. FOSTER,
Secretary of the Interior.

**GEOHERMAL ENERGY DEVELOPMENT PLANNING AND
TECHNICAL ASSISTANCE** §21
Development of Geothermal Energy in the Eastern U. S.
ZJ7CQO
Support: DOE/RA
A. M. Stone
October-December 1979

LIST OF GEOHERMAL REPORTS PUBLISHED BY APL, CY 79

In order to provide information on all significant papers issued in CY 79 by APL on various aspects of geothermal energy, the following lists of reports and internal memoranda are submitted.

FORMAL REPORTS

Report No.	Date	Publication	Author(s)
APL/JHU GEMS-003	Jun	"Economic Evaluation Model for Direct Uses of Moderate Temperature (up to 250°F) Geothermal Resources in the Northern Atlantic Coastal Plain"	R. Weissbrod, W. F. Barron, P. Kroll, and W. J. Toth
APL/JHU GEMS-005	Mar	"A Review of Recent Energy Price Projections for Traditional Space Heating Fuel, 1985-2000"	R. Weissbrod and W. Barron
JHU/APL GEMS-006	Sep	"Geothermal Energy Market Penetration: Development of Model for the Residential Sector"	A. C. Goodman
APL/JHU QM-79-032	23 Feb	"Geothermal Energy Markets on the Atlantic Coastal Plain," <u>Proc. Sixth Energy Technology Conference</u>	W. J. Toth and F. C. Paddison
APL/JHU QM-79-037	Jan	"Fact Sheets Relating to Use of Geothermal Energy (Eastern United States)"	W. B. Chapman (Ed.)
APL/JHU QM-79-086	13 May	"Geothermal Energy in Maryland," Maryland Local Energy Coordinators Conf.	F. C. Paddison
APL/JHU QM-79-163	Jul	"Evaluation of Potential Geothermal Resource Areas"	F. Mitchell
APL/JHU QM-79-261	Dec	"Geothermal Energy and the Eastern U.S., Technical Information Interchange Meeting"	W. B. Chapman (Ed.)
-	1979	"Modelling the Impact of Resource and Economic Conditions of the Competitiveness of Moderate Temperature Geothermal Resources," <u>Proc. Geothermal Resources Council 1979 Annual Meeting, Reno, Nevada, Vol. 3, p. 773.</u>	R. Weissbrod and W. F. Barron
-	1979	"Hydrothermal and Uplift Histories of the Northern Appalachian Basin," <u>Bull. Am. Assoc. Petrol. Geol. Vol. 73, No. 9, p. 1589</u>	J. E. Tillman and H. L. Barnes
-	1979	"Near Term Potential for Geothermal Energy in the Eastern U.S.," <u>Geol. Soc. Am. Abstracts with Programs, Vol. 11, No. 3</u>	J. E. Tillman
Special Report No. 5	Apr	"Cost Analysis of Hydrothermal Resource Applications in the Atlantic Coastal Plain," "Geothermal Energy Markets on the Atlantic Coastal Plain," pp. 87-93 "A Prospectus for Geothermal Energy - The Atlantic Coastal Plain," pp. 99-101 <u>Proc. Symposium of Geothermal Energy and Its Direct Uses in the Eastern United States, Geothermal Resources Council.</u>	R. Weissbrod and W. F. Barron W. J. Toth
APL/JHU brochure	Apr	"Selected Publications on Geothermal Energy by the Applied Physics Laboratory of The Johns Hopkins University"	F. C. Paddison

INTERNAL MEMORANDA

QM-79-001	10 Jan	Program at APL/JHU in Support of DOE/DGE	F. C. Paddison
QM-79-003	9 Jan	Geothermal Fact Sheets for Eastern Region	F. C. Paddison
QM-79-004	12 Jan	Newport News PRDA Response	W. J. Toth
QM-79-007	18 Jan	Test Boring Sites	W. B. Chapman
QM-79-008	18 Jan	Estimated Life Time of 316 Stainless Steel Heat Exchangers in Geothermal Environment	R. W. Newman
QM-79-009	19 Jan	Moisture Addition to Grain Dryers by Vitiated Air Fossil Fuel Heaters	R. W. Newman
QM-79-011	18 Jan	Pulp and Paper Industries Considered for Geothermal Applications	R. W. Newman

Report No.	Date	Title	Author(s)
QM-79-023	2 Feb	Contamination of Geothermal Wells	F. C. Paddison
QM-79-025	9 Feb	Site Selection Committee Meeting	F. C. Paddison J. E. Tillman W. J. Toth
QM-79-029	21 Feb	Hydrothermal Geothermal Development Plan - DOE	F. C. Paddison
QM-79-035	6 Mar	Paper Presented at GRC Symposium	W. J. Toth
QM-79-039	12 Mar	Visit by the Maryland Assistant Legislative Science Advisor	J. E. Tillman
QM-79-046	21 Mar	Narrative Description of Geothermal Effort in the the Eastern U.S.	F. C. Paddison
QM-79-048	22 Mar	Presentation to Salisbury Wicomico Economic Development Corp. (SWED)	W. J. Toth
QM-79-051	23 Mar	Sixth Energy Technology Conference, Washington, D. C. Feb. 26-28, 1979	W. J. Toth
QM-79-052	26 Mar	DOE Region III Small Grants Program	W. J. Toth
QM-79-053	24 Mar	Second NCSL Geothermal Workshop, Delaware Legislature, February 23, 1979	F. C. Paddison
QM-79-055	26 Mar	Briefing Data for R. Black, DOE/RA	F. C. Paddison
QM-79-056	26 Mar	Discussion with SAI	F. C. Paddison
QM-79-057	26 Mar	Discussion with Resource Application	F. C. Paddison
QM-79-062	3 Apr	Geologic Studies	J. E. Tillman
QM-79-063	28 Mar	Heat Exchanger Cost, Geothermal Water to Process Water	R. Henderson
QM-79-064	4 Apr	Heat Exchanger Cost, Process Water to Air	R. Henderson
QM-79-065	4 Apr	Geothermal to Process Water Heat Exchanger Cost versus Well-Head Water Temperature	R. Henderson
QM-79-068	6 Apr	Delaware Geological Survey - DGE Grant	J. E. Tillman
QM-79-070	11 Apr	Metro Efforts on Market Penetration	W. J. Toth
QM-79-073	16 Apr	Delmarva Prospectus, Chapter VIII	J. E. Tillman
QM-79-076	19 Apr	NRC Investigations	J. E. Tillman
QM-79-079	24 Apr	Geothermal Potential of the Newark Triassic Basin, Pennsylvania and New Jersey	J. E. Tillman
QM-79-080	26 Apr	"A Prospectus for Geothermal Energy - The Atlantic Coastal Plain," Roanoke GRG Meeting, visual aids paper	F. C. Paddison
QM-79-082	27 Apr	Trip Report to Water Source Heat Pumps Using Earth Coupling and Solar Assist., Workshop April 19 and 20, 1979	R. von Briesen
QM-79-083	27 Apr	Data for R. C. Stephens	F. C. Paddison
QM-79-084	1 May	DGE/RA Workshop on Eastern Geothermal Resources	W. J. Toth
QM-79-087	7 May	Thermoblast Drilling	J. E. Tillman
QM-79-088	7 May	Visit to USGS Water Resources Division	K. Yu
QM-79-091	8 May	Heat Pump Overview and Suggested Position Paper for DOE/RA and DOE/ET	R. von Briesen C. S. Leffel R. Henderson
QM-79-092	9 May	Possibility of Funding Selected Atlantic Coastal States to Do Geothermal Planning	F. C. Paddison
QM-79-095	11 May	Discussion with the Maryland Water Resources Administration	J. E. Tillman
QM-79-096	11 May	On Some Problems Regarding Planned Crisfield Well	K. Yu
QM-79-098	15 May	Visit to University of Maryland Center for Environmental and Estuarine Studies, Horn Point, Cambridge, Md.	F. C. Paddison
QM-79-099	15 May	Heat Pump/Heat Exchanger System Cost Geothermal Water to Process Water	R. W. Henderson
QM-79-104	17 May	R&D Capability Relative to Renewable Resources	F. C. Paddison
QM-79-106	18 May	26th Geothermal Coordinating Group Meeting	W. J. Toth
QM-79-110	21 May	Suggestions for DGE FY 1980 Program	F. C. Paddison
QM-79-113	22 May	Geothermal Energy Presentation to American Public Works Association Annual Meeting, May 10, 1979	F. C. Paddison
QM-79-114	22 May	A Prospectus for the Development of Geothermal Energy on the Delmarva Peninsula	F. C. Paddison
QM-79-116	24 May	Heat Pump Systems for Utilization of Geothermal Energy	R. W. Henderson
QM-79-117	24 May	Delaware Geothermal Prospectus	J. E. Tillman
QM-79-121	31 May	Trip Report about the Visit to the NASA Wallops Flight Center, Virginia, and Crisfield, Maryland, May 9-10, 1979	R. von Briesen A. Stucki
QM-79-122	1 Jun	Geothermal Energy	A. M. Stone
QM-79-123	1 Jun	Geothermal Energy for Poultry Processing	R. W. Henderson
QM-79-125	7 Jun	Heat Pump Seasonal Performance	R. W. Henderson
QM-79-127	8 Jun	Comments on the Outline for the ASHRAE "Handbook on Geothermal Energy Use and Associated Direct Applications"	W. J. Toth

(continued)

Report No.	Date	Title	Author(s)
QM-79-128	8 Jun	Discussion of Geothermal Energy with the Georgia Power Company	F. C. Paddison W. J. Toth
QM-79-129	8 Jun	Meeting with DOE Region IV Personnel	F. C. Paddison
QM-79-130	8 Jun	Visit to USGS Water Resources - Atlanta	F. C. Paddison
QM-79-141	20 Jun	Schutles Water Well Drillers	J. E. Tillman
QM-79-142	20 Jun	Cost of Geothermal Well	F. C. Paddison
QM-79-144	21 Jun	Geothermal Meeting in Richmond, Virginia	J. E. Tillman
QM-79-145	Jun	Geothermal Energy and the Eastern U.S., A Framework for a Site Prospectus for Geothermal Energy Development, Delmarva Peninsula	F. C. Paddison
QM-79-147	22 Jun	Current Status of GEMS Efforts	W. J. Toth
QM-79-152	28 Jun	Use of Crisfield Geothermal Well	F. C. Paddison
QM-79-155	29 Jun	Industrial Use of Geothermal, Crisfield, Md.	F. C. Paddison
QM-79-156	29 Jun	Meeting with NY SERDA and NY SEO	J. E. Tillman
QM-79-157	29 Jun	Geothermal Potential of Bellows Falls, Vt.	J. E. Tillman
QM-79-158	29 Jun	Maryland Local Energy Coordinators Meeting	F. C. Paddison
QM-79-159	2 Jul	Chemical Analyses of Crisfield Well	W. J. Toth
QM-79-160	3 Jul	Geothermal Energy Confirmed in the Eastern U.S. and Economics of Geothermal Energy in Crisfield, Maryland	A. M. Stone
QM-79-161	3 Jul	Geothermal Presentation to Wicomico County High School Teachers	C. S. Leffel
QM-79-166	10 Jul	GREES/GRITS Models' Equations	W. J. Toth
(QM-79-166A)	(2 Nov)	(Error correction to QM-79-166)	(W. J. Toth)
QM-79-167	12 Jul	Lewes, Delaware and Geothermal	F. C. Paddison
QM-79-169	18 Jul	Trip to Hospital and High School at Crisfield, Maryland on 7-17-79	R. von Briesen
QM-79-170	18 Jul	Program at APL/JHU in Support of DOE/DGE/RA	F. C. Paddison
QM-79-172	19 Jul	Estimating Capital Investment	F. Mitchell
QM-79-176	24 Jul	Storage Tank Cost Geothermal Water	R. W. Henderson
QM-79-177	24 Jul	Loan Repayment and Subsidy	K. Yu
QM-79-178	25 Jul	Pump Cost Geothermal Well	R. W. Henderson
QM-79-180	25 Jul	Capital Investment per Net - MW	K. Yu
QM-79-183	30 Jul	Presentation of Geothermal Potential to Energy Auditors - Maryland Schools	F. C. Paddison
QM-79-184	30 Jul	Discussion of Basement Beneath Delmarva	J. E. Tillman
QM-79-189	2 Aug	Costs for Insulated Storage Tanks	W. J. Toth
QM-79-191	6 Aug	The 20th Annual Conference of the International Heating Association (IDHA) and Visit to the Woods Hole Oceanographic Institute (WHOI) During Week of June 18, 1979	R. von Briesen
QM-79-193	9 Aug	DOE/DGE Request for Geothermal Energy Market Estimates	W. J. Toth
QM-79-196	13 Aug	Resource Magnitude Calculations	W. J. Toth
QM-79-200	17 Aug	Ratio of Extracted Geothermal Energy to Input Pumping Energy	W. J. Toth
QM-79-203	21 Aug	Subcontract to Geraghty and Miller, Inc.	F. C. Paddison
QM-79-204	21 Aug	Lewes, Delaware Geothermal Proposal	F. C. Paddison
QM-79-212	10 Sep	Comments on the DOE Program for the Eastern U.S.	W. J. Toth
QM-79-218	17 Sep	Comments on the DOE Program Plan for the Development and Utilization of Geothermal Resources: U.S. Hydrothermal Eastern Region, Nov. 1978	C. S. Leffel
QM-79-219	18 Sep	Transient Radial Flows in Horizontal Aquifers	K. Yu
QM-79-220	31 Oct	Head Loss and Pumping Cost of a Geothermal Well for Space Heating, Application to Crisfield, Maryland	K. Yu
QM-79-223	25 Sep	Low Frequency Electromagnetic Methods	K. Yu
QM-79-224	7 Sep	Status of U.S. Geothermal Projects	R. Meier
QM-79-228	28 Sep	Drilling Technology Course Held in Houston, Texas, Sept. 10-21, 1979	R. von Briesen
QM-79-233	5 Oct	Presentation of Paper to the AAPG and DOE/EGSP Meeting at Morgantown, Va.	J. E. Tillman
QM-79-235	17 Oct	Heat Requirements for Commercial Space Heating (AS-077)	W. J. Toth
QM-79-236	18 Oct	Cost of Drilling and Testing in the Appalachian Basin	J. E. Tillman
QM-79-238	31 Oct	On Market Penetration of Geothermal Heating System	K. Yu
QM-79-240	24 Oct	Pumping Power and Cost versus Distance Geothermal Process Water Systems (AS-078)	R. W. Henderson
QM-79-242	31 Oct	Presentation to Board of Education, Wicomico County	F. C. Paddison
QM-79-244	1 Nov	Attendance at the ASTM Meeting, Oct 17 and 18, 1979, Philadelphia, Pa.	C. S. Leffel
QM-79-246	2 Nov	Presentation to Delaware Society of Professional Engineers	W. J. Toth

Report No.	Date	Title	Author(s)
QM-79-249	6 Nov	Size Distribution of Sand Particles, Crisfield Well	F. C. Paddison
QM-79-250	6 Nov	To W. F. Barron from W. J. Toth and R. W. Henderson regarding Pumping Energy Equations for a Geothermal Transmission (AS-084)	W. J. Toth R. W. Henderson
QM-79-251	13 Nov	Supplement to: Geothermal Energy in the Eastern U.S. (for talk at Clemson, SC)	F. C. Paddison
QM-79-252	8 Nov	Comparison of Gruy's GEODEC Model with GRITS (AS-085)	W. J. Toth
QM-79-253	9 Nov	The Geothermal Energy Market Study Summary of Coolfont Presentation (AS-086)	W. J. Toth
CQO-2544	12 Nov	The Crisfield, Md. Well and Geothermal Energy	F. C. Paddison A. M. Stone
QM-79-256	13 Nov	Meeting with Dr. John Yewell, State School Construction Department	F. C. Paddison
QM-79-257	13 Nov	Data on Mariculture	F. C. Paddison
QM-79-268	5 Dec	Hydrothermal Resource Confirmation Plan	J. E. Tillman
QM-79-270	6 Dec	Architecture of the Outreach Program - Eastern Geothermal Development	F. C. Paddison
QM-79-276	14 Dec	Delaware Companies with Potential Applications for Geothermal Energy	W. J. Toth
QM-79-281	26 Dec	Self Start Manuals for Specific Industries	W. J. Toth
QM-79-282	19 Dec	Comments on Geothermal Energy in France	W. J. Toth

**GEOHERMAL ENERGY DEVELOPMENT PLANNING AND
TECHNICAL ASSISTANCE** § 22
Development of Geothermal Energy in the Eastern U. S.
ZJ7CQO

Support: DOE/RA

F. C. Paddison, C. S. Leffel, Jr., W. J. Toth, and
R. F. Meier

October-December 1979

**COMMENTS ON LIMITED TASKS:
GEOHERMAL ENERGY DEVELOP-
MENT PLANNING**

**GEOHERMAL SPACE HEATING FOR WICOMICO
COUNTY, MARYLAND, SCHOOLS**

On 12 October 1979, a joint presentation was made by F. C. Paddison, APL, and Edward Philips, the Tri-County Coordinator of Maryland's Coastal Zone Management Program, to the Board of Education and the principals of the schools in Wicomico County, Maryland. Reference 1 documents the presentation and those in attendance. In the presentation, the status of geothermal development in the Eastern U.S. was given. Included was an analysis of the tests of the deep geothermal test well, made to assess the feasibility and cost of converting the Crisfield High School to geothermal space heating (Ref. 2).

The Board of Education later requested technical assistance (Ref. 3) in assessing the economics and practicality of converting to geothermal energy the school at Pittsville, Maryland, which is currently being renovated.

REFERENCES

1. F. C. Paddison, "Presentation to Board of Education, Wicomico County," APL/JHU QM-79-242, 31 Oct 1979.
2. "The Crisfield, Maryland Well and Geothermal Energy," APL/JHU Lett. CQO-2544, 12 Nov 1979.
3. Letter from Malone and Williams, Architects for Wicomico County Board of Education, Re: PSC 22.019.79LP Pittsville School, 14 Nov 1979.

**GEOHERMAL HEATING OF CRISFIELD HIGH
SCHOOL**

On 22 October 1979, F. C. Paddison presented to Eugene Karol, Superintendent of Schools of Somerset County, the results of an APL study of the feasibility and economics of converting the Crisfield High School to geothermal space heating (Ref. 1). Later Dr. Karol requested a similar presentation (Ref. 2) to the Somerset County Commissioners and a presentation to John Yewell of the State School Construction Department. Subsequently, Dr. Karol requested assistance in locating other forms of financial assistance.

On 4 December 1979, a presentation was made at a meeting of the Somerset, Maryland, County Board of Supervisors held at the behest of Dr. Karol. The purpose of the meeting was to persuade the county supervisors to apply for a portion of Maryland's share of the federal subsidy, which is partitioned among the state's applicants by the State Education Office in Annapolis. Dr. Karol is keenly interested in converting the high school at Crisfield, Maryland, to geothermal

heating. A preliminary analysis made at APL indicated that the savings in oil would pay for the installation of geothermal heating (Ref. 1). With the possibility of a federal subsidy under the Conservation Grants Section of the National Energy Act, the savings could be dramatic. After the presentation, the county board took the matter under advisement.

On 13 November 1979, F. C. Paddison visited John Yewell of the State School Construction Department of the State Board of Education. Mr. Paddison presented the results of APL's study of the feasibility and economics of converting the Crisfield High School to geothermal space heating (Ref. 1). The Construction Department has the responsibility for allocating conservation funds under the National Energy Act to the various counties and for ranking the proposed conservation measures. The total funds available to Somerset County are not enough to convert the school. Therefore Mr. Yewell suggested that the county request the assistance of the state legislature to locate additional financial aid. The meeting with Dr. Yewell is documented in Ref. 3.

REFERENCES

1. "The Crisfield, Maryland Well and Geothermal Energy," APL/JHU Lett. CQO-2544, 12 Nov 1979.
2. F. C. Paddison, "Meeting with Somerset County Commissioners," APL/JHU CQO-2825, 11 Feb 1980.
3. F. C. Paddison, "Meeting with Dr. John Yewell, State School Construction Department," APL/JHU QM-79-256, 13 Nov 1979.

**GEOHERMAL PROGRESS MONITOR STRUC-
TURES MEETING**

On 14 and 15 November 1979, R. F. Meier attended the Geothermal Progress Monitor (GPM) Structures Meeting in San Francisco, California. Two draft documents proposed by Mitre Corp. and DOE were discussed: initial design for the GPM and GPM report No. 1. Early monitor outputs will cover the planned and actual performance of direct heat and electric power projects, leasing data for federal lands, and drilling activities. The format for supplying less specific data (in particular, data for geothermally undeveloped areas such as the Eastern United States) has yet to be defined adequately.

REFERENCES

1. "Initial Design for the Geothermal Progress Monitor" (draft), The Mitre Corp. and U.S. DOE, 19 Oct 1979.
2. "Geothermal Progress Monitor Report No. 1" (draft), 6 Nov 1979.

**ASTM MEETING, 17 AND 18 OCTOBER 1979, AT
PHILADELPHIA**

At the request of DOE, the American Society for Testing and Materials (ASTM) met on 17 and 18 October to organize a standing committee on Geothermal Resources and Energy. In a previous meeting, held in May 1979, a preliminary draft had been adopted of the scope and subcommittee organization for an ASTM committee that would be responsible for writing standards and procedures for the geothermal energy effort.

The permanent staff of ASTM functions only as the system manager for active committees (com-

posed of representatives from industry, government, universities, and the public at large) that write and adopt the standards and procedures for the subject industry. ASTM standards and procedures have no legal status; however, they are often incorporated into government and industrial codes and serve as a guideline for procurement contracts.

At the Philadelphia meeting, it was agreed that the scope of the Committee E-45 on Geothermal Resources and Energy was as follows:

The promotion of research, dissemination of information and the development of standard definitions, test methods, specifications and practices for the exploration, production and use of geothermal energy. The consensus of the attendees of the October meeting was that no existing ASTM committee was prepared to decide the requirements for geothermal development and the following subcommittees were adopted for E-45: Field Development (E-45.10), Utilization (E-45.20), Geothermal Residuals (emission controls and fluid disposal) (E-45.30), Coordination (E-45.91), and Definitions and Nominations (E-45.92).

Each subcommittee was divided into two to four task forces, each of which determined the high priority items for which standards and procedures could be written. For example, the consensus of E-45.10 was that standards for geothermal exploration could not be written at this time, but that it was possible to write standards and procedures for fluid and gas sampling and analysis, materials, drilling, and logging, and for surface geophysics. E-45.20 established task groups on materials and on the systems and components for energy recovery, both for direct and for electrical use. E-45.30 established task groups on the sampling and analysis of residual products and on the problems of disposal, abatement, and reclamation.

D. N. Anderson of the Geothermal Resources Council, Davis, California, was elected chairman of the E-45 Committee. Chairmen for the subcommittees were also elected and leaders for the task forces were appointed. The tentative date for the next meeting of the Geothermal Resources and Energy Committee is May 1980 in Denver, Colorado. Dr. C. S. Leffel, APL, is presently assigned to the Logging and Surface Geophysics task force of the Field Development subcommittee.

REFERENCE

1. C. S. Leffel, Jr., "Attendance at the ASTM Meeting, 17 and 18 October 1979, Philadelphia, Pa.," APL/JHU QM-79-244, 1 Nov 1979.

FOREIGN GEOTHERMAL DEVELOPMENT

On 9 October 1979, H. Melton, E. L. Heller, and P. Lowe of the DOE Inspector General's Office visited APL. APL's recommendations for moderate-temperature geothermal development in the U.S. based on the visit of APL personnel to Iceland, France, and Hungary were discussed. The trip report, including the recommendations, is documented in Ref. 1.

REFERENCE

1. "Trip to Iceland, Hungary, and France," APL/JHU QM-78-149, 16 Jun 1978.

GEOTHERMAL DISCUSSION WITH MAYOR PAUL LATTIMORE, AUBURN, NEW YORK

On 17 December 1979, J. W. Follin, Jr., and F. C. Paddison visited the town of Auburn, which is located in Cayuga County, New York. The following people were present: Paul Lattimore, Mayor of Auburn and Chairman of the Energy Task Force of the U.S. Conference of Mayors; Mijay K. Mital, Associate Director, Cayuga County Planning Board; Joshua H. Heintz, Attorney, Auburn Industrial Development Authority; and Tad Marshall, Cayuga County Industrial Development Authority.

Mayor Lattimore has been actively developing a variety of forms of energy in the Auburn area and has attracted a diverse group of industries to the area to take advantage of the energy and labor force. He is interested in geothermal energy and how it might be used in the Auburn area. The depth of sedimentary cover is approximately 5000 ft, and Cayuga County is an area (Refs. 1 and 2) where thermal gradients are higher than normal. The temperature at depth could be as high as 150°F.

A series of reports on the eastern geothermal program, showing the types and costs associated with application of geothermal energy in this temperature range, was discussed. It was suggested that the next step in defining the potential would be to increase the depth and determine the temperature and availability of water of one or more of the natural gas wells planned to be drilled with the help of DOE. The possibilities will be studied, and plans were made for subsequent discussions. Reference 3 documents this visit.

REFERENCES

1. F. O. Mitchell, "Evaluation of Potential Geothermal Resource Areas," APL/JHU QM-79-163/GT, Jul 1979.
2. D. Hodge, "Preliminary Geothermal Investigations in New York State," paper presented at Technical Interchange Meeting, Berkeley Springs, W. Va., APL/JHU QM-79-261, Nov 1979.
3. F. C. Paddison, "Meeting with Auburn, N.Y., Mayor Paul Lattimore," APL/JHU QM-79-283, 28 Dec 1979.

PRESENTATION TO THE DELAWARE SOCIETY OF PROFESSIONAL ENGINEERS

On 20 October 1979, W. J. Toth gave a presentation in Dover, Delaware, (Ref. 1) to the local chapter of the Delaware Society of Professional Engineers. The talk included a general description of geothermal energy, results on the gradient test well program and the deep Crisfield well, and the types of requirements for moderate-temperature thermal energy on the Delmarva Peninsula. Some specific potential uses of geothermal energy on the Delmarva Peninsula were also discussed.

REFERENCE

1. W. J. Toth, "Presentation to Delaware Society of Professional Engineers," APL/JHU QM-79-246, 2 Nov 1979.

PRESENTATION OF EASTERN GEOTHERMAL DEVELOPMENT PROGRAM TO THE TEXTILE INDUSTRY

At the request of David B. Lombard of DOE, APL participated in a Professional Development Program given by Clemson University to the textile industry on 14 November 1979. Status reports on the development of geothermal energy in the Eastern United States (Refs. 1, 2, and 3) by F. C. Paddison were supplied as course text material. The program was entitled "Slashing Today and Tomorrow."

In the textile industry, slashing is the process by which starch is applied to the warp threads to give them strength and to control fuzziness before they are woven on the power loom with the woof threads. In the slashing process, the warp threads are passed through a heated (200 to 210°F) solution composed of water and starch and then over a series of five or more heated rollers to remove the water. The moisture content and stretch are controlled and differ for each type of warp material. The metal rollers are heated internally by steam to about 275°F. Typically, there is no attempt to recover heat or energy.

Most effort today to reduce energy is directed toward reducing water pickup by the warp threads by running the warp through two rollers, which squeeze out some water prior to heating. It is estimated that water pickup could be reduced by 30 to 50% if the pressure loading of the rollers were increased 10 to 20 times. The total energy use per 100 lb of yarn is as follows (Ref. 4):

	% of total	Thousands of Btu
Cooking starch	8	16
Heat losses	10	20
Heating yarn	2	4
Vaporizing water	80	160
Total	100	200

In the finishing and dyeing process, the woven fabric is taken through more wetting and drying processes that use approximately 10 times the energy used in the slashing process.

The weaving plants are located along the fall line and accordingly are not good candidates for hydrothermal or geothermal energy. The finishing and dyeing plants are located in areas where more water is available and are better candidates. However, in either case, the use

of geothermal energy to preheat water for steam is not considered cost-effective. Accordingly, hybrid systems, such as one using moderate-temperature geothermal heat and a semivacuum to draw off moisture, must be analyzed or else located in an area where high-temperature geothermal energy is available.

This presentation is documented in Ref. 5.

REFERENCES

1. C. S. Leffel, Jr., and R. A. Eisenberg, "Geothermal Handbook," APL/JHU SR 77-1, Jun 1977.
2. F. C. Paddison et al., "Direct Applications of Geothermal Energy in the Eastern United States and Estimates of Life Cycle Costs," APL/JHU QM-78-232, 30 Oct 1978.
3. "Geothermal Heat as Supplementary Energy Source in the Eastern U.S.," APL/JHU QM-79-251, 13 Nov 1979.
4. D. L. Nehrenberg, "Current Trends in Slashing Technology," E. I. du Pont de Nemours and Co., Inc., Charlotte, N.C., delivered at Seminar PD 45: Slashing Today and Tomorrow, Clemson University, 13 Nov 1979.
5. F. C. Paddison, "The Textile Industry and Geothermal Energy," APL/JHU QM-79-285, 28 Dec 1979.

GRC MID-ATLANTIC SECTION

Dr. Stanley Weiss was the featured speaker at the quarterly meeting of the Mid-Atlantic Section of the Geothermal Resources Council. The meeting was held on 20 November 1979 in Washington, D.C. Dr. Weiss informed the 29 attendees that Ruth M. Davis had been confirmed to the post of Assistant Secretary of Resource Applications, and the final organization from the merger of DGE and the Division of Geothermal Resource Management (DGRM) had not been made final. Dr. Weiss assured the group that, although there may be some changes in structure, the basic activities and programs would remain essentially unaltered. Randolph Stephens of DGRM summarized the current status of legislative actions being considered by Congress.

The Section is looking forward to having a joint meeting with the New York Section in February. At that time, the new nominations committee will present the slate of nominees for next year's officers, who will be installed at the May meeting.

OPERATIONAL RESEARCH, HYDROELECTRIC POWER DEVELOPMENT

§ 23

Small-Scale Hydroelectric ZP30CQO

Support: DOE/RA

J. Boland, S. Briscoe, and O. Radwick

(Metro Center)

October-December 1979

ECONOMIC, INSTITUTIONAL, AND ENVIRONMENTAL FACTORS IN NORTH CAROLINA, SOUTH CAROLINA, AND GEORGIA

The Center for Metropolitan Planning and Research (Metro Center) is conducting a study of the economic, institutional, and environmental factors affecting potential hydroelectric development at existing dams in North Carolina, South Carolina, and Georgia. This analysis draws on methodologies developed in a similar study (Ref. 1) of the mid-Atlantic states discussed in previous Quarterly Reports. It is divided into four sections: evaluation of economic and financial feasibility of the subset of dams identified in the U.S. Army Corps of Engineers' recently published National Hydro Study; identification of state and local institutional, regulatory, and tax factors; identification of state and local environmental regulations and policies affecting hydroelectric development; and a preliminary review of environmental and social costs associated with alternative conventional and nonconventional means of producing electricity.

ECONOMIC ANALYSIS

The economic analysis to be performed on potential small-scale hydroelectric sites in the south Atlantic states will be substantially more detailed than that used for the mid-Atlantic sites. The economic model has been refined and elaborated to incorporate a much wider range of considerations and to facilitate both sensitivity analyses of key assumptions and impact analyses of various economic incentives for development.

As now constituted, the economic model takes explicit account of

1. Expected future changes in the real cost of alternative forms of energy;
2. Differential effects of expected future inflation on operating costs and on debt service costs;
3. Differences in financial capabilities, constraints, and incentives among the various possible types of developer (i.e., investor-owned utilities, rural electric cooperatives, municipalities, and private developers);
4. The effect of grants, subsidies, and regulatory actions on project feasibility; and
5. The effect of licensing cost and licensing delay time on project feasibility.

For a specific potential site (given site-specific cost and hydrologic information) specification of the type of developer and the base year selling price of the energy produced leads to a determination of feasibility that is based

on net present worth, payback period, and the number of years to first positive cash flow. When aggregated over all possible sites that may be developed by the same type of developer, and when performed for a range of possible base year selling prices, the analysis yields a supply curve that shows the relationship between the base year price offered and the capacity (or energy) that would be made available if all feasible projects were implemented. As the base year price rises, more projects become feasible, as do larger capacities at sites already included.

Supply curves will be derived for each type of developer. Further analysis will show the sensitivity of the supply curves to changes in the assumed rate of increase in the real price of energy, in the assumed future inflation rate, in licensing cost and licensing delay time, and in the financial incentives for development. In the latter category, various possible incentives will be tested for their effect on development, including tax credits (for private developers and investor-owned utilities), accelerated depreciation, subsidized interest rates, grants, regulatory changes, etc. Where the energy generated by the project may comprise the major supply to a single user, the effect of standby charges levied by a utility for back-up service can also be investigated.

The economic analysis model has been developed and tested. Potential sites in North Carolina, South Carolina, and Georgia have been identified, and hydrologic data are available. When cost data are complete, supply curves will be derived. Interviews with existing public utilities in the south Atlantic area (including investor-owned utilities, rural electric cooperatives, and municipally operated utilities) indicate a relatively wide range of running costs, which suggests a wide range of prices offered for the energy. Because supply curves are derived with the assumption that all potential sites face the same selling price, separate supply curves may be required for some states or utility service areas. Other information has been obtained from the utilities in order to determine reasonable bounds for sensitivity analysis of the resulting supply curves and to predict the impact of various economic incentives and regulatory changes.

INSTITUTIONAL, REGULATORY, AND TAX ANALYSIS

With the exception of the shift in geographical focus, the institutional, regulatory, and tax analysis follows the format established in the earlier study. Factors encouraging or inhibiting certain types of developers are examined.

Preliminary research indicates that tax, marketing, and licensing factors in Georgia differ significantly from those in the mid-Atlantic

states. The state tax structure is less complicated. With the exception of the franchise tax, utilities are subject to the same taxes as businesses and individuals, with no differences in rates or exemptions. Furthermore, the utility status for tax purposes is clearly defined: any person or corporation engaged in an electric or hydroelectric power business is taxed as a utility. Municipal services and cooperatives enjoy their usual exemptions.

The analysis of market access is also simplified by the presence of the Municipal Electric Authority and the Ogelthorpe Electric Membership Corporation of Georgia. These two entities are bulk power suppliers to municipalities and cooperatives, respectively, and may be expected to control decisions to purchase or generate small-scale hydroelectric power by these groups. The status of the private business selling power is also more clearly defined in Georgia than elsewhere: any retail sale constitutes utility service and is regulated by the Public Service Commission (PSC). No new utility may be formed without PSC approval; no utility may retail power without being assigned a service area by the PSC. Although the Territorial Act administered by the PSC makes provision for changes in established service areas, the PSC would prefer to reassign an area to an existing supplier than to create a new utility. Under those circumstances, retail markets probably would be closed to new suppliers.

The most significant difference is in the licensing requirements. The only permit required by state law is a dam safety permit (and possibly a water impoundment permit). Several approvals and certifications are administered by state agencies, but their authority derives from federal legislation. Since projects licensed by the Federal Energy Regulatory Commission are exempted from the dam safety permit, it is possible that certain hydroelectric projects would be required to meet only criteria established at the federal level and whatever requirements local permits necessitate. Further research in North Carolina and South Carolina will be conducted to determine whether this general pattern of simplification is common to the southeast region.

ENVIRONMENTAL CONSIDERATIONS

This part of the report will identify environmental considerations that may hinder development of dam sites in the three states. Preliminary investigation indicates that environmental factors depend on the level of government and type of developer involved. Accordingly, state

and local regulations and policies will be examined separately. Permit and approval requirements will be identified and the coordination of state and local procedures assessed. Cost and time implications of these procedures also will be considered, with quantification where such data exist. Using this approach, we can distinguish between major environmental issues that are common to all three states and those that are unique to a particular state or local setting. Such distinctions will form the basis for determining whether each obstacle is properly addressed by federal, state, or local action.

ALTERNATIVE SOURCES OF ELECTRICITY

An accurate estimation of the benefits of hydroelectric power should take into account the costs associated with electricity production by other means. The calculation of these costs is beyond the scope of this study, but this section serves as a first step in addressing the issue.

This research is based on an extensive review of publications issued from 1976 to the present by federal and state agencies and of academic journals in the field of energy and environment. All references to earlier articles were followed up, going back as far as 1963.

From the literature search we have identified environmental/social costs and have documented cost data associated with the generation of electricity by conventional and nonconventional means. The sources of electrical generation under consideration are coal, oil, nuclear, gas, hydroelectricity, solar, geothermal, and shale oil. Within each fuel cycle, various operational stages will be described: exploration, extraction, transportation, component production, plant construction, operation, maintenance, waste disposal, and deactivation. For each stage, the adverse environmental effects and human hazards resulting from power generation will be identified. The discussion of environmental and health impacts will include a description of the character of the impact, the criteria or indexes used for measuring these impacts, and, where possible, a description of the methodologies used to determine external costs.

REFERENCE

1. F. Bennett and S. Briscoe, "Problems of Hydroelectric Development at Existing Dams - An Analysis of Institutional, Economic, and Environmental Restraints in Pennsylvania, New Jersey, and Maryland," JHU/APL HE-004, Vol. 1 (QM-79-237), Aug 1979.

OPERATIONAL RESEARCH, HYDROELECTRIC POWER
DEVELOPMENT § 24
Small-Scale Hydroelectric ZP30CQO
Support: DOE/RA
J. W. Follin, Jr.
October-December 1979

LIST OF SMALL-SCALE HYDROELECTRIC REPORTS PUBLISHED BY APL, CY 79

In order to provide information on all significant papers issued in CY 79 by APL on various aspects of small-scale hydroelectric power, the following list of reports and internal memoranda is submitted.

Report No.	Date	Publication	Author(s)
QM-79-005	17 Jan	Trip Report of APL's 1/9/79 Visit to the Allis-Chalmers Hydro-Turbine Division in York, PA	R. von Briesen
QM-79-017	24 Jan	Tentative Schedule of Trips to the Area Covered by the Southeastern Electric Reliability Council (SERC)	R. von Briesen
QM-79-019	26 Jan	Estimating Hydroelectric Development Costs and Site Specific Data	R. J. Taylor
QM-79-058	27 Mar	Chart Presented at Water Systems Conference	J. W. Follin
QM-79-060	27 Mar	Small-Scale Hydroelectric Program	J. W. Follin
QM-79-108	18 May	Regional Study for Development of Hydroelectric Energy	A. M. Stone
QM-79-133 HE-004, Vol. II	Apr	An Analysis of Industrial, Economic, and Environmental Restraints on Hydroelectric Development at Existing Dams	R. J. Taylor and L. L. Greene
QM-79-134	11 Jun	Hydroelectric Handout	J. W. Follin
QM-79-146	22 Jun	Small-Scale Hydro Power, Visits in Atlanta, Georgia, 12-14 June 1979	C. S. Leffel
QM-79-182	27 Jul	Richmond Briefing on SSH	J. W. Follin
QM-79-187	1 Aug	Small-Scale Hydroelectric Visit to South Carolina, July 24-27, 1979	C. S. Leffel and R. von Briesen
QM-79-190	2 Aug	Small-Scale Hydroelectric Power; Visits to North Carolina DNR Community Development (Water Div.), Power and Light	R. von Briesen and W. B. Chapman
QM-79-206	23 Aug	Visit to Hydro Site at Savage, MD	W. B. Chapman
QM-79-237 HE-004, Vol. I	Aug	Problems of Hydroelectric Development at Existing Dams, An Analysis of Institutional, Economic and Environmental Restraints in Pennsylvania, New Jersey, and Maryland	S. Briscoe and F. Bennett
QM-79-222	25 Sep	Trip Report (SSH) to Jackson, Mississippi, Department of Natural Resources: a) Water Division, b) Fish and Wildlife, c) Air and Pollution Control, d) Office of Energy; and the Electric Power Associations of Mississippi, August 27-29, 1979	R. von Briesen and W. B. Chapman
QM-79-229	2 Oct	Attendance at the S.E. Regional Small Hydro Conference, Asheville, NC, September 19, 1979	C. S. Leffel, Jr.
QM-79-231	5 Oct	Small Scale Hydroelectric Potential in Pennsylvania, Meeting in Carlisle, PA, September 25, 1979	C. S. Leffel, Jr. and W. B. Chapman
QM-79-255	12 Nov	Preliminary Water Flow, Power and Energy Estimates for the Savage, MD Dam Site	C. S. Leffel, Jr.
QM-79-265	20 Nov	Visit to Alabama and Georgia for SSH, Nov 12-16, 1979	W. B. Chapman and R. von Briesen
QM-79-263	26 Nov	The Termination of the Hydroelectric Development at the High Falls State Park in Georgia	R. von Briesen
QM-79-267	27 Nov	SSH Visit to Florida, Oct 16-18, 1979	E. Boyd and R. von Briesen
QM-79-273	5 Dec	Low Head Hydro - New England Reprise	R. Thrall
QM-79-278	18 Dec	Visit to Baltimore District Office, Army Corps of Engineers	C. S. Leffel, Jr., and R. von Briesen

 

1. *Phragmites* spp. (Poaceae)

 

OPERATIONAL RESEARCH, HYDROELECTRIC POWER DEVELOPMENT

\$25

Small-Scale Hydroelectric ZP30CQO

Support: DOE/RA

J. W. Follin, Jr., C. S. Leffel, Jr., and

R. von Briesen

October-December 1979

COMMENTS ON LIMITED TASKS: SMALL-SCALE HYDROELECTRIC POWER

THE BALTIMORE DISTRICT OFFICE, U. S. ARMY CORPS OF ENGINEERS

The "Preliminary Inventory of Hydropower Resources" (Ref. 1) was published and the "National Hydro Study, Form 1" (NHSF1) was completed in July 1979 by the U.S. Army Corps of Engineers. Reference 1 was the first published list of dams to give the drainage area and average annual stream flow for dam sites estimated to be capable of supplying more than 50 kW of hydroelectric power.

The NHSF1 is available as a magnetic tape that can be used to obtain a computer printout. It contains data on stream flow duration and cost and income estimates for various sizes of hydroelectric power installations at the dam sites in the inventory. The bottom line is a benefit/cost ratio for various installed capacities. The optimum installed capacity for a given site was selected on the basis of the greatest positive difference between the annual benefit and the annual cost, when the annual cost was calculated for the retirement of the capital cost in 50 years at an interest rate of 6-5/8%.

We have been aware, from visits to the District Corps offices in mid-1979, that the results of the NHSF1 were being rechecked. The object of the visit to John Miller of the Baltimore District office on 12 December 1979 by C. S. Leffel and R. von Briesen was to determine what the Corps was doing to update the results shown in the NHSF1.

Mr. Miller stated that the NHSF1, which was designed as a rough screening tool, used incomplete cost data with the result that the benefit/cost ratios are too high. Also, the optimum power installation at a given site is biased toward a high-power-capacity installation that matches a high value of stream flow, which exists for only a small percentage of the time - in other words, a low value for the annual plant factor.

The Corps is now redoing the study as the "National Hydro Study, Form 2" (NHSF2). The new study not only includes information that is not available in NHSF1 but also, and more importantly, calculates the costs more accurately using Ref. 2. Although results from NHSF2 are not presently available, there are preliminary printouts in the District offices. For the Baltimore District, which is essentially the Susquehanna and Potomac River basins, NHSF2 reduces the number of feasible sites for development from 80 (in NHSF1) to about 25. For example, the summary results for the Savage River site in western Maryland are as follows:

	NHSF1	NHSF2
Average stream flow	165 ft ³ /s	165 ft ³ /s
Power head	114.7 ft	129.4 ft
Installed capacity	3424 kW	1428 kW
Annual energy produced	8008 MWh	5733 MWh
Annual cost	\$162 584	\$192 060
Annual benefit	\$417 280	\$179 373
Net annual benefit	\$254 696	-\$12 686
Annual plant factor	0.27	0.46
Benefit/cost	2.57	0.93

The conclusion is that the economic results of NHSF1 are unusable in their present form. However, the printout of NHSF1 does contain valuable information: stream flow duration data are given for the first time for a specified dam site, and the complete printout contains, at least in some instances, useful information about the condition of the dam. Thus, the economic feasibility of a site can be estimated using the printout of NHSF1 and Ref. 2.

The economic analyses for both NHSF1 and NHSF2 have been made using the flow duration curves and fixed values for installed capacity and generated energy. Both programs contain a provision for sequential power potential analysis in which the seasonal variations of energy value, permissible reservoir height, water flow restrictions, and evaporation rates can be included. The new study contains information on reservoir operation that will make sequential power potential analysis more accurate.

REFERENCES

1. "Preliminary Inventory of Hydropower Resources," U.S. Army Corps of Engineers, Institute of Water Resources, Ft. Belvoir, Va., Jul 1979.
2. "Feasibility Studies for Small-Scale Hydropower Additions, a Guide Manual," six volumes, the Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, Calif., Jul 1979.

SOUTHEASTERN VISITS

Trips have been made to Alabama, Florida, and Georgia to gather information. The visits included discussions with state energy offices, state water administrations, major electrical utilities, power-producing cooperatives and municipalities, offices contained in various departments of the Department of Natural Resources (DNR) pertinent to the use of small-scale hydroelectric (SSH) generation, and regional and division offices of the U.S. Army Corps of Engineers. Some points of interest from the visit to Alabama and Georgia from 12 to 16 November 1979 are

1. The dissolved oxygen (DO) concentration is recognized as a problem in Alabama. Many impoundments vary between 4 and 5 ppm. State law says streams and rivers should

have 5 ppm. The main utility in Alabama, the Alabama Power Company, has already added aspirators to several dams and soon all its major power-producing dams will have them. All new construction by this utility will aim for a DO of 6 ppm. This is yet another problem that must be considered by an SSH producer that uses a slow-moving, fairly large impoundment as a water source.

2. The Alabama Electric Cooperative is spearheading SSH in Alabama. It has filed applications for preliminary permits for three sites with the F.E.R.C.
3. About 18% of Alabama's electricity is generated by hydroelectric power. Most of the power is generated by the TVA and the U.S. Army Corps of Engineers at very large dam sites.
4. The Georgia Water Control Act states that no stream or river can have a surface water withdrawal of more than 100 000 gal/day ($0.15 \text{ ft}^3/\text{s}$) without a permit from the DNR Environmental Protection Division. This means that the tailwaters from hydroelectric plants could not be dumped into a different stream without a permit. Most large hydroelectric installations would not have this problem, but some SSH could be affected by canals or extended raceways that use old hydroelectric plant sites that used to dump tailwaters into different streams to achieve more head. Getting the permit may not be a problem, but it adds to the list of permits that must be obtained by the potential SSH producer.

Some main points of interest from the visit to Florida on 16-18 October 1979 are:

1. The potential for SSH in Florida is limited because of the terrain. Where it is favorable, SSH is either already being used or plans are being made for its implementation. The proposed 8.8 MW Jackson Bluff Hydroelectric Project for the City of Tallahassee has just won a Program Opportunity Notice (PON) to help the \$10 million project get on-line. The Florida Public Utilities Co. uses a spring-fed lake for hydroelectric power near the City of Marianna. The springs power a 100 kW generator that has a 100% duty cycle.
2. The Florida State Energy Office has had no requests for small hydroelectric licensing, although there has been interest in tidal flow generation in the 27 inlets on the east coast of Florida.

The ecological problems typical for these states are as follows:

1. Low DO concentrations in slow moving streams and rivers are typical for Gulf and Atlantic Coastal Plains.
2. Biological drawdown, a severe impoundment drawdown lasting from two to six months to kill fast-growing water plants (such as the water hyacinth, which, if left unabated, would change the ecological environment), is being studied by the Hydro Science Co. Alabama has not required this type of drawdown in the past but may require it in the future, depending on the results of the study. Such a drawdown, if required, would heavily influence a potential SSH producer. The need to do a biological drawdown is very

important for impoundments in the Florida panhandle.

REFERENCES

1. E. H. Boyd and R. von Briesen, "S.S.H. Visit to Florida," APL/JHU QM-79-267, 27 Nov 1979.
2. R. von Briesen and W. B. Chapman, "Visit to Alabama and Georgia for S.S.H.," APL/JHU QM-79-265, 20 Nov 1979.

HYDROELECTRIC DISCUSSION WITH MAYOR PAUL LATTIMORE, AUBURN, NEW YORK

During APL's 17 December 1979 visit to Auburn, New York (Ref. 1), Mayor Paul Lattimore drove APL representatives around the city and indicated the proposed hydroelectric sites. Starting with Lake Owasco (also the city water supply), there are six sites on the Owasco River that use the 145-ft drop as the river passes through the city. The Mayor, with personnel from the General Electric Co. (GE), is planning six hydroelectric generating plants and civil works along this outflow. GE has proposed a novel concept at one site to obtain energy without rotating machinery. Air is compressed isothermally by the entrainment of air bubbles in the falling water column and later is separated in an underground chamber. The compressed air is used thereafter in a special gas turbine without compressor stages to generate electricity at peak load hours. A copy of the GE proposal (Ref. 2) has been obtained and is in the APL Hydro Library.

REFERENCES

1. F. C. Paddison, "Meeting with Auburn, NY, Mayor Paul Lattimore," APL/JHU QM-79-283, 28 Dec 1979.
2. "Hydro Compression Gas Turbine Package Power Plant (HCGT)," General Electric Co. Proposal No. 79AES51, 8 Oct 1979, submitted to DOE, Idaho Operations Office, Program Announcement DE-PA-07-79 ID12055.

INTERNATIONAL SYMPOSIUM ON SMALL-SCALE HYDROELECTRIC POWER - WATERPOWER 1979

J. W. Follin, Jr., and R. J. Taylor participated in the International Symposium on Small-Scale Hydroelectric Power - Waterpower '79, 1-3 October 1979. Dr. Taylor presented a synopsis of the material contained in Ref. 1.

REFERENCE

1. R. J. Taylor and L. L. Green, "Problems of Hydroelectric Development at Existing Dams - An Analysis of Institutional, Economic, and Environmental Restraints in Pennsylvania, New Jersey, and Maryland," APL/JHU HE-004, Vol. II (CPE-7901) (QM-79-133), Apr 1979.

SEISMOTECTONIC STUDIES

§ 26

New England Seismotectonic Studies, Weston

Observatory F7K6CQO

Support: Nuclear Regulatory Commission, Reactor
Safety Research

J. E. Tillman

October-December 1979

NEOTECTONIC INVESTIGATION IN CONNECTICUT

Several of the largest earthquakes ever recorded in the U.S. have occurred in the East. However, earthquakes occur less frequently in this area than elsewhere in the U.S. so that a

general awareness of this hazard is limited. Over the past decade, siting studies for critical facilities, such as nuclear generating stations, have become progressively more sophisticated and have revealed many major fault zones tens to hundreds of kilometers in length in the Appalachian Mountain system. Much of the seismicity in the East (Fig. 1) can be related to these faults. However, the association of earthquake epicenters with fault zones (the field of seismotectonics) is not always obvious. In fact, earthquakes are only rarely associated with the surface rupture of fault zones.

More sophisticated investigations need to be made to determine the seismic suitability of an area before a critical facility is built. The present state of the art for such an evaluation involves the integration of multiple disciplines and techniques, e.g., field mapping of

Fig. 1 Earthquake epicenters 1800-1972. Contours of serial distribution of earthquake epicenters with epicentral intensity of MM III and greater (from Hadley and Devine, 1974). (79-4/57)

faults and fractures, mechanical analysis of fault geometries, land form analysis, insitu stress measurements, and geophysical and imagery analyses.

The Nuclear Regulatory Commission funds investigations in regions where nuclear energy is used to meet the electrical generation needs of the residents and where historic seismicity reveals a potential problem caused by instability and adjustments in the crust. One of their ongoing projects is centered in New England and is managed by the Weston Observatory of Boston College. Because of his experience in evaluating the Ramapo Fault along the Hudson River, the author has been requested to assess the tectonic framework of western Connecticut and southeastern New York -- an area of recurrent seismicity. The above-mentioned techniques have been used to identify several very important crustal features.

The area of investigation lies on the eastern edge of what was the continental margin (American Plate) in Paleozoic times. Major breaks in the aeromagnetic and gravity signatures across this zone suggest the possibility of large deep-seated fault zones. Previous investigations in the area failed to identify the faults; the complex structural patterns were explained as the interference patterns from multiple phases of folding. During the course of this work, several periods of faulting have been documented, and a large zone of reverse faulting has been defined. The latter appears to coincide with backthrusting in New York, Pennsylvania, Maryland, Massachusetts, and Vermont. It can be shown that this zone has been a major zone of weakness for over 600 million years, and isostatic adjustments on the present continental margin are causing the reactivation of the old faults today.

CONCLUSION OF TESTS OF THE APL CORE HEAT EXCHANGER AS AN EVAPORATOR

Shell-less, folded aluminum tube heat exchangers containing ammonia as the working fluid are part of the APL concept for Ocean Thermal Energy Conversion (OTEC) plantships. Vertical planes of tubes, each plane consisting of seven tubes connected in parallel and nested together (Ref. 1), form a heat exchanger module. Seawater from a head pond flows downward over the tubes and out the bottom of the module.

A full-scale core test unit of the proposed heat exchanger has been tested as an evaporator at the Argonne National Laboratory (ANL). The unit, fabricated by the Trane Company, consists of three full-length folded aluminum tubes contained in a water box. The objectives of the tests were to obtain experimental data on this novel design and to validate or to modify the analytical simulation that will be used to design the plantship heat exchanger. This report presents additional test results that were not reported in Ref. 2.

DISCUSSION

Reference 2 contains a description and photographs of the core test unit. That report covered the results of the first 56 tests conducted during April and May 1979. In September and October, an additional 41 tests were conducted to investigate the effects of changes in the ammonia inlet and outlet piping and the water treatment. In the first 38 tests, a swirl element (see Fig. 3 of Ref. 2) was installed in the first pass of each tube, and each tube was connected to a demister. For tests 39 through 56 — and all subsequent tests — the swirl elements were removed. In tests 57 through 75, the individual flowmeters and inlet valves were removed and a single flowmeter was installed upstream of the inlet manifold. This was done to eliminate the pressure drops in the ammonia inlet lines that could have favorably affected the flow stability of the unit. A single common demister was then used for tests 76 through 97. The stability of operation was not affected by the inlet and outlet piping changes. In tests 93 to 97, water without rust inhibitor was used.

Figure 1 presents the measured thermal performance in terms of a modified overall heat transfer coefficient, U^* , correlated with a combined flow parameter, $(Re_w Re_{NH_3})^{1/2}$, where Re_w and Re_{NH_3} are the Reynolds numbers of the water and ammonia flows, respectively (see Refs. 2 or 3). The results of all 97 tests are within $\pm 10\%$ of the correlating equation shown in the figure. However, the correlation should be considered to be limited to the ranges of test conditions cov-

$$U = \left[\frac{1}{h_{NH_3}} + \frac{d_i \ln d_o/d_i}{2k} + \frac{d_i}{(d_o h_w)} \right]^{-1}$$

$$U^* = \left[\frac{1}{U} - \frac{d_i \ln d_o/d_i}{2k} \right]^{-1} \quad d_i = 0.224 \text{ ft}$$

$$\frac{d_i \ln d_o/d_i}{2k} = 0.0001272 \quad d_o = 0.250 \text{ ft}$$

$$k = 96.67$$

- Tests 1-38, individual demisters, swirlers inserted
- △ Tests 39-56, individual demisters, swirlers removed
- Tests 57-75, individual demisters, swirlers removed
- ▲ Tests 76-92, common demister, swirlers removed
- Tests 93-97, common demister, swirlers removed, untreated water

Fig. 1 Correlation of thermal performance results and comparison with predictions of the original analytical simulation. (79-4/4)

ered. The experimental uncertainty in the U^* measurement has been calculated as $\pm 4\%$ for any given configuration over the testing range, and the total data spread including effects of the configuration changes outlined above is estimated to be $\pm 9\%$.

During the tests, ANL had added small quantities of an antirust agent (Nalco Chemical Co. N-8330) to the water system. Significant amounts of foaming of the water was observed at the top of the water pond at flow rates greater than 3600 gpm, and the agent was suspected to be a cause of the foaming, along with the configuration of the water entrance piping at the top of the pond. Since the foaming may have been carried down through the tube bank, it was investigated closely. During the September-October test period, water samples were drawn at the entrance and exit of the water pump, which was located downstream of the test box. No bubbles were seen in the sample at flows of less than 3600 gpm, but bubbles were seen at higher flow rates. A limited number of tests were repeated (93 to 97) with water that did not contain the antirust agent. They showed no significant differences in thermal performance on pressure drop from the previous tests. Bubbles were still observed at the higher flows, but in lesser amounts. At this point, it was judged that the water inlet configuration was the contributing cause of the foaming at higher flows and that it should be redesigned for future testing (as a condenser). Subsequent inquiries to the manufacturer of the antirust agent confirmed its tendency to foam. An antifoaming agent will be used in future testing.

Fig. 2 Water pressure drop (Δp_w) and Euler number (Eu) versus water velocity in minimum area gap (V_w). (79-4/5)

Analyses of the data show that if foaming does have an effect at high rates of water flow, its magnitude is within the error band of the measurements of U , since the U 's measured for combinations of low water flow and high ammonia flow were equal to those for high water flow and low ammonia flow. In terms of the correlating parameter, these conditions overlap and agree within the precision of the measurements. It is felt that extrapolations of the results of these tests to the pilot plant design (discussed below) are not affected since the extrapolations are confined to results based on a water flow of less than 3600 gpm.

The pressure drop across a tube bank is a function of the transverse and lateral pitch ratios of the bank, the fluid, and the maximum velocity in the minimum area passages of the bank. It is characterized by a Euler number as defined in Fig. 2. For a staggered tube bank, the transverse pitch is defined as the distance (normal to flow) between similar rows (6.0 in. for the core unit), and the lateral pitch is defined as one-half the distance between tubes in the same tube row along the direction of the flow (1.875 in. for the core unit). Thus, the transverse and lateral pitch ratios (i.e., pitches divided by tube diameter) for the core unit are 2.0 and 0.625, respectively.

Data from Ref. 3 suggest that the Euler number decreases as the transverse pitch ratio increases or the Reynolds number increases in the range of interest (33 000 to 100 000); the Euler number went from 0.15 to 0.11 for Reynolds numbers 30 000 to 70 000 for a bank with a transverse pitch ratio of 2.2. Data from the present tests (Fig. 2) show that the Euler number derived from a curve fit of the pressure drop data varied from about 0.15 to 0.13 over the range of test conditions, which agrees with the trends of Ref. 3 with respect to Reynolds number and transverse pitch ratio. The full-scale pilot plant design uses a 2.63 by 0.59 staggered tube configuration that should have a lower Euler number (about 0.10, see Refs. 1 and 4) than that measured in these experiments.

The results of the tests were used to modify the analytical simulation so that the calculated predictions agreed with the experimental observations. With the modified simulation, calculations were made for a pilot plant designed to produce 10 MW_e net; the evaporator ammonia flow was varied while the heat exchanger geometry, the water flow rate, and the ocean temperature conditions were held constant. A basic assumption of this investigation is that the overall improvement experimentally observed for the evaporator performance also applies to the condenser performance; experimental data for the condenser are yet to be obtained. The calculations show up to a 23% increase in net power (compared to the baseline case), or an evaporator flow rate of 2 lbm/s/tube. The baseline power system was originally sized to produce 11.2 MW_e for propelling the ship. Discounting the propulsion power requirement puts the APL power system on the same basis as that used by others. On this basis the estimated maximum net power of the unit is 38% above nominal.

A draft final report summarizing the entire evaporator core test (Ref. 5) was submitted to the DOE sponsor in December 1979.

FUTURE PLANS

The core test unit will be tested as a condenser, commencing about 15 January 1980, at conditions that are compatible with the evaporator tests.

REFERENCES

1. J. F. George, D. Richards, and L. L. Perini, "A Baseline Design of an OTEC Pilot Plant-ship," APL/JHU SR 78-3 (draft), May 1979.
2. Section 13, Quarterly Report, Apr-Jun 1979, APL/JHU EQR/79-2.
3. N. Afgan and E. U. Schlunder, "Heat Exchangers," *Design and Theory Sourcebook*, Ch. 4, Scripta Book Co., Washington, D.C., 1974.
4. P. P. Pandolfini and R. A. Makofski, "Circumferential Heat Transfer and Pressure Drop in Tube Arrays with a Low Lateral Pitch Ratio in Cross Flow," APL/JHU CP-066, Jun 1978.
5. P. P. Pandolfini, J. L. Keirse, and J. A. Funk, "Testing of the APL/JHU Shell-Less Folded Tube Heat Exchanger Core Test Unit as a Evaporator," APL/JHU BBP-79-135, Dec 1979.

RECOVERY OF LANDFILL METHANE

The recovery of methane from landfills is a relatively new technology that is growing fast throughout the country. Methane, the major constituent of natural gas, is generated in sanitary landfills as organic material decomposes and is collected, processed, and used as a source of energy. There are now eight recovery projects for commercial landfill methane in the United States. Table 1 lists these landfills, their locations, the end uses of the recovered gas, and the quality and quantity of gas sold.

The first landfill gas recovered for commercial use was at the Palos Verdes, California, landfill in June 1975. Reserve Synthetic Fuels, Inc., extracts from the landfill 1.5 million cubic feet per day (MMCFD) of gas. After the removal of carbon dioxide, dehydration, and compression, 0.75 MMCFD of high Btu gas is sold to the Southern California Gas Co. Reserve Synthetic Fuels, Inc., also operates a system at the Operating Industries landfill that upgrades the heating value of the gas, and 1 MMCFD is sold to the Southern California Gas Co. Similarly, at the Mountain View landfill, the Pacific Gas and Electric Co. produces 0.25 MMCFD of treated gas for injection into the Pacific Gas and Electric Company's pipeline.

At the Sheldon Arleta landfill, the recovery project of the Los Angeles Department of Water and Power extracts 1.5 MMCFD of landfill gas and delivers it to the Valley Steam Power Plant where it is used to generate electricity. At Azusa, California, the Azusa Land Reclamation Co., Inc. operates a system that supplies the Reichhold Chemical Co. with 0.5 MMCFD of boiler fuel. Azusa Land Reclamation is also studying the possibility of generating electricity with the landfill gas at the Azusa landfill for sale to either the Southern California Edison Co. or the City of Azusa. Watson Energy Systems, Inc., operates a system at the Ascon landfill in Wilmington, California, that supplies approximately 1 MMCFD of landfill gas to a nearby Shell Oil Refinery.

SCS Engineers designed a gas recovery system at the City of Industry, California, that provides 0.6 MMCFD of landfill gas used as boiler fuel for heating a swimming pool and on-site buildings. At the Cinnaminson landfill in New Jersey, the Public Service Electric and Gas Co. supplies the Hoeganaes Corp. with 0.25 MMCFD of landfill gas; in January 1980 sales will increase to 1 MMCFD.

Half of these recovery systems have come on-line during the past year, and many feasibility studies are under way. APL is presently involved

Table 1
 Landfill methane recovery projects.

Landfill	Location	End use	Quality of gas sold (Btu/scf)	Quantity of gas sold (thousand ft ³ /day)
Palos Verdes	Rolling Hills Estates, Calif.	Injection into utility gas line	1000	750
Mountain View	Mountain View, Calif.	Injection into utility gas line	700	250
Azusa	Azusa, Calif.	Boiler fuel for chemical plant	500	500
Ascon	Wilmington, Calif.	Fuel for oil refinery	530	1000
Operating Industries	Monterey Park, Calif.	Injection into utility gas line	1000	1000
Cinnaminson	Cinnaminson, N.J.	Fuel for steel plant	600	1000
Sheldon Arleta	Los Angeles, Calif.	Fuel for utility electricity generation	500	1500
Industry Hills	City of Industry, Calif.	Boiler fuel for heating swimming pool and building	500	600

in a feasibility study for the National Park Service (NPS) at two landfills in Washington, D.C.: Kenilworth and Oxon Cove. If feasible, the NPS will use the landfill gas to heat greenhouses and to provide heat for a facility to produce alcohol to fuel lawn mowers and other small engines used on federal parklands around Washington (Ref. 1). The study will provide preliminary estimates of the quantity and quality of gas recoverable at the two landfills. Fourteen test probes have been installed at Kenilworth and seven at Oxon Cove. A probe consists of 1/4-in. poly-flow polyethylene tubing encased in 1-in. PVC pipe, 10 to 22 ft long, with holes in the lower 1 or 2 ft of the PVC pipe. After the probes were placed in drilled 4-in. diameter wells, the wells were backfilled with gravel and cover material.

The probes were installed to formulate initial estimates on the quality of gas present at various locations in the landfills. Gas samples collected at each probe have been analyzed by gas chromatograph. Typically the methane concentration is in the range of 50 to 70%, although

some samples showed concentrations as high as 98%. The drilling of the probe holes provided information on the depth of the cover material, the depth and types of fill, and the depth of the water table. These data were used to determine the location of the test wells.

During January 1980, 3-in. PVC pipe with slots in the lower 5 ft will be installed in 10-in.-diameter test wells. Long range pumping of the wells will provide data to estimate the quantity of gas available at the landfills and the quality of gas that can be expected with continuous extraction. The testing program will provide the necessary information to design the layout for the gas collection system and to determine the rate at which the gas could be withdrawn from the landfills for the proposed gas utilization systems.

REFERENCE

1. P. Hodge, "Scientists Find Gas 'Lakes' Under Garbage," The Washington Post, 6 Dec 1979.

Research by: CQO

Support: DOE/Task X/N00024-78-C-5384

J. E. Tillman

October-December 1979

UNCONVENTIONAL GAS SOURCE— EASTERN DEVONIAN SHALES

Large quantities of natural gas occur in the thick sequences of Devonian brown shales in the Appalachian, Illinois, and Michigan Basins. Figure 1 (from Ref. 1) shows the extent of these rocks, the thickness of the formations, and the location of historical production. The gas in the shales is not widely exploited because shale is a fine-grained "tight" rock with low permeabilities. Thus, only low flow rates are obtained from wells penetrating those rocks. In areas of commercial production, reservoirs are larger because of the zones of extensive natural fracturing.

DOE has a program to identify areas of natural fracturing and to improve the technology for artificially "hydrofracturing" the shales. Their Eastern Gas Shales Project (EGSP) is managed from the Morgantown Energy Technology Center. On 2 October 1979, the author presented the results of his work in the field of fracture differentiation and hydrofracturing to the American Association of Petroleum Geologists at the Eastern Meeting in Morgantown, West Virginia (Ref. 2). On 3 October, he was asked to present the paper to the management of the EGSP. This paper (Ref. 3) describes a new technique for determining the relative ages of fractures and faults by integrating mechanical and geochemical analytical methods. By evaluating field data and measuring homogenization temperatures of fluid inclusions in fracture-filling mineralization, it is possible to understand fluid migration and fracture development in sedimentary basins. The techniques have direct application in assessing areas for the extraction of gas from shales.

FUTURE PLANS

The Morgantown Energy Technology Center has invited APL to evaluate how we can best contribute to its overall program for economic gas extraction. A meeting is planned for February 1980.

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1. S. P. Cremean, "Novel Fracturing Treatment in the Devonian Shale," Proc. First Eastern Gas Shale Symposium, Morgantown, W.Va., 1977.
2. J. E. Tillman, "Presentation of Paper to the AAPG and DOE/EGSP Meeting at Morgantown, West Virginia," APL/JHU QM-79-233, 5 Oct 1979.
3. J. E. Tillman and H. L. Barnes, "Hydrothermal and Uplift Histories of the Northern Appalachian Basin," Am. Assoc. of Petrol. Geol. Bull., Vol. 63, No. 9, 1979, p. 1589.

Fig. 1 Devonian shale basin of Eastern United States (from Ref. 1). (79-4/54)

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