VERMIR SF.

RESEARCH ENGINEERS AND GEOPHYSICISTS

REYKJAVÍK ICELAND

PRELIMINARY REPORT

ON THE

SUPPLY OF GEOTHERMAL STEAM FOR THE PROPOSED DIATOMEOUS EARTH PLANT

AT LAKE MÝVATN

THE STATE ELECTRICITY AUTHORITY
Reykjavík, Iceland

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(0) SUMMARY

The geothermal area at Námafjall near Lake Mývatn in northern Iceland is part of one of the major high-temperature fields in Iceland.

Test drillings so far carried out (2 boreholes) have not yielded the necessary flow of steam (25 tons/hr) required for the operation of the proposed diatomeous earth plant, nor shown the highest attainable temperatures. It is, however, expected that inflow temperatures of 225 °C or higher, and sufficient flow of steam can be secured by drilling production boreholes of 600 meters or deeper. The chemical composition of the thermal water is given as well as the gas content and gas analysis for the geothermal steam, (refer tables 1 and 3).

No serious problems of corrosion or scaling are anticipated.

It is expected that the production boreholes can be operated at a back pressure of about 6 - 8 atm. abs. at the wellhead. On the basis of this steam with a temperature of 150 °C and moisture content of 2% or less could be supplied to a plant located upto 5 km away from the boreholes.

Some economic aspects inherent to the utilization of geothermal energy are discussed, and the transmission costs for the heat energy analysed and compared for 3 alternate methods of transport. The use of steam as heat-carrier appears to be the most economical in the present case, and the transmission costs would amount to 6.80 Icel. kr/ton of steam for a distance of 5 km, and less for shorter distances refer Fig. 9.

The overall costs of the steam supplied to the plant cannot be determined with any accuracy until the necessary flow of steam has been secured by further drilling. It is however shown that (refer Fig. 10) significant reduction in steam price would result if the total steam requirements of the plant increase from the specified 25 tons/hr.

(1) INTRODUCTION

KÍSILIÐJAN HF has in a letter dated 28 July 1964 to the ATVINNUMÁLA-RÁÐUNEYTI aked for the following information regarding the supply of geothermal steam to the proposed Diatomeous Earth Plant at Lake Mývatn:

(1) Estimated steam pressure at a plant erected at a distance of 500 - 1500 m from the present steam boreholes in Bjarnarflag.

(2) Moisture content in the steam supplied to the plant.

(3) Contents of gases in the steam.

(4) Analysis of water and steam.

(5) Estimated difference in the cost of the steam supplied to plant sites in in 500 - 1500 m distance from the present boreholes.

It is further stated that calculations should be based on the assumption that the plant would require 25 tons steam per hour.

Mr. Jakob Gíslason, Director General of the State Electricity Authority of Iceland has entrusted VERMIR SF with the compilation of the pertinent data contained in the following report.

During a meeting in Reykjavík between Messrs. G.M. Randall and R.A. Lowell of KAYSER ENGINEERS INTERNATIONAL, Baldur Líndal of KÍSILIÐJAN H/F, and Sveinn S. Einarsson of VERMIR SF on 7 August 1964 it was agreed that VERMIR SF should prepare a diagram showing the estimated incremental unit cost of the heat energy versus the length of the supply line up to a distance of 5 km from the boreholes, for steam as well as superheated water as heat carrying medium.

It was further agreed, that an aerial photograph and a map showing the principal tectonic faultlines and fissures in the area between Námafjall and Mývatn should be sent with this report to KAYSER ENGINEERS INTERNATIONAL.

In gathering the basic data Vermir s/f is indepted to the Department for Natural Heat of the State Electricity Authority for the temperature logging of the boreholes and various other assistance, and to the University Research Laboratory in Reykjavík for analysing samples of water and gas.

(2) THE GEOTHERMAL RESOURCES AT LAKE MÝVATN

(2.1) The Námafjall-Krafla Geothermal area.

The mount Námafjall is the southern part of a large hydrothermal system which probably extends some 10 - 12 km to the north upto and beyond mounts Krafla and Leirhnjúkur, refer map on Fig. 1.

This is a high-temperature area with prolific surface display of steam vents, sulphur deposits and spectacularily altered rockformations particularly in the Námafjall area and also around Krafla and Leirhnjúkur. A system of tectonic fault lines and fissures with slightly northeasternly direction runs through the area and interconnects the southern and northern parts, and consequently it is natural to consider this geologically as a single geothermal system. Volcanism has been very active in this area and as late as in the years 1724 - '30 and again in 1746.

The Námafjall-Krafla system is one of the major geothermal areas of Iceland with visible signs of thermal activity scattered over an area in excess of 30 - 40 km^2.

Seismic refraction studies carried out in the Mývatn area (Pálmason 1963) indicate that the uppermost about 600 m consist of series of lava and tuff formations of Quaternary age with P-velocity of 2.8 km/sec followed by 1000-1300 m thick layer with P-velocity of 4.2 km/sec probably Tertiary flood basalts. Under the flood basalts is about 2000 m thick layer with P-velocity of 5.1 km/sec which again rests on a denser layer with P-velocity of 6.3 km/sec.

It may be assumed that the hydrothermal circulation system extends from the surface down through the floodbasalt layers and possibly deeper. The base temperature is not known definately, but it can be infered from temperature logs of the existing boreholes that it will be higher than 225-230 °C. A temperature of 222 °C has been measured in borehole No. 2 at Bjarnarflag.

(2.2) Results of Test Drilling.

Two boreholes, No. 1 and No. 2, were made at Bjarnarflag on the western fringes of Námafjall in 1963. They are 265 m and 431 m deep respectively and located on the opposite sides of a spectacular fault line some 200 m apart. Some typical details of those boreholes are shown on Fig. 2. Temperature logs for same are shown on Figs. 3 and 4.

(2.21) Borehole No. 1.

The first temperature logs (October and November 1963) show a bottom temperature of 218 °C. The shape of the temperature-depth curve indicates that the base temperature has not been reached, it will probably be considerably higher.

After the borehole had been blowing for 3 months, the output of the borehole was tested. Fig. 5 shows the calculated flow of steam and water respectively according to this test (a) assuming an inflow temperature of 218 °C (b) assuming an inflow temperature of 193 °C.

Fig. 3 shows further a temperature survey that was made in August 1964, after the borehole had been blowing for 9 months. At the same time the output of the well was tested with the results shown on Fig. 6.

The bottom temperature of the well has dropped from 218 °C to 193 °C, and the output decreased very considerably.

An obstruction was observed in the well at a depth of 190 - 195 m in August 1964 allowing only passage of objects of maximum 50 mm diameter.

Two different explanations are possible as regards the observed drop in temperature :

(1) The measured output of the borehole is considerably less than would be expected, if the water could flow freely into the well at the existing temperature. The flow of water to the well may therefore be restricted and this again would result in a pressure drop in the water passages of the rock adjacent to the bottum of the borehole when it has been blowing for sometime. This again would lead to flashing of some of the water with a substantial drop in temperature.

(2) It is known that a layer of 110 - 120 °C water is found only 60-70 m above the bottom of the borehole. A leakage of such water into the feeder system of the borehole could explain the drop in temperature.

(2.22) Borehole No. 2.

The temperature-depth curve for this borehole shown on Fig. 4 is rathar unusual and could indicate that relatively cold water (105 - 115 °C) is entering the borehole at one or more places and cooling it off almost to the bottom. This borehole does not yield any water or steam.

An obstruction at about 170 m hindered temperature survey below that depth in August 1964.

(2,23) Conclusions.

The results of the drilling of the two boreholes are inconclusive as regards (a) the maximum temperatures attainable in the area, and (b) the possibilities of guaranteeing sufficient steam to fulfil the requirements of the proposed diatomeous earth plant.

It is likely that higher temperatures can be found than those obtained as yet by drilling deeper.

The main problem at present is to find out why the bottom temperature in borehole No. 1 has fallen. A number of measures are being initiated in order to clarify this question.

This borehole is probably too shallow in order to sustain reliable production. Too shallow a borehole would aggravate the problems resulting from limited inflow (ref. (1) page 7) due to insufficient bottom pressure. A deep borehole extending all the way into the firm basalt series underneath would also reduce the danger of infiltration of colder water from above.

Experience from other high-temperature areas like Hveragerdi, where steam production from wells shallower than 300 m has proved to be unstable, supports this view.

If borehole No. 2 could be salvaged by sealing the inflow of relatively cold water by cementing or by installing a deeper casing, valuable information will no doubt result, as well as increased steam production. Even so the present boreholes can hardly sustain steam production of the order of 25 tons/hr, and at any rate no reserve will be available from them.

With view on this the drilling of at least one new borehole seems to be appropriate. Such a borehole should be sufficiently deep in order to cut into the underlying basalt series.

(2,3) Chemical Composition of the Thermal Fluids.

Table 1 gives the chemical composition and some physical data on the water phase from borehole No. 1 at Bjarnarflag.

It must be noted that the samples are taken at atmospheric pressure (100 °C). The samples accordingly represent the residual water after the flashed steam fraction has been separated off.

For comparison similar data for a borehole (No. 3) in the Hveragerdi high-temperature field in southern Iceland is given in table 2.

TABLE 1

ANALYSIS OF WATER FROM BOREHOLE NO. 1 AT BJARNARFLAG, IN THE NAMAFJALL AREA

Date of sampling	21 Feb. 1964 ppm	21 Feb. 1964 epm	18 August 1964 ppm	18 August 1964 epm
Total solids (105 °C)	905.2		884.0	
Hardness as $CaCO_3$	6.8		7.8	
Methyl alkalinity as $CaCO_3$	210.5		225.5	
Phenoltalein " " "	102.0		106.0	
SiO_2	428.8		424.0	
Ca	x)		< 0.5	
Mg	x)		< 0.5	
Na	121.0	5.30	125.0	5.44
K	16.5	0.42	13.0	0.33
Total anions		5.72		5.77
HCO_3	7.9	0.13	16.5	0.27
CO_3	122.4	4.08	127.2	4.24
CO_2	x)		15.8	
SO_4	97.3	2.03	68.8	1.43
Cl	12.7	0.36	16.2	0.46
F	1.1	0.06	ca. 1	
Total anions		6.66		6.40
Specific resistance (microohm 25 °C)	1377		1261	
pH	9.65		9.65	
Sulfids as H_2S p.p.m.	x)		71.0	

x) Not determined

TABLE 2

ANALYSIS OF WATER FROM BOREHOLE NO. 3, HVERAGERDI, IN SOUTHERN ICELAND

		Maximum	Minimum	Average
Total solids (105 °C)	ppm	1126	968	1057
Hardness as $CaCO_3$	"	7.0	5.8	6.3
Metyl alkalinity as $CaCO_3$ ...	"	144.0	105.0	129.0
Phenoltalein " " " ...	"	114.0	71.0	94.0
SiO_2	"	506.8	422.0	467.0
Ca	"	2.6	0.9	2.4
Mg	"	1.6	0.1	0.6
Na	"	230.0	182.5	203.0
K	"	28.5	22.0	26.1
CO_3	"	52.8	34.0	41.8
OH	"	28.9	9.2	20.1
CO_2	"	49.8	21.8	36.9
SO_4	"	75.1	52.8	62.2
Cl	"	216.4	174.4	195.2
F	"	2.2	1.7	1.9
Sulfids as H_2S	"	24.2	6.6	12.7
Spec. resistance microohm 25 °C		1061	915	994
pH		9.80	9.47	9.64

TABLE 3

ANALYSIS OF GASES IN GEOTHERMAL STEAM FROM BOREHOLE NO. 1 AT BJARNARFLAG

Date of sampling			Feb. 1964	Aug. 1964	Aug. 1964
H_2S	volume %	....	15.3	8.6	7.8
CO_2	" "	....	21.2	15.1	14.4
O_2	" "	....	0.1	0.0	0.0
H_2	" "	....	55.2	64.0	65.5
CH_4	" "	....	1.7	2.3	2.4
N_2 & A	" "	....	6.2	10.0	9.9

Table 3 shows an analysis of the non-condensable gases in the steam of the borehole at Bjarnarflag.

The gas content of the steam condensed at atmospheric pressure was found to be about 172 ml gas per kg steam, i.e. 0.1 % by volume and 0.01% by weight.

At the operating pressure that will be considerably higher than the pressure at which the samples for the analysis shown were taken, perhaps 6-8 atm. abs., less water will flash off as steam and the concentration of dissolved solids in the water phase will be correspondingly less than shown. Concurrently the gas content of the steam phase will be relatively higher.

(3) TECHNICAL AND ECONOMIC ASPECTS

(3.1) Steam pressure and temperature.

The fluid flowing into the boreholes at sufficient depth is considered to be superheated water. As the water ascends towards decreasing pressure, flashing initiates when the hydrostatic pressure in the borehole corresponds to the vapour pressure of the water, and boiling continues upwards maintaining the temperature-pressure equilibrium of saturated steam.

The boreholes issue a two-phase mixture of steam and water. The dryness fraction, i.e. the quantity of steam that can be produced from each kg of water flowing into a borehole, is a function of the inflow temperature and the back pressure on the well-head.

The inflow temperature is fixed, the backpressure on the wellhead, however, can be controlled within certain limits. These limits are governed partly by the flow characteristics of the borehole and partly by economic considerations. Generally the flow characteristics of a steam-water borehole has the shape shown on fig. 7. The relationship between the dryness fraction, inflow temperature and back pressure is shown on the nomographic chart on fig. 8.

For a given inflow temperature the dryness fraction decreases rapidly with increasing backpressure, and this again means that a higher number of boreholes is required in order to sustain a given steam production. This increases the unit cost for the steam, unless the enthalphy of the water phase can be utilized simultaneously.

Assuming that inflow temperatures of 225 - 230 °C or higher can be attained as previously stated by successful drilling in the Bjarnarflag area, it should be technically possible to operate the boreholes with a backpressure of 6 - 8 atm. abs. at the well-head. The pressure drop in the steam supply lines from the boreholes to the user depends on the sizing of the pipes, and the distance. With an initial pressure of say 7 atm. abs. the steam could be delivered to a plant up to 5000 m away with a pressure of 5 atm. abs. and a temperature of above 150 °C.

(3.2) Moisture content of the steam.

The moisture content of the steam supplied to the consumer is dependent upon the efficiency of the separators used.

Centrifugal separators at the boreholes can deliver the steam phase with a moisture content of 2% or less. To this is added some condensate due to heat losses in the main pipeline, which again is dependent on the degree of insulation used.

Too efficient insulation of the pipe line is not always feasible (a) because of cost, and (b) because it may be desirable to let some condensate dilute the geothermal water carried-over with the steam.

A second separator at the premises of the consumer would yield steam with less than 2% moisture.

(3.3) Problems of corrosion and scaling.

If proper selection of materials is observed no serious corrosion problems are likely to be encountered in connection with the use of geothermal water and steam of the composition encountered at Bjarnarflag, as long as access of oxygen is excluded.

Table 4 gives some of the results of a corrosion test that was carried out with thermal fluids from borehole No. 3 at Hveragerdi in 1960 - 1961. The test was carried out in accordance with ASTM method A 224 - 46. The samples that were formed as discs mostly with 1 sq.dm surface area were exposed to the following environments:

A. Geothermal fluid, i.e. unseparated geothermal water and steam mixture drawn direct from the borehole.

B. Dry steam, separated from A.

C. Aerated dry steam, i.e. dry steam mixed with air.

D. Condensate of dry steam.

The duration of the test was 149 days.

The experience seems to indicate that deposits of scale inside pipes and other equipment in contact with geothermal water is not a serious problem if care is taken to avoid too low temperatures (80 - 100 °C), and to keep the heat exchanger surfaces accessible to cleaning.

Deposit of calcite, however, frequently happens in the upper parts of the boreholes where flashing is vigorous. Such deposits are easily removed by a portable drill.

TABLE 4

CORROSION RATES AND PITTING RATES IN INCHES PER YEAR

Excerpt of results from surface corrosion tests at borehole No. 3, Hveragerdi

	A		B		C		D	
	Geothermal fluid		Dry steam		Aerated dry steam		Condensate	
	a	b	a	b	a	b	a	b
Cast carbon steel	0.00077	P	0.00066		0.00095	0.0159	0.00316	P
13% Cr. S-steel			0.00021		0.00528			
Mild steel	0.00140	P	0.00073		0.00235	0.0196	0.00263	0.007
18/8/1 steel	(0.000006)		0.00001		0.00001	P	0.00001	
S. 80 steel	0.00013		0.00016		0.00139		0.00003	
60/40 brass	0.00019	0.0044	0.00012		0.02355		0.00004	
Monel	0.00378	P					0.00046	
Copper	0.00648		0.00350	0.0037	0.0300 x)		0.00340	
70/30 As. brass			0.00078		0.0494			

a. Corrosion rates ipy, calculated from weight loss.

b. Pitting depth, max. in ipy.
P= small pits

x) Corrosion rate during 4 weeks only.

(3.4) Some economic aspects.

The unit cost of geothermal energy ex borehole is substantially determined by the cost of drilling the boreholes. This latter again is influenced by many factors such as:

(a) The geology and geophysical conditions of the thermal area.

(b) The flow and temperature characteristics of the boreholes.

(c) Process requirements such as minimum steam pressures and temperatures, which govern the operating back pressure of the boreholes.

(d) The utilization of the enthalphy of the water phase.

The first two factors, (a) and (b), are beyond control, whereas (c) and (d) can be controlled within certain limits.

Generally the total heat flow from a borehole decreases with increasing back pressure, due to reduced mass flow. The available primary steam fraction however falls off still more rapidly, as the dryness fraction decreases almost lineally with increased temperature. Use of the primary steam fraction alone is therefore a rather inefficient utilization of geothermal energy and can lead to a relatively high unit cost for the steam. If the enthalphy of the water phase can be utilized simultaneously no additional drilling costs are involved and the overall unit cost for the heat energy is reduced.

This is illustrated by the following example. A borehole with an inflow-temperature of say 225 °C would at a back pressure of 7 atm.abs. yield 0.132 kg steam and 0.868 kg water of 164 °C for each kg flowing in. If the steam fraction were condensed and the condensate wasted at 100 °C, it would yield 73.8 kcal only per each kg of inflow. The water fraction on the other hand could yield another 56.9 kcal if it were wasted at 100 °C, i.e. an increase of about 77%. The utilization of the water phase would thus effect about 44% reduction in the unit cost of utilized heat energy.

For many applications pressurized high-temperature water can replace steam as heating medium. Modifications in design of equipment towards this end may in many cases be justified or econonomically feasible where the use of geothermal energy is contemplated.

(4) TRANSMISSION OF THE HEAT ENERGY

(4.1) Available methods of transmission.

The ideal method of transmitting the geothermal heat energy would be that of installing a deep-well pump below the level where flashing begins in the borehole and use the pressurized water as heat carrier. Such pumps would, however, have to withstand an ambient temperature of over 200 °C continuously, and are not available.

In practice the boreholes yield a two-phase flow of steam and water mixture. Transmission of the two-phase mixture over a distance of a few hundred meters or more would entail a very considerable pressure loss and corresponding decrease in the temperature of the mixture. In order to avoid this the two phases will have to be separated at the wellhead.

There are in principle 3 methods of transmitting the heat energy to distant users:

Alternative (I) Transmission of the steam fraction alone, and wasting the water phase.

Alternative (II) Transmission of the steam and the geothermal water in separate pipelines.

Alternative (III) Transferring the heat energy from the geothermal steam and water to pressurized fresh water that is used as heat carrying medium.

(4.2) Analysis of the transmission costs.

For the purpose of determining the most economical mode of transmission for the heat energy to a plant using 25 tons of steam per hour, or the equivalent thereof, located at a distance of upto 5 km from an assembly point in the geothermal area, the 3 alternatives mentioned in the previous paragraph have been analysed in detail.

The basic assumption made are as follows:

(a)	Inflow temperature to boreholes	218 °C
(b)	Operating back pressure at wellheads	7 atm. abs.
(c)	The heat carrying medium is wasted at the plant as water of	100 °C
(d)	Maximum allowed heat loss in transit, (or min insulation thickness 1")	4%

(e) Annual capital charges (7% interest, 20 years depreciation time, sinkingfund contribution) 9.44 %

(f) Annual time of operation under full load (load factor) .... 7000 hrs.

(g) Cost of electric power .... 0.56 kr/kWh

The results of the computations are shown in the following paragraphs. For sake of comparison all transmission costs are calculated per 1 Gcal = 10^9 cal as unit for useful energy, hence 1 kr/ton of steam = 1.795 kr/Gcal.

(4.21) Alternative (I):

Geothermal steam only is delivered to the plant, and the geothermal water wasted.

Steamflow	25 tons/hour
Temperature of steam at plant	150 °C
" " wasted condensate	100 °C

The tramsmission costs per Gcal are shown on Fig 9.

The discontinuities are due to changes in diameter for the pipeline.

The maximum transmission cost for a distance of 5 km is 12.20 kr/Gcal.

(4.22) Alternative (II):

Geothermal steam and geothermal water are delivered to the plant through two separate pipelines.

Steamflow	13.8 tons/hour
Steam temperature at plant	150 °C
Flow of geothermal water	29 kgs/sec
Temperature of water at plant	160 °C
" " wasted condensate and water .	100 °C

The overall transmission cost per Gcal is shown on Fig. 9.

The transmission cost over 5 km is 15.50 kr/Gcal.

(4.23) Alternative (III):

Pressurized high-temperature fresh water delivered to the plant. The estimated cost of providing fresh water and operating costs of the heatexchanger station are included in the transmission costs.

Flow of water	....	79 kgs/sec
Temperature of water at plant	....	150 °C
" " wasted water	....	100 °C

The transmission costs are shown on Fig. 9.

Transmission costs over 5 km are 21.90 kr/Gcal.

(4.24) Discussion:

The above analysis indicates that in the present case, i.e. supply of 25 tons/hour of steam or the equivalent over a distance of maximum 5 km, the use of steam alone as heat-carrying medium is the most economical. The maximum transmission costs of 12.20 kr/Gcal equals 6.80 kr/ton of steam.

No regard has been given to the cost of the heat ex borehole. Because of the limited number of boreholes required to sustain the necessary heat production, the difference in drilling costs between the 3 alternatives can hardly influence the outcome to any great extent.

It must however be kept in mind, that the obove calculations are based on wasting the effluent water at 100 °C.

If there were other uses for its heat content such as space heating (district heating, greenhouses etc.) the available energy for each degree additional drop in effluent temperature would be as follows:

Alternative	(I)	25,000 x 1 =	25,000 kcal/hr
	(II)	(13,800 + 29 x 3,600) x 1 =	118,000 "
	(III)	79 x 3,600 x 1 =	248,000 "

(4.3) Cost of the steam.

The unit price of the heat energy ex boreholes cannot be determined with any certainty until the necessary amount of steam has been proven by further drilling. Accordingly the overall cost of the heat energy cannot be computed at this time.

However, assuming a token price of 15 kr/ton of steam ex borehole based on the use of 25 tons/hr for 7000 hours per year, a crude estimate can be made of the cost of the steam for varying plant requirements, and at varying distances between the plant site and the boreholes. This is shown by the curves of Fig. 10.

These curves indicate that the steam prices will fall off very rapidly if the plant requirements exceed 25 tons/hr. This is noted here as it may have some influence on the economic size of the plant.

(5) APPENDIX

Tectonic faultlines and fissures in the Mývatn area.

The area east of Lake Mývatn is characterized by an extensive system of tectonic faultlines and fissures with slightly northeasternly direction. Figure 11 shows the location of some of the more spectacular ones in the area between Lake Mývatn and Námafjall. This mapping is based on aerial photographs and knowledge of localities, but not on a geological survey of the area.

The faultlines and fissures extend no doubt south of the main road. In this area the features are more or less covered by recent lava flows.

The area east of the dotted line "A" is considered to be a potential production area for geothermal steam.

If a plant site were selected on the new lava north of the steam bath, no steam boreholes should be located west of the dotted boundery line "C". The shaded area between "B" and "C" would be exposed to carry-over of water droplets when boreholes located near the boundery line "C" were blowing to the atmosphere.

Due attention must be taken to the faultlines when building sites are selected.

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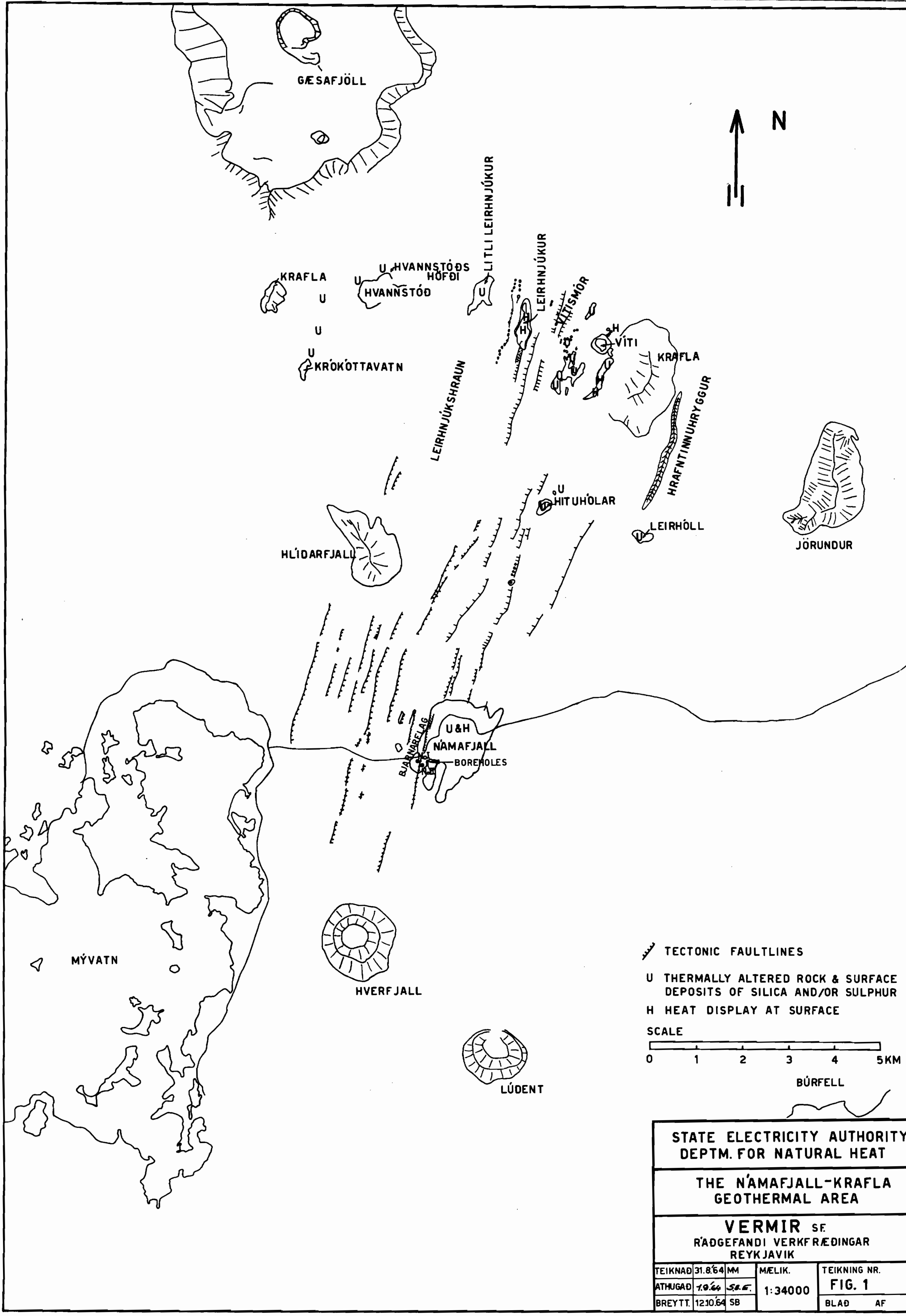

STATE ELECTRICITY AUTHORITY
DEPTM. FOR NATURAL HEAT

THE NÁMAFJALL-KRAFLA GEOTHERMAL AREA

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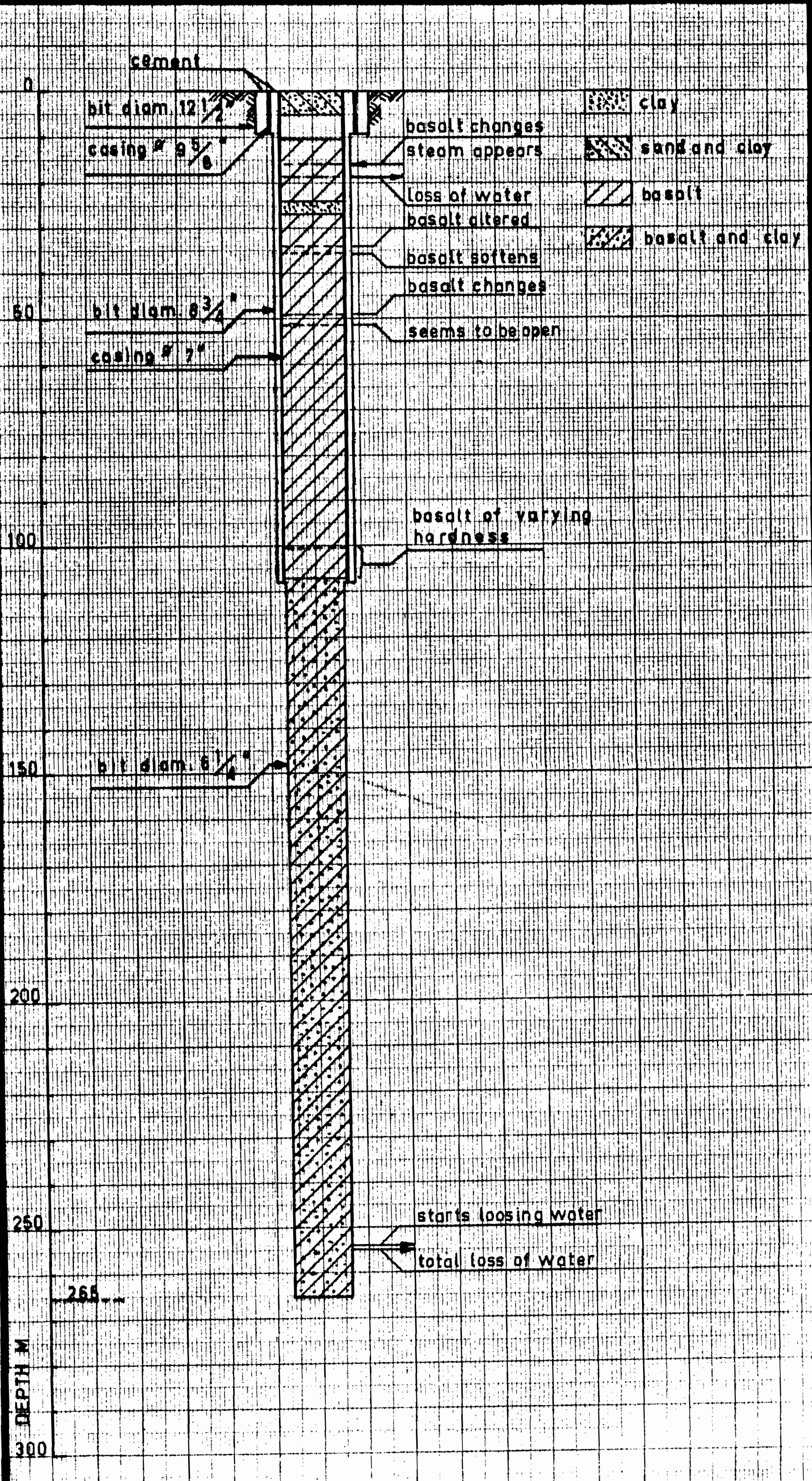
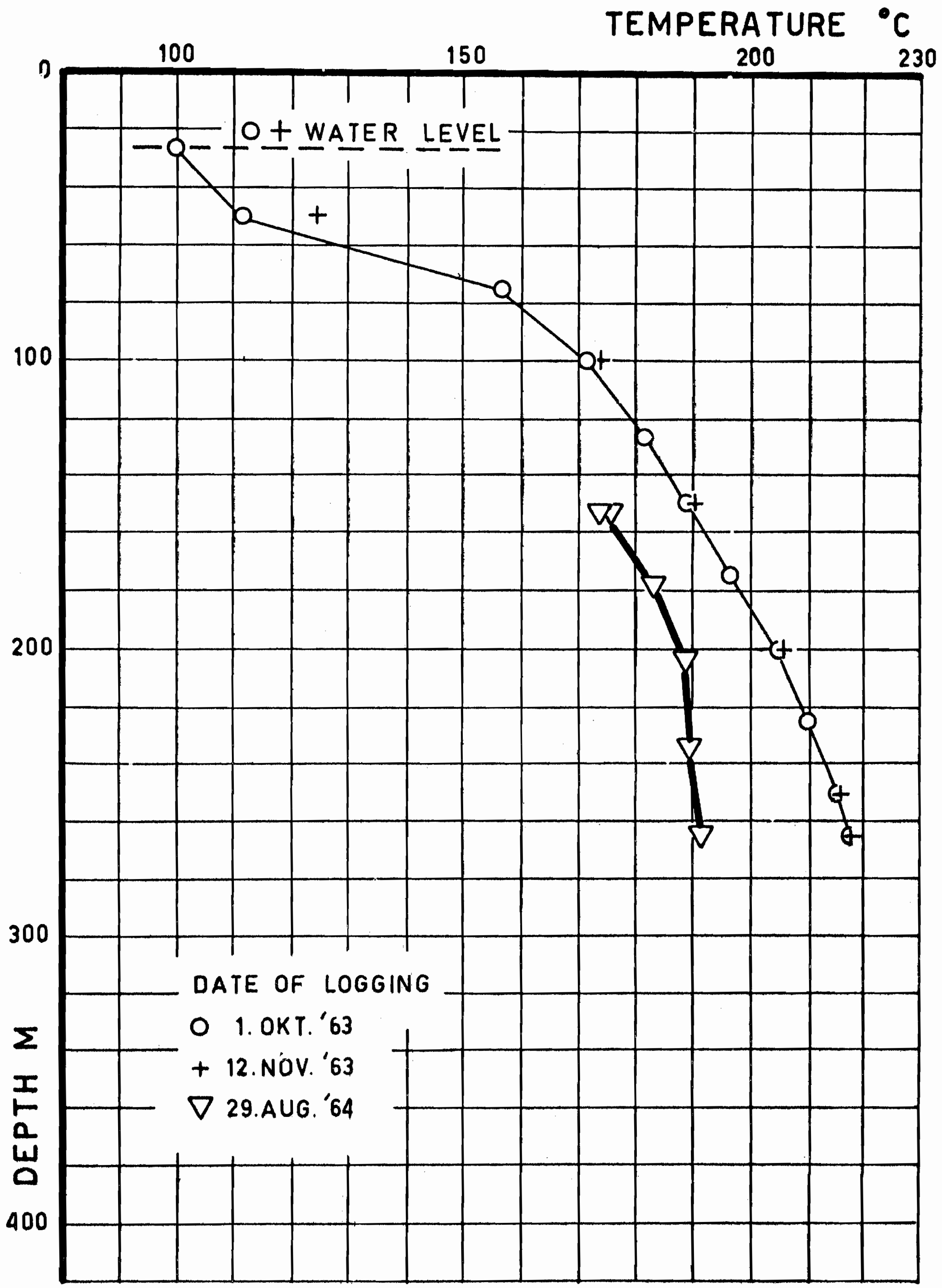
RÁÐGEFANDI VERKFRÆÐINGAR
REYKJAVIK

TEIKNAÐ	31.8.64	MM	MÆLIK.	TEIKNING NR.
ATHUGAÐ	1.9.64	S.E.	1:34000	FIG. 1
BREYTT.	12.10.64	SB		BLAÐ AF

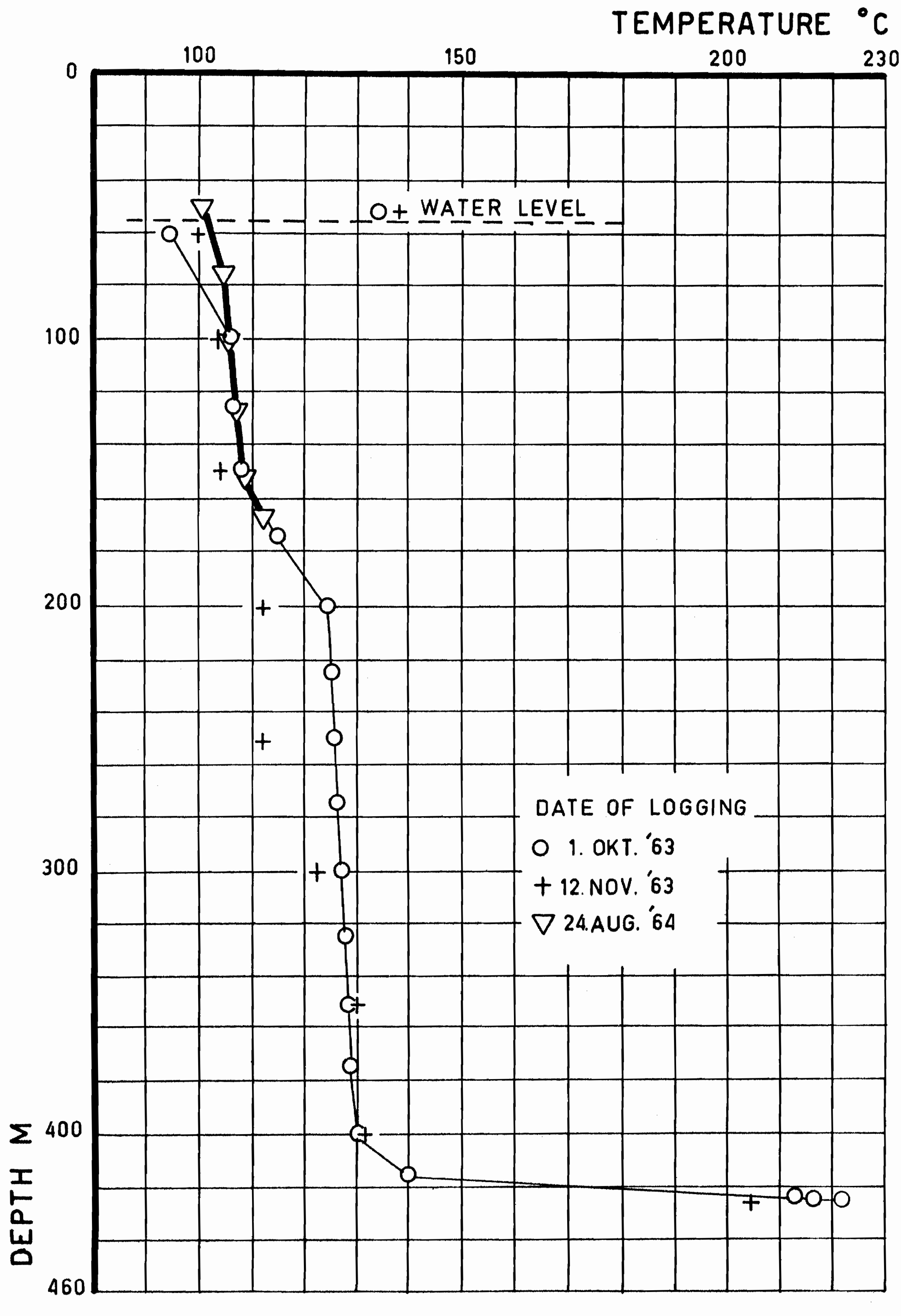
VERMIR S.F. REYKJAVÍK	STATE ELECTRICITY AUTHORITY DEPTM. FOR NATURAL HEAT Steamwell No. I at NÁMAFJALL DRILLING DATA	6-OCT.'64 SB / KB FIG. 2



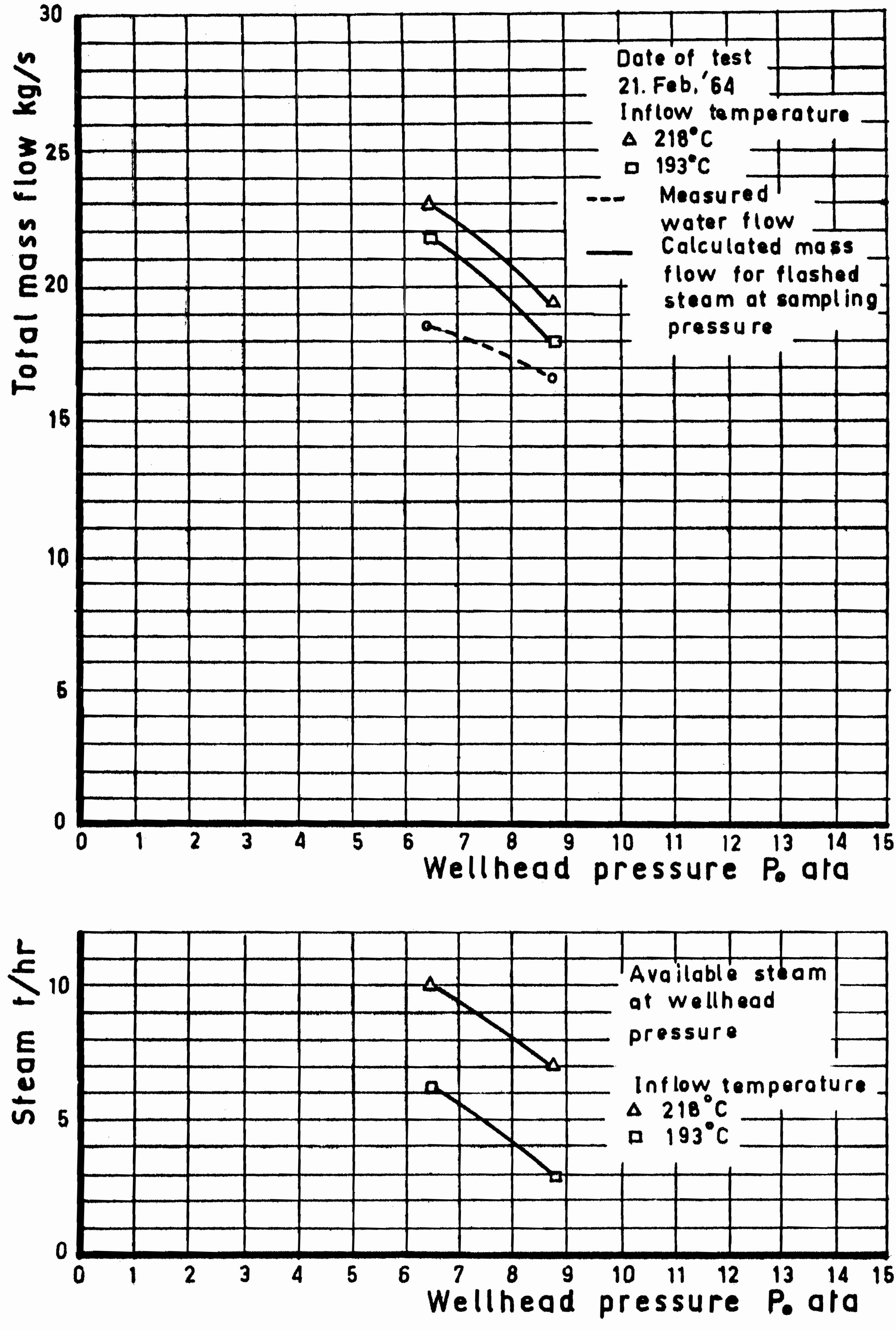
VERMIR S.F. REYKJAVÍK	STATE ELECTRICITY AUTHORITY DEPTM. FOR NATURAL HEAT Temperature log for steamwell No I at NÁMAFJALL	7-SEPT.'64 SSE/SB FIG.3



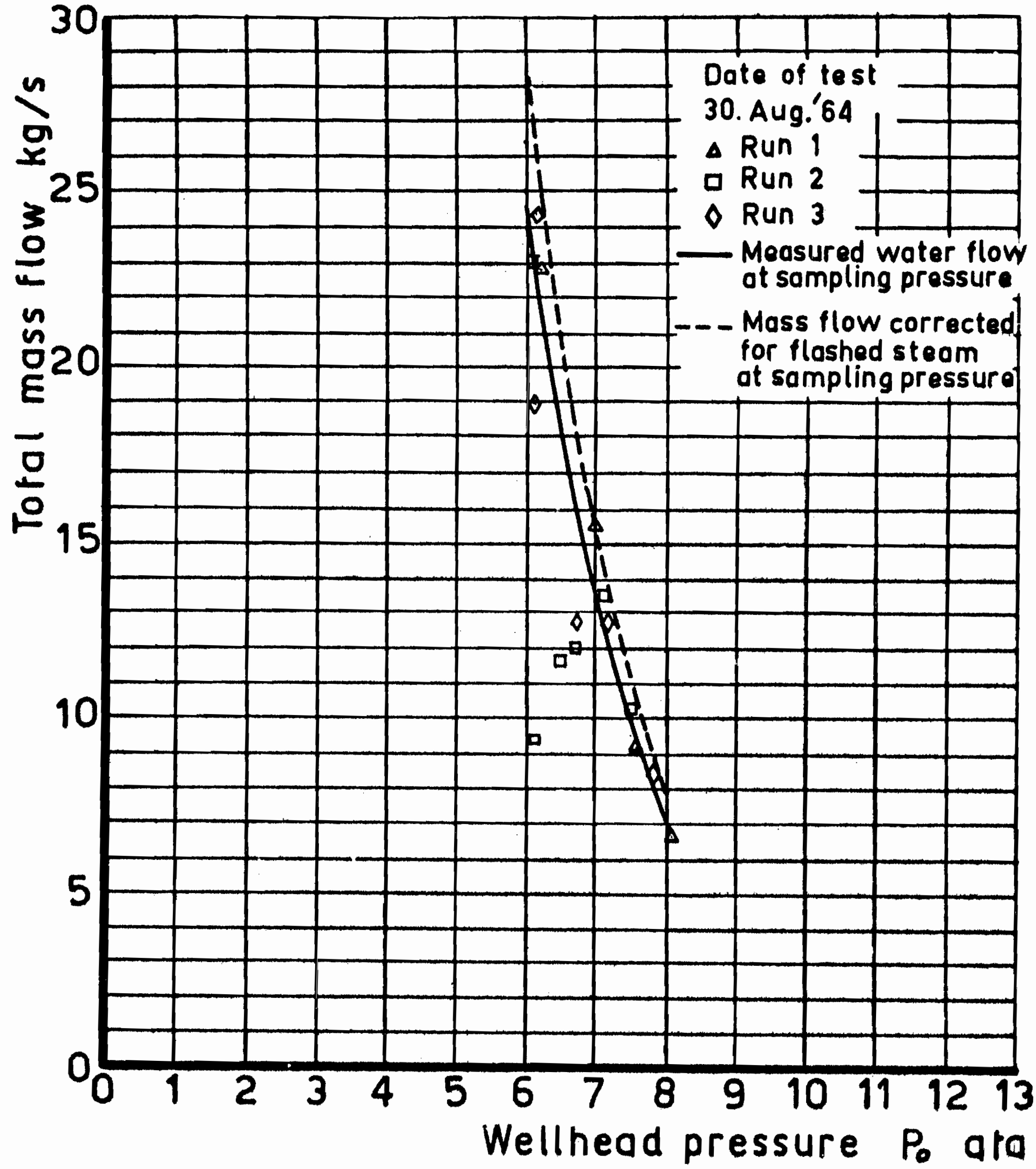
VERMIR S.F. REYKJAVÍK	STATE ELECTRICITY AUTHORITY DEPTM. FOR NATURAL HEAT Temperature log for steamwell No II at NÁMAFJALL	12-SEPT.´64 SSE/SB FIG. 4

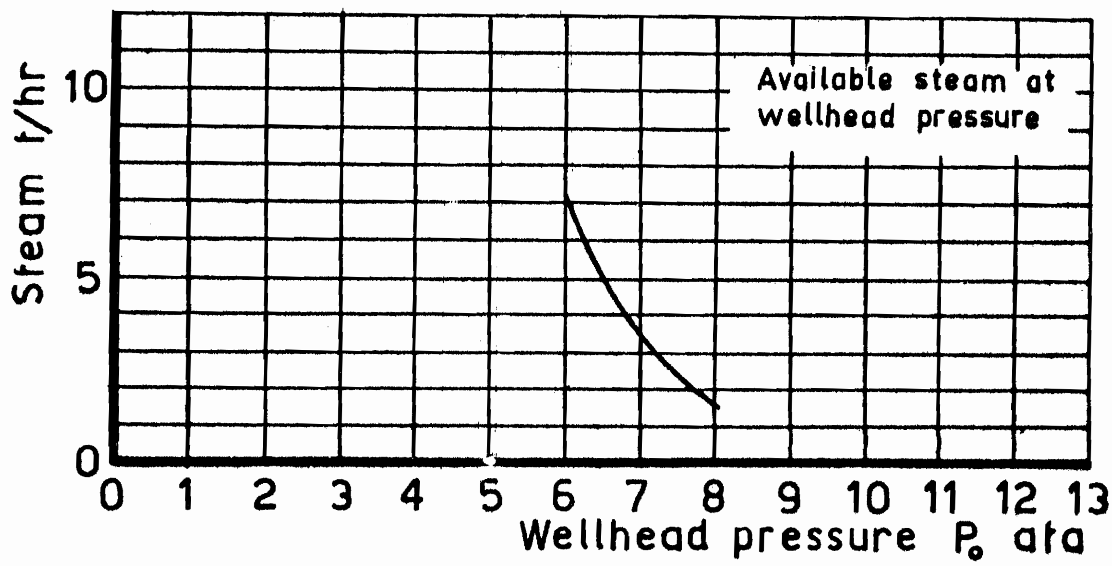


VERMIR S.F. REYKJAVÍK	STATE ELECTRICITY AUTHORITY DEPTM. FOR NATURAL HEAT Flow characteristics for steamwell No I at NÁMAFJALL	10. OCT. '64 SB/KB FIG. 5

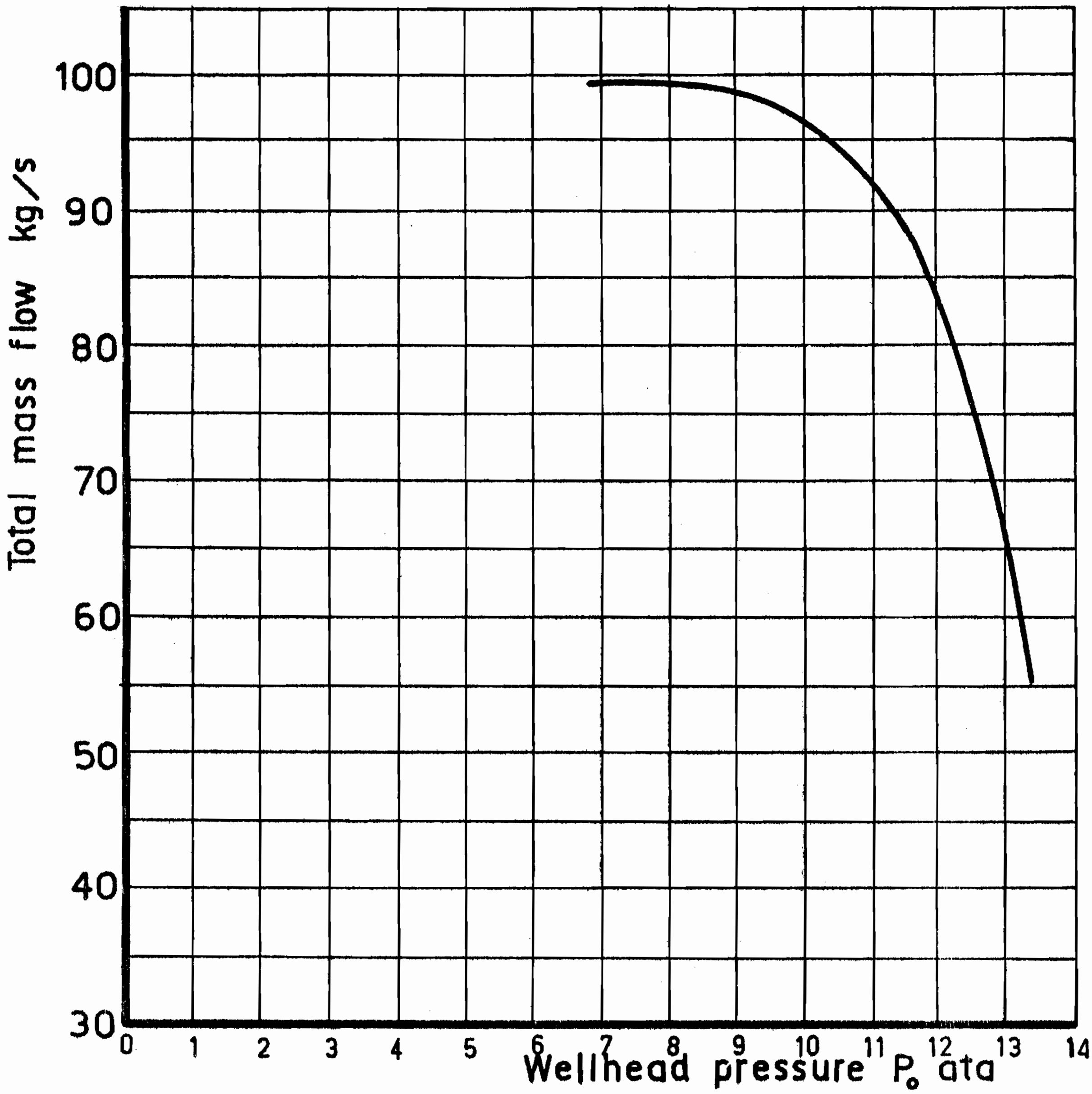


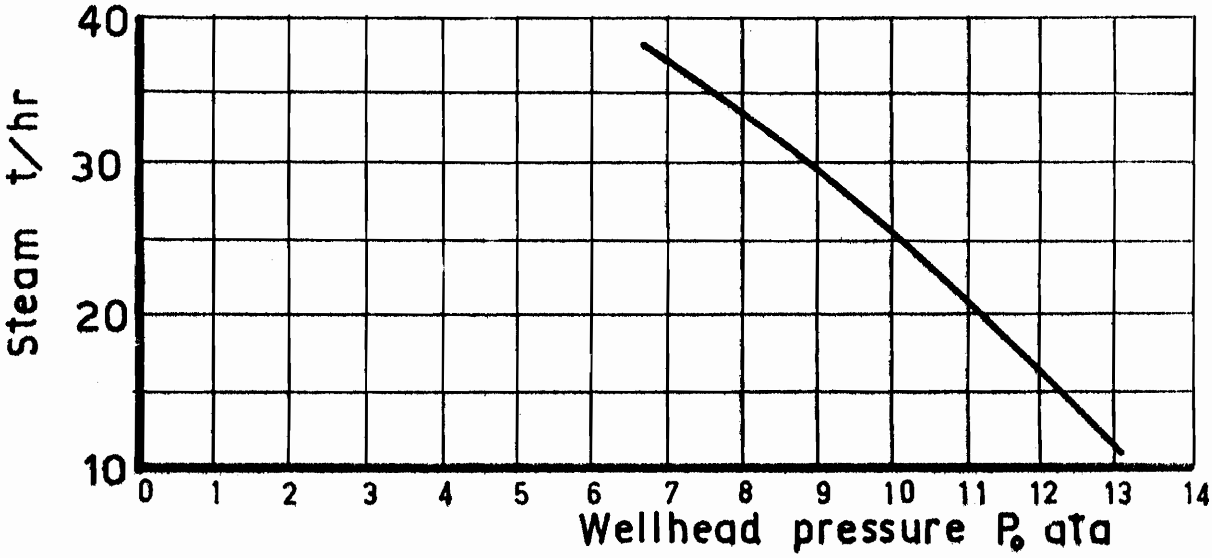
VERMIR S.F. REYKJAVÍK	STATE ELECTRICITY AUTHORITY DEPTM. FOR NATURAL HEAT Flow characteristics for steamwell No I at NÁMAFJALL	30.SEPT.'64
		SSE/SB
		FIG. 6



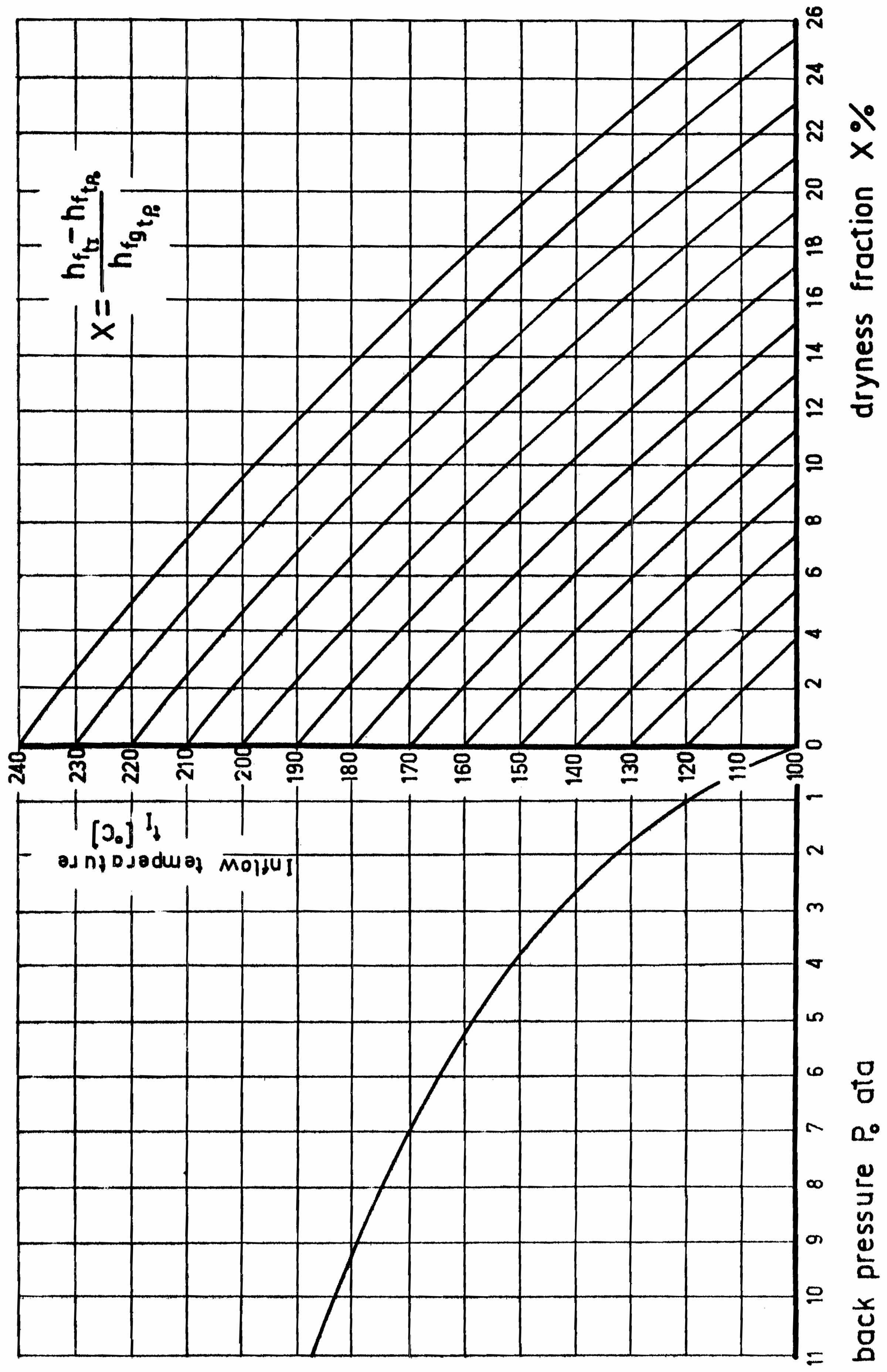


VERMIR S.F. REYKJAVÍK	STATE ELECTRICITY AUTHORITY DEPTM. FOR NATURAL HEAT Flow characteristics for steamwell No. G-8 HVERAGERÐI	10-OCT. '64 SB/KB FIG. 7





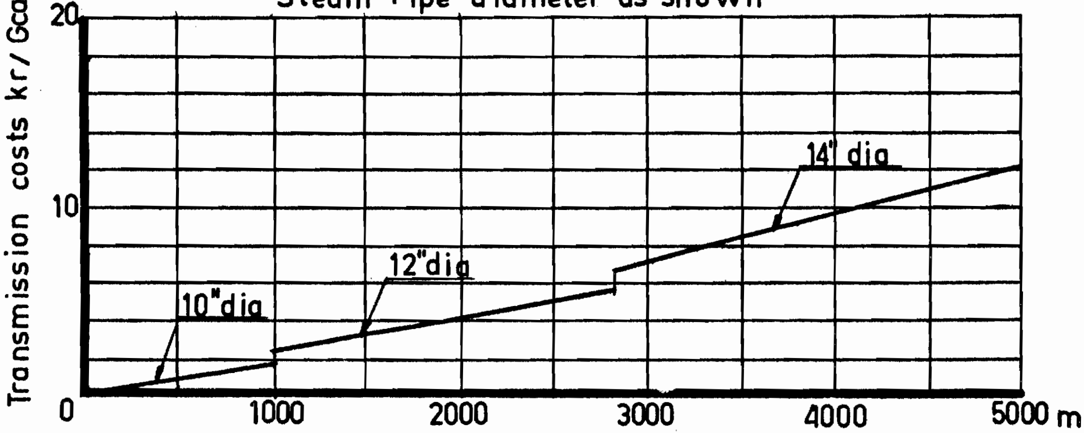
VERMIR S.F. REYKJAVIK	STATE ELECTRICITY AUTHORITY DEPTM. FOR NATURAL HEAT	14. OCT. '64
	Diagram showing the relation between dryness fraction, inflow temp. and backpress'r.	SB / KB
		FIG. 8



VERMIR S.F. REYKJAVÍK	**STATE ELECTRICITY AUTHORITY DEPTM. FOR NATURAL HEAT** Transmission costs for heat energy	13-OCT 64 SB/KB FIG. 9

Alternative I Transmission costs for Geothermal Steam of 25 ton/hr

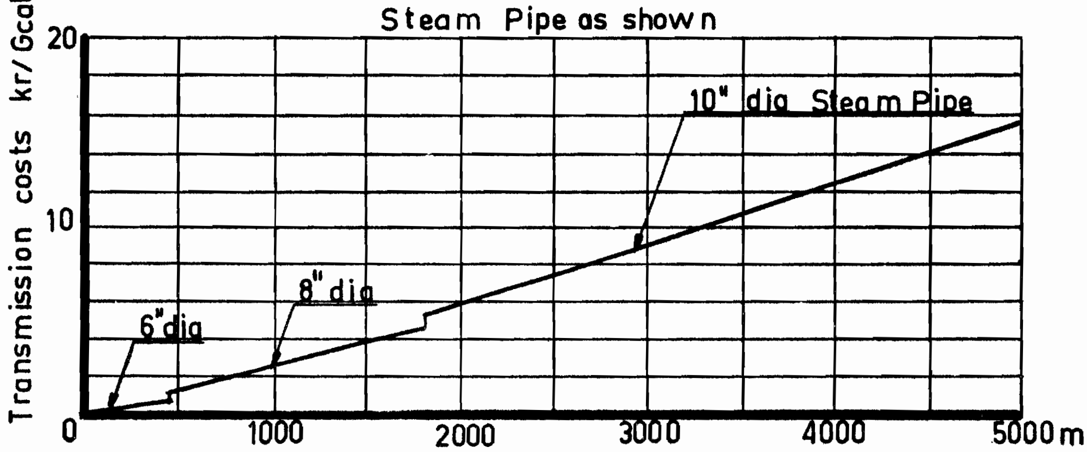
Steam Pipe diameter as shown



Alternative II Overall Transmission costs for geothermal steam and water

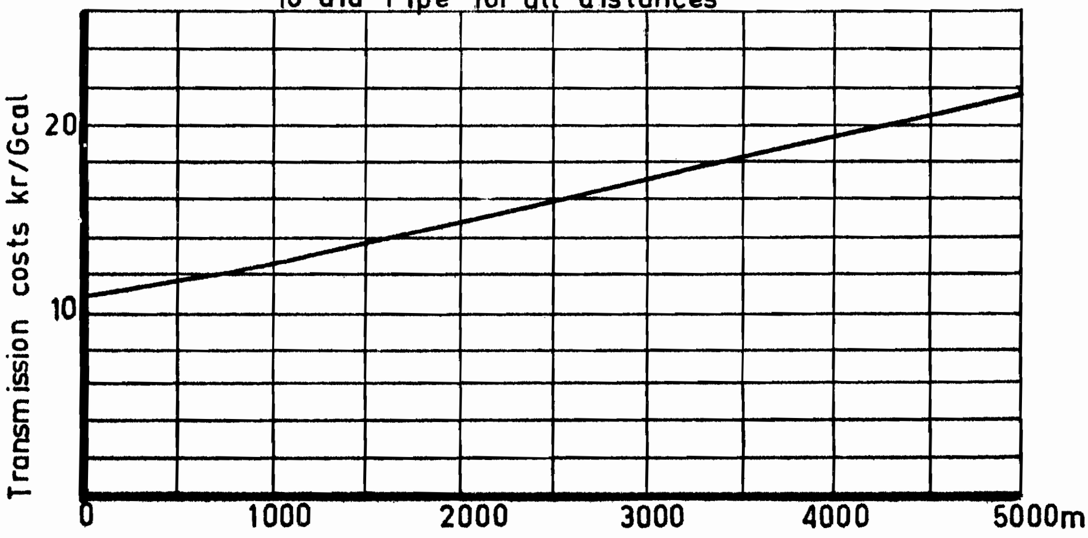
6" dia Water Pipe for all distances

Steam Pipe as shown

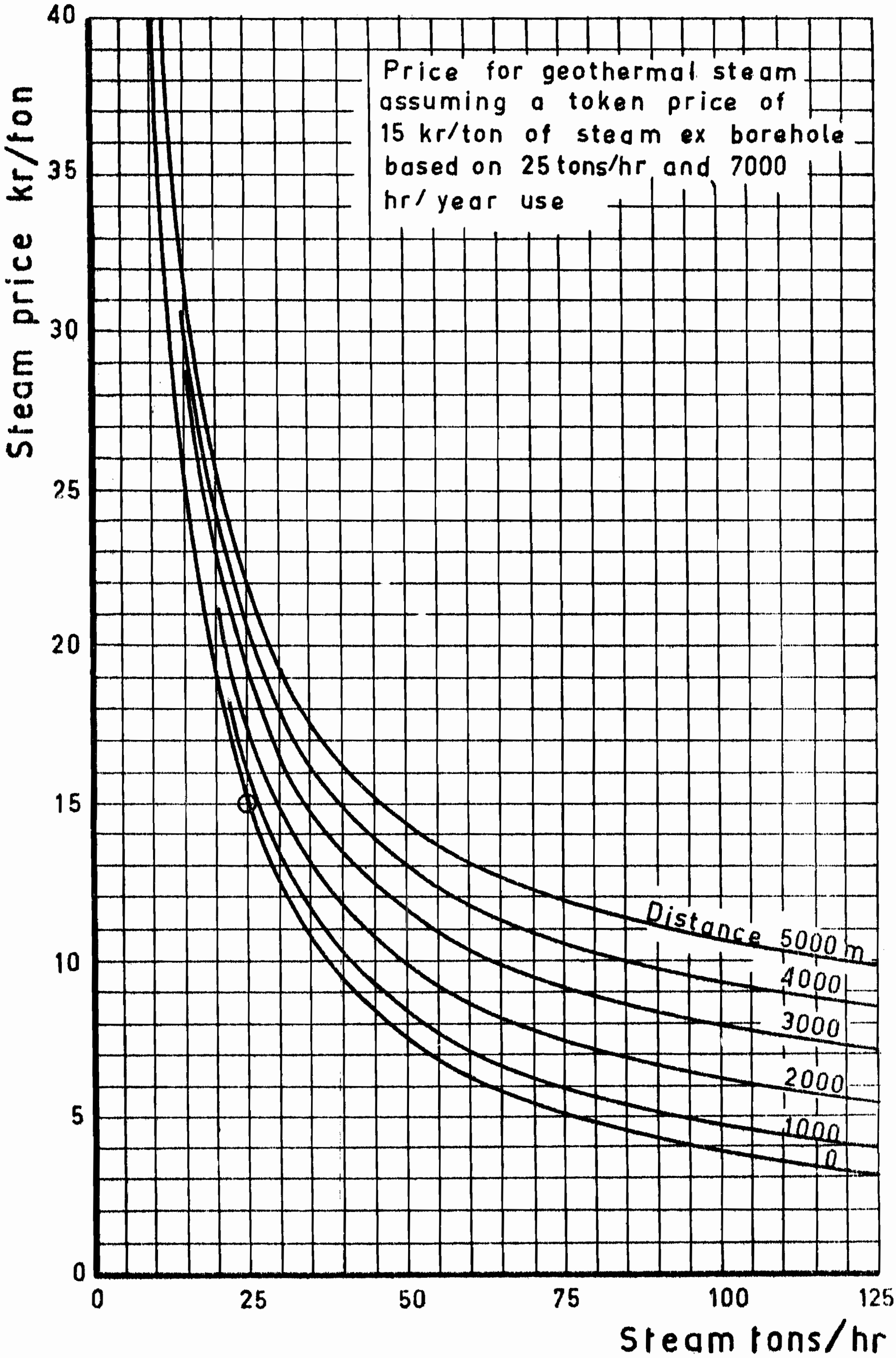


Alternative III Transmission costs for pressurized hightemperature water

10" dia Pipe for all distances



VERMIR S.F. REKJAVIK	**STATE ELECTRICITY AUTHORITY DEPTM. FOR NATURAL HEAT** Typical steam price	13-OCT. '64
		SB
		FIG. 10



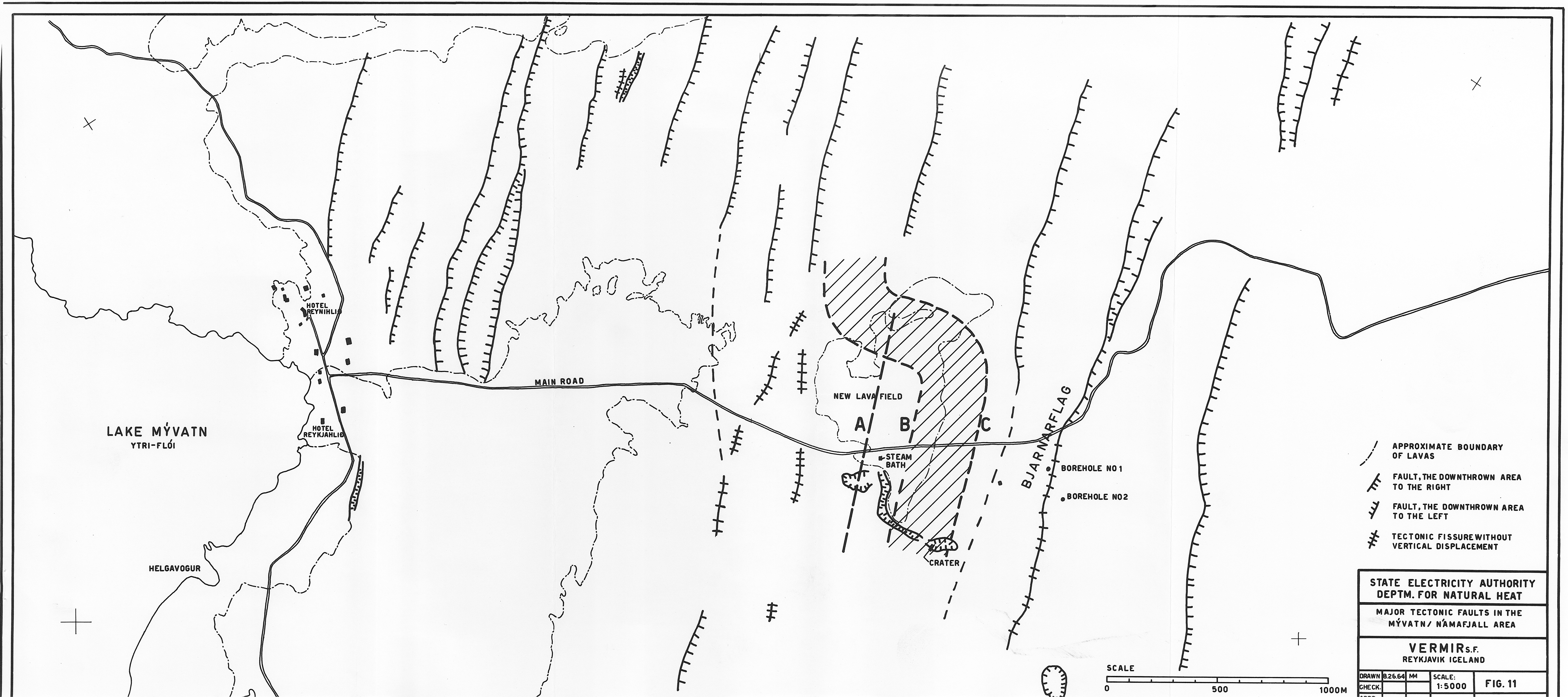

HOTEL REYNIHLIÐ
MAIN ROAD
LAKE MÝVATN
YTRI-FLÓI
HOTEL REYKJAHLÍÐ
HELGAVOGUR
NEW LAVA FIELD
A
B
C
STEAM BATH
CRATER
BJARNARFLAG
BOREHOLE NO 1
BOREHOLE NO2
APPROXIMATE BOUNDARY OF LAVAS
FAULT, THE DOWNTHROWN AREA TO THE RIGHT
FAULT, THE DOWNTHROWN AREA TO THE LEFT
TECTONIC FISSURE WITHOUT VERTICAL DISPLACEMENT
SCALE
0
500
1000M
STATE ELECTRICITY AUTHORITY
DEPTM. FOR NATURAL HEAT
MAJOR TECTONIC FAULTS IN THE
MÝVATN/ NÁMAFJALL AREA
VERMIR S.F.
REYKJAVIK ICELAND
DRAWN 8.26.64 MM
CHECK.
SCALE: 1:5000

FIG. 11