

**Ministry of Industry  
National Energy Authority of Iceland**

# **Geothermal Energy and its Use in Iceland**

**Jónas Elíasson**

**Icelandic delegation invited to Tibet, China, June 1986**

## GEO THERMAL ENERGY AND ITS USE IN ICELAND.

### 1.1 Geothermal research of NEA

Iceland is situated on the divergent plate boundary of the Mid-Atlantic Ridge as evidenced by high heat flow and volcanic and tectonic activity, and is therefore rich in geothermal resources (figs 1 & 2). The geothermal energy is mainly used for space heating and the consumption is steadily increasing (figs 3). Furthermore geothermal energy is used in industry and for electrical power production.

The National Energy Authority (NEA) is a Government organization responsible for (1) advise to the Government in the field of energy, (2) investigations and research into the country's indigenous energy resources and (3) analysis of energy systems and policy options. NEA operates under the ministry of industry; it is headed by a 3 member board of directors, appointed by the minister.

NEA has one general director, under him are 4 main divisions each headed by a director. The largest of these is the Geothermal Division with 6 sections with a staff of 63 specialists and research assistants (fig. 4a & 4b).

The geothermal division of NEA is responsible for practically all geothermal prospecting in Iceland. Its activities are known to the community of geothermal scientists throughout the world. Staff members of NEA have published numerous articles in international journals and conference proceedings. We are happy to note that Icelandic and Chinese geothermal scientists are well aware of each others works and there has always been mutual respect and understanding between the geothermal experts of Iceland and China.

Geothermal experts outside NEA are found in the University of Iceland and within the communities of Icelandic geologists and civil engineers.

The Icelandic delegation consists of the following persons:

Dr. Jónas Elíasson, Board Chairman NEA

Mr. Jakob Björnsson, Dir. Gen. of NEA

Mr. Karl Ómar Jónsson, Fjarhitun Consulting Eng.

Dr. Gudmundur Pálmason, Dir. Geothermal Div. of NEA

Mr. Sverrir Thorhallsson, Head of Techn. Sec. NEA

Dr. Hjalti Franzson, Geothermal Geologist, UNU Geothermal Train. Prog.

## 1.2 Geothermal prospecting

When investigating a new potential site for geothermal development the NEA follows as close as possible the plan shown in fig 5, in which there are 5 major decision points.

At each decision point the investigation may be continued, delayed, rescheduled or terminated, without any loss of information retrieved so far. But even if the investigation continues without any delays, it must be anticipated that the program takes 10 years before commencement of construction.

Because of this, NEA tries to carry out the 2 - 3 first investigation phases at the most promising sites even before definite plans for the use of the energy are made. Because of this, Icelandic towns with geothermal energy within reach, have been able to construct power plants (mainly district heating systems (DHS)) in much shorter time than the 10 years they would need if the investigation were to start from zero. Partly because of this, there has been a rapid development in the DHS sector in Iceland, as you have already seen.

These first phases of scientific investigation include everything short of drilling. These first phases cost about 5% of the total investment, and we rely very much on geological, geochemical and geophysical prospecting, which precede a decision to drill.

I will not describe in detail the methods and technologies as most of them are well known. I show you as an example this map of a regional Schlumberger resistivity survey (fig. 6); with this kind of survey we can reach about 1000 m down. A regional survey of this kind is very time consuming, especially if the terrain is difficult, and as it is important and relatively inexpensive we increasingly rely on this kind of survey. I will later show you some examples of more specialized Icelandic technologies, and following that you will have the opportunity to ask every member of the delegation questions relating to those. To give you an example that Icelanders have learned something from fellow scientists in China I show you a head-on resistivity survey which we call the Chinese method (fig. 7).

## 1.3 Reservoir investigations

In the last three phases the emphasis changes from surface exploration to investigations of the geothermal reservoir.

In reservoir investigations all the usual logging and sampling tech-

niques are utilized. The geological characteristics of the reservoir rely on drill cutting analysis, core sampling being an exception. This example of a typical well log (fig. 8) shows most of the geophysical and geological logging obtained during the drilling operations.

When drilling of the well is completed, completion tests and other reservoir engineering studies are carried out. Later you will hear more about the chemical technologies applied in reservoir engineering in Iceland. The aim of the reservoir studies is to be able to construct a computer model of the geothermal field that is linked to the performance of individual wells (fig.9).

The reservoir investigation studies are particularly important for low temperature fields. Today Icelandic DHS's are experiencing a serious decline, both in pressure and temperature.

#### 1.4 Geothermal Training Programme

On grounds of a need for a geothermal training scheme, the Government of Iceland and the United Nations University decided in 1978 to operate the UNU Geothermal Training Programme in Iceland. Since commencing in 1979 it has been financed by these two bodies.

The UNU Geothermal Training Programme is executed by the Geothermal Division of the National Energy Authority of Iceland, but is also linked with the University of Iceland. Supervisors and instructors are drawn from the staffs of both institutions, and in some cases from other specialized geothermal institutions in Iceland as required. A studies board is responsible for the academic contents of the training. An attempt is made to integrate the training of participants into the geothermal exploration and utilization projects that are in progress in Iceland at the time of training. In some cases, however, participants bring with them data from geothermal projects in their home countries and work on the data under the supervision of specialists. Fig. 10 shows a simplified organizational structure of the Training Programme.

Priority for Fellowships is given to candidates from developing countries where geothermal exploration and development is already under way. An attempt has been made to assist individual countries in building up a cadre of specialists representing the various disciplines.

Participants must have a university degree in science or engineering



and a minimum of one year practical experience in geothermal work. The training is conducted in English, which the participants must speak fluently.

Fourty four UNU Fellows and three UNDP Fellows have come for 6 - 8 months training (fig. 11 & 12). Two UNDP fellows have come for 3 months training. There have been 11 UNU Special Fellows and 1 UNDP Fellow on shorter study trips.

Twelve Chinese Fellows have been trained in various geothermal subjects in the UNU-Geothermal Programme. Further to that 5 have come as special fellows.

## 2.1 The principle of total use

The primary use of geothermal low-temperature resources is for various domestic purposes. But the first industrial use of high-temperature geothermal resources was to produce electricity from dry steam wells. Later people learned to use liquid domonated resources for the same purpose by first separating the steam and throwing the water away.

This technology only uses a small fraction of the total energy, the rest must be disopsed of in the environment. This sometimes creates difficult thermal and chemical pollution. In space heating systems the efficiency of energy utilization is much higher. The Icelanders were the first to harness geothermal energy in large district heating systems (DHS).

Today, geothermal energy experts are looking for ways to make total use of the energy. This means to find feasible ways of using all energy downstream of the power stations and DHS systems (fig. 13).

Fully integrated total use systems are yet to be built. But in the following chapter I will describe a power station in Iceland called Svartsengi where this principle has been applied to some extent.

## 2.2 The Svartsengi power system

The wells in Svartsengi geothermal field are fed by 240 fluid which is a mixture of sea water (2/3) and fresh water (1/3). The fluid from the wells is piped to high pressure steam separators (fig. 14). The steam drives the electric turbines and the exhaust steam is used to heat fresh water in the heat exchanger. There is also a bypass high pressure steam line for boosting the water to the final temperature.

The low pressure steam is produced by flashing the water from the high pressure separators under vacuum. Vacuum is maintained by a barometric column. The low pressure steam is used for preheating and deairating the fresh water for the DHS system (figs 15 & 16).

### 2.3 Heat supply and downstream applications

The fresh water comes from cold ground water resources in the area. The hot water produced is 120°C instead of the normal 80 - 90°C delivered to houses. Because of this the water can be conveyed over large distances in pipelines in an economical way. The municipal distribution heating system is on the other end of the pipeline and is a two-pipe system (tour retour). Before entering the distribution system, the water passes through a pumping and mixing station with storage tanks (fig. 17). The feed water from the power plant is cooled down to 80°C service temperature by mixing it with almost equal quantities of retour water. In this manner a large portion of the downstream water of the DHS system is reused.

The effluent geothermal brine has proved itself to be very suitable for health spa (fig. 18). Many people come from far way to bath in the disposal pond downstream of the low pressure separators. Very favourable theraputic effects have been reported, expecially on the disease psoriasis. Geothermal springs around the world are known for this theraputic effects, and this health spa is a very attractive downstream application for geothermal energy.

### 3.1 District heating systems (DHS)

Large geothermal DHS systems are a special Icelandic technology. They supply hot water in pipes to the customers and are primarily used for space heating in general. In homes we normally use radiators with thermostatically controlled valves to provide the heat. In industrial buildings air blowers are more common. Hot air from air blowers can also be used in all kinds of industrial drying processes. In Iceland it is used for drying of hay, wool, hides, seaweed, fish and lumber.

The DHS systems are either single or double pipe. Single systems only provide you with hot water, but when it has been used it is disposed of through the sewage system. Double systems return the water from radiators and air blowers. The municipal system of Reykjavík is a combination of both.

The chemical composition of the water is very important. Too much

oxygen in the water corrodes the pipes and dissolved minerals can cause scaling problems.

The largest district heating system in Iceland which serves a population of 130.000 is in the city of Reykjavík (figs 19 & 20). The city covers an area of 28 sq. kilometers, and has an average heat load density of 20 MW pr. km<sup>2</sup>. The peak load is 560 MW. It has an advanced pressure and temperature control system where both automatic systems and computer technology is applied.

The local geothermal source has temperature ranging from 80 - 120°C approximately. Downstream applications are mostly numerous outdoor swimming pools and snowmelt pipes in sidewalks and parking lots.

### 3.2 Industrial drying processes

The direct use of geothermal energy in Icelandic industry, drying and evaporation processes, has been increasing during the last decades.

The following examples can be mentioned:

A diatomite plant at Lake Mývatn, operated since 1967 (fig. 21).

A sea chemicals factory at Reykjanes that produces mainly salt. This is a pilot plant. (fig. 22).

A seaweed drying plant at Reykhólar. It dries, grinds and packs the seaweed. (fig. 23).

### 3.3 Electric power production

Production of electric power from geothermal resources is small in Iceland (42 MW), because of ample access to economical hydropower resources. Hydropower is also a very advanced technology in Iceland and very much within the field of activity of NEA.

There are three power stations producing electricity from geothermal energy in Iceland and the fourth one is planned. You have already heard about Svartsengi, the others are more conventional.

#### 4.1 Cleaning well scalings

Scaling deposits are a problem in a number of high temperature geothermal wells. The chemical composition differs from field to field, but calcite scaling is most common. Low temperature wells and dry steam wells do not suffer scaling.

The scaling deposits have to be cleaned from the well to maintain production. In most countries the cleaning operations are usually quite similar to drilling and the wells may be out of operation for some weeks. In Iceland, a special technology has been adapted to deal with scaling problems (fig. 24). One design measure was to increase production casing diameter from 9 5/8 inch to 13 3/8 inch, which resulted in an increase in interval between cleaning operations from 7 months to 24 months in the case of Svartsengi. This alone is very important and the wider well program does not increase the drilling costs appreciably.

The second part of this technology is to drill the scaling plug away without stopping the flow. It has taken some time to develop the special equipment necessary for this operation. The use of it shortens the time it takes to clean the well to a few days as well as increasing the lifetime of the well. During the operation the well is discharging and producing at less than half the normal rate. This ensures that the plug cuttings are discarded from the hole and thus do not accumulate at the bottom of the hole.

#### 4.2 Special downhole logging techniques

There are several downhole logging techniques that are used more extensively in Iceland than in other countries. I will mention a few.

Temperature logging by thermistor equipment is common in Iceland and is used where the temperature is not too high for the thermistors. The use of thermistor logging makes frequent calibration necessary, but the field operations are much simpler than by other methods.

Accurate pressure gauging can reveal important information such as barometric efficiency, earth tides and pressure effects of minor earthquakes. Most importantly, however, accurate pressure gauging is necessary if computer model predictions are to be made of the long term pressure transients in the reservoir. The most accurate pressure gauging is done with water level gauges, either bubble or wire-and-float gauges. These water level measurements followed by computer model studies have made it possible to predict very accurate-

ly the drawdown of the Svartsengi field (fig. 25).

A technique to take photographs downhole has been developed in Iceland. This is important when casing damages occur, and repairs have to be planned. On the fig. 26 you can see a casing collapse that was successfully repaired because the downhole photograph revealed the nature of the damage.

#### 4.3 Chemical indicators of reservoir state

Careful chemical studies of reservoir fluids are necessary to cope with fluid transport and heat exchange problems, as well as revealing important reservoir parameters.

To do so, the chemical samples of the water have to be taken very carefully as to preserve the deep water parameters. If this sampling technique is applied, it is possible to calculate the deep water composition from samples taken at surface. This is very important, because it makes it possible to monitor changes in reservoir state from investigations at the surface.

The calculations of the deep water parameters are done with a special computer program developed in Iceland and is a standard procedure in geothermal investigations (fig. 27).

Hydrothermal alterations are also extensively studied. They give an indication of the temperature evolution of the geothermal system (fig. 28).

#### 5.1 State to state agreements

All bilateral assistance contracts and development aid programs in which Iceland participates are on the basis of state to state agreements. Many such arrangements are organised in a special institution for cooperation and development under the Foreign Ministry of Iceland.

When such contracts are made and funding provided by the government, the task itself is normally assigned to a state organization, company, firm or individual that is thereby made responsible for the Icelandic part of the work.

Iceland also participates in various development programs within the framework of the United Nations and other international organizations. The geothermal experts on NEA's staff have been in 28

countries on missions from international agencies.

## 5.2 Company to company agreements

Technical cooperation is also possible within the framework of company agreements. In bilateral agreements of that kind it is usual that each party pays its own cost. Icelandic state organizations are normally willing to make their knowledge and experiences available to colleagues abroad.

Agreements of this kind are usually very informal. To take an example, if a foreign scholar contacts an Icelandic institution and expresses interest in visiting the institution for shorter or longer time, his visit is normally agreed upon without further formalities.

## 5.3 Consultation services

Icelandic firms and institutions are willing to provide consultation services to foreign countries. To facilitate export of consultation, the Icelandic Government has established a special firm ORKINT Ltd. Orkint is the marketing branch of NEA and has already begun operation.

ORKINT can contractually agree to any kind of consultation services, both services provided by NEA and third parties. In the latter case ORKINT will enter a joint venture agreement with the third party or include them as subcontractors. In this manner it is possible to gain access to technologies outside NEA through ORKINT.

## 5.4 Project management

In the last 20 years Icelandic companies have been building and operating projects in the investment range of 100 - 200 million US\$. These projects are financed with syndicated loans obtained on the international market.

In this manner the following energy projects have been completed:

- Burfell hydroelectric power plant 210 MWe 1969
- Sigalda hydroelectric power plant 150 MWe 1976
- Krafla geothermal power plant 60 MWe 1980
- Hrauneyjafoss hydro power plant 210 MWe 1980
- Svartsengi DHS & el. power plant 100 MWt 1980

Construction costs for the electric power plants are of the order of magnitude 800.000 US\$ for each megawatt. All these projects are completely under Icelandic management except the first, Burfell, where considerable technical input was received from abroad. Today such projects are completely an Icelandic undertaking; financing, planning, designing, building and operating. Only mechanical and electrical machinery is imported.

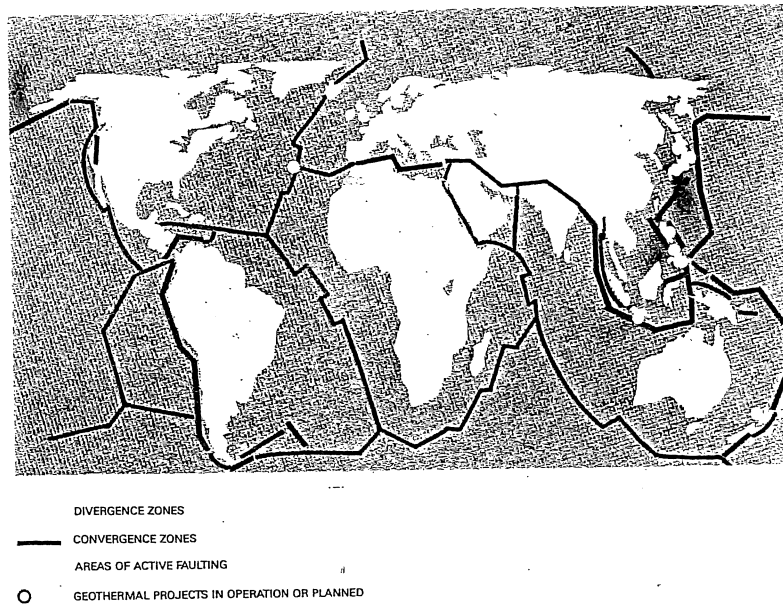


Figure 1 Mid-Atlantic Ridge Plate Boundary

#### GEOLOGY AND GEOTHERMAL RESOURCES OF ICELAND

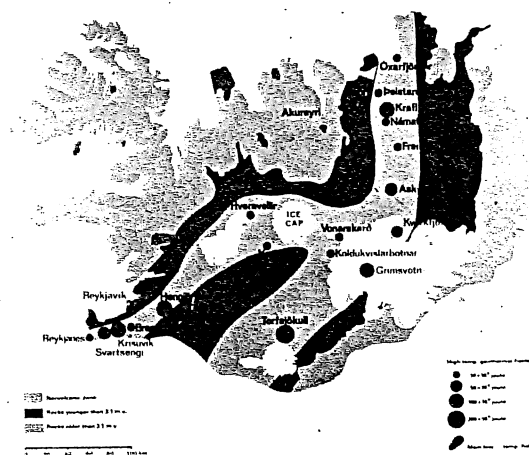


Figure 2 Geothermal resources of Iceland

#### ENERGY SOURCES FOR SPACE HEATING IN ICELAND

Percent of houses (space) heated with different energy sources

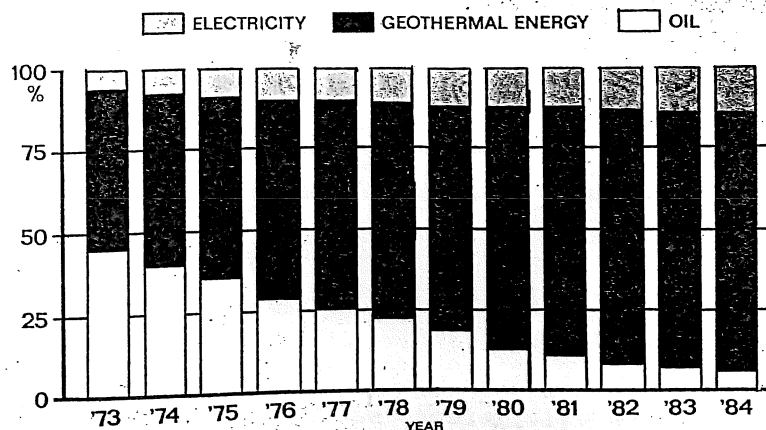
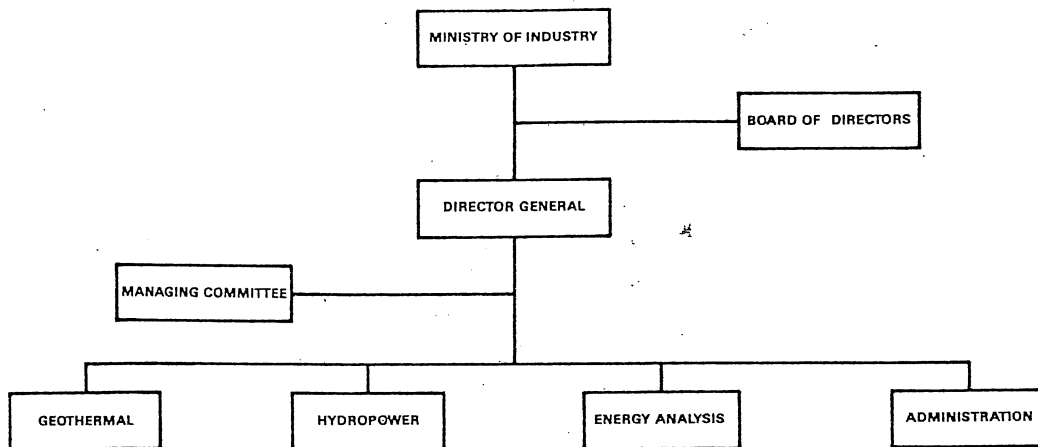


Figure 3 Energy sources for space heating in Iceland



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#### Geothermal Division

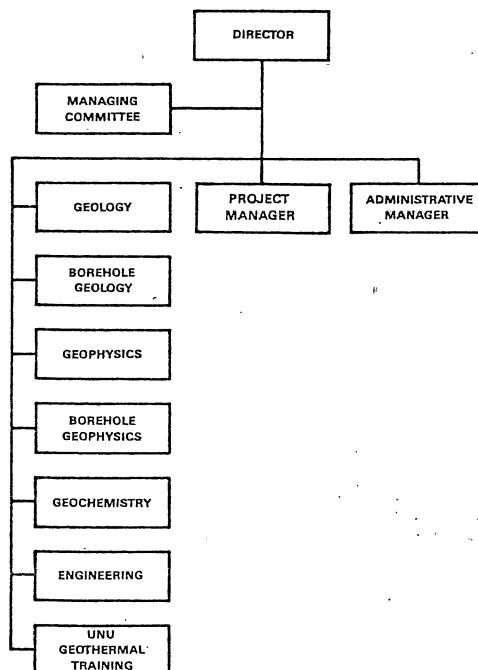


Figure 4 Organization chart

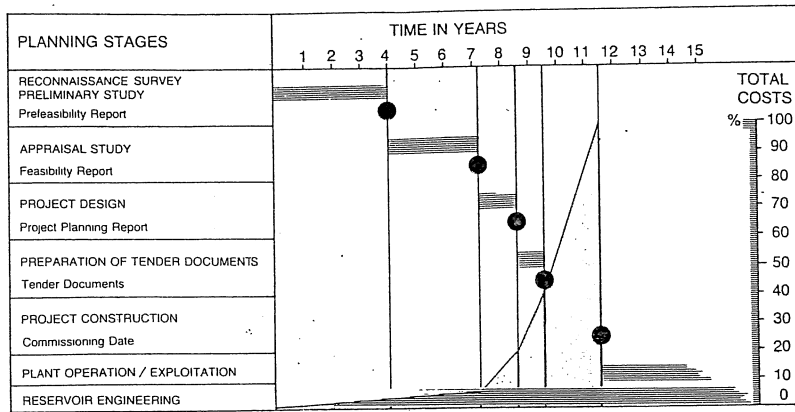


Figure 5 Prospecting schedule

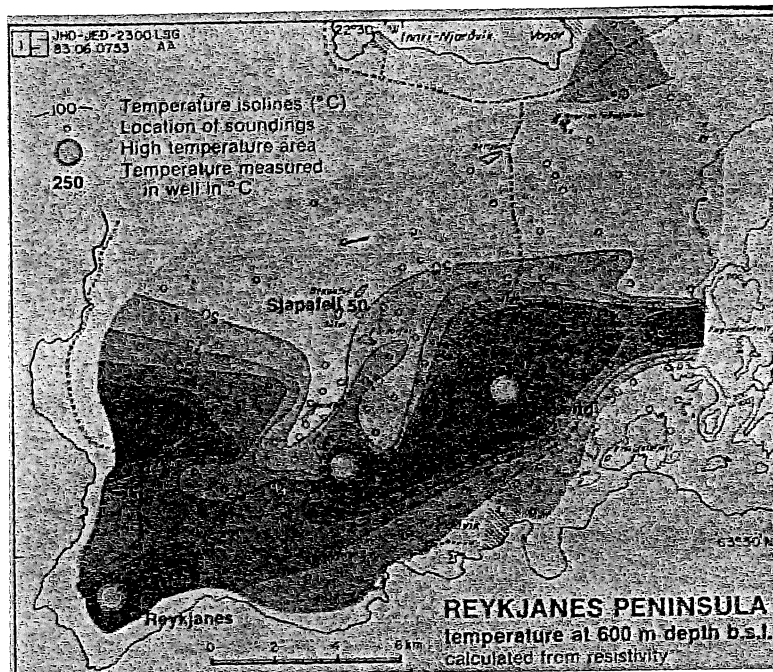


Figure 6 Schlumberger survey of Reykjanes

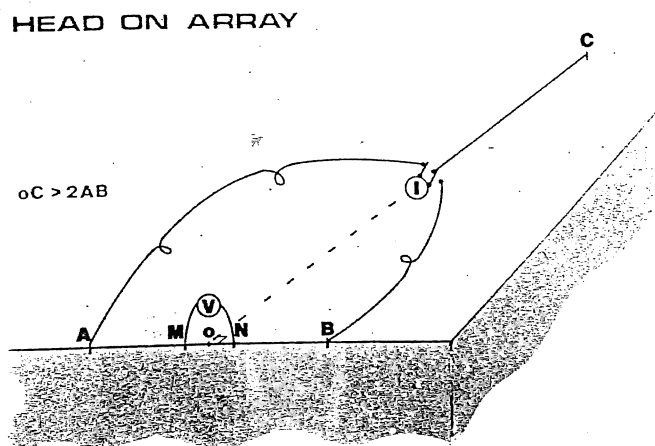


Figure 7 "Chinese" Resistivity survey

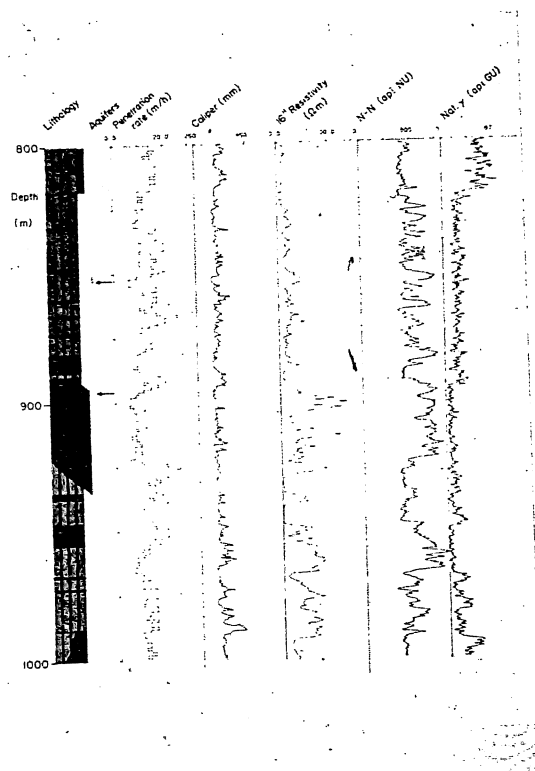


Figure 8 Typical downhole log

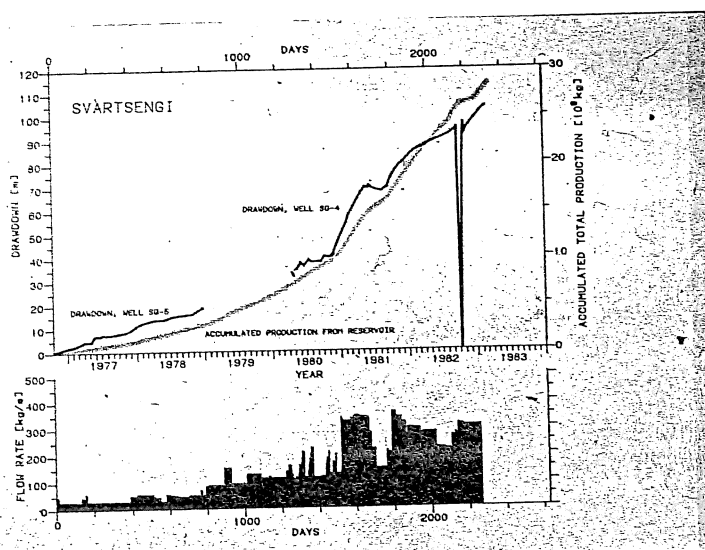


Figure 9 Computer model studies

GEOLOGICAL EXPLORATION	GEOPHYSICAL EXPLORATION	DRILLING TECHNOLOGY	BOREHOLE GEOLOGY	BOREHOLE GEOPHYSICS	RESERVOIR ENGINEERING	FLUID CHEMISTRY	GEO THERMAL UTILISATION
Lecture Course (4 Weeks) — Exploration — Geosciences — Engineering — Development — Computers  Seminars and Field Excursion (2 Weeks)	Lecture Course (4 Weeks) — Exploration — Geosciences — Engineering — Development — Computers  Seminars and Field Excursion (2 Weeks)	Lecture Course (4 Weeks) — Exploration — Geosciences — Engineering — Development — Computers  Seminars and Field Excursion (2 Weeks)	Lecture Course (4 Weeks) — Exploration — Geosciences — Engineering — Development — Computers  Seminars and Field Excursion (2 Weeks)	Lecture Course (4 Weeks) — Exploration — Geosciences — Engineering — Development — Computers  Seminars and Field Excursion (2 Weeks)	Lecture Course (4 Weeks) — Exploration — Geosciences — Engineering — Development — Computers  Seminars and Field Excursion (2 Weeks)	Lecture Course (4 Weeks) — Exploration — Geosciences — Engineering — Development — Computers  Seminars and Field Excursion (2 Weeks)	Lecture Course (4 Weeks) — Exploration — Geosciences — Engineering — Development — Computers  Seminars and Field Excursion (2 Weeks)
Specialized Training (8-12 Weeks) — Field geology — Maps and photos — Structure — Hydrogeology — Mapping — Eroded volcanics — Recent volcanics	Specialized Training (8-12 Weeks) — Heat flow — Magnetics — Tectonics — Resistivity — Gravity — Seismic — Modeling	Specialized Training (8-12 Weeks) — Rig operations — Cementing — Wellhead design — Site preparation — Completion — Management	Specialized Training (8-12 Weeks) — Drilling — Petrological logs — Alteration — X-Ray — Clay minerals — Aquifers — Modeling	Specialized Training (8-12 Weeks) — Well testing — Logging — Flow testing — Injection — Mathematics — Modeling — Simulation	Specialized Training (8-12 Weeks) — Well testing — Logging — Flow testing — Injection — Mathematics — Modeling — Simulation	Specialized Training (8-12 Weeks) — Sampling — Thermodynamics — Deposition — Corrosion — Downhole pumps — Power plants — Separators — Feasibility — Management	Specialized Training (8-12 Weeks) — Pipelining — Deposition — Corrosion — Downhole pumps — Power plants — Separators — Feasibility — Management
Project Work (8-12 Weeks) — Selected topic	Project Work (8-12 Weeks) — Selected topic	Project Work (8-12 Weeks) — Selected topic	Project Work (8-12 Weeks) — Selected topic	Project Work (8-12 Weeks) — Selected topic	Project Work (8-12 Weeks) — Selected topic	Project Work (8-12 Weeks) — Selected topic	Project Work (8-12 Weeks) — Selected topic
Report Writing (4-8 Weeks)	Report Writing (4-8 Weeks)	Report Writing (4-8 Weeks)	Report Writing (4-8 Weeks)	Report Writing (4-8 Weeks)	Report Writing (4-8 Weeks)	Report Writing (4-8 Weeks)	Report Writing (4-8 Weeks)

Figure 10 Program organization

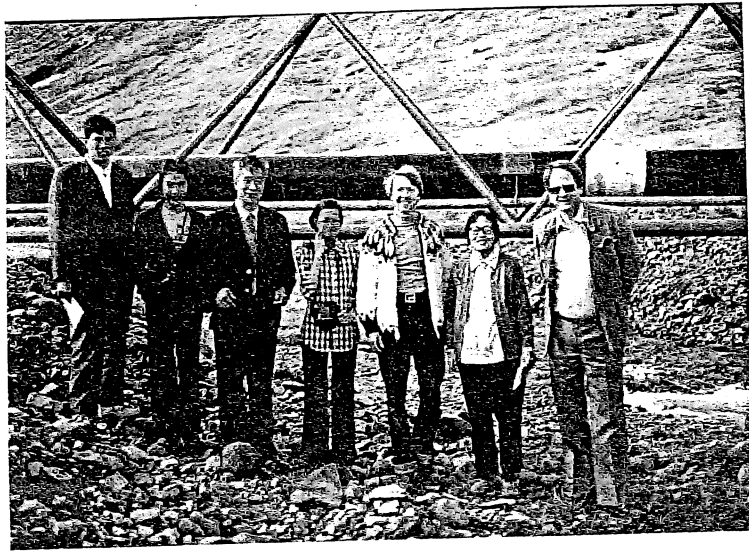
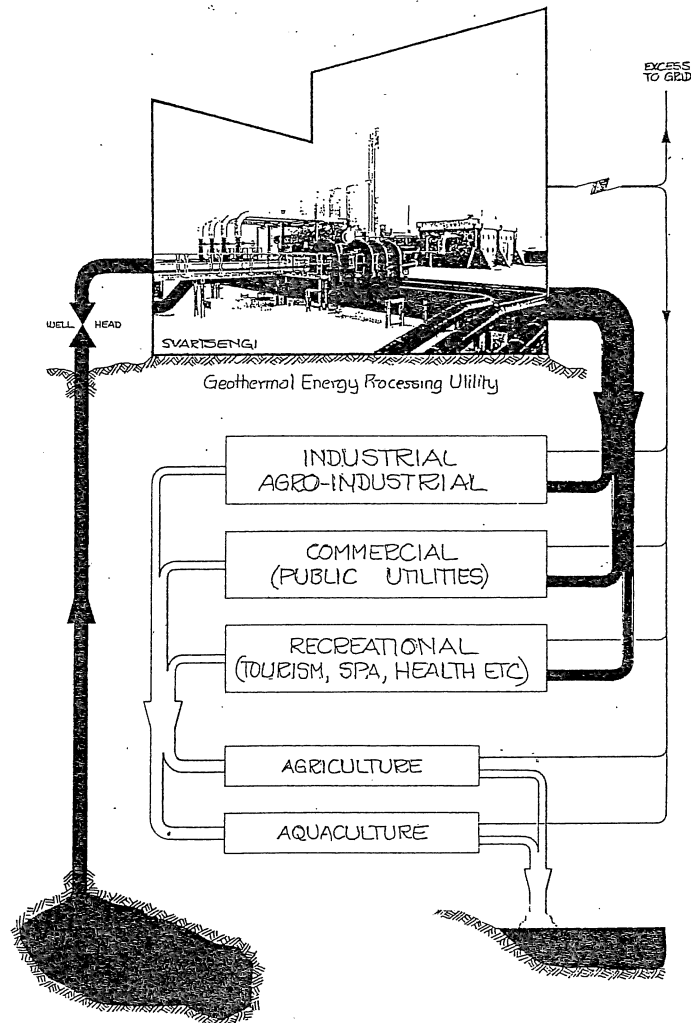


Figure 11 Trainees from different countries



Figure 12 Students at work

## Total Geothermal



ORKINT of Iceland

Figure 13. Total use scenario

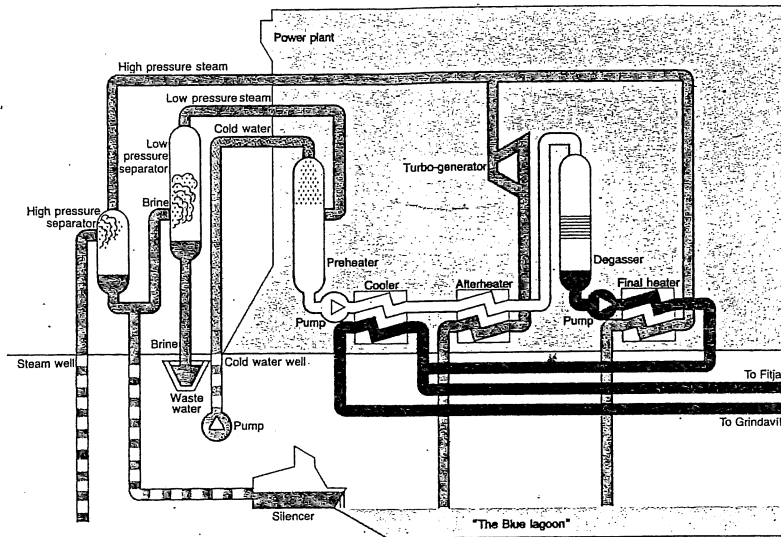


Figure 14 Diagram, power station II

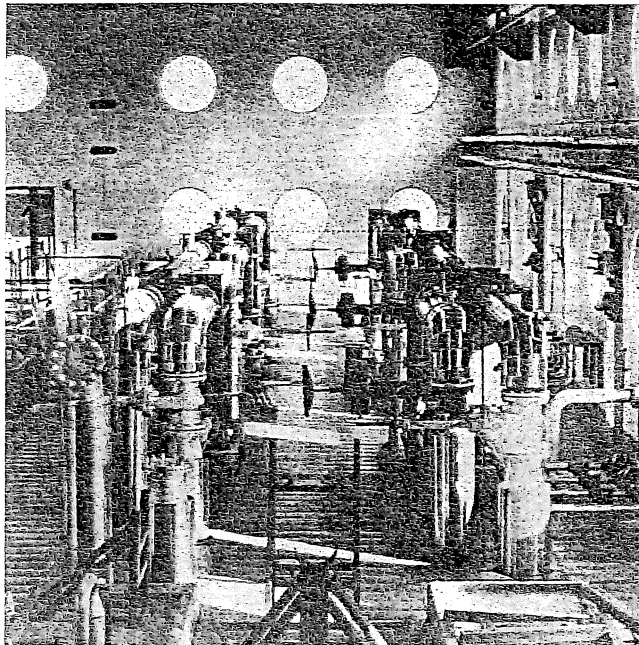


Figure 15 Inside view, power station II

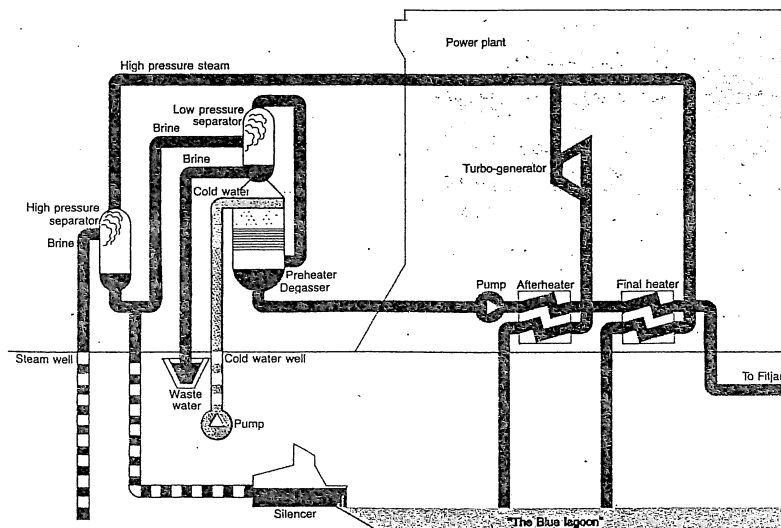


Figure 16 Diagram, power station II

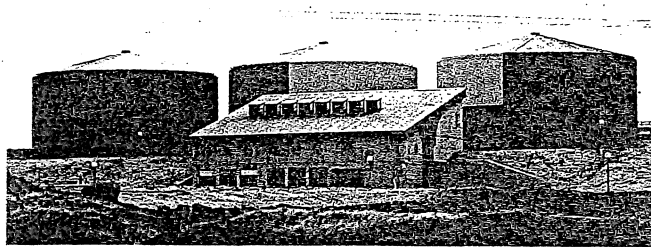


Figure 17 Keflavik town pumping station

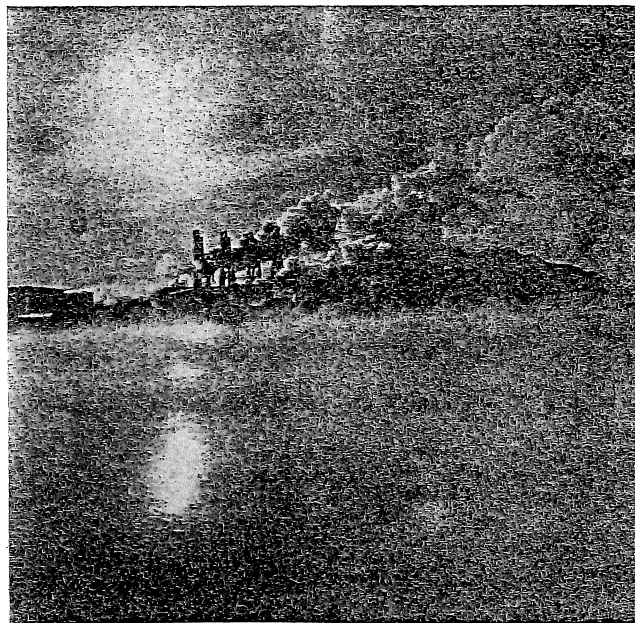


Figure 18 The blue lagoon



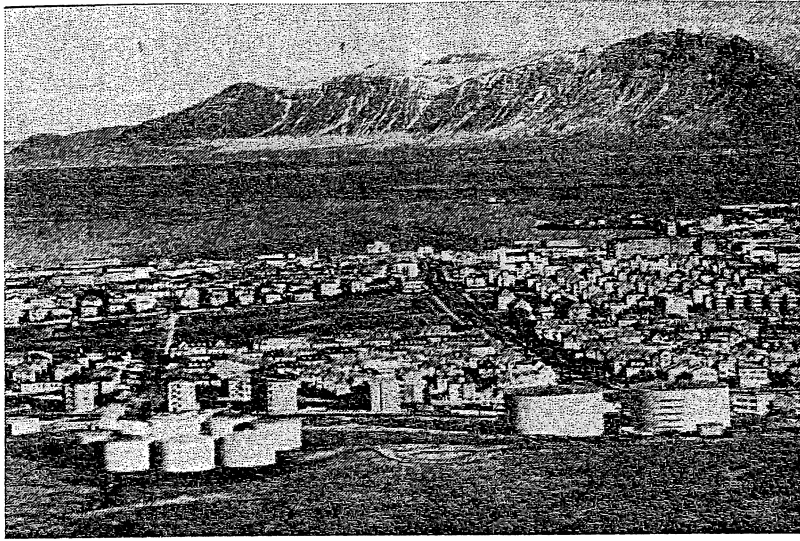


Figure 19 Reykjavik

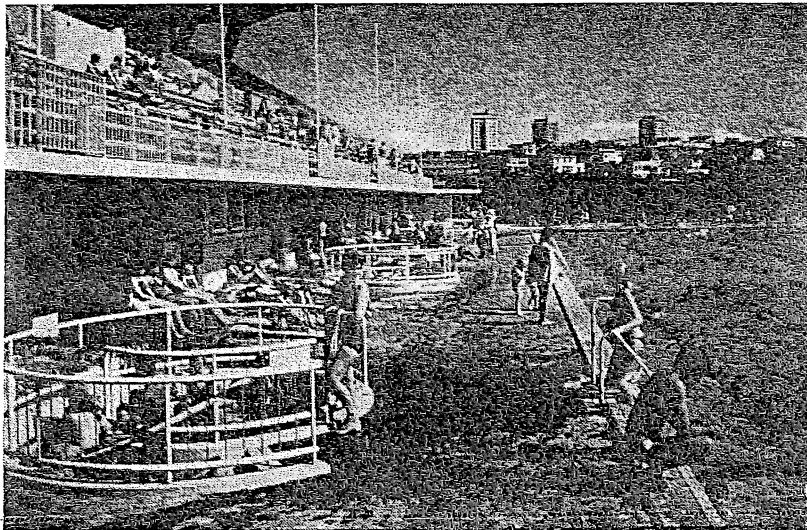


Figure 20 Reykjavik

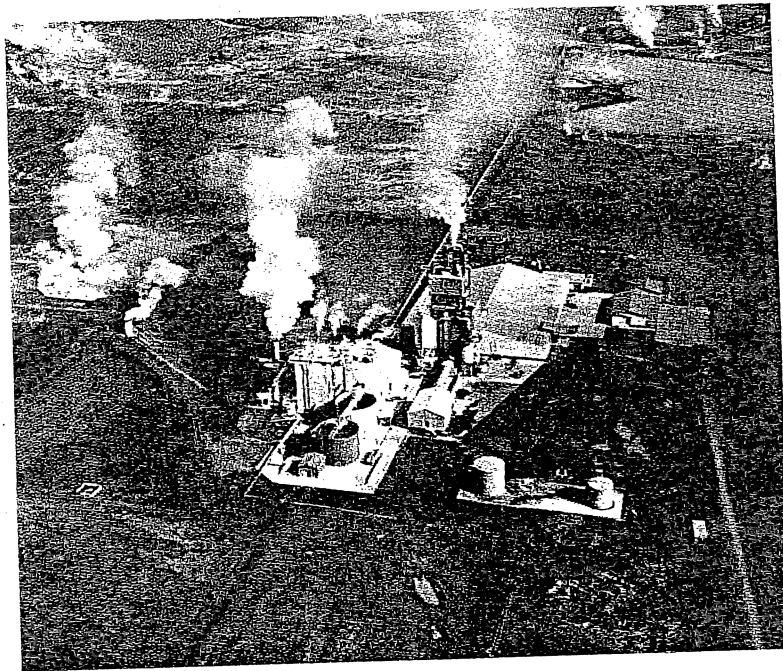


Figure 21 Diatomite plant

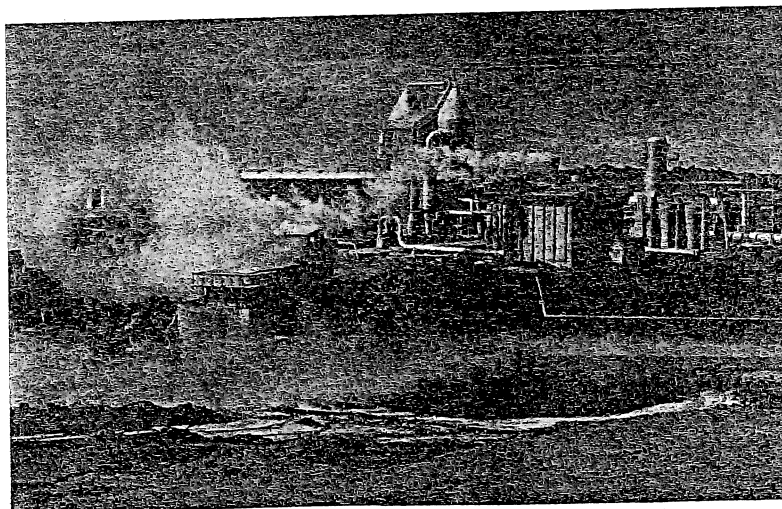


Figure 22 Seachemicals factory

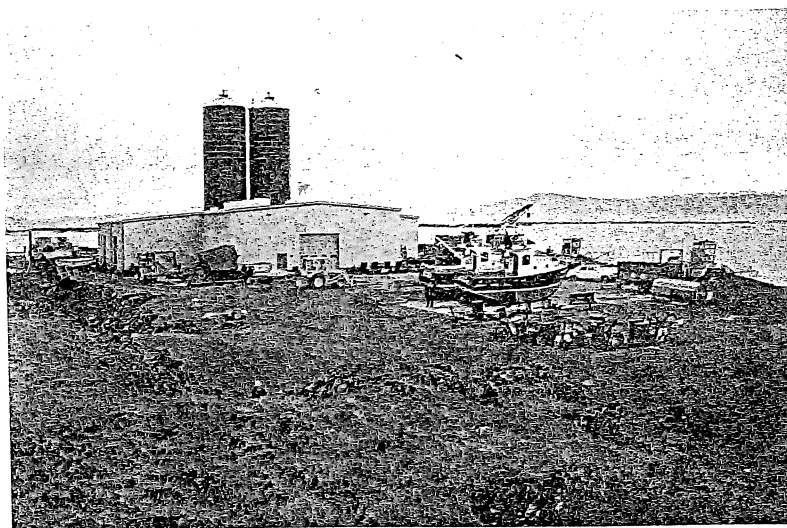


Figure 23 Seaweed factory

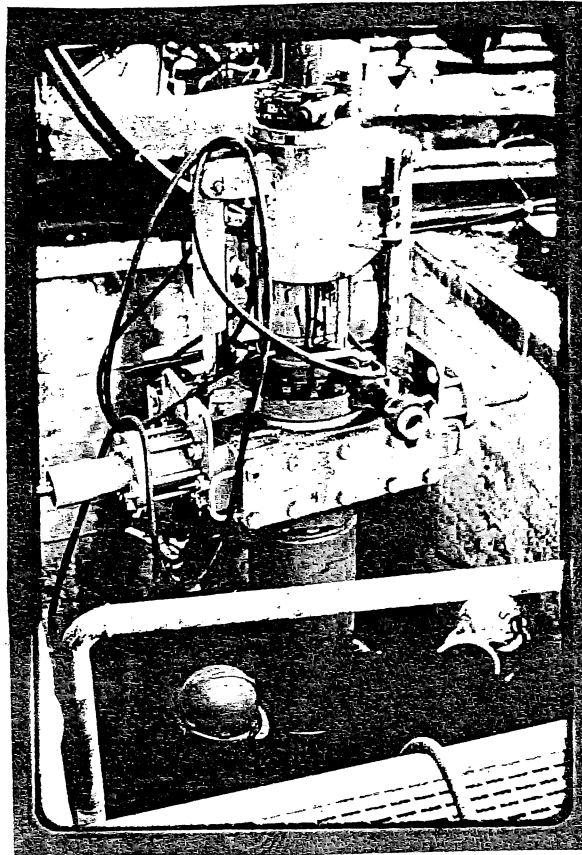


Figure 24 Cleaning operations

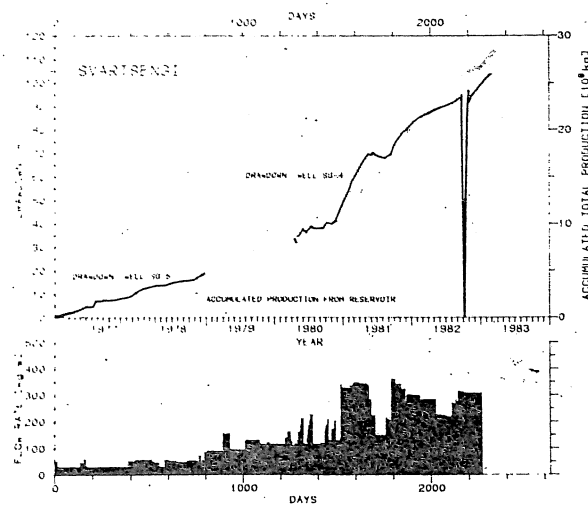


Figure 25 Drawdown of Svartsengi field

<p>ORKUSTOFUN JHD 1981-05-25 HOKJOUR</p>									
<p>2300-120-104-790528-3008</p>									
<p>PROGRAM WATCH1</p>									
<p>WATER SAMPLE (PPH)</p>									
PH/DEG.C	7.53/20.0	GAS (VOL.%)	DEGREES C	240.0 (MEASURED)					
S102	534.60	CO2	97.70						
NA	8037.00	H2S	0.80						
K	1245.00	H2	0.10						
CA	1343.00	O2	0.00						
MG	1.620	CH4	0.10						
CO2	32.60	N2	1.30						
S04	40.50	*							
H2S	0.16	*							
CL	17010.00								
F	27470.00	LITERS GAS PER KG							
CONDENSATE/DEG.C	0.67/20.0	MEASURED DOWNHOLE TEMP.							
AL	0.0700	DEPTH (METERS)							
B	8.6500								
FE	0.1960	CONDENSATE (PPH)	63.0	100.0					
NH3	0.6670	PH/DEG.C	72.0	200.0					
NO3	0.042	CO2	721.50	300.0					
PO4		H2S	18.80	400.0					
*		NA	0.00	500.0					
		NH3	3.800	700.0					
			243.0	900.0					
			243.0	1100.0					
			242.0	1300.0					
			242.0	1500.0					
			242.0	1650.0					
<p>CONDENSATE WITH NAOH (PPH)</p>									
CO2	0.00								
H2S	0.00								
<p>IONIC BALANCE :</p>									
<p>IONIC STRENGTH = 0.49693</p>									
<p>DEEP WATER (PPH)</p>									
S102	424.53	CO2	417.16	0.00	0.00	0.107E+01			
NA	6381.75	H2S	5.54	0.00	0.00	0.585E-02			
K	988.54	H2	0.01	0.00	0.00	0.333E-02			
CA	1066.40	O2	0.00	0.00	0.00	0.000E+00			
MG	1.286	CH4	0.09	0.00	0.00	0.471E-02			
S04	32.16	N2	2.06	0.00	0.00	0.500E-01			
CL	13505.59	NH3	0.53	0.00	0.00	0.513E-04			
F	0.13					0.333E+02			
DISS.S	21812.46					0.340E+02			
AL	0.0556								
B	6.1679								
FE	0.1556								

Figure 27 Calculations of reservoir state

