

KRAFLA GEOTHERMAL

POWER PLANT

Visit by R S Bolton,  
Chief Geothermal Engineer  
Ministry of Works and Development  
New Zealand 10 - 30 July 1973

Report prepared for the  
Ministry for Industry, Iceland

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Ministry of Works and Development, New Zealand.

### Summary:

The basic problem at Krafla is the division of responsibility for construction of the project, coupled with a lack of coordinated programming of the work as a whole. The most satisfactory solution to this is, of course, the establishment of the permanent body to control Krafla. However, it is unlikely that this can be accomplished in time to be of immediate benefit to the project.

Technical problems, particularly in connection with the wells, have caused misgivings concerning the viability of the project. However, these can be overcome, and, in the opinion of the writer, there is no justification for considering Krafla to be technically unsound.

The various recommendations have been made with the objective of producing 60 MW from Krafla Geothermal Power Plant by 1981 in mind, at the same time utilising the existing organisations. Some longer term suggestions have also been made.

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### Introduction

From the 10th to 30th July 1978, I visited Iceland at the invitation of the Ministry for Industry of the Icelandic Government to examine and report on various aspects of the Krafla Geothermal Power Scheme, and to make such comment and recommendations as may appear necessary. The authority and terms of reference for the visit are contained in the letter from Dr Gunnar Thoroddsen, Minister of Industry to the Commissioner of Works, Ministry of Works and Development dated May 17th 1978, and the telex

message dated May 25th 1978, copies of which are attached.

Itinerary

The visit was arranged to follow a conference organised by the United Nations University. The conference concluded on 9th July with a visit to a number of geothermal installations in Iceland, including Krafla.

Monday 10 to Tuesday 18 July. In Reykjavik.

On Monday 10th a briefing was held with Mr Páll Flygenring, Secretary for Industry, Mr Jakob Björnsson, Director General of Orkustofnun, Dr Einar Tjörvi Eliasson, Director of the Krafla Executive Committee, and Mr Karl Ragnars and Dr Valgardur Stefánsson, senior staff from Orkustofnun.

The remainder of this period was spent in discussions, visits to geothermal installations, to drilling rigs and associated store and workshop, and in report writing.

Wednesday 19 and Thursday 20 July. At Krafla, Namafjall and Husavik.

Friday 21 July - Sunday 23 July. In Akureyri.

Discussions and report writing.

Monday 24 July to Saturday 29 July. In Reykjavik.

Further discussions, visits and completion of draft report. Discussion of conclusions with Dr Gunnar Thoroddsen. Discussion of draft report with staff of Orkustofnun, the Krafla Executive Committee and the Ministry for Industry.

Sunday 30 July. Depart Reykjavik for Singapore.

Institutions involved with Krafla

In addition to the Ministry for Industry, the various institutions associated with Krafla are:

a) Orkustofnun.

Responsible for all investigation, for drilling, for installation of steam collection and transmission system, for well measurements, and for maintenance of the steam supply.

Responsible to the Ministry for Industry.

b) Krafla Executive Committee

Initially responsible only for the erection of the power plant, but now, due to the existing situation regarding power generation, is also responsible for its maintenance and operation. This is intended to be a temporary committee.

Responsible to the Ministry for Industry.

c) Laxárvirkjun

A company responsible for generating power in the north of Iceland, and transmitting it to the city of Akureyri. Owned 35% by the state, and 65% by the city of Akureyri. Krafla power station is in its area.

d) National Power Company

A company responsible for generating power in the south of Iceland, and transmission to Reykjavik. Owned 50% by the state and 50% by the city of Reykjavik.

e) State Electric Power Works

Responsible for generation in most other areas in Iceland, and for all transmission except to Reykjavik and Akureyri. Presently installing the transmission line to the east which Krafla will help to supply.

Responsible to the Ministry for Industry.

### Krafla Organisation

While the technical problems have undoubtedly contributed to the difficulties at Krafla, the basic problem arises from the division of responsibility for arranging finance and for construction. It is appreciated that when the arrangements were made in 1974, they were considered to be temporary. The Krafla Executive Committee was to be dissolved, and the Krafla scheme taken into the proposed reorganised national power system. However, it is now four years later, and discussions are still going on over the proposed reorganisation.

It may appear that the organisation at Krafla has developed along similar lines to those at the Geysers field in California where separate organisations are responsible for steam supply, and for power generation. However, at the Geysers, each organisation is quite separately funded, whereas at Krafla, all funds come from the same source. Also, each organisation at the Geysers has a binding contractual obligation to the other with penalties enforceable at law. This of course, does not exist at Krafla. For these reasons, the Geysers does not really offer a valid comparison.

In some respects, the situation at Krafla is more like that in New Zealand. In both places, the funding is from a single source, the State, and in both cases, two organisations are involved in the construction. However, in New Zealand only one financial authority is obtained for the complete project, as opposed to the separate financing at Krafla. There is also a substantial difference in the natures of the organisations. In New Zealand, both organisations have been in existence for many years. They are engineering based organisations whose function is among other things, to design and construct power schemes. At Krafla however, one organisation is known to be temporary, and the other is a scientifically based organisation which has grown very rapidly, and which through force of circumstances, has become actively involved in major engineering works.

Thus, neither the Geysers or New Zealand afford a true comparison with Krafla. In other words, Krafla has developed in its own way which unfortunately appears to be as two separate projects.

Factors which have contributed to this situation include:

- i) Programming: When the responsibilities for the Krafla Executive Committee and Orkustofnun were first defined, no responsibility was assigned for programming the work as a whole to ensure that all parts would be completed at the appropriate time. Not only has this directly influenced the present situation, indirectly, it has increased other difficulties, and of course costs.

Programming was discussed extensively during my visit, and is covered in more detail later in this report.

- ii) Financing: The Krafla Executive Committee and Orkustofnun are each responsible for arranging the finance for their own section of the work. This is done in accordance with the accepted procedures required by the Government. That is to say, annual estimates are prepared on the basis of a work programme drawn up for the forthcoming year. These are submitted in September for approval in the finance law in December. If the estimates are approved, the cash is made available through the year on the basis of a monthly cash flow.

Up to, and including 1976, powerhouse construction and steamfield development were reasonably in step. However, Orkustofnun had difficulty in getting their work programme for 1977 accepted, which meant, in

turn that they were unable to get authority for the estimated expenditure. It is considered that the situation which arose in connection with the 1977 work is the direct result of the lack of overall programming mentioned above.

It also appears that from time to time, Orkustofnun have had problems when their authorised monthly cash flow requirements were not met. The Krafla Committee do not appear to have had this problem. It is considered that there are two reasons for this, the first being the difference in the composition of the two organisations, while the second results from the imbalance in the Orkustofnun organisation discussed more fully later.

iii) Communication: From both discussions and my own observation, it is clear that there are difficulties with communication and that this has contributed materially to the present situation.

Basically, this is a problem which can only be solved by the individuals themselves. However, the organisations can help by, among other things:

- providing positive direction.
- making sure that the common objective is known, understood and accepted by all.
- proper programming.
- acknowledging how important communication is.

iv) Orkustofnun organisation: The organisation has grown very rapidly over the last few years. Also, while it is a scientifically based organisation, it is responsible for a substantial engineering work. The rapid growth, with the emphasis on increasing the technical staff has lead to an unbalanced organisation. The organisation is discussed later, but it appears that these imbalances are also contributing to the present situation at Krafla.



- v) Coordination: When separate groups are working together for a common objective, proper coordination of their activities is essential. This need was recognised by the appointment of a committee by the Ministry for Industry to provide such coordination for Krafla. However, the committee does not appear to have the necessary authority, so that coordination is, in effect, still lacking.

Giving the committee the necessary authority will be a help in improving the situation, but only to the extent that both groups accept that authority.

It is clear that responsibility for the Krafla Geothermal Power Plant will eventually be transferred to the State Electric Power Works, or to Laxárvirkjun, or to a new body formed as part of the proposed reorganisation of the electrical generating industry in Iceland. However, the negotiations over conditions, financial obligations and reorganisation inherent in such a transfer of responsibility mean that it can be of little benefit to Krafla in the immediate future.

It would be possible for the transfer to the State Electric Power Works to take place quite rapidly, simply by assignment by the Ministry for Industry. However, this choice was available when the Krafla Executive Committee was formed, but was not taken then for reasons of which the writer is unaware. Unless these reasons are no longer valid, an assignment by the Ministry for Industry to the State Electric Power Works is unlikely to take place without considerable negotiation.

The solution which appears to be emerging is that the Krafla Committee takes full control of the project, and contracts the services of Orkustofnun as necessary. Had responsibilities been assigned in this manner when the Krafla Committee was set up the present situation would be much easier. However, in the present situation if not handled carefully, such reassignment

will be taken as a reflection on the ability of the staff of Orkustofnun. This would be most unfortunate, as although the organisation may have difficulties, there is no doubt in my mind that the technical competence of the staff of Orkustofnun is very high.

This solution will not be easy to put into effect. However, it will be seen that its adoption will remove or minimise three of the factors contributing to the difficulties, financing, programming and coordination, and implies a substantial improvement in communication which is necessary. Also its adoption would put Orkustofnun in the same relationship to the Krafla Committee that it already has on other projects with which it is associated. It is in fact, very difficult to escape the conclusion that the Krafla Executive Committee should take full control of the work. However, it must be again emphasised that the Krafla Committee is a temporary organisation lasting only until permanent arrangements for the Krafla scheme can be completed.

For this solution, good communication will be absolutely essential. Between the two organisations the change should be discussed, the details agreed and a formal notification of such reorganisation made as soon as possible. Within Orkustofnun, a detailed explanation of the change should be given to all staff. This should, among other things, include the reasons why the change was considered necessary.

An aspect which should not be overlooked is that the Ministry for Industry is already responsible for coordination, and has a committee set up for that purpose. As noted earlier, the committee has insufficient authority at the present time. Given the proper authority, which should among other things, include responsibility for programming the whole work, this committee could help make the reassignment of responsibilities easier.

While the difficulties faced by Orkustofnun are essentially a separate problem, their solution is not completely independent of the solution for Krafla. In particular, care will have to be taken that any contract between the Krafla Committee and Orkustofnun will not make Orkustofnun's difficulties worse by asking for conditions which conflict with their own internal arrangements and requirements.

#### Comments on Orkustofnun

Orkustofnun is composed of four divisions, hydro-electric investigations, economic geology, geothermal, and the economic division. The State Drilling Company is assigned to Orkustofnun by direction from the Ministry for Industry.

The geothermal division is responsible for investigation and field development of all geothermal fields in Iceland, in some cases directly for the State as owner of the field, in other cases, under contract to the owner who would normally be a public utility. In Iceland, the owner of the land has full rights to the energy. In general, Orkustofnun is not directly involved with utilisation. It is funded from money authorised in the annual finance law (budget) which is passed in December of each year, and by its contract earnings.

The State Drilling Company is set up as a private company. It works under contract, and its only source of funds is its contract earnings. Capital expenditure in new rigs is funded by the State but from discussions, funds for the purchase of new tools and equipment were sometimes a problem. The geothermal division of Orkustofnun control most of the State Drilling Company's work either directly as in the case of Krafla or indirectly as consultants to utilities who contract the drilling separately.

In 1968, the total staff of Orkustofnun, excluding the State Drilling Company, totalled 30, whereas at the present time, it is now 100. Generally speaking, an expansion of this size, unless carefully planned will result in difficulties, some of which can

be seen in Orkustofnun at the present. The most noticeable is that the increase in staff has been almost entirely technical, with very little change in the size of the administrative staff. The main effect of this is that senior staff carry most of the additional administrative load with the consequence that their function of directing the work suffers. It also means that administrative work which should be done is not being done at all, or not being as effectively as it could be. For instance, ensuring that once estimates were approved, the cash flow comes through as required is properly speaking, an administrative function.

Rapid expansion, particularly in a technically based organisation means the organisation will be composed mainly of young people, technically highly competent, but, in a lot of cases, lacking the sense of responsibility to the group gained by experience working in an older organisation.

Another aspect of rapid expansion is that work methods which may have been suitable before expansion took place, may not be suitable in an expanding organisation. For instance, it is often customary in scientifically orientated organisations to encourage staff to spend time on work in keeping with the objectives of the organisation, but of special interest to themselves. They would not of course, neglect work allocated to them by their seniors. However, it is questionable whether the same practice should be followed in a rapidly expanding organisation, which is engaged in commercial work. There will always be a tendency to carry out the work of most interest, with less emphasis on the more routine work.

Krafla is one of a number of projects Orkustofnun is working on, and is unique in its organisational form, and to a lesser extent, in the technology involved. It is unlikely that staff will work exclusively on one project, and will require some guidance as to priorities. This can best be provided in the annual programming of the total work load of Orkustofnun.

The foregoing observations have prompted the following suggestions which may help with the present situation.

- 1) The administrative section of Orkustofnun should be strengthened, basically to provide support for the whole organisation, but with special emphasis on assistance to senior staff.
- 2) Within the geothermal division there are two complementary lines of responsibility, one discipline orientated, the other project orientated. This is a usual way of working and is essential when a number of different disciplines are involved in a project. However, the project leader is selected from one of the different disciplines, of which he remains a practising member. He thus has a dual work loyalty, to the project he leads, and to his discipline. This could lead to a conflict of interest which would be better avoided.  
  
It would be preferable to have fewer project leaders, and make them responsible for more than one project, with no responsibility for work in their own discipline. They would then be responsible only to their immediate superior.
- 3) Within the geothermal division additional technical support is required by Dr Valgardur Stefansson, and Mr Karl Ragnars, who have too many, and too wide a range of people reporting directly to them. This is a direct result of the rapid expansion.
- 4) Job descriptions should be prepared for all technical staff in the organisation. In addition to describing the work, they should show who the person is responsible to, who he's responsible for, who or at what level he is entitled to deal with outside organisations, and the extent of the authority for making decisions carried by the job.

- 5) The annual work programme prepared in conjunction with the estimates should define priorities among the different projects Orkustofnun is working on.
- 6) The importance of good communication should be emphasised on every occasion.

Orkustofnun is a scientifically orientated organisation with a substantial involvement in a major engineering work. While there must always be a close liaison between the engineering and scientific disciplines, in a project of the magnitude of Krafla, it would be more usual for the scientific work to be provided as a service. The basic reason for this is that in undertaking engineering work, a different approach is required as compared to scientific work. I have the strong impression that in Orkustofnun, the two functions are not clearly separated, and that because the organisation is scientifically orientated, on occasion, the scientific aspects tend to be emphasised at the expense of the engineering.

The various suggestions above have, of course had this in mind. There is however, a more radical suggestion which is offered for consideration. This is that the engineering and scientific functions of Orkustofnun be completely separated by forming two new organisations. One would be responsible for all the Government's engineering work, and the other for all state funded scientific and industrial research work. The State Drilling Company would of course be incorporated into the engineering organisation if the suggestion were to be adopted.

The parallel between this suggestion and the situation in New Zealand is very obvious. The Ministry of Works and Development is responsible for carrying out the majority of the state funded engineering works using either their own staff and workmen, or consultants and contractors. Likewise, the Department of Scientific and Industrial Research is responsible for the majority of state funded research work, and in doing so, provides scientific

advice and services not only to the Ministry of Works and Development, but also to other government departments, and to the public in general. Both departments cover a very much wider range of activities than just geothermal. The relationship between the two departments, both generally, and with particular regard to geothermal work is a close one, and one that has worked extremely well over the years.

It is appreciated that Orkustofnun has been set up by Act of Parliament, and that the change suggested would require a change in the law. This, of course, would take time, and the completion of Krafla would not be affected by such a change. Adoption of the suggestion would however, have a marked influence on future geothermal projects.

### Drilling

#### a) Organisation

The State Drilling Company has 5 rotary rigs ranging in size from a Mayhew 1000 to the large 3,000 m electric rig. It also has a number of cable tool rigs used for the initial work on the geothermal wells (setting surface casing) and diamond drilling rigs used mainly for foundation investigation work. With this number of rigs operating, and on occasions working in different parts of the country, the company organisation is not adequate. The inadequacy lies in the fact that Mr Isleifur Jonsson who is head of the company has all the tool pushers in charge of the rigs, plus the personnel in charge of cementing, purchasing, administration and stores reporting directly to him. The day to day operations should be the responsibility of staff junior to him, and there is no doubt improvement would result from the appointment of additional staff.

The minimum additional staff recommended is:

- 1) A drilling engineer to control both the big rigs.
- 2) A drilling engineer to control the three failing rigs.
- 3) A drilling engineer to control all the small rigs.

The remainder of the organisation including purchasing could remain as it is for the present. It is important however, that the whole organisation be reviewed periodically to see that it can cope with the work. For instance Mr Sigurdur Benediktsson may need additional help if drilling mud is to be used. Also, it is suggested that a relatively junior person be appointed under him to keep the drilling records up to date.

The most important effect of adding the drilling engineer will be on the rig tool pushers. They will have someone to discuss their day to day problems with and to get advice from, and will generally be able to form a working relationship which is impracticable under the present system. Their need for this is shown clearly by their requests for training.

Training is discussed later, but another advantage of appointing this group will be that training should be a part of their job. They will be permanent staff, and the dead period during the winter should be used by them on preparation and running of training courses, attending training courses overseas, familiarisation with new equipment etc.

The problem faced by the drilling company in retaining staff and workmen not only over the winter months, but in those periods when insufficient work is available is fully appreciated. Indeed, had it not been for this, the increase in staff recommended would have been higher.

A possible solution to this problem may be to reduce the number of rigs operating and programme the drilling work to take a longer period. This may mean that some communities may be a little delayed in getting geothermal energy. At the same time however, this could save quite a lot of expenditure, both directly and indirectly.



A second solution would be for the State to start an exploration programme, covering areas which may someday be developed, but for which there is no immediate need. Wells in these areas would of course be drilled only if there was no programmed work available for the company elsewhere.

In discussing Orkustofnun, it was suggested that some day it may be considered desirable to separate the scientific and engineering groups, and that the State Drilling Company be taken in with the engineering group. This should have a benefit in making the retention of the more senior or experienced staff and workmen in the State Drilling Company easier.

b) Techniques

With one exception, it is difficult to comment on drilling techniques because to make proper comment, it would be necessary to stay with the rig over a period when it was working.

The exception is the use of drilling mud. The reason for not using drilling mud appears to be that it is not necessary when drilling in the cooler wells, and that it is expensive. However, drilling mud has two advantages in high temperature drilling as compared with using water. One is that it will save a lot of rig time in regaining lost circulation, particularly prior to running casing. From the description of conditions in the upper or cased part of the well, the mud will seal all minor fissures, but it will still be necessary to cement off, or use gunk plugs on the larger losses.

What is more important is that by better control on lost circulation, better casing cementing will result. Improvements have already been made to cementing techniques compared to those used on the earlier wells. Nevertheless, it is essential that the casing cementing be the best possible, otherwise there will be the continued possibility of casing failures.

In using mud, desanders and a cooling tower will be required and it will probably be found desirable to re-arrange the surface plumbing. Also, storage of mixed mud will be required on site, and the disposal of reject or surplus mud provided for.

Nevertheless, I recommend that drilling mud be used on all the high temperature wells at Krafla and elsewhere until the 9 5/8 casing has been set.

c) Training

Training crews is best carried out on the rig, where they pass through the various stages of roustabouts or roughnecks, derrickmen, driller and tool pusher, at each stage learning new techniques from the more senior people. At crew level, language problems would prevent them taking advantage of training courses, and other overseas training which would be available. Attendance at these would probably be confined to the drilling engineer, and in some cases, tool pusher level. The benefits of this training could be passed on by in house training schools.

As noted earlier, the winter period would give an opportunity for in house training, and the strengthened organisation suggested would make it easier for such training to be organised.

The possibility of a drilling engineer from New Zealand visiting Iceland during the drilling of a well was discussed during the visits of both the Orkustofnun and Krafla Executive Committee representatives to New Zealand, and again during my visit. As advised, this will not be possible this year due to the current expansion of our own work but could be considered for next year. It is suggested that a decision be made when both Icelandic and New Zealand drilling proposals for next year are known.

### Programming

Programming was discussed extensively, both in the long term, and in more detail, for the rest of this year, and for next year.

The principal objective was stated to be the generation of 60 MW from Krafla by the 1981/82 winter. A small amount can be provided by the rehabilitation of existing wells, but a substantial amount will be required from new wells. Allowing for unproductive wells, approximately 20 new wells will be required. It is not possible to guarantee that every well will be successful, and a success ratio of two useable wells in every three drilled would be considered good.

However, steam field development is well behind power station requirements, and the attempts to remedy this are being programmed on an ad hoc basis. Bringing the power station up to full load would be considerably assisted by proper programming.

It appears that present programming is influenced principally by finance and by differences of opinion on what work should be carried out in the steam field.

Financing is always easier in an atmosphere of success. However, it is not desirable to tie the two together too closely in the short term, as this will almost invariably delay the achievement of the long term objective. If finance is to be a constraint, this should be built into the programming, if necessary by modifying the objective.

The differences in opinion on what work should be carried out arise from the conflict between the need to get steam to the power station, and the need to complete investigation of the field. Both of these are legitimate needs, and almost the only way the necessary compromise can be ensured is by proper programming.

Not only must the longer term objective be technically feasible, it must be financially acceptable, and indeed acceptable to all interested parties. If there are any objections or constraints, then either they must be removed, or if this is not possible, the objective redefined. The programme must of course be flexible enough so that changes can be made if unforeseen circumstances arise, and must be reviewed periodically to see whether any changes are in fact necessary.

In order to meet the long term objective, an average of 6 or 7 wells will need to be drilled in the next three construction seasons. This is considered to be attainable provided as much work as possible is done this year to assist with next year's work. The essential work this year is the preparation of roading, and site preparation for some of next year's wells.

The proposal for work this construction season for which approval had just been received was also discussed. This proposal was for the rehabilitation of wells 3, 10 and 11, and the connection of these wells plus well 1 to the steam transmission system. After discussion, the proposal was modified to the rehabilitation of well 11, drilling a new well, and connecting this well and well 1 to the steam supply system. The modified programme is considered to be feasible, should supply as much steam to the powerhouse as the original proposal would have done, and will supply considerably more information of assistance in siting wells for next year than did the original. This has been quoted at some length to illustrate the type of compromise required between the needs for the power-station, and the investigations.

It also illustrates the point that in working towards the main objective, the programme can, and should allow for intermediate objectives, in this case the provision of more steam to the powerhouse this construction season. The intermediate objectives should not, however, be allowed to influence the programme to the detriment of the main objective.

To conclude this discussion on programming, it is essential that a programme be drawn up to meet the required objective of 60 MW from Krafla by 1981. This should be costed in as much detail as practicable, and should of course, cover all the work necessary, including drilling, steam transmission, investigations, well measurement, well and steam field maintenance. The programme and cost estimate should receive approval in principle from all interested parties. Full recognition must be given to the fact that any programme to meet the objective will be a crash programme, requiring immediate decisions, and requiring that the funds be made available as required. If approval is not forthcoming, then the objective will have to be restated, and a further programme drawn up.

It should be noted that the approved programme will not take the place of the annual estimates. Because of the changes which will be necessary as the programme develops, annual estimates of expenditure will still be required, the approved long term programme being used to support these estimates.

#### Well Location

Considerable flexibility is necessary in making a final selection for a site. It is usually a compromise of which the scientific work is only one factor. Among others would be land use and environmental considerations, with the final site being determined by access and site preparation. In New Zealand, a site is selected initially on the basis of compromise between the scientific disciplines in the Department of Scientific and Industrial Research. It is supplied to the Ministry of Works and Development as a grid reference with the understanding that a change of up to 150 m could be made without going back to the DSIR. Anything more than that would be referred to them for further consideration, and in one exceptional case a shift of 1 km was agreed.

There is a difference between siting investigation wells and siting production wells. For the former, little is usually known about the field, and although the wells are always located with the object of

producing steam, the information they provide is just as important. Production wells are usually sited when a lot of information is known about the field and wells can be sited to produce steam with a much greater certainty. Factors such as pipeline layouts also affect siting.

In the case of Krafla where investigation and production drilling are being carried out at the same time, even more of a compromise is necessary. The need to produce steam for the powerhouse requires a reasonable certainty that a well will produce, and this must be balanced against the need to extend the knowledge of the field. The compromise in this case was to locate the new well close to, but outside the producing area already defined by drilling, and in an area where all other factors suggested gave the best chance of getting steam.

In geothermal drilling, it has been customary to refer to only two stages of drilling, investigation and production. Properly speaking, a third intermediate or appraisal stage should be recognised. The three stages would then be:

- Investigation drilling - the initial wells drilled, usually small in number, which establish whether the field being investigated has any potential.
- Appraisal stage - these wells are those drilled to give a reasonably reliable estimate of the potential of the field and to provide more detailed knowledge of the field.
- Production stage - wells drilled to realise the potential.

For practical purposes, there is little difference between the latter, as both are intended to produce steam. From a financial point of view, there is probably a little more risk in the appraisal stage because as well as steam, the wells are still looking for information. There is however very much less risk than at the investigation stage. In my opinion, Krafla drilling has passed the investigation stage, and is in the appraisal production stage.

### Field Management

Initially, there was a lack of downhole pressure data from Krafla which appears to be the result of transferring low temperature aquifer practices to high temperature aquifers. From discussion, however, it is clear that this lack had already been recognised and that downhole pressure runs are now given the same attention as are temperature runs.

It is appreciated that with the power station operating, it is difficult to get downhole measurements. However, if the field is to be properly managed, regular measurements are essential. At present, this should include all wells because they are relatively few in number. They should all be measured as nearly as possible at the same time, and at this stage, they should be measured not less frequently than annually. If possible, this should be reduced to six monthly intervals. It is also worth taking pressure and temperature runs whenever a well is taken off the steam supply.

The importance of these measurements in field management cannot be emphasised too much, and it is recommended that a programme be drawn up in which station operation permits regular measurements.

### Deposition

Deposition occurs in most geothermal fields to a greater or lesser extent. Krafla has the distinction of having two different types occurring at different levels in the same well, calcite in the upper levels, and silica/iron in the lower.

The chemistry of calcite deposition is well known, and has been described for Krafla as well as other fields. The calcite deposition which has been occurring comes from the flow from the upper aquifer, and there is the clear indication that casing off this aquifer, should prevent this form of deposition from occurring

in the future.

At this stage, not enough is known about the silica/iron deposition occurring from the lower aquifer to be able to predict its behaviour. In well 10 for instance, the deposition occurred very rapidly, while in 11, none has yet been observed. One useful piece of information from the well 10 clean out is that the silica/iron deposit was easily drilled out.

The individual constituents of the deposits have been reported the proportions in which they occur in a sample taken at the surface, but related to a specific depth in the well. The method cannot give a reasonable estimate of the total quantity involved, nor of the depth over which it occurs. This information can be useful, and by taking a little trouble could be obtained.

The procedure is:

- 1 Run baskets of different diameters into the well. A plot of the basket diameter against the depth reached gives the upper profile of the upper deposit.
- 2 Drill out the top deposit only, using drilling bits of different diameters, starting with the smallest. A plot of bit diameter against depth at which it runs out of the deposit gives the lower profile of the top deposit.
- 3 While drilling the upper deposit, debris will fall onto the lower deposit which would make the use of the baskets difficult. However, by lowering the drill pipe and bit carefully onto the deposit it will be possible to determine the point at which the bit starts drilling the deposit. The upper profile can thus be determined, together with the lower.

It is preferable not to try drilling through both deposits on the one trip because while drilling the lower one, the drill pipe will almost certainly damage the upper.



The main limitation on this technique is imposed by the size of drill pipe available. To get a reasonable profile, it should be the smallest possible, but the smallest possible may be the rig drill pipe.

The profiles obtained enable a reasonable estimate of the total quantity involved, and its location. An average composition from samples taken at the surface would enable the quantity of each constituent to be obtained.

The silica/iron deposition occurs at 1500 metres and below. If this is going to occur frequently, then consideration should be given to purchasing a rig for cleaning out. The main requirements will be that it is mobile and has the necessary depth capacity. Mobility is important, as speed of rigging up and tearing down will be critical. It is unlikely that the rig best suited for cleaning out will be suitable for drilling new wells. However it is too early to do much planning on drilling rigs until more is known about the silica/iron deposition, particularly the number of wells which will be affected.

It is understood that techniques for cleaning out deposits with the well discharging, are being developed for Swartzengi and these no doubt, will be used at Krafla also.

Even though more information is required about the silica/iron deposition before it is understood as well as the calcite deposition, on the information that is available at present, it does not appear that chemical deposition will cause significant problems in the operation of the powerhouse.

#### Casing Damage and Repair

Out of 10 wells completed at Krafla, 3 are known to have damaged casing. This is a fairly high proportion, and somewhat naturally gives rise for concern.

From an examination of the data sent to me, and from discussion in Iceland, it is my opinion that the failure in wells 3 and 5 resulted from the expansion and contraction of a long, uncemented length of casing, while the failure in 7 was a casing collapse resulting from the expansion of a pocket of water sealed in the 9 5/8 - 13 3/8 annulus.

There is no doubt about 7, the photograph of the damage showing it to be a typical collapse failure.

In the case of 3, the horizontal displacement of the broken ends is what would be expected if the casing above and below the break was lying against opposite sides of the 13 3/8 casing. The vertical displacement can be accounted for by an uncemented length of less than 600 m and a temperature rise or fall of 100°C. Added to this, the cementing of the casing was bad, and the well had been discharging for some time. This combination of circumstances leaves me in no doubt that expansion and contraction of poorly cemented casing was the reason for the failure.

The casing in 5 is not broken, but contains a bend or bulge. As in the case of well 3, the casing cementing was bad, and it is probable that a substantial length of the 9 5/8 casing is uncemented.

Instruments and calipers could pass the damage as could the pin on a 4 1/2 drill pipe tool joint. This is approximately 6" in diameter. Nothing bigger in diameter was tried. A light lowered into the well disappeared in a 2 metre length.

It has been suggested that ground movement is the cause of the damage. The problem with this suggestion is that movement of this nature should also show up in other ways, but this does not appear to have been the case.

An alternative explanation is that the casing has failed as a column by buckling, sideways movement being restrained by the 13 3/8 casing. This explanation also fits the known facts, and does not require any external supporting evidence. It is for this reason that I have formed the opinion that the failure is the result of temperature expansion and contraction of a uncemented length of casing.

The repair of well 3 was discussed in connection with programming, and is to be deferred meantime. The casing below the break is filled with gravel, which will be more costly to remove than sand would have been. However, what is more important is that the casing below the break is uncemented. If the casing is left without cement in the annulus, then there is every chance that a further break will occur. The repair of 3 will thus require the use of perforating equipment which will have to be purchased.

Before any further work is done on well 5, more information should be obtained about the damage.

This would include - sounding with various diameter plugs to get some idea of the horizontal displacement.  
- use of a lead tube to get some indication of the shape of the upper side of the damage.  
- photograph the damage.

The reason for trying to find out more information is that if the damage is due to a failure resulting from temperature expansion, then the casing is uncemented, and perforation will have to be considered in planning any repair.

The best method of repairing casing failures is to prevent them, and there is no doubt at all that a good casing cementing job is the best insurance against casing failures. This has been discussed under drilling.

If a failure has occurred, whether it has to be fixed or not, the main thing is to find out as much as possible about it. It is on the basis of this information that the repair is planned, and the better the information, the more likely success will be.

### Recommendations

Various recommendations have been made in the body of the report. These are listed below in the order in which they occur.

It is recommended:

- 1 that the Krafla Executive Committee be formally given full responsibility for the Krafla Geothermal Project until permanent arrangements for control of the project are made.
- 2 that the Ministry for Industry's coordinating committee be given the authority necessary to make it effective.
- 3 that the administrative section of Orkustofnun be strengthened.
- 4 that project leaders in Orkustofnun should not be required to carry out work in their own discipline.
- 5 that additional technical assistance be given to Dr Stefansson and Mr Ragnars.
- 6 that job descriptions be prepared for professional staff in Orkustofnun.

- 7 that Orkustofnun's annual work programme define the priorities among the various projects they have in hand.
- 8 that three drilling engineers be appointed to the staff of the State Drilling Company.
- 9 that every effort be made to overcome the problem of retention of staff and workmen in the State Drilling Company when there is insufficient work for all rigs.
- 10 that drilling mud be used in the high temperature wells until the production casing has been cemented.
- 11 that a work programme for completion of the project as a whole be drawn up to meet the objective of generating 60 MW by 1981/82, or such other objective that may be set.
- 12 that the station operation be programmed to permit regular downhole measurements which are essential for proper field management.

Of these, the most important are considered to be numbers 1, 2 and 11.

It should be noted that in addition to the above, the report contains various suggestions which while not being given as recommendations, have some significance in the long term. The most important of these concern Orkustofnun (P.12-13), the visit of a drilling engineer from New Zealand (P 16) and the purchase of drill rigs (P 23).

### Conclusion

It is clear that Krafla project has had a lot of problems in its relatively short history. Some of these have been covered in this report, but others, such as the project becoming a political issue, and the unfavourable publicity it has received have not as they are outside my terms of reference.

I would however like to make it very clear that from the information I have been given and my own observation, it is my opinion that Krafla should not be considered a failure. There have been technical problems, and there will no doubt be more, but the technical capability to overcome these is in Iceland, and the problems will be overcome. With proper planning, and the full cooperation of all parties, I am confident the station could be up to full load by the 1981/82 winter.

### Acknowledgements

I would like to express my appreciation of the assistance I have received from the staff of Orkustofnun and the Krafla Executive Committee during my visit. My inability to read Icelandic has meant that substantially all my information has had to be gained by discussion. In all cases, this has been frank and open, and has inevitably taken a lot of time for a lot of people which has been given unstintingly. Without the friendly cooperation I have received, this assignment could not have been undertaken, and my sincere thanks go to all concerned.

Finally, I would also like to record my thanks to the Commissioner of Works of the New Zealand Ministry of Works and Development for his permission to undertake this assignment.

R S Bolton  
Reykjavik and Wellington  
July-September 1978