# STATE ELECTRICITY AUTHORITY
# ICELAND

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# FINAL REPORT ON 16MW
# GEOTHERMAL POWER STATION

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MERZ and McLELLAN,
32, Victoria Street,
London, S.W.1.

APRIL, 1963

MERZ AND McLELLAN

CONSULTING ENGINEERS

ALAN E. POWELL, M.I.C.E., M.I.MECH. E.
ARTHUR HOWELL, M.I.MECH. E., M.I.E.E.
CHARLES L. BLACKBURN, M.I.E.E.
E. LEWIS E. WHEATCROFT, M.I.MECH. E., M.I.E.E.
HAROLD J. BEARD, M.I.E.E.
WILLIAM H. DIXON, M.I.MECH. E., M.I.E.E.
WILSON W. CAMPBELL, M.I.MECH. E., M.I.E.E.
ARTHUR W. PEDDER, M.I.MECH. E., M.I.E.E.
THOMAS W. WILCOX, M.I.E.E., MEM.A.I.E.E.

CONSULTANTS

~~JAMES R. BEARD, C.B.E., M.I.C.E., HON.M.I.E.E., FEL.A.I.E.E.~~
T. GRAEME N. HALDANE, M.I.C.E., M.I.E.E., FEL.A.I.E.E.
FREDERICK C. WINFIELD, M.I.E.E., FEL.A.I.E.E.
SIR JOHN HACKING, M.I.E.E.
DR. ALBERT PARKER, C.B.E., F.R.I.C., M.I.CHEM.E., M.I.GAS.E.

ALSO
32, VICTORIA STREET, LONDON, S.W.1.
AND
CARLIOL HOUSE, NEWCASTLE UPON TYNE 1

TELEX: 53224 (ALL OFFICES)

MILBURN,
ESHER,
SURREY.

TELEGRAMS: AMBERKRAFT ESHER
TELEPHONE: ESHER 2345

YOUR REFERENCE ..........
OUR REFERENCE BW

10th April, 1963

THE DIRECTOR GENERAL,
The State Electricity Authority,
Reykjavik,
Iceland.

Dear Sir,

**16 MW GEOTHERMAL POWER STATION AT HVERAGERDI**

We have pleasure in presenting our Report on the proposed 16 MW geothermal power station at Hveragerdi, prepared in accordance with verbal instructions confirmed in our letter (Reference BW/KT) dated 5th September, 1962 and your letter (Reference EB/SSE/sg) dated 9th October, 1962.

The purpose of the report is to present the basic design and cost estimates for a geothermal power station having a gross output of 16 MW at design conditions from a single condensing machine. The net electrical output will be somewhat in excess of 15 MW in winter but may fall slightly below 15 MW in summer depending on seasonal variation in the condenser vacuum.

This report has been preceded by two others. The first dated March 1961 dealt with the geothermal power possibilities of the steamfield near Hveragerdi and considered the design and capital cost of a station sited on the Varmá River to produce a gross output of 17 MW from two 8.5 MW condensing turbo-alternators. A supplementary report dated December 1961 dealt with proposals for a 10 MW non-condensing power station comprising two 5 MW sets exhausting to atmosphere.

A preliminary investigation carried out in 1962 of a site closer to the apparent centre of gravity of the steamfield, as deduced from drillings up to that time, has revealed its suitability for a power station. The conclusions in the present report are based on the use of this site, the advantages of which are discussed in the text.

Tenders for the 16 MW turbo-alternator set have now been received, also estimates have been prepared by the Authority's civil engineers for the particular layout adopted. Hence the price and performance of the principal item of plant and the cost of the civil works are now to be regarded as somewhat more definite than our previous estimate.

Our main findings are as follows:

1. The estimated capital cost of an initial stage comprising one condensing turbo-alternator of 16 MW gross output is 161.5 million kronur (£1,339,000). The life of the plant is taken as 20 years with the exception of the wells and a small drilling rig for which a 10 year life has been assumed. On this basis and with interest at 7% per annum, the estimated cost of generation is 20 Aurar per kWh (0.4 pence per kWh).

2. The orthodox arrangement of jet condenser, in which the condenser is positioned immediately beneath the turbine exhaust and for which the above-mentioned capital cost figure is appropriate, is preferred to an alternative arrangement incorporating an outdoor type condenser. The orthodox design is well proven and we find that for the site under consideration its use results in marginally lower overall expenditure.

3. The cost of steam at the wellheads is calculated to be kr 5.75 (11.5 pence) per metric ton. This figure includes interest and sinking fund on the capital cost of the wells and an allowance for stores, materials and labour to maintain them but excludes oncost and risk allowances.

We are, Sir,

Yours faithfully,

MERZ and McLELLAN

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## DESIGN OF POWER STATION

### Site selected

The proposed new site lies about 2 kilometres north north west of Hveragerdi in the western part of the valley at the foot of Hellisheidi and approximately 700 metres south of Well No. 8 as shown on Plate 1.

The general features and advantages of the site may be summarized as follows:-

1. The site is closer to the steamfield now drilled than the first site chosen and thus the cost of transmitting steam to the station is reduced.

2. The ground formation is suitable for the construction of a spray pond at little higher cost than the dam on the Varmá River proposed in the original scheme. The overall cost of the circulating water system is reduced, partly because of the simplified pumphouse construction now permissible.

3. The ground contours provide natural elevation of the power station building over the spray pond with desirable saving in height of building for a scheme employing the orthodox type of jet condenser positioned immediately beneath the turbine.

4. The change of site enables a reassessment of

turbine inlet pressure to be made. We propose that this should be increased from 3 kg/cm$^2$ gauge to 4 kg/cm$^2$ gauge. We regard the higher pressure as a better compromise for the shorter pipe runs and slightly worse condenser vacuum.

5. The length of transmission line to connect the station to the existing 138 kV line between the Sog and Ellidaár switching stations is slightly reduced, from 2.8 to 2.2 kilometres.

6. Complete independence of the river for cooling reduces the temperature rise of the river to that caused by rejection of the hot water from the wells. This can be minimized by the use of cooling cascades and hence any objection by fishing interests should be more easily dealt with.

7. The land is not agricultural and is owned by the State and the site is further removed from other properties, the owners of which might have raised objection.

<u>Foundation conditions</u>

According to a report prepared by the Authority's geologist, Jón Jónsson, the site is on the youngest lava flow in the valley, the thickness of which is 3 to 5 metres. It is a rather fine grained basalt lava with few and small phenocrysts of plagioclase resting on a bed of gravel of unknown thickness but which is 3 to 4 metres where it crops out farther south at the River Varmá. It is thought to be thinner than this at the site. The gravel bed rests on another lava flow which is basalt, very rich in phenocrysts of plagioclase and with some olivine. This flow seems to be some 4 to 6 metres thick or possibly greater and very likely rests on a third flow of basalt lava. It is stated that the strata will form an extremely stable foundation for the proposed power station.

The general nature of the sub-strata is already known from well borings nearby but trials have not been made to determine the load bearing characteristics. However no difficulty is expected to arise. The load imposed on the foundation area by the power station building, if regarded as uniformly distributed over the main slab, will be of the order of $\frac{3}{4}$ ton/ft$^2$ (8 ton/m$^2$). The main slab will be a minimum of $\frac{1}{2}$ metre thick with local deeper excavations for the main columns and foundation block which may be contiguous.

## Layout and building construction

A site plan is shown in Plate 2 and a station layout in Plate 3. The initial installation is a single 16 MW condensing turbo-alternator. A longitudinal arrangement has been adopted as being cheaper where only one set is to be installed in the first stage. Further development to a second stage is allowed for. If use is then to be made of flash steam from the hot water yielded by the wells, a dual pressure machine would be used but the general layout would be similar, lower pressure steam pipework being required as well as the main steam pipework. The flash plant would probably be located out of doors near the station.

The space allocated to the control room, office accommodation, cable chambers and switchgear has been considerably reduced compared with the original scheme. This has been made possible partly by reason of the single machine requiring less space than two smaller machines and by making greater use of the turbine room for housing auxiliary electrical equipment. The control room is at operating floor level and corbelled out from the face of the main building to keep down the size of the annexe. It may be architecturally more acceptable to continue the projection down to the roof of the workshop; the shaft could then enclose a stairway. We do not visualize any other use for this additional space.

Prefabricated, prestressed concrete panels and structural members are proposed in the building designs prepared by the civil consulting engineer, Sigurdur Thoroddsen of Reykjavik. The use of this type of construction has the advantage that adverse weather conditions should interfere less with the building programme than if in-situ construction were adopted. The building would be monolithic with the basement slab as well as the machine foundation and the design would take into account horizontal forces arising from seismic accelerations up to 0.1g. Heat insulation is by precast lightweight pumice concrete slabs and patent glazing would be used.

The main axis of the station is shown in a north/south direction with future expansion taking place to the north. The basement level is at 78.5 metres, the present general level of the ground in the area, and the operating floor is at 89.7 metres. The machine, which is 14.2 metres in overall length, is placed longitudinally in the turbine house with the turbine end towards the loading bay. The generator is adjacent to the generator transformer and 138 kV switchgear compound at the south end of the station. The 10.5 kV connections would go straight out from the generator circuit breaker, housed in the turbine foundation block at basement level, to the generator transformer.

Access for heavy loads is through the workshop. This has the advantage that plant can be transferred from the turbine room to the workshop without passing out-of-doors. During the early stages of the construction period, equipment awaiting erection can be stored in the workshop as workshop facilities will not then be required. We visualize that, later on, field equipment such as drill rods, valves, pumps and even vehicles can normally be stored under cover in the space allocated for loading bay and workshop, though it will of course be necessary to move such equipment out of the way when carrying out a turbine overhaul, since a clear loading bay will be required for setting down major turbine components.

Office accommodation and store rooms are provided at two levels and space is allocated for a mess room and other welfare facilities.

Turbine inlet pressure

The selected turbine inlet pressure is a compromise and we now propose 4 $kg/cm^2$ gauge. There are several reasons for increasing the inlet pressure.

Initially 3 $kg/cm^2$ gauge was adopted to suit the well characteristics as then ascertained, and the high vacuum attainable for part of the year with river cooling, taking into account such factors as turbine exhaust wetness. With the station now independent of the river, back pressures materially lower than the nominal design figure of 2 inHg abs (0.07 $kg/cm^2$) will seldom be attained. The calculated wetness for 4 $kg/cm^2$ gauge and design vacuum is 14% which is about the recommended limit. This assumes that the steam contains 1% moisture at turbine inlet and follows convention in making no allowance for removal of water at any interstage drains provided in the cylinder casing. The efficacy of such arrangements is difficult to assess but we think in fact the exhaust wetness will be less than the calculated 14%, possibly by as much as 2 points.

With reduced transmission distance the pressure drop in the steam supply pipes is lower. The size of pipe can also be reduced at the higher steam pressure. 4 $kg/cm^2$ still allows for some fall off in wellhead pressure, hence there will normally be some throttling at the turbine.

Turbine steam rate is expected to be reduced by 7% by raising the stopvalve pressure from 3 to 4 $kg/cm^2$. There is however a similar reduction in the yields of the wells as the wellhead pressure is increased from the original 5 to 5½ $kg/cm^2$ gauge. On balance the adoption of the higher turbine inlet pressure reduces the overall capital expenditure. Moreover, if at some future date the heat in the boiling water is utilized by production of flash steam at about atmospheric pressure, the higher wellhead pressure marginally increases the power available from the flash steam.

Steam rate and design of turbine

The steam rate expected for the inlet conditions of 4 $kg/cm^2$ gauge 151.5°C with 1% moisture present and a back pressure of 0.07 $kg/cm^2$ abs is 7.8 kg/kWh. This does not include the steam required for jet ejectors which we put at about 1 kg/s.

The basic principles for the design of the turbine are unchanged in increasing the size from 8.5 MW to 16 MW. We propose that the tip speed of the blading should still be limited to 900 ft/s (273 m/s), and we recommend that the total exhaust area of the double-flow machine should be approximately 3.6 $m^2$ to achieve an economic leaving loss. At least one tender has been received complying with requirements. Blade material will be left in the soft condition. Erosion shields may possibly be accepted on the last blades where if they come off they can do little harm.

Arrangement of condenser

After full consideration of other alternatives we have come down strongly in favour of the conventional arrangement for the jet condenser positioned immediately under the turbine; the barometric pipe drops vertically down into a sump. Return of the circulating water involves construction of a sump at a depth of about 5 metres below the basement and connection by an open channel to the pumphouse at the pond.

We have considered an outdoor condenser, the main ostensible virtue of which is reduction in basement height by about 5 metres. Manufacturers were invited to tender for turbo-alternator plant with conventional or outdoor jet condensers and bids received showed that the extra cost of the outdoor condenser would be about £10,000 FOB. After allowance is made for the various oncosts discussed under 'Estimate of Costs'(p.20), the extra cost of the plant erected would be approximately £18,000. The saving on building costs for the turbine room according to estimates prepared by Sigurdur Thoroddsen is about £17,000. However an annexe would have to be provided to house some of the equipment located in the turbine house in the orthodox scheme, the cost of which is not covered by the civil estimates.

The technical objections to the outdoor condenser were dealt with in our previous report and the most important of these is the possibility of corrosion in the exhaust duct. The extra cost quoted above assumes the use of mild steel for the exhaust duct but the corrosion rate on unprotected mild steel could be sufficiently high to justify corrosion resistant steel. Natural protection of mild steel against corrosion by $H_2S$ is partly a function of metal temperature and is likely to be less in Iceland than in California or Italy. On the Geysers plant in California however the exhaust duct is of Type 304 stainless steel (18% chromium 8% nickel class). As some 50 tons of steel are involved, the extra cost for 18/8 stainless steel over that for mild steel might be of the order of £20,000. This might be reduced by the use of stainless steel clad plate if obtainable. One further objection to the outdoor arrangement is that water precipitated from the exhaust steam must be removed and this requires the use of an extraction pump or ejector which constitutes a small additional complication better avoided in the plant. Erection of the outdoor condenser would also require special provision for lifting tackle as the vessel stands some 17.5 metres above ground at its highest point. Because of these drawbacks we prefer to adhere to the indoor arrangement we have good experience with.

Circulating water system

At the site under consideration the Varma River is too small to offer significant river cooling capacity. A spray cooling system is therefore proposed operating in closed circuit independent of the river. A pond some 15,000 $m^2$ in area will be required for the initial installation of one 16 MW set (possible extension to 25,000 $m^2$ is kept in mind in case of installation of a second 16 MW set). A preliminary survey of the site area carried out by Sigurdur Thoroddsen has revealed that a shallow basin can be formed by bulldozing away 1 to 2 metres of top soil and loose lava. Sealing of the bottom and sides can be effected with clay available in the vicinity. The depth is unimportant but about 1 to 1½ metres is a reasonable figure. Water to be circulated is 20,000 Imperial gal/min = 1520 litre/s. Seepage from the pond should be kept reasonably low as the loss from the spray system arising from evaporation and drift loss might average about 2½% of the water quantity in circulation. This loss, amounting to 38 litre/s, is almost made up by the exhaust steam condensed, which at full load is 36 litre/s including an allowance for steam jet ejectors. The deficiency can be made up by diverting a supply from the Reykjadalsá River. This involves building a small intake dam at a point west of Well No. 8 and laying about a 6 inch bore pipe over a distance of about 500 metres to the pond. The pipe capacity would be about 30 litre/s which is amply sufficient to cover high drift losses under prolonged abnormal wind conditions. Freezing of the spray pond is not a problem as the temperature will be well above $0^{o}C$ at normal load. In emergency caused by freezing of the make-up supply, water might be pumped from the Varmá by fire pumps.

The main circulating water pump and booster pump are accommodated in a detached unattended pumphouse at the spray pond. The pumphouse is 6½ m x 14 m by 6 m high and a loading bay is provided at the south end. A 5-ton runway will handle equipment during installation and maintenance. The pumps proposed are of the horizontal spindle type and priming of both is effected by the main ejectors sucking through the condenser and circulating water delivery pipe (and use of a balance snifter connection). Duplicate pumps are not considered necessary. Neither non-return nor isolating valves are required at the initial stage but provision is made for inserting an isolating valve in the CW delivery pipe if and when a second stage is proceeded with. Interconnection of the two CW delivery pipes would then enable either condenser to be supplied separately from either CW pump. Simple rack screens at the CW pump inlet will suffice to prevent any trash from entering the system. Self-cleaning screens are not justified in the absence of leaves and vegetable matter with jet condensers having sizeable nozzles. Trouble with growth of vegetation is thought unlikely. A fine strainer is provided for each auxiliary cooling water service, such as the oil coolers and the alternator air coolers, where tubular heat exchangers are used.

The circulating water pump will deliver 20,000 Imperial gal/min (1520 litre/s) against a net head of 46 ft (14 metres). The motor rating will be about 260 kW assuming an overall efficiency of 80% for pump and motor.

Circulating water will be delivered to the turbine room in a single steel pipe, about 90 cm in diameter laid approximately at ground level, except in vicinity of the turbine house where it is elevated so as not to restrict access in the area reserved for steam pipes. Semi-flexible joints will be used.

Water sprayed through jets into the condenser will descend the barometric tube into the sump and return along the channel to the booster pump suction bay which is connected to the pond by an overflow pipe to control the level in the channel. Gases released from the water in the sump and culvert will be prevented from entering the turbine room by a water seal where the barometric tube passes through the floor. The gases will be vented from the sump along the culvert, which will be sealed in the vicinity of the building, and emerge clear of the station. All water drains in the turbine room will be piped to the sump. The object of these measures is to prevent risk to personnel or corrosive attack of components in the turbine room which might occur if local concentrations of $H_2S$ were allowed to build up.

The booster pump will deliver 20,000 Imperial gal/min against a net head of 41 ft (12.5 m). The motor rating will be 235 kW. The pump draws warm water from the forebay and delivers to the sprays. The two pumps might well be identical and could be driven by a single 500 kW motor.

## Wells

Table 1 shows the steam yields of wells so far drilled. No. 1 and No. 5 are omitted. No. 1 was abandoned in 1960 after the bore was deepened. No. 5 is used as a reference bore for monitoring temperature in the steamfield. No. 4, a low yielder, is disregarded.

Well 2 is approximately 1500 metres from the proposed station site, roughly twice the distance of any other well. Connecting Well 2 into the steam transmission system would be relatively costly hence we ignore it in anticipation of further successful drilling nearer the station. The four remaining wells yield about 56 kg/s. The nominal steam requirement for 16 MW gross electrical output is 36 kg/s, including 1 kg/s for ejectors. Hence to cover the nominal requirement by 100% margin an additional 16 kg/s of steam must be proven. One further well drilled up the valley might reasonably be expected to suffice in the light of the consistent success attained in recent drilling.

TABLE 1

STEAM YIELDS AT 5.5 $kg/cm^2$ gauge

| Well No. | kg/s |
|---|---|
| 2 | 7.0 |
| 3 | 16.7 |
| 6 | 8.5 |
| 7 | 7.7 |
| 8 | 23.0 |
| Total | 62.9 |
| Steam required for 16 MW | 36 kg/s |
| Total steam required to provide safe margin | 72 kg/s |

A total of five operational wells is the minimum on which full output could be guaranteed. This will allow the best well, at present No. 8, to be shut down for maintenance, and the four remaining wells with a combined yield of 49 kg/s will cover the station output. There would normally be sufficient margin to permit either Well 6 or Well 7 to be off for maintenance at the same time as Well 8, or alternatively on standby duty. Calciting encountered earlier on Well 2 is reported as not serious on Wells 3, 6, 7, and 8. They were blown at 3 to 5 $kg/cm^2$

gauge for about 4 months during 1961 and for a further test period of six months started in November 1962. A fall off of 0.5 to 1 kg/cm$^2$ occurred on Wells 6 and 7 during the first week but thereafter no significant change in pressure was detected. Well No. 8 is particularly free of calciting.

In order to keep down the cost of pipes and also roads to wells, and to ensure a high proportion of good yielders it seems very desirable to drill duplicate wells close to existing ones. In general these will not be utilized at full output simultaneously, one of each pair being normally held in reserve or undergoing cleaning out.

Separators

The yields of the wells vary considerably and if one standard size separator is to be used then it is probable that the high yielding wells, such as 3 and 8, will require two separators in parallel, each of the other wells having only one. If the total discharge of Well 8 were passed through a 36 inch separator, similar to that built by the Authority for field testing, it would probably have a relatively poor performance in that the wetness at outlet might be as high as 5%, whereas ½% or less might be achieved with two in parallel, each with a steam throughput of about 11 kg/s. It is true that most of the water carried over will be removed in a second stage of separation at the station, but one disadvantage of a high carryover is that the water reaching the station will have a high dissolved solids content. The desired dilution by condensate from heat loss, of the bore water carried into the transmission pipe, is lessened with higher carryover and there is consequently greater risk of deposits forming on the blading. A high separating efficiency at the wellhead is therefore desirable and the performance of the prototype separator is accordingly of considerable interest.

We visualize that a second stage of water separation will be carried out at the station in a vessel on the lines of that indicated in Plate 3. This also serves as a steam receiver. The duty of this separator is considerably easier than for the wellhead type because of the lower water content. At the wellhead some 99% of the water is to be removed but at the station 70% or 80% removal will be sufficient and we expect 85 may well be achieved.

Steam pipes

The new site is fairly centrally situated with respect to the wells, apart from No. 2 which we have suggested should be omitted from the scheme. We propose that three transmission pipes should be used initially: one from Well 3, another from Wells 6 and 7 combined, and a third pipe from Well 8 coupled with the additional well which has yet to be drilled. We refer to this as Well 9 and assume that it is drilled close to Well 8. There would clearly be financial and other advantages to be gained from standardizing on pipe size for the three lines. This would enable pipe supports, lagging and valves to be universal. If 18 inch bore tube is adopted throughout the velocity will be about 30 m/s for Well 3, resulting in an acceptable pressure drop. In the line from Wells 8/9 the velocity would be 45 m/s for a throughput of 23 kg/s giving a correspondingly higher but still acceptable pressure drop. The operating characteristic of Well 8 permits a high pressure drop to be accepted without economic penalty. Nevertheless we have assumed 22 inch bore for this line for the purpose of estimating though ideas cannot be finalized until sufficient wells have been drilled. A compromise of 20 inch diameter all round is also possible.

Design pressure for pipes and equipment

The design pressure for pipes and separators would be 150 $lb/in^2$ and the hydraulic test pressure to be applied to completed components, such as pipes, separators and valves, would be at least $1\frac{1}{2}$ times design pressure, in accordance with relevant design standards.

Electrical features

The electrical connections are shown in Plate 4. Generator voltage is 10.5 kV. The output will be stepped up to 138 kV to connect into the existing 138 kV single-circuit line over which the power generated at the Sog River stations is transmitted to the Ellidaár substation on the outskirts of Reykjavik. This line passes within $2\frac{1}{4}$ km of the proposed station. It has a nominal rating of 120 MVA (96 MW at 0.8 power factor) and is at present transmitting about 70 MW. A third 15.5 MW machine is scheduled for commissioning at the Irafoss hydro-electric station by the end of this year and the load transmitted to Ellidaár will then rise to 81.5 MW. (About 4 MW will be tapped off for local supplies between the Sog switching station and Hveragerdi village). When the geothermal station comes into service the transmitted load will rise to 96 to 97 MW. A synchronous condenser rated at 16 MVA is to be in service at the Ellidaár steam plant of the Reykjavik Municipal Electric Light and Power Works towards the end of 1964 and this will reduce the amount of reactive power carried by the line and enable over 100 MW to be transmitted.

The rupturing capacity assumed for the 138 kV circuit breaker is 1500 MVA. The 138 kV breaker and 19 MVA generator transformer are placed in a fenced enclosure on the same side of the road as the power station and at the south end. The 10.5 kV connections from the generator circuit-breaker are brought out through the end wall of the turbine room directly onto the transformer. The 3-winding 10.5/11/0.4 kV auxiliary transformer serves as a combined station/unit transformer, the third winding giving an alternative feed to the local 11 kV distribution system. It is housed in an annexe to the turbine room at the south end of the station.

The calculated fault duty on the 10.5 kV switchgear, for 20 MVA installed generating capacity and including all other system extensions at present visualized, is a little under 350 MVA and can be held at this level if the station capacity is doubled at a later date. Space has been allocated for an extension to the switchyard for a possible future doubling of generating capacity.

A duplicate arrangement of electrical connections would be adopted for the second generator and generator transformer as shown dotted in Plate 4. A second auxiliary transformer will be required and the two 400 V auxiliary boards can be coupled together and fed from either transformer in emergency.

Supply of auxiliaries

The two principal auxiliaries are the circulating water pump and the booster pump rated at about 260 kW and 235 kW respectively. As mentioned previously they might be combined on a single shaft and driven by one motor. Even this arrangement would not necessitate a higher voltage than 400 V. It may also be decided to use a water jet ejector in which case this will require a booster pump with motor drive.

Other electrical auxiliaries with much smaller ratings include the stand-by motor driven lubricating oil pump, a motor driven oil purifier with heater and a blower with heater for drying out the turbine after a shut down. Small supplies are required for station lighting, cooking, turbine room crane and the workshop. We propose that the auxiliary power requirements totalling about 680 kW should be supplied by a 2 MVA-400 V winding of the above-mentioned 3-winding transformer. The rating selected is sufficient to meet in emergency the auxiliary power requirements of two 16 MW sets. The third winding is also rated 2 MVA and will supply load to the local 11 kV distribution system. Maximum load on both outputs is not expected simultaneously. Hence the primary winding is rated 3 MVA.

On load tap change is provided so as to maintain reasonably constant voltage to both the power station and the local supply irrespective of generator voltage.

## ESTIMATE OF COSTS

### Capital expenditure

Table 2 gives an estimate of capital cost for a station having one 16 MW condensing turbo-alternator with the condenser placed in the orthodox position underneath the turbine. The net output of the station will ordinarily be about 15.4 MW and will vary seasonally within small limits according to the vacuum, the highest output being available in winter. The nominal sent out output has been put at 15 MW.

The estimates, in so far as they relate to imported material, are based primarily on price data collected in Great Britain, the price level being that ruling in 1962, and on tenders received for turbo-alternator plant. No escalation has been allowed for since we do not know whether prices will rise or by how much in Iceland or in the country of supply. For some time world prices have shown a tendency to fall.

Estimated costs for the civil works comprising power station building and foundations, circulating water pumphouse, spray pond and culvert, cold water supply for circulating water make-up, houses for station operators, roads and bridges, and construction camp on site, were prepared by the Authority's Civil Consulting Engineer (Sigurdur Thoroddsen). Tenders for the turbo-alternator and auxiliary plant were received in October

1962 and building sizes are based on the plant dimensions supplied by the preferred tenderer. The total cost of wells to date, including field surveying and testing, the use of drilling rig and accessories, casing and provision of master valve, amounts to approximately kr 21 million (£175,000). (Allowances bring this up to kr 25 million.) This has been increased pro rata to cover the extra steam required. The rental of the large drill and cost of labour is included in the above price. A small drilling rig for cleaning out the bores has been allowed for separately.

Allowances for contingencies and engineering together have been put at 10%. Interest during construction is also shown at 10%, a token figure only since the amount will depend on the terms of payment to be fixed for the various contracts.

The first column shows the FOB price of all contract equipment and materials to be imported into Iceland. The second column headed 'Extra on FOB' shows the amount included to cover freight and insurance, import duty and tax (including a 3% sales tax on domestic materials and services) and these amounts have been assessed on the FOB prices of imported equipment and material at the following rates: turbo-alternators 45.5%; pumps 49%; pipework 61 to 77%, (depending on diameter); electrical equipment 55%; and 50% for any other items not specifically mentioned. The third column shows the estimated overall contract price which includes the cost of erection.

## TABLE 2

## ESTIMATE OF CAPITAL COSTS

| | £(Sterling) | | |
|---|---|---|---|
| | FOB | Extra on FOB | Total cost in Iceland |
| Turbo-alternator and spare turbine rotor | 207,000 | 94,000 | 311,000 |
| Civil works* | | | 208,000 |
| Steam transmission | 45,000 | 28,000 | 108,000 |
| Wells | | | 196,000 |
| Drilling rig (well cleaning) | | | 20,000 |
| Electrical equipment | 98,000 | 54,000 | 162,000 |
| CW system | 21,000 | 11,000 | 35,000 |
| Spray cooling system | 6,000 | 4,000 | 30,000 |
| Cranes | 10,000 | 5,000 | 16,000 |
| Disposal of hot water | | | 20,000 |
| | | | 1,106,000 |
| Contingencies (including engineering), 10% | | | 111,000 |
| | | | 1,217,000 |
| Interest during construction, 10% | | | 122,000 |
| Total | | | 1,339,000 |
| Cost per kilowatt installed | | | £83.7 |

* Civil works includes power station buildings, foundations, cooling pond, circulating water pumphouse, houses for station operators, roads and bridges and construction camp.

Cost of energy production

Using the capital estimate in Table 2 we arrive at the cost of energy production as follows:

| | Annual charges £(Sterling) |
|---|---|
| Interest on total capital 7% on £1,339,000 | 93,700 |
| Sinking fund contribution on total capital less cost of wells and drilling rig 2.5% on £1,078,000 (20 year life) | 27,000 |
| Cost of wells: | |
| Sinking fund contribution Basis 10 year life 7.24% on £237,000 | 17,100 |
| Plus materials and stores for cleaning out and maintenance on 5 wells | 5,000 |
| Sinking fund contribution on drilling rig Basis 10 year life 7.24% on £24,000 | 1,700 |
| Maintenance on other equipment, outside labour plus materials | 30,000 |
| Operating salaries and wages | 15,000 |
| Administration and general expenses | 10,000 |
| Total | 199,500 |

On energy generated
8000 hours use of maximum demand at 15 MW = 120 GWh

Generated cost: 0.4 pence (20 Aurar) per kWh

Conversions

Costs may be converted to different currencies as follows:

| | | | |
|---|---|---|---|
| £1 | = 120.6 Iceland kronur | = $2.8 US |
| 1d (penny) | = $£\frac{1}{240}$ = 0.5 kronur | = 1.16 cent US |

The above is computed on an interest rate of 7% and a nominal life in the case of most assets of 20 years. A life of 25 years is frequently used for thermal plant but in this case we have preferred 20 years in view of the high load factor assumed. The normal history of orthodox thermal plant is that it operates at high load factor during the first few years and thereafter its utilization falls as new and more efficient units, having lower running costs, are added to the system. Thus it is seldom called on for more than 40% load factor over 25 years life because of overall system economics. Geothermal plant may be in a different category but there is no experience of 20 years operation as yet so we cannot cite load factors actually obtained over life of plant or even be categorical about likely availability. We therefore consider it is prudent to allow for a shorter life in assessing generation costs. High availability is intended to be assured by provision of a spare steam rotor. This is the most vulnerable item and the spare can be inserted within 24 hours in case of trouble.

For the wells a 10 year life has been assumed. This means that we allow for wells to be replaced at 10 year intervals and even if it were necessary to drill more remotely in order to continue to provide steam over the life of the station we would not regard this as seriously affecting the calculations. We see no reason to distinguish between the lives of other assets except for the small drilling rig used for cleaning out the bores. In particular the pipework, on which we allow 20 years, according to our experience will not show any shorter life than for instance the turbines.

Cost of steam per ton

From the above costs we can take out those attributable to production of steam at wellheads. These are as follows:

Capital cost

| | |
|---|---|
| Wells | £237,000 |
| Drilling rig (for maintenance) | 24,000 |
| Disposal of hot water | 24,000 |
| | £285,000 |

Annual charges

| | |
|---|---|
| Interest @ 7% on £285,000 | £19,950 |
| Sinking fund 7.24% on £285,000 | 20,627 |
| Maintenance | 5,000 |
| Labour | 4,000 |
| | £49,577 |

The steam utilized per annum is expected to be approximately 36 kg/s for 8000 hours = 1.035 million tons.

Hence the cost per ton is 11.5 pence or 5.75 kronur.

This is based on the historic cost and ascertained yields of all the wells drilled to date. The assumption is made that additional steam can be won at the same price. If the station is to be operated by another concern the price for steam might be related to the above figure with appropriate allowance for oncosts and risk.

Possible extension to Stage II

The extension of the station to 30 MW by a second stage consisting of a similar machine (except that it might make use in part of pass-in flash steam from the hot water) is estimated to cost about £67 per kilowatt. The completed station would then cost £75 per kilowatt installed. The estimates are not shown in detail because the parts which would differ markedly from the first stage, namely the transmission pipes for hot water depend on the locations of supplementary steam wells. These and the flash tanks can only be given token prices at the present stage. The spray pond would be extended by roughly 10,000 $m^2$ to provide the required cooling capacity. No allocation has been made for any additional transmission line or for electrical extensions at the receiving end since this will depend on the timing of the further extension in relation to general system development.

The operating costs would be roughly 10% lower on the doubled output primarily because of the lower financial charges but also because the staff would need little augmentation. Experience by that time may well show that a smaller ratio of spare bores will suffice on the greater number.

## Staffing

The operating staff required for a geothermal station may be taken as about the same as that in a hydraulic station containing the same number of generators. Hydraulic stations are a better guide in this respect than fuel-fired steam stations in which the staff is largely occupied on the boilers and their associated coal handling and ash disposal plant, which do not arise in this case. In line with the State Electricity Authority's practice we visualize that the operating staff will consist of the following:

Station superintendent

Shift staff, 3 shifts each consisting of shift charge engineer and assistant charge engineer

Electrician

In addition there will be a day staff consisting of maintenance crew, including drillers, mechanics and general labourer: Total 16 men

The drilling crew of five men will normally be engaged on the redrilling of wells every other week, doing maintenance work on the wellhead and other equipment when they are not engaged on drilling. It is difficult to visualize exactly how much work the wells will entail, but since a crew capable of using the drill must be kept together they should preferably be capable of this dual function of drilling and routine maintenance to keep down operating costs.

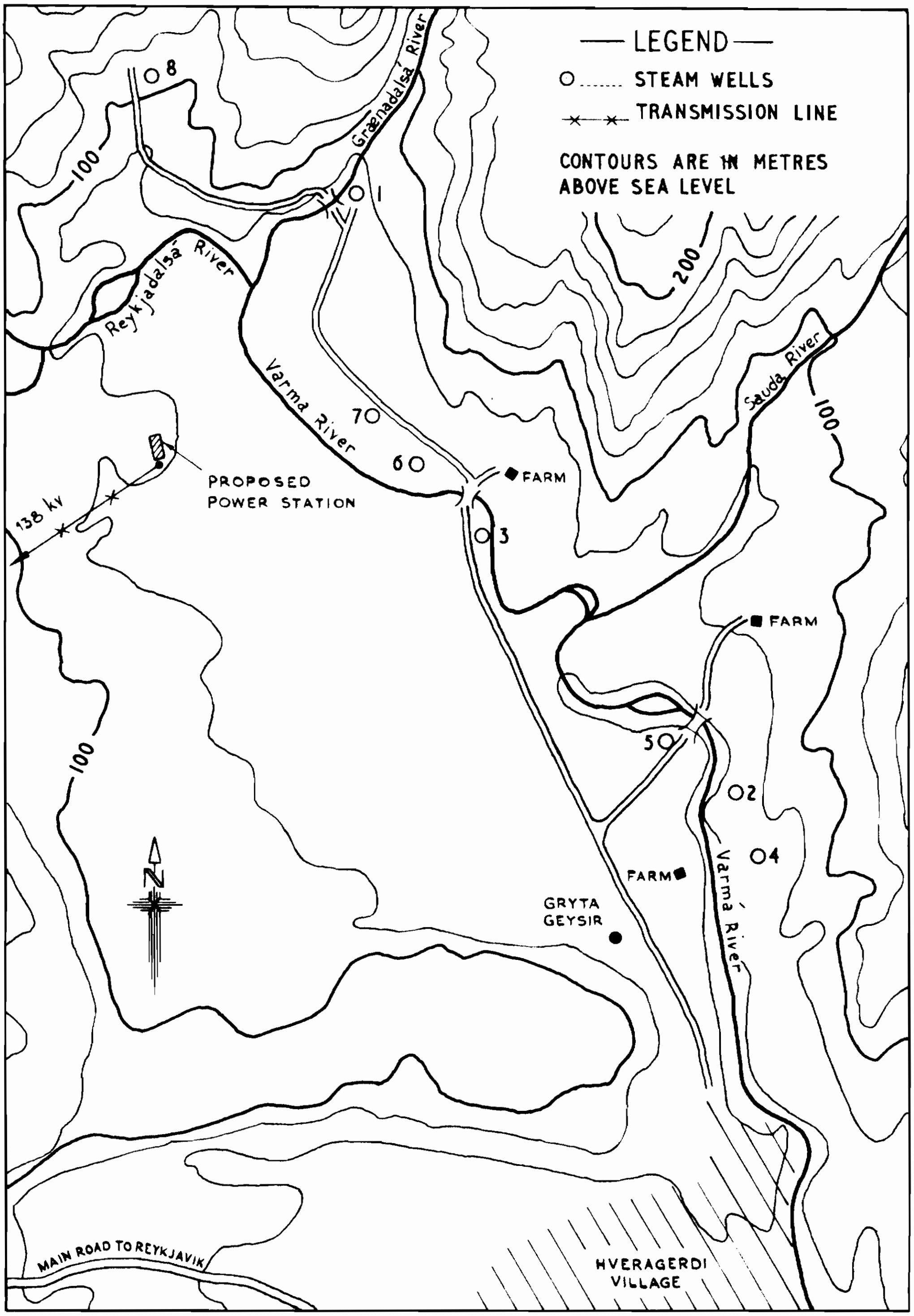
There will not ordinarily be sufficient work to keep workshop staff occupied in this station, and it will be found more economical to form a central overhaul and breakdown group available to all stations, hydraulic and steam, provided of course that staff is sufficiently adaptable to work on both types of plant. We do not think that this should create difficulty unless it is contrary to trade union practices.

We have not seriously considered remote control since we consider the technology is not yet sufficiently established for the plant to be left unsupervised nor are the possible contingencies readily visualized.

We consider that the circulating water pumphouse should not be attended since the pumps will be started from the station and there will be no valves to operate. There will of course have to be a routine daily visit to inspect the level in the pond, condition of the intake screens and to check over the gland and bearing temperatures and lubrication of the pumps. Once a year each pump will have to be overhauled and for any major work we consider they would be removed to the workshop.

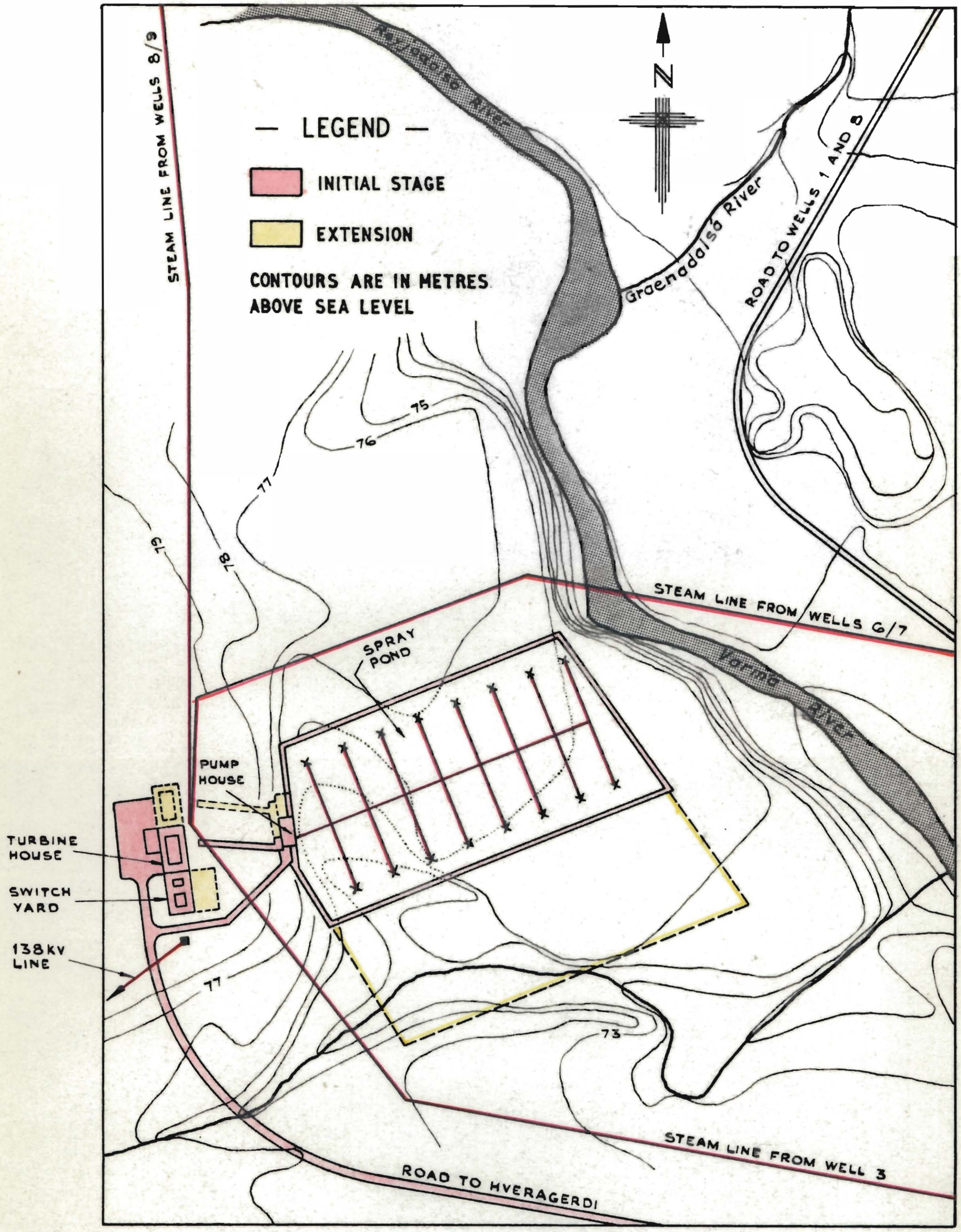
As there will ordinarily be no high voltage switching to be done at Hveragerdi we think that the whole control including 138 kV gear can be done by the shift charge engineer or his assistant who will be in telephone communication with the switching stations at Ljósafoss and Elliðaár.

The wellhead equipment and pipelines require no constant attention but periodic inspections once per week are to be recommended when wellhead gauges and other instruments are to be read and logged. Less frequently all valves need to be operated to avoid seizure. Instrumentation both in the field and in the station can advantageously be kept to a minimum. The most important pressure is that of the steam received and this can be read on a mercury manometer. Vacuum pressure would be indicated by an absolute mercury gauge. Temperatures are within the range of mercury thermometers. Thus basic instruments of the simplest kind are adequate.

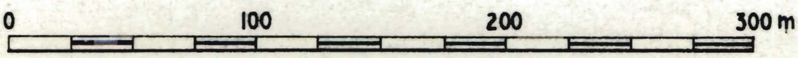


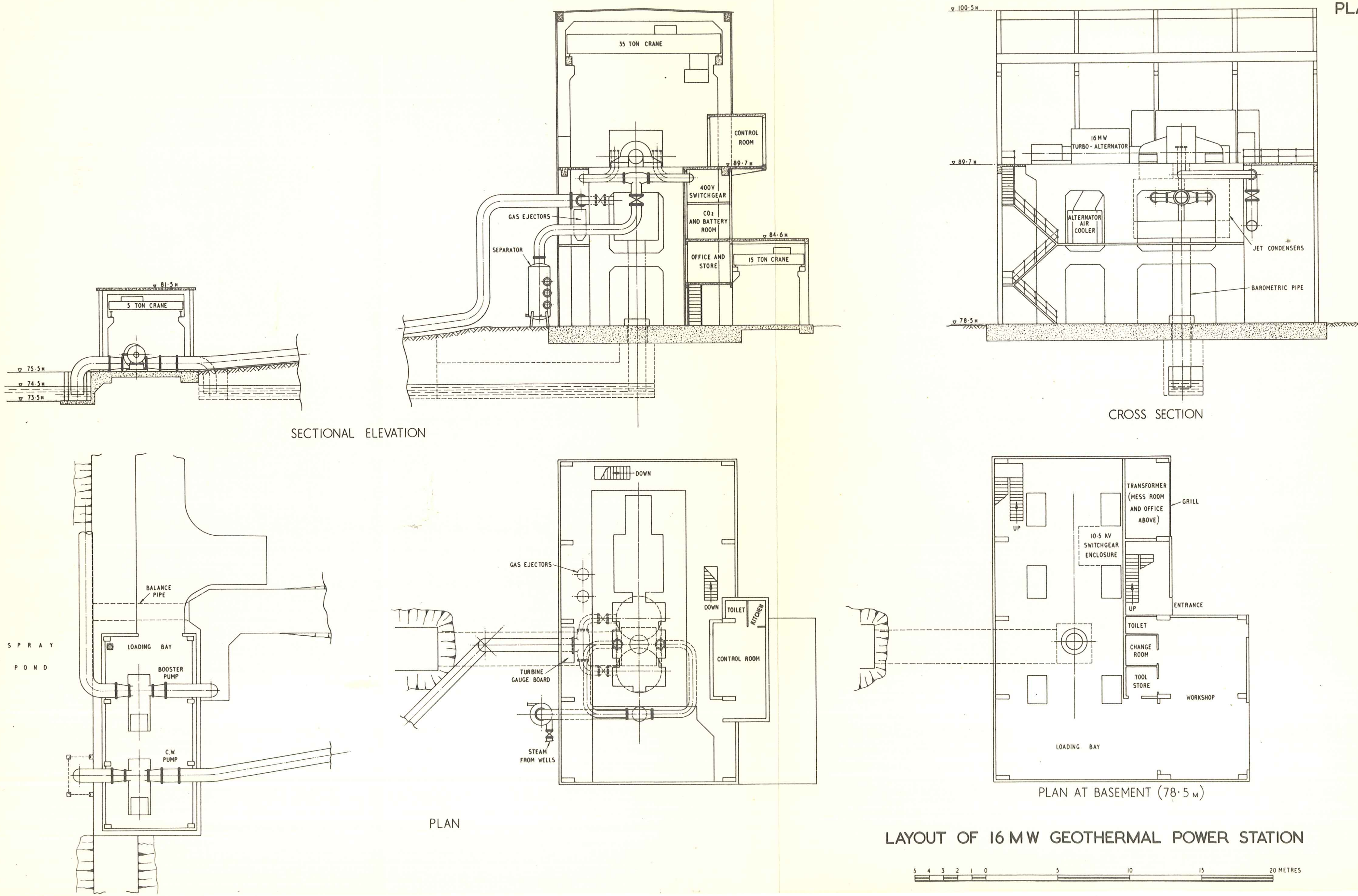

# HVERAGERDI STEAMFIELD

0 100 200 300 400 500m




SITE PLAN OF PROPOSED POWER STATION






## LAYOUT OF 16 MW GEOTHERMAL POWER STATION

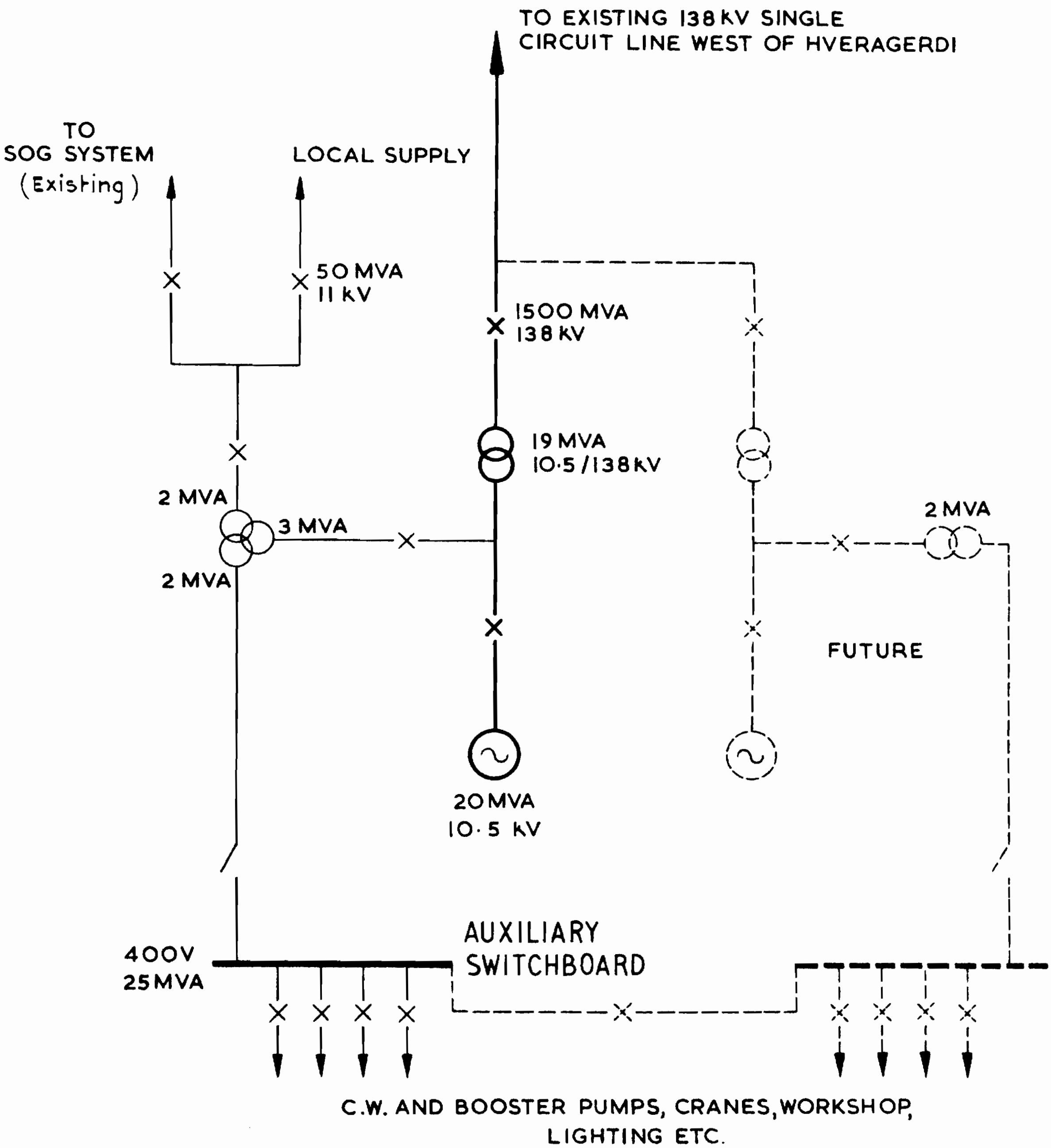



DIAGRAM OF ELECTRICAL CONNECTIONS