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25 YEARS OF OPERATION AT WAIRAKEI GEOTHERMAL POWER STATION

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ABSTRACT

November 15, 1983, represents the twenty-fifth anniversary of the commissioning of the first generator at Wairakei geothermal power etation (ref 1). The opportunity has been taken to summarise the historical development leading to the first power and to review a quarter of a century of generation. The performance of the borefield and station plant is described together with the more significant incidents of 25 years of service. The paper concludes with a brief look at current and future developments.

NOMENCLATURE

HP High pressure, originally at 12.5 bar g but reduced with time to 6.2 bar g in 1982.

IP Intermediate pressure at 3.5 bar g, the steam pressure intermediate between HP and low pressure steam.

LP Low pressure steam at 0.05 bar g at the. manifolds in the station however at a higher preeeure in the transmission line of 1.7 bar g where it is sometimes referred to as ILP, or intermediate low pressure.

OUTLINE OF THE WAIRAKEI DEVELOPMENT

The impetus in 1947 for the development of Wairakei came from severe electricity shortages following two dry years which restricted hydro generation and a desire by the Government for the electricity eupply to be independent of imported fuel (ref 2).

In 1948 visits were made by senior government engineers to Larderello, Italy, to study the power development there.

While observations at Larderello were important in providing an understanding of the overall approach to *harnessing* geothermal power, the geological conditione were so different that the development of the Wairakei resource would have to depend on decisions reached and ideas developed in New Zealand.

Perhaps the most important *thing* Larderello contributed to New Zealand was its success, because there *is* no doubt that the successful development at Larderello strongly influenced the decision to proceed at Wairakei.

In 1949 a Geothermal Advisory Committee (GAC) was set up comprising 7 representatives drawn from 3 government departments - the Department of Scientific and Industrial Research (DSIR) whose involvement with thermal activity dated back to the 1920s, the Ministry of Works who were in effect the construction agency of the Government and the State Hydro-electric Department (now the Electricity Division of the Ministry of Energy) who had the responsibility for planning and operating the power eupply system.

The brief of the committee *was* to bring together the necessary skills to develop and direct the Wairakei geothermal field.

Drilling and scientific investigations proceeded rapidly so that by early 1953 steam capable of producing 20 MW of electrical power had been proved by shallow drilling (~300 m). The engineers and scientists were also extremely confident that greater output could be achieved by deeper drilling and eo bigger drilling rigs were purchased.

The United Kingdom Atopic Energy Authority (UKAEA) had expressed an interest in establishing a heavy water production plant in conjunction with the power station and approval in principal for the construction of a combined plant was given by the Government in May 1953.

In August 1953 consultants from the United Kingdom were engaged to report on the feasibility and financial cost of the two aspects of the project.

Their report in early 1954 resulted in the Prime Minister announcing in his budget speech the decision to proceed with a plant to produce 40 MW of electric power and 6 tonnes/annum of heavy water as a joint venture of the NZ Government and the UKAEA. Figure 1 shows in diagramatic form the arrangement of the project.

In late 1954 a new organisation, Geothermal Development Limited (GDL), was formed to plan, design and build the combined plant. Its first action was to appoint separate consultant engineers for each part of the plant.

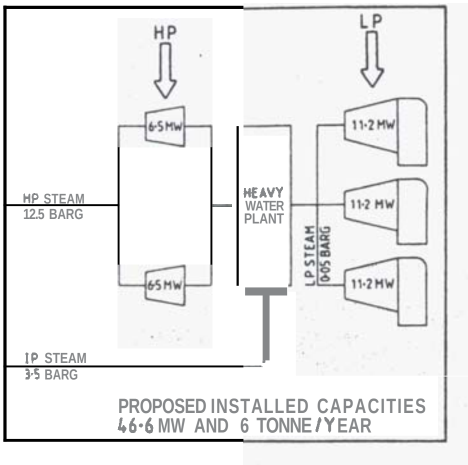

Figure 1. Schematic of original proposal for power and heavy water plant.

As the first geothermal power project in New Zealand and only the second to be undertaken in the world, the work at Wairakei was in many respects novel. Consequently, the preliminary estimates prepared in 1954 were based on design concepts not previously developed in detail. The translation of these concepts into workable form presented problema, particularly for the heavy water plant.

By the end of 1955 detailed engineering costings of the respective plants doubled the cost of the heavy water plant and increased by one-third the coat of the power plant.

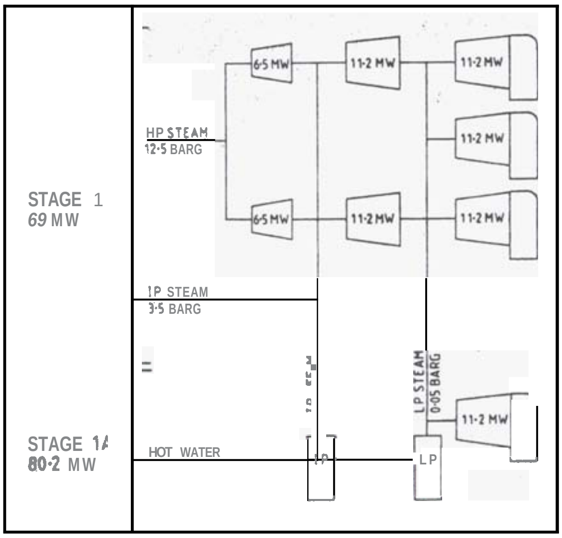

Figure 2. Schematic of stage 1 and stage 1A power station development.

In January 1956 the UKAEA decided not to proceed with the heavy water plant due to the escalation of costs and in consequence GLD became defunct.

However, the first contracts for the turbo generators and associated equipment were let in mid 1955 and fabrication was well advanced. Proposals for a power only project were therefore called for and the adoption of 2 11.2 MW IP machines to replace the heavy water plant was accepted. Figure 2 shows the equipment arrangement for the stage 1 power development.

The inclusion of a pilot hot water scheme was implemented about this time. Hot water from the borefield was to be transmitted to a flashplant looated alongside the power station. A diagrammatic arrangement of stage 1A is also shown in figure 2.

Construction of stages 1 and 1A were not far advanced when the consultants were asked to prepare proposals for additional generating capacity because more steam than expected had been found. This resulted in the installation of 2 more 11.2 MW HP machines in the 'A' station and 3 30 MW mixed pressure (MP) sets in 'B' station which was to be located some 30 metres from 'A' station. This brought the total installed capacity of the Wairakei development up to 192.6 MW. Figure 3 shows diagrammatically the arrangement of this plant.

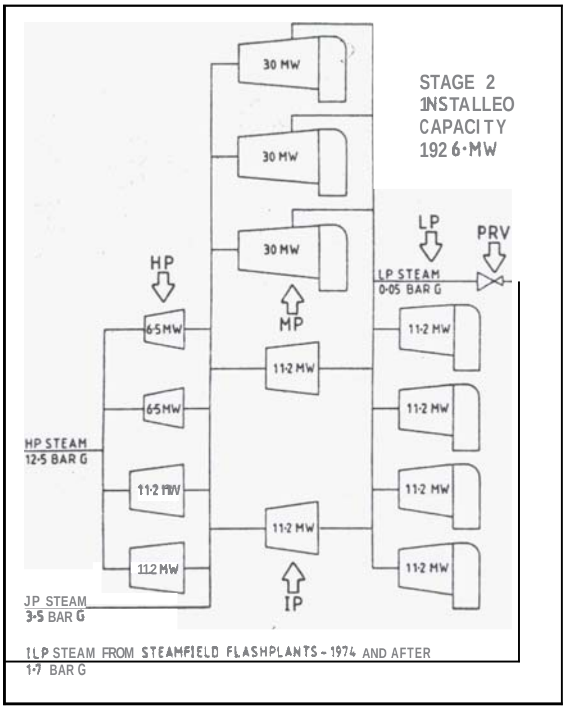

Figure 3. Schematic of stage 2 development with added LP line in 1974.

A further extension of 'B' etation wae allowed for in the design which would have consisted of 2 more 30 MW mired preeeure sets.

On November 15, 1958, the first eet in the 'A' station was synchronised to the national grid. The remaining machines and plant of the stage 1, 1A and 2 development proceeded at regular intervals, the last machine being synchronised to the grid in October 1964.

In October 1963 the consultants were asked to report on a projected etation at Te Mihi which lies approximately 2 km west of the main Wairakei production area. This report was prepared and approximately 20 wells known ae the 200 eeriee were drilled to test the area. This project was abandoned when it was realieed the Te Mihi and Wairakei production were from the same source.

DEVELOPMENT SHORTFALLS

The early 1960s represented an end to the early euphoria and a change to an attitude of consolidation.

Firstly, the reeervoir rundown wae an established fact with loeeee in both pressure and steam production being acaentuated with the increased field production necessary to supply the 3 30 MW sets commieeioned between August 1962 and October 1963.

Secondly, the pilot hot water scheme was abandoned. This scheme involved the collection of waste water from 5 HP bores and 2 IP boree in the eastern borefield. Two-phase flow transmission was not considered to be practicable at this early date and the concept of allowing the water to boil in the lines was regarded as unacceptable for fear of producing unpredictable and poseibly disastrous water hammer phenomena (ref 3).

A minimum of 0.6 bar above the vapour pressure along the whole pipe line was epecified and this was to be achieved by a combination of pumping to raise the hydraulic pressure and attemperation by mixing HP and IP watery.

At the station the transmitted fluid was to be divided between 2 parallel paths through a flaehplant constructed between 'A' and 'B' stations. When fully loaded the plant was expected to produce 100 tonnes/hour of IP eteam at 3.5 bar g and 88 tonnes/hour of LP eteam at 0.2 bar g from 0.34 m^3/s of HE' water at 193°C or with a 3% attemperation 143 tonnes/hour of IP steam and 127 tonnes/hour of LP steam from 0.51 m^3/s of mixed HP and IP water.

Commissioning of the flaehplant began in July 1963 using 3 HE' bores to provide 0.08 to 0.1 m^3/s to one side of the flashplant and 19 tonnes/hour of IP and 24 tonnes/hour of LP steam was produced.

However the water output from the boree was dropping dramatically and by April 1964 the flash-plant was out of production. No coneideration was given to extending the system to other boree for fear a similar result would eventuate,

Little remains of thie first attempt to harness the energy in the separated water. The area between 'A' and 'B' stations has been cleared and the large vertical header tank for the transmission system which was a feature of the borefield landscape for many yeare was taken down ae recently as 1978. It is being considered for an air receiver at the atation.

The water transmission line was converted to eteam transmission end other plant hae found alternate uses ae vacuum-drying veeeele and water eupply sand filters.

Production drilling continued through the early and mid 1960s and peak power from the atation was achieved in 1965 of 173 MW, some 19 MW short of the installed capacity. However this was ended when it wae realieed that the effort wae yielding diminishing returns.

The electrioity supply situation in the country in the summer of 1967 to 1968 was such that a partial shutdown of the field for a period of 3 months from 21 December 1967 to 2 April 1968 was permitted to etudy the effects of reducing the draw off on the rundown. Pressure recovery of some 0.9 bars was observed before output was resumed at the station.

The laet bore to be drilled at Wairakei was completed in 1968 and was a deep bore, some 2255 m. It bottomed out without striking a production zone below the preeent production horizon and ran into several temperature inversions. Had 121 struck a deep production zone the history of Wairakei could have been quite different. Instead, the emphasis of utilisation shifted from exploration and expansion to one of the consolidation.

Thie initial phase of Wairakei involved the drilling of over 120 boree (102 directly for the Wairakei development plus the Te Mihi, 200 series) with few major incidents.

In January 1960 a broken casing in bore 26 some 183 m below the ground allowed the deep production fluid to enter a surface-connected fault zone from which it buret forth creating a violently eteaming crater, eeveral smaller steam vents and boiling mud pools (ref 4).

The out-of-control well was brought under control by drilling a deviated bore, 26A, epudded 61 m away to intercept bore 26 in the open hole some 450 m down. This operation was supervised by an American drilling team and allowed the successful plugging of bore 26 and the restoration of the landscape. An extended bore 26A and another bore 26B now occupy the area.

Two other incidents involved blowouts of investigation holee in the Te Mihi area where reservoir fluid was not contained during the drilling operations and broke out into the countryside (ref 5). Bore 204 is perhaps the most famous, becoming known as the "Rogue Bore" with its rumbling and shaking of the ground, it remained a tourist attraction until 1973 when it ceased its activity.

GENERATION HISTORY

A summary of Wairakei production data from 1959 to 9983 is given in table 1.

YEAR	RESERVOIR			STATION		
	At depth pressure Barg	Mass withdrawn M tonne	Apparent enthalpy kJ/kg	Energy GWh(e)	Peak power MW(e)	Load factor %
1959	58·6	37.34		6		
1960	54.5	47·84		169	50·6	37·9
1961	52·8	42.25	1095·5	384	64·0	68·5
1962	50·3	51·80	1100.2	491	65·6	85·5
1963	46.9	73·40	1097·9	761	131·1	66·3
1964	44·1	70·80	1135·1	1004	148·4	77·0
1965	42·8	65·80	1151·4	1194	173.0	78·8
1966	42.1	64-30	1139.7	1255	166·0	86·3
1967	41·4	59·60	1132·8	1268	170·8	84·7
1968	40·7	47·70	1146.7	1058	166·8	72.2
1969	39·9	55·80	1131·1	1207	165.7	83·1
1970	39.0	56.00	1131·1	1243	159·8	88.8
1971	38·5	54·30	1103·9	1185	153.4	88·2
1972	38·1	52·50	1109·5	1174	149·3	89·6
1973	37·8	48·20	1115·8	1175	147·7	90·8
1974	37·7	47.00	1112.8	1162	148·6	89·3
1975	37·5	46.10	1109·7	1249	159·0	89·6
1976	37.4	47·60	1090·7	1272	158·1	91·6
1977	37.2	46·50	1088·8	1232	152·9	92·0
197%	37·1	48·30	1093·0	1158	145·7	89·6
1979	37·0	45·85	1070·4	1190	145.7	92·9
1980	37·2	47·68	1067·4	1062	142·1	85·1
1981	37.5	46·98	1055·0	1155	144·2	91·4
1982	37.5	46·90	1048·7	1079	142·2	86·6
1983				1118	139·8	91·3

Table 1. Summary of production data from 1959 to 1983.

In reviewing the production history of Wairakei emphasis should be placed on the unite of electricity produced (kilowatt hours) rather than peak power (megawatts) since this more realistically demonstrates the value of the station as a revenue producing plant.

Peak power has to be used, however, for evaluating the changes that have occurred but this does not invalidate the previous statement. The number of unite generated comes from a combination of the availability of the plant for generation and the quantity and quality of the steam produced in the borefield.

Since 1970, which incidentally was the year the last gas exhauster was replaced by steam ejectors, Wairakei has maintained a load factor around 90 percent and has achieved a reputation for reliability (fig 4). Therefore there would seem to be little that can be done on power plant availability to improve the output of the station. Effort has consequently concentrated on the supply and quality of the steam.

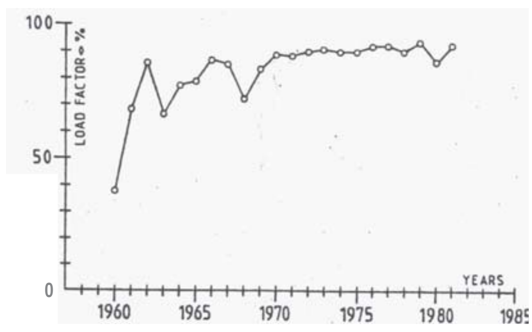

Figure 4. Station load factor.

These factors, however, are affected by the rundown of the borefield to the extent that operational strategies have had to cope with both a fall in pressure and a drop in steam production.

The HP machines in the 'A' etation were back pressure sets, their exhausts together with additional IP steam from the borefield providing the IP inlet steam. The exhaust from the two IP back pressure sets in 'A' station is passed to the LP inlets. Apart from the short-lived pilot hot water soheme, additional LP steam from the borefield was not available until a new LP line came into service in 1974.

Heme, any flow reduction through the HP machines reduced the flow available for IP and LP generation unless additional IP steam, or LP steam after 1974, was available from the borefield.

If the HP manifold pressure is held, the output from the HP bores falls because of rundown, the HP throttles have to be closed in and generation falls. Bores would ultimately fail to supply at HP conditione and would have to be derated to IP conditions in a single step.

Alternatively, the HP manifold pressure can be allowed to drift downwards as the borefield pressure and the ability of the wells to supply at a given pressure diminishes. The throttles on the HP machines remain fully open but the power potential of the turbines is reduced according to the formulae:

$$MW = 0.873P - 4.37 \quad \text{for 6.5 MW set} \quad \text{(i)}$$

$$\text{and } MW = 1.613P - 8.452 \quad \text{for 11.2 MW set} \quad \text{(ii)}$$

Where P is in bar g
MW is power in MW.

This reduction in power is reflected in a reduced flow through the machine caused by the increased specific volume associated with the decrease in pressure. Bores, however, do not have to be derated but remain on line supplying at the reduced pressure.

The latter alternative was adopted at Wairakei and the gradual reduction of the HP manifold pressure has been a feature of operations since 1963 (fig 5).

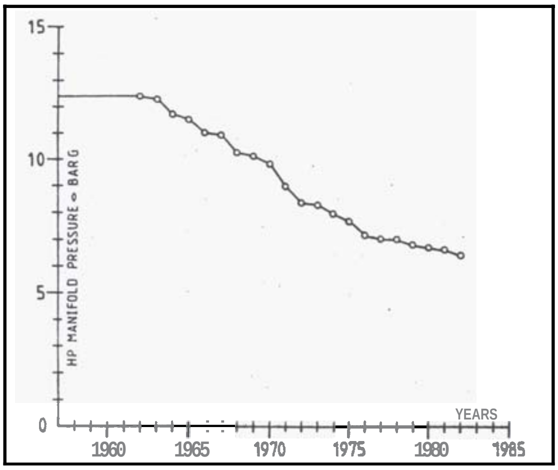

Fig 5. HP manifold pressure.

Analysis of the power available from the HP machines over the years together with the power shortfall in the rest of the system, illustrates further the results of these strategies (fig 6). The failure of the borefield to supply sufficient HP steam before the pressure reduction of the HP manifold began meant that the full HP capacity was never realised and began to fall in 1965 from the peak in 1964 of 28 MW.

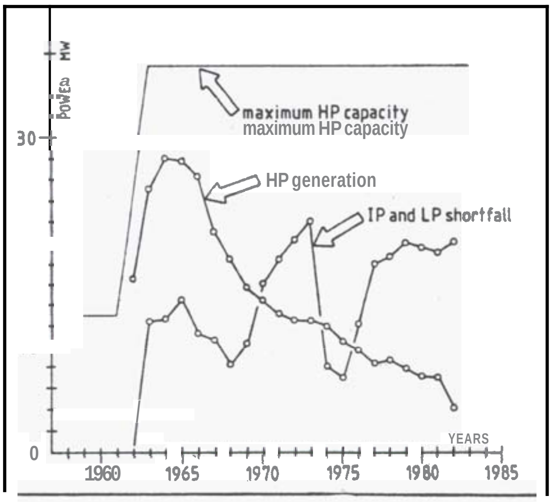

Figure 6. HP generation compared to HP and IP generation shortfall.

The availability of additional steam to make up the shortfall in the IP and LP system disappeared with the completion of drilling operations in 1968. Thereafter, shortfall which had been falling from the 1963 level rose rapidly to exceed the HP power output for the first time in 1970.

This is possibly the first time that elimination of all HP generation could have been considered, assuming that the increased output from the derated HP wells could fill the IP and LP shortfall in capacity and so leaving the generation unchanged.

However, use of flashed steam from the separated HP borewater had not been abandoned with the demise of the pilot hot water scheme.

Double flash units were installed on 3 HP wellheads from the mid 1960s and the concept shown to be practicable. A recommendation in 1970 to extend double flashing to triple flashing by the installation of centralised double flash units producing IP and LP steam from HP water, was accepted.

A major part of this project was the construction of an LP 1219 mm diameter steam pipeline which was commissioned in 1974. Shortfall in the IP and LP side of the plant once again fell below the HP generation, but by 1976 had increased and the complete elimination of HP generation coupled with derating of all HP wells to IP conditions could again be regarded as a possibility.

However, this was not given serious consideration as the step change from HP to IP was still regarded as large and the effect on the recently installed flashplant system would have been dramatic.

Instead, a policy of connecting previously unused wells and piping additional water to the flashplants was pursued to maximise the use of the flashplants and the new LP steam transmission line. This work was constrained to within the existing borefield boundary.

The reduction in the HP manifold pressure continued to bring the threshold pressure, below which HP generation could not be sustained, closer. This latter period of pressure reduction was done as much for aiding the weaker HP bores to remain on line as for an increase in generation.

In 1980, serious consideration was given to removing the HP machines from service and tests were conducted which confirmed that derating all the HP wells to IP conditions would result in a slight increase in generation (ref 6). The gain was not, however, sufficient to eliminate the total shortfall and a source of additional steam was sought. Three bores drilled as part of the Te Mihi investigations appeared to be eminently suitable to bring into production and recommendations to proceed with their reticulation were also made in 1980.

Derating of all the HP bores to IP conditione which involved both wellhead and flashplant modifications together with two balancing crossovers in the borefield, began in November 1982 when the station was shut down to isolate the HP machines from the steam supply and fit 2 crossovers from the HP to the IP manifold. One crossover alsoincludeda connection for distributing the IP steam from the 3 additional (200 series) bores to the IP lines and steam from 2 of theee bores has been fed to the station since June 1983.

Between 1964 and 1983 the production of unite from the station has remained remarkably consistent and has averaged 1172 GWh/annum (fig 7). From 1958 to 1965 annual production increased by some 200 GWh/annum as the various turbines were completed and brought onto load, however this tailed off in 1966 and 1967 to less than 100 GWh increase for the 2 years.

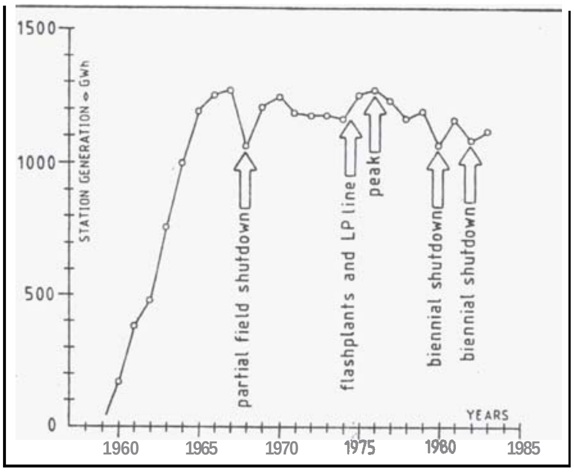

Figure 7. Station generation.

The dip in annual production of the partial shutdown of the field is clearly shown in 1968 followed by a period of fairly consistent production until the effect of introducing double flash units and the LP steam transmission line in 1974 was felt in the 1975 statistics.

Indeed, 1976 represents a record for production of 1272 GWh and some fall off is evident since that date. A further operational feature which shows in the statistics is the advent of biennial rather than annual shutdowns for station manifold and pipeline inspections. Alternate years are thus up or down depending on whether the period included a shutdown or not.

In this paper the mass withdrawal from the borefield has been multiplied by the apparent enthalpy to give the heat extracted which has then been divided into the units generated and plotted to give some indioation in the changes in utilisation of the resources that have occurred (fig 8).

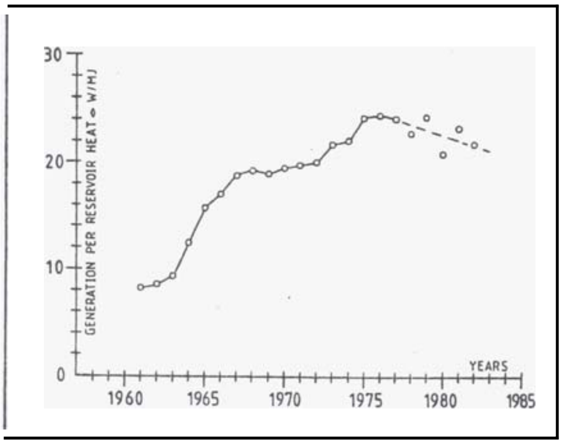

Figure *8.* Ratio of station generation to heat removed from the reservoir.

A steady rise through to 1967 represents the improvements in harnessing the field output to generation followed by a more or less constant period which ran through to 1972 when the effect of flashplants introduced into the field began. A peak in 1976 which coincides with maximum generation was due to peak production from triple flashing. Since that time the HP pressure has been falling away, reducing the effectiveness of the IP side of the flaehplants. The points alternating above and below the dotted line in figure 8 are caused by the biennial shutdown and are not representative of the trend.

Wairakei then has seen, and will continue to eee, more or less continuous changee to maintain the all important generation.

PERFORMANCE OF STEAMFIELD PLANT AND MATERIALS

In general, all the steamfield equipment has given good reliable service. There has been a need, however, to maintain constant vigilance to contain the effects of ground movement on the pipelines and guard against the effects of both internal and external corrosion.

The choice of mild steel as the main material for all wellhead, flashplant and steam transmission equipment has proved a wise one, provided oxygen can be excluded from the geothermal fluid. Table 2 shows some of the principal materials used at Wairakei (ref 7).

CYCLONE SEPARATORS

Initial erosion problems with the cyclone separators, due to grit and pumice discharged with the fluid being swirled around the bottom of the chamber by the cyclonic action, were solved simply by welding vanes to the bottom surface to trap the well debris.

PLANT ITEM	MATERIAL DETAILS
Uell down hole casings	API 5'
Well-head Master Valves	API 6
Well-head Steam Separators and Water Drums	BS1501-161
HP and IP Steam Transmission Pipelines	BS806 Class B
LP (1200 mm dia) Steam Transmission Pipeline	BS3601 (1962) SFW Grade 26
Turbine Casings Inlet	Cast Carbon Steel
Turbine Casings Exhaust	BS1501-161-B
HP; IP and LP Rotor Forgings	BEAMA No 3 grade 3
MP Rotor discs	BEAMA No 2 grade 3
MP Rotor shaft	BEAMA No 3 grade 3
Turbine revolving blades	Stainless iron
Jet Condenser shell	BS1501-161 Grade B
Main steam field isolating valves	Cast steel body with stainless/steel spindles

Table 2. Schedule of principal materials used at Wairakei.

WELLHEAD SILENCERS

Following early failures of reinforced concrete stack pipes of wellhead silencere, trials were begun in 1965 to assess the suitability of timber for silencer stack pipe fabrication. Various timber and preservative treatments were tested.

The most successful was found to be radiata pine treated with a 5 percent PCP (Pentachlorphenol) by weight in Shell industrial oil No 4. A silencer made in this material remained in service for 11¼ years before replacement was considered necessary. All silencers in continuous service are now made with this form of treated timber. Silencers which diecharge only occasionally, and hence would allow the wood to dry out, are made from steel.

GROUND SUBSIDENCE

Withdrawal of fluid from the Wairakei geothermal field has caused extensive ground subsidence in the region (ref 8). The maximum subsidence is now about 7.6 m and is continuing at a rate of about 400 mm per annum.

Fortunately, the area of maximum surface subsidence is very small and to date neither the vertical movement, which is associated with subsidence, nor the consequential differential settlement (tilt) has so far created any insurmountable difficulties. All problems so far encountered have been caused directly by ground surface strain.

The region of maximum subsidence fortunately occurs outside the production field. However, the steam transmission pipes and the main open culvert hot water drain which runs parallel with the steam mains have been affected by the ground movement. Modifications to these structures have been, and will continue to be, necessary.

In the case of the main drain, it has been necessary to incorporate sliding joints within the outfall drop structure, which lowers the hot water 25 m in 5 unequal steps to the discharge point in the Wairakei steam.

While working on this drain modification, leakage from a diversion flume caused the drain structure to fail following the washout of the supporting pumice alluvium. The drain caused an almost total steamfield shutdown for 3 days until alternative drainage facilities could be organised.

The steam mains are affected by ground movement altering the distance between the pipe anchors. No provision has been made to accommodate this movement and at expansion loop anchors it is necessary to periodically cut a small length (0.3 m) out of the pipe downstream of the loop, move the loop to catch up with the ground movement and then place the cut out length in the resulting gap in the pipe on the upstream side of the loop.

New smaller collection pipelines are now prestressed to delay the first readjustments because of ground strain.

SILICA DEPOSITION

Mineral deposition from geothermal water has caused no problems in wellhead equipment or within the steam pipelines, but presents a major cleaning problem in the open and covered hot water drainage system. Silica deposits grow to a thickness of 100 to 140 mm on the floor and walls of the drains in the yearly period between cleanings.

Keeping the drainage system clear of these deposits is a major maintenance expense in the operation of the station.

Attempts to interest New Zealand industry in the silica from the drains has not been successful as surface water run-off contaminates the deposits. The only possibility of utilising this waste product would be by its extraction from the fluid before discharging into the drain system.

STEAM TRANSMISSION LINE CORROSION

Potentially the most serious corrosion problem was the discovery of damage in the main steam transmission lines during the shutdown in November 1977.

The corrosion was attributed to the flaw of nearly neutral condensate, containing dissolved CO_2 and H_2S gasses, *along* the bottom of the pipe. It was limited to the wetted area and consisted of hand-sised patches of exposed coding pipe surface followed by deposited magnetite which in heavily attacked areas was in the form of well developed octahedral crystals.

The corrosion was most pronounced in the 2 762 mm HP lines and the measured deptha of the pitting indicated that the severity increased progressively from the borefield towards the station.

Corrosion pits extended through more than half of the 12.7 mm pipe wall in the worst affected 150 m length, but in general averaged 3 mm deep in one line and 1.5 mm deep in the other (ref 9).

Remedial work in the first instance consisted of rotating some 1000 m of each line through 180° to remove the coded area from further attack and gain time while investigations for causes and cures were carried out. One section of 150 m was replaced completely.

Investigations eventually centred on inhibitors. No significant corrosion had taken place within the wellhead equipment or in the upfield end of the pipelines, and the presence of a natural inhibitor was surmised within the bore water.

Since separation is not 100 percent efficient, a small amount of bore water ie carried over into the pipelines. This water is "scrubbed" by condensation and removed at the drainpots every 150 m along the pipe length.

Tests on the drainpot discharges revealed that where the presence of carried over bore water was measurable, corrosion did not occur. Silica was used as a tell-tale and a level of at least 10 ppm appeared to inhibit corrosion completely.

A lesser figure of 1 ppm of silica at the last drainpot before the etation, was adopted to limit the chloride level in the station during bore water injection trials in one of the two HP lines. Trisodium phosphate was injected into the other line at a rate sufficient to make a significant *change* in the alkalinity of the condensate.

When actively corroding, the bare patches along the pipe bottom migrate slowly upstream and use was made of this to develop a monitoring technique of photographing reference lengths of line after 6 to 12 months service and *comparing* the patch positions - where there was no movement, there was no corrosion.

After further detailed evaluation of both corrosion inhibiting techniques it was decided in June 1982 to adopt the bore water injection as the long-term solution. Equipment to implement this bas been procured and is currently being installed.

COOLER WATER DOWNFLOWS IN WELLS

In 1980 measurements *using* a downhole spinner showed that in 2 non-productive wells, substantial quantities of 150°C water are flowing downwards in the open hole section of the well and dispersing into the production zone. It is possible that similar activity is occurring in other welle and in natural fissures.

Radioactive tracers have been used to detect this inflow in surrounding producing wells. The full implication of this is still being considered. However, so far it has not been possible to detect *any* effeot on the heat output of the surrounding wells, even though the downflow ie in excess of 200 tonnes per hour and is known to have been occurring for some years.

A "workover" on one of the downflow wells has successfully stopped the cooler water inflow. The well was restored to production at a level comparable with what it was before it stopped producing some years previously. However, production since has been very erratic and it looks as if this well will fail in the very near future.

WELL DOWNHOLE CONDITION

Since many of the wells were drilled prior to the station commissioning, and so are older than 25 years, it would be imprudent not to recognise this fact. Investigations involving bore integrity are therefore carried out from time to time as symptoms appear.

Perhaps the most interesting feature of these investigations recently has been the introduction on a trial basis of closed-circuit television equipment down the bores.

An underwater camera belonging to the Electricity Division has been lowered into several wells and video tapes made of the findings. The [redacted] depth attainable has been limited by the cable to around 200 m

Camera temperature limitations of 50°C have restricted its use to quenched wells for periods of short duration and the runs down bore 58 have been the most successful to date. Scrape marks on the casing, casing joint condition and am area of buckled casing were clearly revealed.

However it is far from being a proved technique and failures have outweighed successes so far.

PERFORMANCE OF POWER STATION PLANT AND EQUIPMENT

The effect of the once proposed heavy water distillation plant on the plant of the stage 1 development was to create a complex of small machines and auxiliary equipment with a consequential larger maintenance commitment than has been the case for the 3 'B' station 30 MW machines.

Additionally the 2 IP machines purchased as late substitutes for the distillation plant have been less reliable than the other turbines due to proneness to vibration problems and blade failures.

The combination of saturated steam and the presence of hydrogen sulphide gas in the steam requires a greater degree of vigilance than on other turbines of the same pressure and temperature. A programme of turbo-generator overhauls after each 24 000 hours of running has been more than justified by the high availability factor for the plant. Under certain circumstances the 'B' station machines are allowed to extend towards 32 000 hours before overhaul.

For each type of turbine a spare rotor was purchased, 5 in all, and these have been invaluable in minimising generation losses and easing maintenance timescales.

TURBINE BLADE MATERIAL

Turbine blades on all machines were made from 13 percent chromium iron and supplied in the soft (non-martensitic) state with a Brinell Hardness in the range 160-190. In this condition there was considerably less risk of stress corrosion cracking in the geothermal steam environment.

The blade tip speed at the wet end of the turbines was restricted to 275 m/s in order to minimise erosion of this soft material since no erosion shields were fitted.

However, during the first years of service erosion damage to exhaust end blades on the MP and LP machines was quite marked. The damage was not dressed in any way and the rate of erosion slowed considerably.

The same effect has been noted with the bringing into service in recent years of new and rebladed rotors with initial erosion rates being quite high. Damage to the 30 MW MP sets presents no risk to the integrity of the blades and recent inspections indicate the blades are good for quite a few years yet.

The 11.2 MW LP sets have a smaller blade section and erosion tended more towards the tip of the blades which did present a threat to the integrity of the blades at the banding rivet and from fatigue.

Blade failures on these machines, all of which occurred after 110 000 hours of operation, were not fifth stage exhaust end blades but first stage blades. The LP rotors were therefore completely rebladed and the use of the spare LP rotor considerably eased the logistics of carrying out this exercise. The spare unused LP rotor was put into one machine to free its rotor for reblading. The rebladed rotor was placed in another machine to free its rotor for reblading and so on.

No blade failures have been recorded on the 30 MW MP sets and the oldest rotor has as of 31 July 1983 been running over 166 000 hours. No blade failures have occurred on the HP sets though this is not so significant an achievement as they ran for so little time fully loaded.

The 11.2 MW IP machines which were late substitutes for the heavy water plant have only 3 blade rows compared with 5 rows on the HP sets and 10 rows on the LP sets of the same size and 15 rows on the MP sets.

Blade failures, due primarily to the bending stresses in the blades being well above that applicable to contemporary machines, have been a feature of their operation. A recent evaluation of the history of these machines indicated an incident about every 22 000 hours, the most recent event occurring August 1983 when 2 first stage blades were shed from No 1 machine. The rotor was removed and replaced with the spare unit.

Higher strength blades for these machines was suggested, manufactured from FV520, a 14 percent chromium 5 percent nickel material. Several rows have been purchased and fitted. Evaluation has been frustrated by premature blade failures attributable to other factors than the material and a proper test of FV520 has not yet been carried out.

TURBINES

In November 1982 with the derating of the HP production wells to IP production, the 4 HP turbo alternators were de-commissioned and thus the life of the first machine to be commissioned at Wairakei, G2, was ended after 153 627 hours of running. G2, like G3, is a 6.5 MW set and no plans for their future use have been made so the 2 machines remain in 'A' station.

G5 and G6, the 11.2 MW machines, however, have been removed from their foundations and taken to the workshops at Huntly power station for extensive overhaul before being sited at the new Ohaaki power station.

In 1980 the opportunity was taken to completely dismantle the shrunk-on keyed discs from a 30 MW MP rotor (in view of previous failures of this type of rotor construction at the Hinkley Point power station in the UK), and give it an extensive examination because hydrogen sulphide bad been identified as an agent for stress corrosion cracking. No metallurgical defects were discovered.

Other fixed 'parts of all machines remain basically in good condition. Some erosion damage to! the casings and the outer cast iron rim of . several diaphragms was discovered. In some of the latter cases stainless steel erosion shields have been fitted by machining away the damaged area and recessing in a stainless steel shield which is finally seal welded. This has considerably extended their lives. In other cases new diaphragms have been fitted.

It is more pertinent to talk of rotor running hours than machine hours since the spare rotors have been brought into service. Several rotors, particularly the IP ones, have seen service in more than one machine.

Only 2 rotors supplied as original equipment are currently in service, the others having been. rebladed or are the current spare, and these in G11 and G12 have accumulated some 166 504 hours and 160 885 hours respectively up to 31 July 1983.

One event of significance affecting the turbines in the early years was a case of "standby corrosion".

Due to imperfect isolation, steam seeped into the casing of the idle machine from the exhaust end. The presence of air and condensation proved a particularly noxious and corrosive mixture and the rotor and diaphragms suffered attack.

Improved methods of isolation, assisted by hot air ventilation for drying out turbines after shut-down, have prevented a recurrence of this trouble.

JET CONDENSERS

The jet condenser shells are made from mild steel with the wetted surfaces epoxy ooated (Calvinac). This coating has stood up remarkably well considering the preeence of warmth, moisture, oxygen and hydrogen sulphide, and still exists over some 80 to 90 percent of the total internal surface area.

Site application of the original epoxy coating has proved very difficult and station staff have had to use a different epoxy coating for repair. work. This substitute material, however, has a service life of only 4 to. 5 years.

A significant problem with the condenser bodies is that corrosion, once begun, proceeds rapidly to excavate very deep pinhole cavities which have on occasions penetrated the shell. Repairs to corrosion pits are made by welding, but if the welds are not *ground* smooth and epoxy-coated, corrosion proceeds extremely rapidly by the weld fusion zones.

The impact forces of the cooling water on the condenser floor-plates have resulted in these plates frequently becoming detached. However, by strengthening the mounting framework and making the floorplate attachments more resilient by introducing rubber washers at *each* joint interface, and by the use of stainless Beleville washers, station staff have had some success in containing this problem.

GAS EXTRACTION SYSTEM

High-speed centrifugal *gas* exhausters installed on the LP machines proved very unreliable mechanically and were replaced with steam-driven ejectors. These have proved to be very reliable, but inefficient in the use of steam.

The ejector condenders are mibject .to heavy sulphur encrustation and corrosion in this area is fairly severe. In general, ejector condenser bodies with epoxy linings last about 6 years, although one of the original ejector condensers coated with Calvinac epoxy is still in service.

Until 1971, gas-extraction and water discharge pipework from the ejectors suffered badly from corrosion due to the presence of hydrogen-sulphide and was replaced with polyester asbestos pipework. This has given exceptional service and is expected to last indefinitely.

ELECTRICAL EQUIPMENT

The only satisfactory material found for electrical contacts at Wairakei has been platinum, silver and even gold contaminates rapidly in the hydrogen sulphide polluted atmosphere.

Copper must be tinned to avoid corrosion and wires must be stripped using thermal strippers, otherwise the "nicks" in the tinning caused by blade strippers allow corrosion to begin, resulting in the tails falling off the wires.

Brush gear has been a continuing source of trouble and requires constant routine maintenance.

COOLING WATER DISCHARGE CULVERTS

Due to the use of jet condensers at Wairakei, hydrogen sulphide gas gets carried over into the cooling water qulverts where it collects in pockets above the water level.

The culvert design is such that during normal operation the culverts do not run full and there is a 200 mm gas space above the water level. Hydrogen sulphide which collecting in this space oxidises to sulphuric acid which attacks the exposed wet concrete, causes the surface to crumble and break away.

Those areas of culvert below the operating water level show little or no sign of deterioration.

Concrete loss on the roof areas of the culverts has been extensive. *On* large areas the first layer of reinforced steel has been exposed, and in places the steel has been completely corroded through. The integrity of the culvert structure is still adequate, but a permanent solution to the problem remains undiscovered.

Since 1974 a teat programme has been evaluating possible palliative methods for the culvert roof corrosion problem and testing concrete protective coatings for new geothermal installations. To date the most promising results have been achieved by spraying the corroded roof with a urethane expansion foam to a depth of 37 to 50 mm.

Care is taken to make this surface reasonably smooth as an elastometric polyurethane sealing coating (Irathane 141) is applied to it to provide resistance against chemical attack.

WAIRAKEI CURRENT AND FUTURE DEVELOPMENTS

REINJECTION

In line with undertakings given at the Ohaaki power station water right hearings, the Electricity Division is investigating the feasibility of reinjecting the waste geothermal effluent from the Wairakei power station. This work has now been actively underway for more than a year.

The main objective in reinjection is to eliminate the present surface discharge of hot effluent into the Waikato River and in such a manner that the reinjected fluid has no detrimental effect on the production of the field. Indeed, it is hoped that a measure of "at depth" pressure recovery will be achieved which would be of benefit to the long-term management of the field.

Following geothermal financing rearrangements earlier this year a Reinjection Committee was formed to oversee this work. The committee consists of senior staff from the DSIR, MWD and Electricity Division under the chairmanship of the division's district manager, Hamilton. A 2 stage approach has been adopted to the implementation of reinjection at Wairakei.

The first stage involves confirming the feasibility and acceptability of the system and allows for the reinjection of up to 20 percent of the waste water into one or more existing or specifically drilled wells. The first *stage* work is expected to cost $2 000 000 and the time scale to complete is late 1984 at the earliest and mid 1985 at the latest. The area under investigation is shown in figure 9.

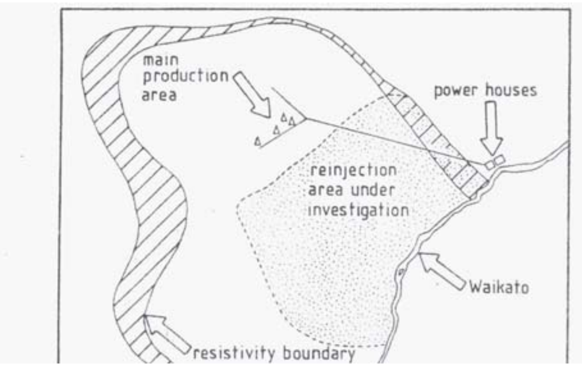

Figure 9. Reinjection area under investigation.

The second stage is to implement the reinjection of all the waste water, over 4000 t/hr. The cost of reinjection (March 1983 figures) is estimated to be *of* the order of $15 000 000.

At Wairakei there is need to tread cautiously with reinjection as 25 years' exploitation of the field has created "at depth" conditions which could, by injecting the effluent into the *wrong* location, detrimentally affect the steam production of the field. Also, since the temperature of waste fluid is very close to the silica saturation temperature, there is a danger the silica could build up in the pipelines and reinjection wells rendering the system inoperable.

No financial return on the reinjection investment can be claimed from greater energy production. Financial justification for this large investment will therefore have to be based mainly on the long-term potential of the Wairakei field.

It will therefore be necessary for the Wairakei Reinjection Committee to address such questions as the need for further production drilling, deeper drilling, connection of further 200 series wells and ultimately the redevelopment and repowering of the project, and report on these aspects in the submission to the Joint Ministers seeking financial approval to implement full-scale reinjection.

FUTURE OUTPUT

With the removal of the HP turbo generators, the remaining power plant is capable of a gross generated output of 157.2 MW. It is the intention of the Electricity Division that this level of output be maintained provided economic means are available to sustain this production.

As all the available methods of sustaining the output from the existing field have been utilised, maintenance of this output will in the future have to be from further drilling, provided it can be shown that drilling will not re-accelerate the field rundown. The effect of connecting the 200 series wells on the system should be a good indication of what effect further drilling will have on the system. Limits may well have to be recognised in the output from the current production area and bore depths.

It is recognised that future production may have to be at greater depth, or alternatively the eastern production area which has lower enthalpy outputs may have to be abandoned in favour of additional normal depth wells drilled in the Te Mihi area where the enthalpy of the well output is greater, hence steam fraction is larger.

The Electricity Division recognise further production drilling could be necessary at Wairakei and has made budget provision for such work in the 1986/87 and 87/88 financial years.

STACEY

POWER PLANT REMAINING ECONOMIC LIFE

As to how long the power plant can continue to be economically maintained and remain operationally viable, it can only be reported that no insurmountable deterioration of the machine is occurring at present.

The LP machines have all been rebladed and if the same life expectancy can be obtained from these blades as was obtained from the initial set, then the rotors of these machines should last another 15 to 20 years before further reblading becomes necessary.

The mixed pressure 'B' station machines which rotate at 1500 rpm, as against 3000 rpm of the 'A' station machines, are still performing very reliably and there are no plana for a reblading programme on these machines. A recent vibration incident on Unit 12 did give cause for concern, as it was first thought some blades had been shed, but investigations showed the vibration problem was caused by loosening of the generator windings. This was easily corrected.

The old adage about British Thompson Houston (BTH) equipment being designed "Bloody Thick and Heavy" implying its long lasting ability, ie proving true at Wairakei. Problems axe being faced with the procurement of ancilliary equipment spares as many of the manufacturers of this equipment axe no longer in business. But NZ industry and the power station's own manufacture of the required items have coped adequately with the situation.

An example is the manufacture of spare bronze strainer plates for the rotary water screens.

In this case it was necessary for station staff in conjunction with McEwen Industries to design and build a semi-automatic drilling machine to manufacture the strainer plates on the station. This required accurate drilling and taper reaming of over 22 000 holes/plate, with a total of 30 plates being required.

CONCLUDING REMARKS

Much has been written about Wairakei from its inaeption and it has captured the imagination of many people not just because of its novelty but for its acknowledged success for New Zealand.

It would seem fitting on the eve of 25 years' generation at Wairakei, to pay tribute to the many people from all levels who have contributed to its success over the years and played no small part in achieving its enviable reputation.

Visitors from all over the world continue to call by and many now have their own geothermal power stations whose origins can be traced through the first steps taken at Wairakei. It is hoped that they in their turn will reach 25 yeare and beyond.

So as the second 25 years begins, Wairakei looks forward to playing a continuing role in the generation of power in New Zealand.

ACKNOWLEDGEMENT

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