B.C. HYDRO

MEAGER CREEK PROJECT

REPORT ON ACTIVITIES

1983/84 AND 1984/85

VOLUME I - TEXT

STATION PROJECTS DIVISION
PROJECT MANAGEMENT DEPARTMENT

June 1985

VR426

This report was prepared for the British Columbia Hydro and Power Authority ("BC Hydro"). BC Hydro does not:

(a) represent, guarantee or warrant to any third party, either expressly or by implication: (i) the accuracy, completeness or usefulness of; (ii) the intellectual or other property rights of any person or party in; or (iii) the merchantability, safety or fitness for purpose of; any information, product or process disclosed, described or recommended in this report,

(b) assume any liability of any kind arising in any way out of the use by a third party of any information, product or process disclosed, described or recommended in this report, or any liability arising out of reliance by a third party upon any information, statements or recommendations contained in this report.

Should third parties use or rely on any information, product or process disclosed, described or recommended in this report, they do so entirely at their own risk.

MEAGER CREEK PROJECT
REPORT ON ACTIVITIES
1984/85 AND 1985/86

CONTENTS

VOLUME I - TEXT

FIGURES

SECTION 1.0 - SUMMARY

Geothermal fluids at temperatures between 190° and 200°C have been intersected in all three deep exploratory wells in the South Reservoir area at Meager Creek. However, the host rocks are characterized by low overall permeability and porosity.

Testing and monitoring of the deep exploratory wells was conducted from 1983 to 1985. The program consisted principally of temperature measurements, flow testing and chemical sampling. In addition, an airlift was undertaken on well MC-3.

1.1 TEMPERATURE MEASUREMENTS

A total of 15 temperature surveys were conducted on the three deep exploratory wells during 1983/84. In addition to ongoing monitoring of the static wells MC-2 and MC-3, temperature data from the producing well MC-1 was obtained (Volume II).

Well MC-1 was inaccessible for several months after test production was begun in November 1982, but three temperature surveys were conducted on well MC-1 during 1983. The temperature profiles indicate that fluid is produced from approximately 1400 m depth, and rises isothermally to about 200 m. At this point, the fluid begins to boil and the apparent temperature drops markedly towards the surface. A possible cool inflow is indicated by a slight downward inflection in the curve at a depth of 150 to 250 m. Temperatures at the bottom of the well remain in the 230° to 235°C range, indicating that testing over the course of the year has not noticeably affected the preproduction thermal regime. Two later surveys in 1984 were obstructed at a depth of approximately 700 m. The information obtained in the upper portion of the hole indicates a continued warming trend.

Three temperature surveys in well MC-2 (commencing in July 1983) indicate a minor temperature rise of 3° to 5°C over the long static time since November 1982. The temperature profile is indicative of conductive heating over most of the length of the drill hole with minor inflections at 1400 and 2900 m. The well remained dormant through 1984.

As with MC-2, well MC-3 demonstrated a small, long-term temperature rise since November 1982. Nine temperature surveys conducted during late 1983 showed a significant temperature increase at depths below 3000 m. This increase prompted a flow test on the well. Rising temperatures were postulated to be a reflection of increased permeability at the No-Good Zone intersection, and that an airlift from depths below 2500 m would stimulate flow from this previously untested zone. A later temperature survey confirmed that the warming trend continues.

1.2 FLOW TESTING AND MONITORING ON WELL MC-1

Well MC-1 has been under test production from the Meager Creek Fault Zone since November 1982. Betweeen 1983 and 1985 the wellhead pressure discharge rates were measured daily until October 1984 and discharge fluids were sampled and assayed regularly for standard chemical components (Volume II).

Pressure and flow rate are regulated by adjustments to the valve system on the wellhead, thereby controlling the depth of the flashpoint within the well bore. An optimal pressure of 200 to 220 kPa was established over the previous flow record and has been maintained whenever possible. This pressure allows a flow rate of approximately 15 to 17 t/h of geothermal fluid to discharge from the outlet. The discharge comprises approximately 15 percent steam and 85 percent low salinity "brine" (approximately 6000 ppm TDS) at a temperature of 96°C.

Periodically, the well bore becomes plugged with carbonate-silica scale precipitated from the geothermal fluid. Although pressure maintenance at the wellhead has proven to be the most effective scale control procedure, mechanical scale removal has been required on a number of occasions. Well pressure records show periods where the well was choked by excessive precipitation of carbonate scale and pressure and flow rates could not be maintained. At these times, the well bore has been cleared by a specially designed scale hammer. The hammer was dropped onto the scale blockage, chipped away the soft accretion and allowed improved flow. The most effective tool for scale removal, however, appears to be a small drilling rig. A B.C. Hydro diamond drill Boyles 56A complete with BOP was employed to ream out the well bore following the May 1984 blockage. Since that time, well performance has been improved substantially, and scale accumulation has been minimal.

1.3 STEAM TURBINE DEMONSTRATION ON WELL MC-1

A 20 kW steam turbine was installed in the spring of 1984 to further the scope of the test program and demonstrate the potential for development of the geothermal resource for power generation (Volume II). The production fluids appear to be relatively free of toxic elements, and calcium and silica contents are within acceptable limits. No extraordinary treatment of the geothermal production fluid should be necessary.

1.4 AIRLIFT ON WELL MC-3

A 5° to 8°C temperature increase in MC-3 encouraged interest in the well. Particular consideration was given to the No-Good Zone, a permeable structure at a depth of 3025 m.

A flow test entailing an airlift through endless tubing to a depth of 2500 m was conducted in early November 1983. The airlift stimulated flow from the No-Good Zone, producing wellhead pressures approaching 800 kPa, although spontaneous discharge was maintained only for a period of approximately 20 minutes. Under the low pressure conditions imposed by the airlift, cool (160°C) near surface waters were flowing into the bore faster than the discharge rate of fluids from the No-Good Zone. As such, the downflowing waters soon quenched the flow from the No-Good Zone, suppressing the high pressure discharge from depth.

SECTION 2.0 - INTRODUCTION

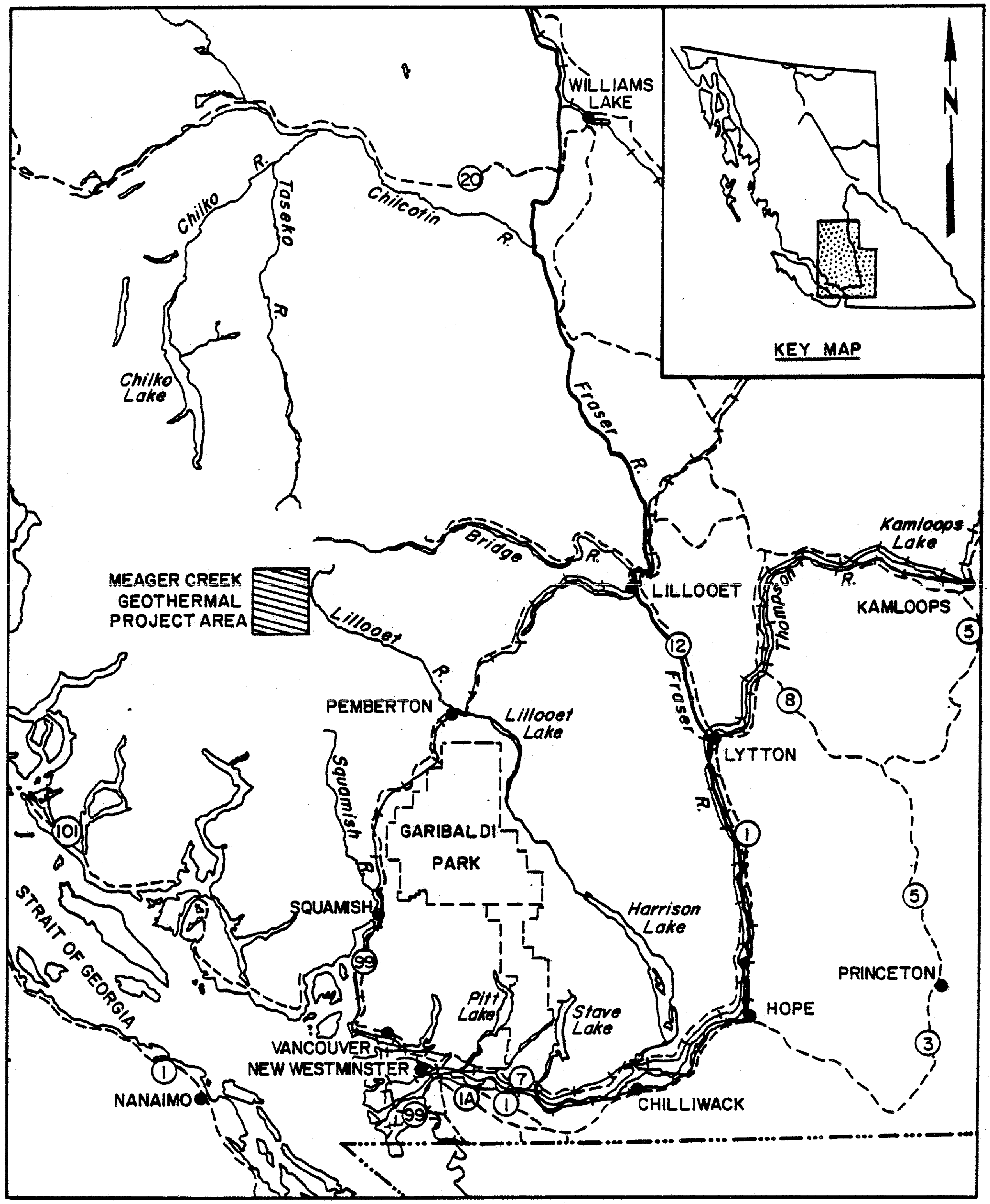
2.1 LOCATION AND ACCESS

The Meager Creek Project area is located approximately 200 km north of Vancouver in the rugged Coast Mountains of southwest B.C. (Fig. 1). A good, gravel-surfaced logging road follows the Lillooet River valley for 50 km to the Meager area from the end of the paved highway at Pemberton Meadows. Flooding in early October 1984 damaged several river and creek crossings and repairs were completed in May 1985.

2.2 PREVIOUS WORK

Geothermal investigations at Meager Creek have been in progress since late 1973. B.C. Hydro became involved in 1974 with a small-scale diamond drilling project designed to evaluate the thermal characteristics of the Meager Creek Hotsprings and the surrounding area (Fig. 2). Subsequent investigations identified and localized a potential resource area on the lower flanks of Pylon Peak, some 5 km upstream from the main vent of the Meager springs (B.C. Hydro, 1982).

Exploration culminated with the drilling of three, large diameter rotary holes during 1980 to 1982. Reaching depths of 3000 to 3500 m, the holes were drilled to assess various targets identified in earlier studies. The program resulted in one well, MC-1 capable of long-term, sustained steam production. The two other wells, although unable to produce steam spontaneously in their present state, have been valuable in the development of interpretive models for the geothermal reservoir.



LOCATION MAP

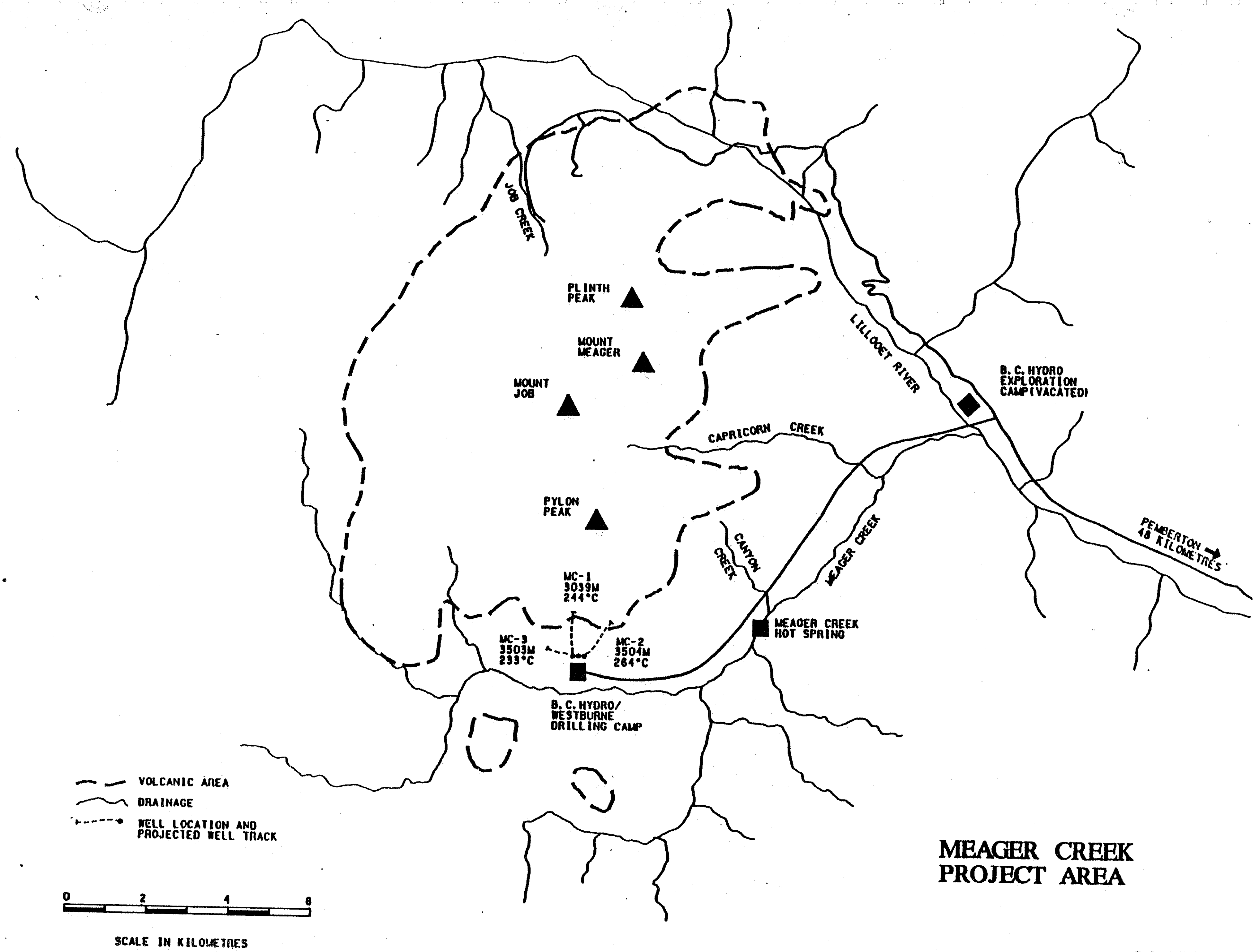
LEGEND

- – – – HIGHWAY
- –+–+– RAILWAY
- ● CITY, TOWN

0 20 40 60 80 100 km

SCALE

FIGURE 1



MEAGER CREEK PROJECT AREA

FIGURE 2

2.3 WORK DONE IN 1983/84 AND 1984/85

Due to the poor economic climate and low electrical load forecasts, the geothermal drilling program was suspended in August 1982. Since that time, activity at the Meager Creek Project has been restricted to testing and monitoring of the three deep exploratory wells.

MC-1, the first deep exploratory well, was in test production from November 1982 to October 1984. Thermal fluid was discharged to a silencer/separator unit where wellhead pressure was recorded continuously with a clock-driven pressure gauge recorder and flow rate was measured and recorded daily until October 1984. In addition, periodic temperature surveys and chemical sampling were conducted to monitor changes in the thermal regime.

During the course of production, the MC-1 well bore became obstructed by a substantial carbonate scale deposit. However, the blockage was successfully removed by mechanical means and further scale deposition has been inhibited by maintaining constant pressure at the wellhead.

MC-2 and MC-3 remained dormant for most of the 1983 to 1985 period. Standing water levels in the wells were recorded regularly and periodic temperature surveys were run.

Increased temperatures and indications of improved crossflow at depth in well MC-3 prompted a flow test in early November 1983. Continual airlifting for a period of 20 hours resulted in a series of discharges achieving peak pressures of 850 kPa. Because of the casing and liner configuration within the bore, however, a cooler surface water downflow quenched the flow approximately 20 minutes after the airlift was ceased.

A small steam turbine was installed and tested on production well MC-1. The turbine which was originally tested as an 80 kW binary unit in Imperial Valley, California, was rebuilt and redesigned as a 20 kW axial flow steam turbine. The 20 kW_e demonstration turbine was loaned to B.C. Hydro by the Electric Power Research Institute (EPRI) who monitored the collection and interpretation of test data. The unit performed well in a series of 25 tests conducted during the summer 1984.

A study of the geochemistry of the Meager Creek geothermal field was conducted by Dr. J. Moore of the Earth Science Laboratory of the University of Utah Research Institute. The study was funded by the U.S. Department of Energy and was completed in the summer of 1983. The results were reported in a paper presented to the Geothermal Resources Council 1983 Annual Meeting in Portland, Oregon.

Dr. Moore's studies continued in 1984 and these additional results were published in the paper, "Geologic and Geochemical Investigations of the Meager Creek Geothermal System, British Columbia, Canada" in January 1985. His analysis of the alteration mineralogy of drill core samples identifies at least two distinct periods of hydrothermal activity. Temperatures for the second period (that associated with the geothermal activity in the Meager Creek geothermal system) may be 50°C to 150°C higher than those observed at present. He notes that extensive carbonate precipitation which has sealed fractures in the upper portion of the reservoir may account for this temperature decline.

Dr. Moore is planning to continue his studies in 1985, detailing the origin and history of the thermal fluids at Meager Creek.

Another study, performed by Dr. M.M. Ghomshei, concentrated on the compilation and interpretation of geochemical data from water samples collected during earlier exploration stages at Meager Creek. The findings of the study tend to concur with Dr. Moore's conclusions.

The Meager Creek well site was scheduled for abandonment by November 1984. However, flooding in October stranded much of the equipment on site. The early onset of winter precluded further demobilization and all remaining equipment was winterized and was stored at the well site until road access was restored in May 1985. The site was vacated by mid-November, although the dormant camp was visited regularly to guard against vandalism and snow damage. B.C. Hydro plans to vacate the site by October 1985.

SECTION 3.0 - RESULTS

3.1 WELL MC-1

MC-1, the first deep exploratory well drilled at Meager Creek, was spudded in mid-July 1981 and completed 4 months later. The well intercepted geothermal water ascending along the Meager Creek Fault at a depth of 1600 to 1800 m and is capable of sustaining continual discharge of 195°C fluids from this zone.

Ongoing monitoring of production from well MC-1 was augmented by numerous other activities during 1983 to 1985. Temperature surveys were run and the chemistry of the discharged fluid was monitored in order to become better acquainted with the geothermal reservoir characteristics.

By the spring of 1984, a small steam turbine had been installed on MC-1. The test program which saw Canada's first geothermal power production was conducted through the summer 1984.

(a) Pressure and Flow Measurements

Well MC-1 was undergoing production testing since early November 1982. The tests were conducted in order to determine the viability of long-term production from the thermal reservoir. Continuous production was to help ascertain the chemical signature and any chemical changes of the thermal water, the nature of the fracture system at depth and the long-term effects of production on reservoir characteristics. The tests were also to indicate the severity of corrosion of surface equipment by the saline thermal waters.

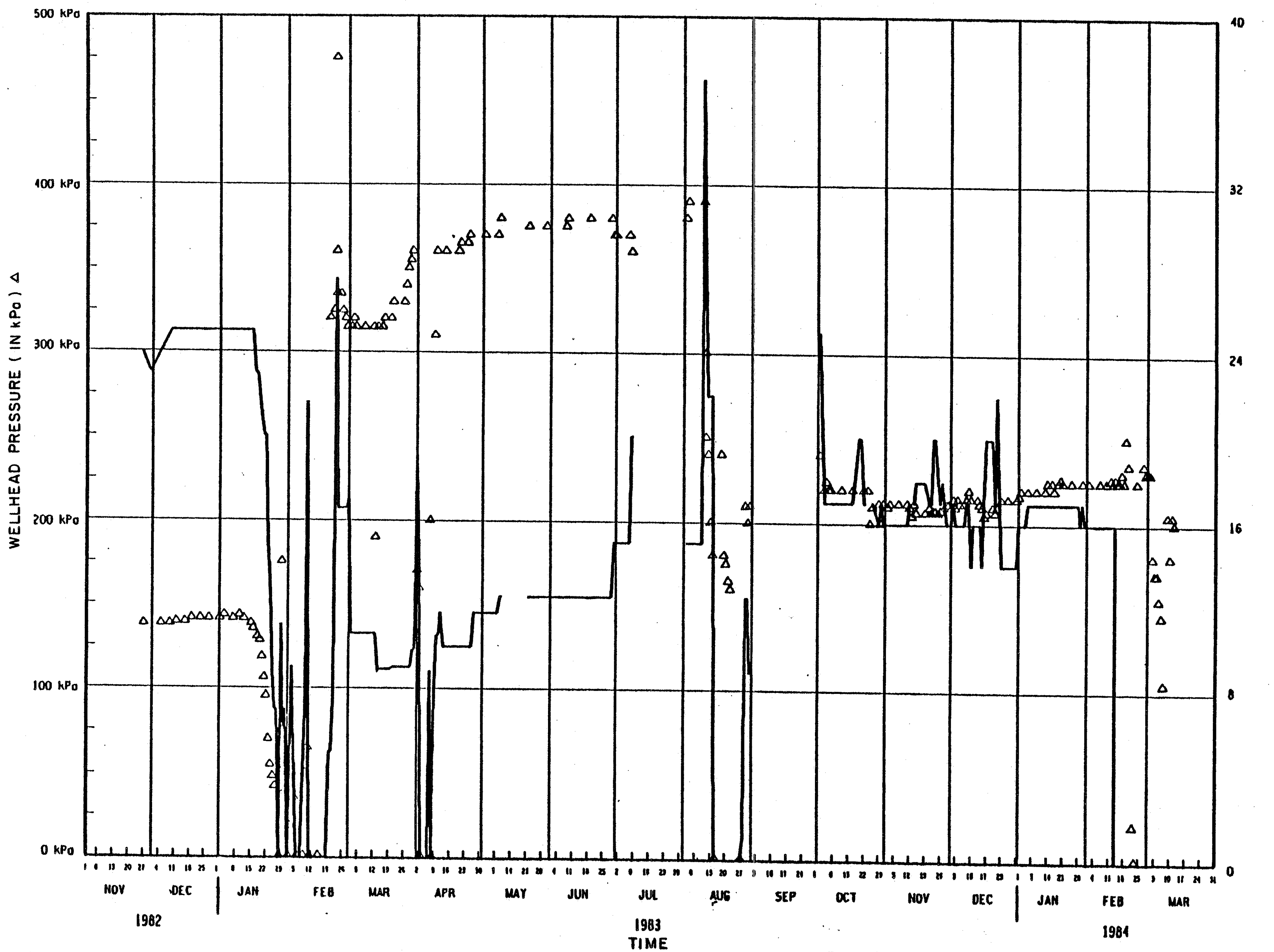
Wellhead pressures were monitored continuously with a clock-driven pressure gauge recorder mounted on a side-valve of the wellhead assembly. The chart was changed daily at which time the flow rate from the well was recorded. Flow was measured by means of a V-notch cut into the weir box of the separator/silencer unit. The total discharge from the well was estimated by adding 15 percent (to account for the steam fraction which escapes from the top of the separator/silencer) to the total liquid flow as calculated from the V-notch reading. The flow rate was recorded daily.

To inhibit scale deposition within the well bore, the master valve was kept slightly choked and the wellhead pressure was maintained at the highest level possible while allowing continuous flow. The geothermal fluid, saturated in carbonate and silica minerals, will deposit scale whenever high pressure or temperature conditions subside. When the fluid reaches its flashpoint, the pressure and temperature drop appreciably, and scale deposition occurs. By choking the master valve, the flash point could be manipulated to occur either at the outlet or within the wellhead, where scale can more easily be removed.

During test production, wellhead pressures were maintained at 200 to 220 kPa which resulted in an average flowrate of approximately 17 t/h (Fig. 3). This is equivalent to approximately 4500 kW_t or 700 kW_e assuming 10 percent efficiency of conversion.

(b) <u>Well Blockage</u>

Fig. 3 shows three periods where production was interrupted (January 1983, September 1983 and March 1984). The January stoppage resulted from the deposition of a hard siliceous-carbonate scale in the well bore at a depth of approximately 200 m. Precipitation of the scale occurred under lowered pressure



MC-1 TEST PRODUCTION PRESSURE-FLOW PROFILE

FIGURE 3

conditions caused by conducting the production test at full discharge.

The blockage was temporarily removed by surging the well pressure. When flow was re-established, the discharge contained pebble-sized chunks of the scale as well as numerous fragments of torn rubber. Larger pieces of the carbonate scale contained in the discharge displayed a concentric pattern of radiating calcite/aragonite crystals up to 1 cm in length. This configuration suggests an episodic deposition sequence rather than continual precipitation which might be anticipated from an established production test.

It is believed that rubber was torn from the "centralizers" (the annular spacer placed between the drill string and the casing which is designed to minimize string vibration during drilling). Over several months of exposure to elevated temperatures and pressures, the rubber compounds became embrittled and the centralizers disintegrated. The rubber may have been a key component in formation of the blockage.

The blockage reformed and again choked off flow from the well in mid-August. Various options for scale removal including acid and carbon dioxide injections were considered. However, because of economic considerations, mechanical methods were eventually employed. The blockage was removed by hammering on the constriction with a specially prepared steel rod attached to a 1 cm diameter cable from the drill rig. The rod was drawn to the top of the wellhead with the "sandline" winch and was released, running freely into the hole and pulverizing the scale deposit. Although chemical treatment is available for scale control, mechanically breaking the scale proved to be simpler and more cost effective, given the localized scaling problems in MC-1.

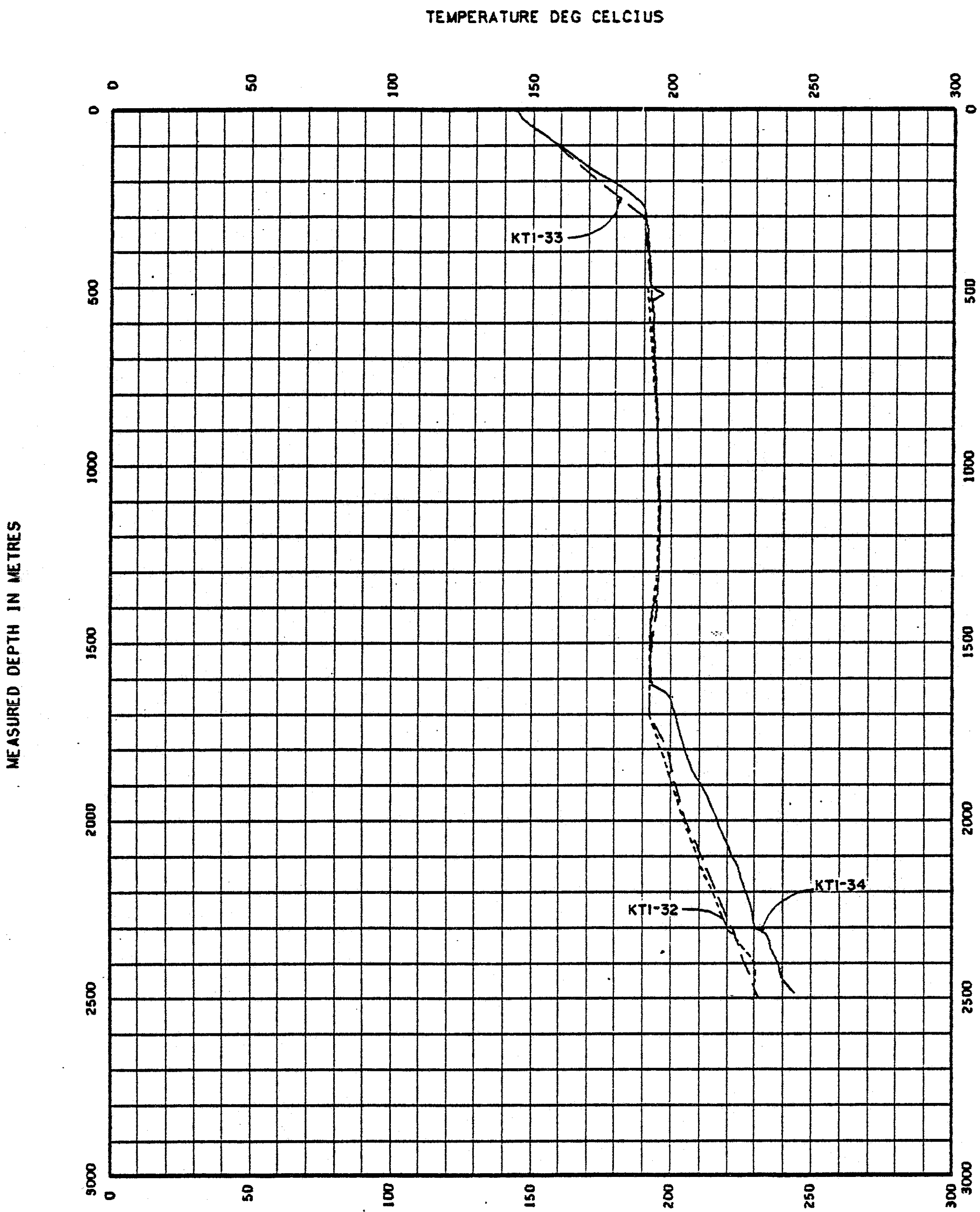
Decreased fluid production, again caused by scale deposition, began to interface with turbine testing in May 1984 and a diamond drill with a 6-inch reaming shell was used to ream the scale from the casing. A B.C. Hydro Force Construction Boyles 56A drill rig equipped with a bag-type blowout preventer was set up on log cribbing and specially designed elevated platform over the MC-1 wellhead. Using NQ rods and a reaming shell, the hole was cleared to a depth of 600 m. The operation was complete in approximately 6 days.

Well performance was significantly improved by this cleaning process which increased pressures by approximately 15 percent and flow by 10 percent. In addition, the recurrence of the scale deposition was delayed as the well showed no signs of any production decrease until the completion of the monitoring program. The diamond drill rig remained on site in case another cleanup operation was warranted.

(c) Temperature Measurements

Since November 1982 the MC-1 well was inaccessible to the temperature probe below approximately 800 m, probably because of slippage of the liner hanger. Removal of the blockage in MC-1 allowed data collection from the producing well to a depth of 2500 m. A total of three temperature surveys (KT1-32 to KT1-34) were conducted. A final survey, KT1-35, was attempted following the May 1984 well bore cleanup. This survey encountered an obstruction at a depth of approximately 700 m. The blockage is attributed to possible problems with the liner hanger at this depth.

Fig. 4 shows a compilation of these surveys. The temperature profiles are characterized by a rapid, near surface temperature increase to a depth of about 250 m where the curves become almost



MC-1 TEMPERATURE SURVEYS 1983-84

FIGURE 4

isothermal. A slight depression of the temperature between depths of 1000 and 1400 m may indicate a cooler, surface water downflow and invasion of the well bore through the perforated liner.

Below a depth of 1400 m the fluid temperature increases sharply, indicating conductive heating within a static water column. Hot production fluids enter at a depth of 1300 to 1400 m. Here, the fluid boils, separating into steam and liquid fractions. The 2-phase fluid ascends to surface where the temperature drops to the ambient boiling point and releases the gas phase to the atmosphere via the silencer/separator unit.

However, because MC-1 has penetrated an unconfined thermal "aquifer", choking the main valve and increasing the wellhead pressure above a value of approximately 250 kPa simply causes the fluid to resume its original ascent path along the Meager Creek Fault.

Temperatures in MC-1 have been fairly constant although a slight warming trend has been noted. However, because no temperature data is available for the well between December 1982 and September 1983, it is unreasonable to compare preproduction temperature surveys with those taken under dynamic (production) conditions. However, comparison between KT1-32 (September 1983) and KT1-35 (September 1984) indicate an overall warming of 3 to 8°C/a and a decrease in the depth of the flashpoint to approximately 130 m.

(d) Well Chemistry

In addition to regular discharge sampling of MC-1, an EPRI mobile chemical sampling unit was brought to the site in early August 1983. The portable lab (designed and operated by Rockwell International scientists on contract to EPRI) contains some of the most advanced and specialized geothermal sampling equipment available. EPRI brought the lab to Meager Creek in order to evaluate various chemical parameters of the production fluid. In addition to ascertaining the severity of scale problems and corrosive properties of the fluid, the lab performed a variety of other evaluations including waste water and steam fraction toxicity determinations (Ref. 34).

The analysis of periodic sampling of the production fluid from well MC-1 was reviewed by Dr. Morteza Ghomshei, working for the Meager Creek Project under a UNESCO post-doctorate fellowship. A paper entitled "Geochemical Evidence of Chemical Equilibria in the South Meager Creek Geothermal System" represents a summary of his findings. Raw water chemistry data and ionic strength vs. time interpretations were also determined (Ref. 34).

3.2 WELL MC-2

The second deep exploratory well, MC-2, was drilled during the winter of 1981/82 and underwent moderate testing the following spring. Although temperatures in excess of 270°C were encountered, and the permeability of the host rock was higher than well MC-1, the flow was insufficient to allow for sustained fluid production at the time of testing. MC-2 intercepted the Meager Creek Fault at approximately 2100 m, however the fluid pressure at this depth within the zone is less than the hydrostatic pressure of the static water column in the well bore and any production is effectively suppressed.

MC-2 remained largely inactive during the testing and monitoring program of 1983/84. A number of temperature surveys were run on the well during the summer and standing water level was monitored regularly. However, after difficulties in retrieving the temperature probe from the hole during a survey in late-August 1983, activity on the well has been minimal.

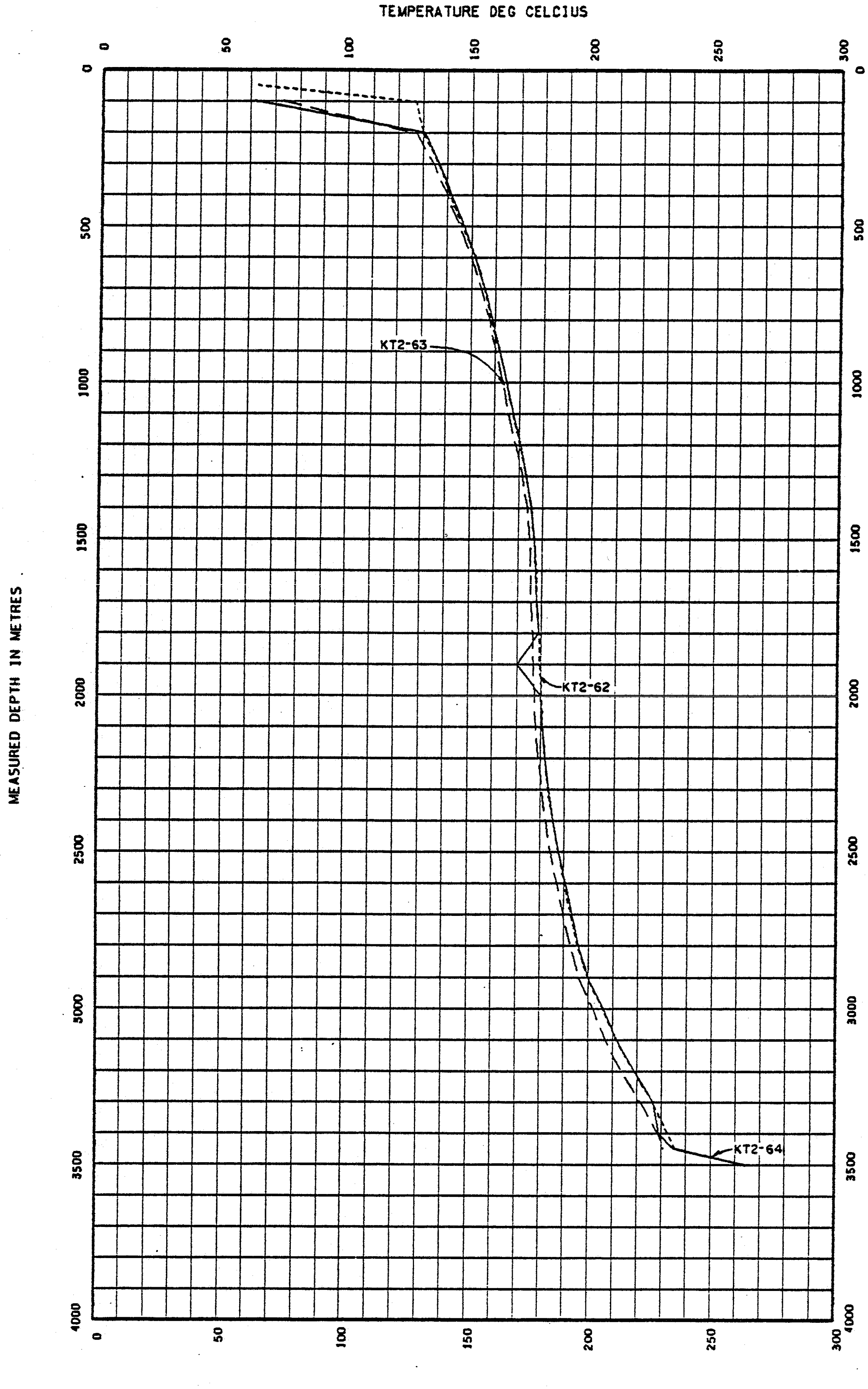
Three temperature surveys were conducted (KT2-62 to KT2-64; Fig. 5), and a significant increase in temperature was noted over comparable surveys performed approximately 8 months earlier. A general increase of approximately 5°C was noted in the lower portion of the well. The strong increase in the temperature gradient beginning at a depth of 2300 m became more pronounced as the well experienced longer static times. Detailed temperature traverses did not identify any new, or previously undocumented water inflow zones.

(a) Lost Equipment Recovery

A temperature probe was lost downhole during a survey run in late August. Numerous attempts at recovering the lost probe were made with the wireline and specially designed fishing tools. However, the tensile strength of the wireline proved inadequate to pull the lost probe and tangled wire nest past the top of the liner hanger. Fishing for the tangle was continued with the "sandline", a 1 cm steel cable and winch assembly which is part of the on-site drill rig equipment. Again, a specially prepared fishing tool was attached and this time the temperature probe was recovered uneventfully. After a month in the hole, the case of the temperature probe was covered with a fine coating of hard siliceous-carbonate scale and, apart from minor maintenance, the tool itself was fully functional. MC-2 is again clear to a total depth of 3503 m.

3.3 WELL MC-3

Well MC-3 was spudded in June 1982 and completed in early August. MC-3 had zones with good permeability and high temperatures, but formation damage from the invasion of drill fluid and the liner configuration have decreased the permeability significantly.



MC-2 TEMPERATURE SURVEYS 1983-84

FIGURE 5

Well MC-3 received considerable attention during the course of the monitoring and testing program of 1983/84. In addition to 10 temperature surveys being conducted, MC-3 was the subject of an airlift and stimulation attempt in early November 1983. The well, however, remained dormant through 1984 with several temperature surveys being conducted in late September.

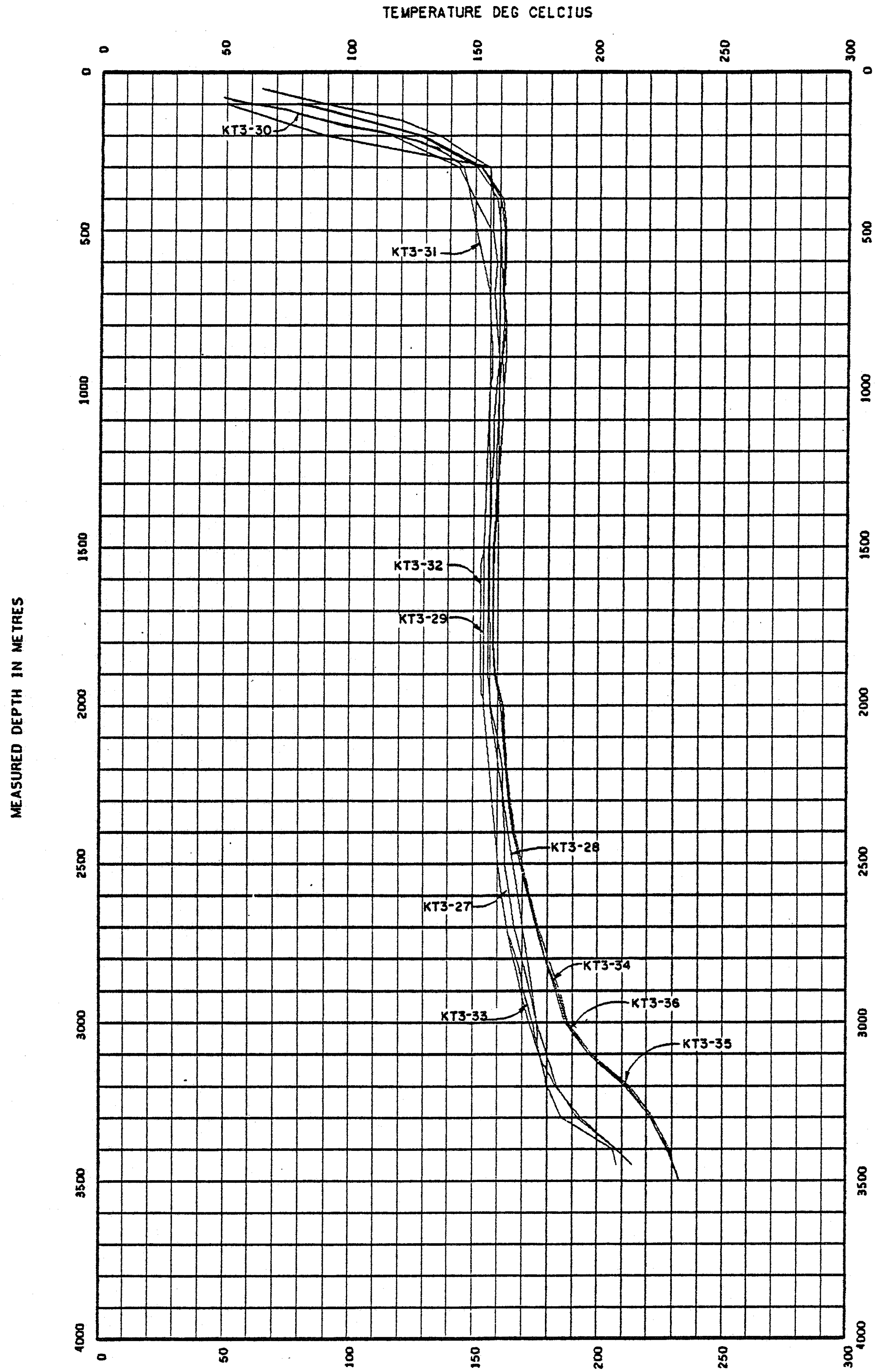
(a) Temperature Measurements

A series of 10 temperature surveys were run on Well MC-3 between mid-July 1983 and late-September 1984. Surveys KT3-27 to KT3-36 (Fig. 6), as with MC-2, indicate a long-term warming trend on the order of 3° to 5°/a. The shape of the temperature profile remains essentially unchanged and compares favourably with surveys conducted under similar conditions in late 1982, indicating that downhole fluid flow conditions have not altered.

A long, static period (November 1982 to July 1983) has not affected the temperature profile between the depths of 400 and 2000 m. The isothermal temperature profile between the depths of 400 and 2000 m would indicate that some form of hydraulic communication exists between upper and lower production zones. Cooler, 160°C surface waters appear to be flowing down the well bore to the 2000 m depth.

At the 2000 m depth, the fluid temperature increases slightly, indicating either an inward flow of warm water masking the effects of the cooler surface water, or the unsuppressed regional thermal gradient (i.e. the water column below 2000 m is static).

At a depth of 3000 m, the temperature again makes a major upwards inflection. The increase in gradient at this point is attributed to a sizable inflow from the No-Good Zone encountered at a depth of 3025 m during drilling. At that time, lost circulation material was pumped into the hole to avoid excess fluid loss during



MC-3 TEMPERATURE SURVEYS 1983-84

FIGURE 6

drilling. However, the material did not wash out after drilling was ceased and the otherwise permeable zone remains clogged.

Temperature data recently collected near the bottom of the hole (3000 to 3500 m) reflects a significant increase in thermal activity, indicating that the lost circulation material may have been freed and hotter thermal fluids were being introduced to the well bore.

(b) Flow Testing

The possibility of improved flow of thermal water approaching 230°C from the No-Good Zone prompted a flow test on well MC-3 in early November 1983.

(i) Test Description

"Airlifting" is a common procedure used to stimulate production from oil, gas and geothermal wells. Compressed gas is pumped into the hub of a spool of flexible steel ("endless") tubing while the tubing is slowly lowered into the hole. Gas rising through the static water column decreases its effective density and, consequently, the hydrostatic pressure. As a result, the 160°C fluid boils, forcing cooler water up the well bore ahead of the rapidly rising column of steam. In effect, the hole could be "pumped dry" to the depth of the end of the tubing as more of the column is vaporized.

In well MC-3, it was proposed that the endless tubing be run into the hole to the depth of the No-Good Zone. Given a sufficient pressure differential, the remainder of the lost circulation material could be expelled from the zone, and hot water would be produced spontaneously.

The flow test on MC-3 entailed an airlift procedure at depth within the well bore. Endless tubing was brought to the site by Nowsco Well Services and high-pressure air compressor pumps were supplied by International Air Drilling Services. This style of test had been attempted on MC-3 in October-November 1982, although the tubing was not extended to the 2500 m depth at that time.

(ii) <u>Observations</u>

The airlift progressed smoothly for approximately 20 hours while the tubing was lowered steadily into the hole. Care was taken not to over-pressure the tubing or compressors by slowing the endless tube feed rate while the hole boiled "dry" and the hydrostatic pressure subsided. During this time, hourly observations of wellhead pressure, discharge temperature, and flow characteristics were recorded. In general, a bell approximately 1 m diameter was formed at the outlet of the 6-inch (15 cm) diameter horizontal discharge pipe. The outlet temperature was consistently 93° to 97°C, near the boiling point under ambient atmospheric pressure.

While at a depth of approximately 2300 m the pressure suddenly rose, and the discharge increased. The compressors were stopped and the tubing was partially withdrawn because of a concurrent equipment breakdown. The well discharged a steam bell approximately 3 m in diameter. The flow was sustained for a period of about 20 minutes and pressures approaching 850 kPa were recorded on the pressure gauge at the wellhead. When the flow stopped, the tubing was again pressured up and lowered to a depth of 2400 m. Again, the well flowed at about 700 to 800 kPa for 20 minutes after the air compressors had been shut down. Although this process was repeated several times, the flow failed to sustain, choking itself off after about 20 minutes in each instance.

Following completion of the airlift, a temperature survey was attempted. However, the probe could not be lowered past a depth of 900 m. Apparently the probe was catching on the liner hanger. Later attempts at the temperature survey did manage to pass the 900 m mark and access the bottom of the hole.

(iii) Evaluation

Although well MC-3 is considered to have a very low overall permeability, this test has demonstrated that certain zones encountered in the well are capable of production for a period of 20 minutes.

3.4 TESTING OF 20 kW DEMONSTRATION TURBINE

(a) Turbine Acquisition and Installation

In July 1983, preparations were begun for the acquisition of a small turbine to be tested on the producing well MC-1. Arrangements were made with the Electric Power Research Institute Inc. of Palo Alto, California (EPRI) to supply a rotary separator turbine (RST). Conventional geothermal turbines, with the exception of binary cycle turbines, require higher temperature dry steam (usually combining the flow from several wells). The RST is a total flow-type turbine, ideal for the Meager Creek application as it utilizes both the steam and water fractions of the discharge from a smaller, cooler flow. Unfortunately, EPRI became involved in a legal dispute with the RST supplier and the equipment could not be supplied.

However, EPRI was able to provide a small, axial flow demonstration plant developed by Barber-Nichols Engineering of Denver, Colorado. This single flash steam turbine was installed and tested under varied conditions during spring and summer 1984. The test program was completed in October 1984. However, before it could be demobilized, flooding stranded the equipment on site. The separator, turbine and generator were winterized and remained at Meager Creek until May 1985.

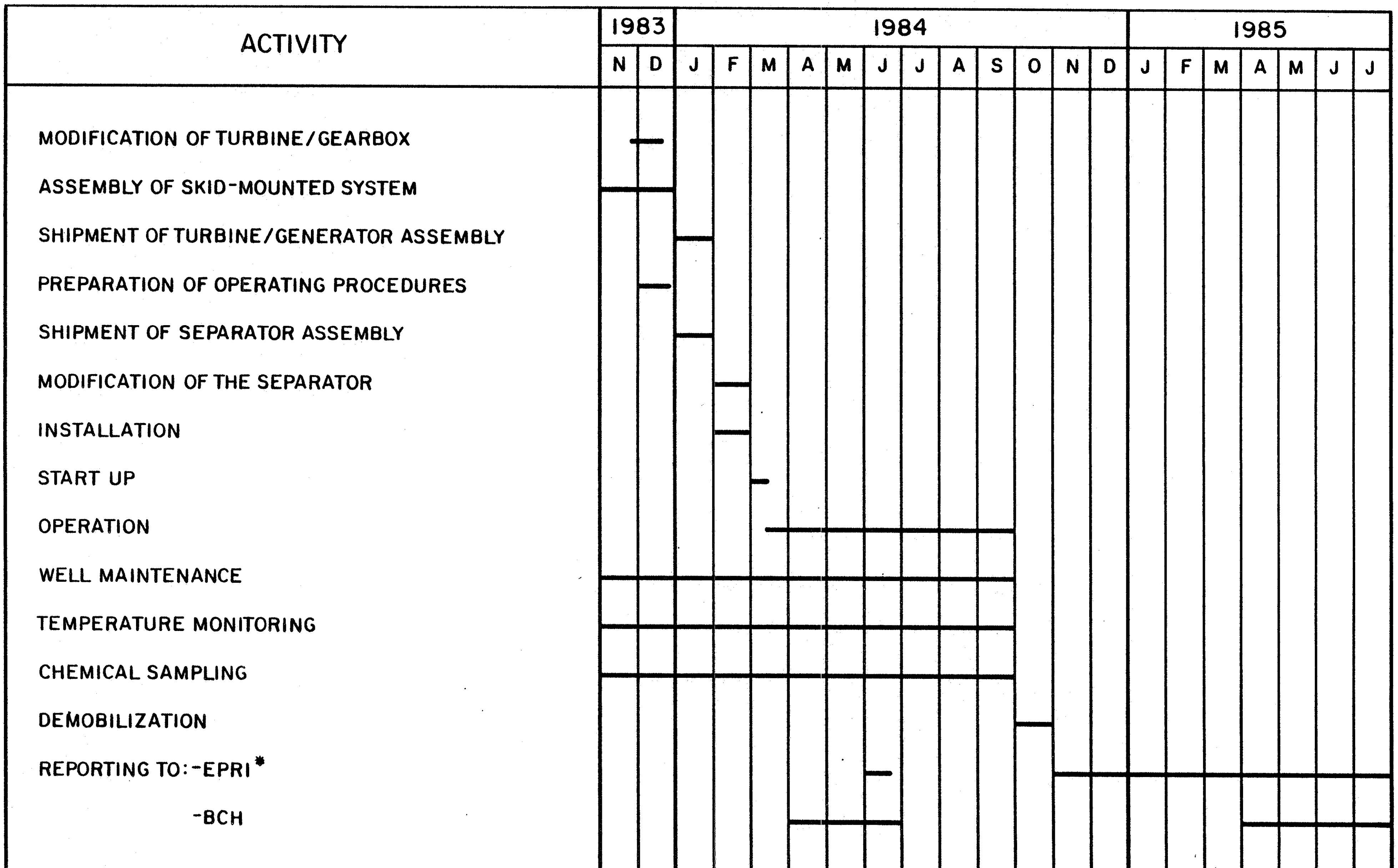
On-site preparations for the steam turbine began in late 1983 with the delivery of the generator, separator, and turbine to Meager Creek in mid-November. Installation proceeded slowly because of logistical difficulties imposed by the approaching winter season.

A reconditioning of the separator unit required much of the first 3 months of installation. The equipment supplied had been previously used and arrived at the site in only fair condition. Installation was completed by April 1984 and the testing program began shortly thereafter (Fig. 7).

(b) Turbine Testing

In order to provide EPRI with a reasonable working assessment of the steam turbine, a variety of tests were designed and conducted during summer 1984. Twenty-four tests were run. They ranged in length from 1 to 6 hours. Chemistry, temperature, pressure, flow rate and power output at a number of points in the separator-turbine test loop (designated, for example, T1, P1, F6a, W8 in Fig. 8) were recorded. The power was spilled to a load bank.

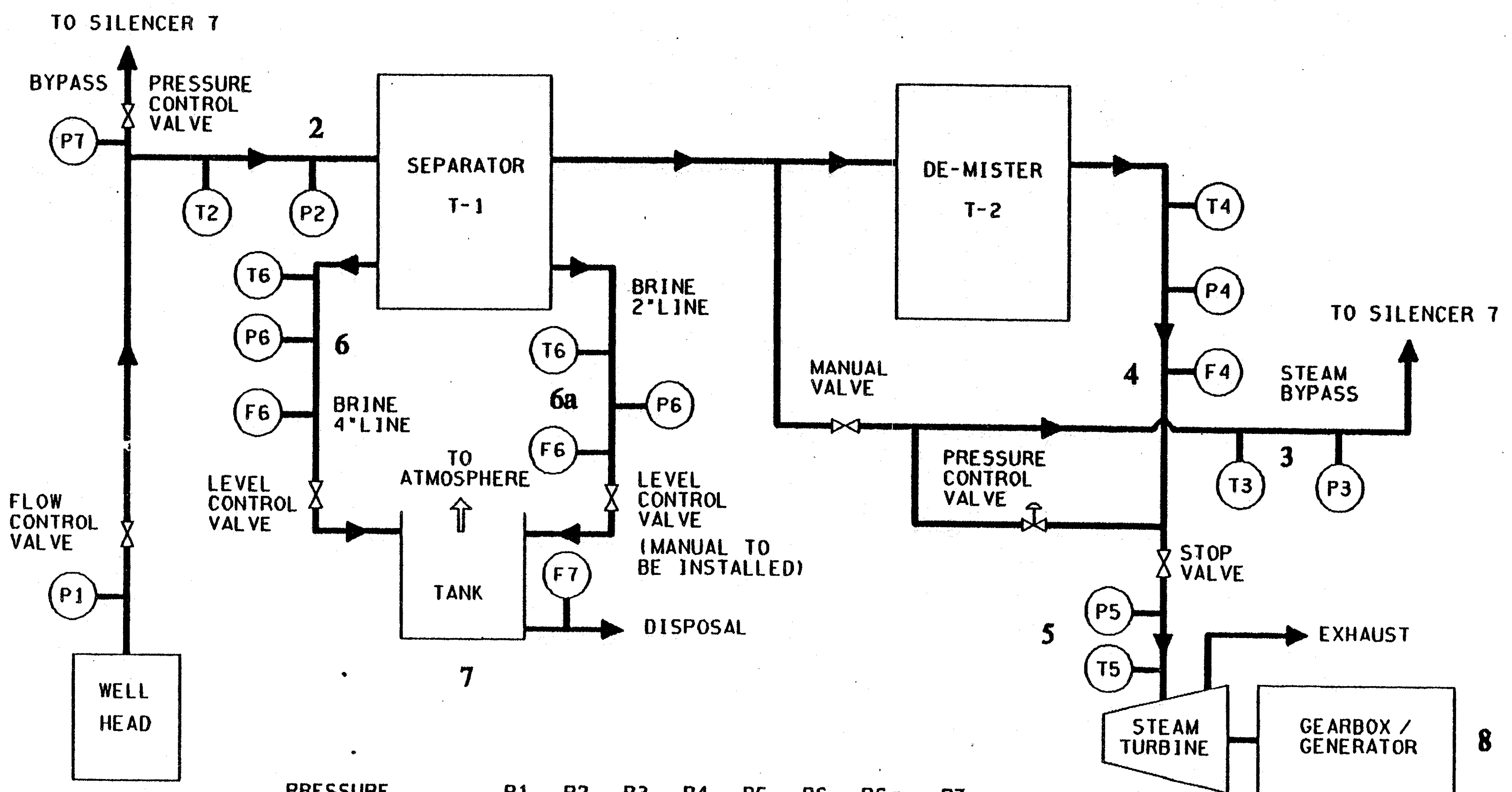
Although the steam turbine is rated at 20 kW_e, the output of the power tests ranged from 9 to 30 kW_e. In order to achieve a higher electrical output, a larger input line would be required and additional nozzles installed. As set up, the 100-mm (4-in) input



* NOTE:
DRAFT REPORT WAS SUBMITTED TO EPRI AT THE END OF MAY 1985

MEAGER CREEK PROJECT
TESTING SCHEDULE

FIGURE 7



PRESSURE	P1	P2	P3	P4	P5	P6	P6a	P7	
TEMPERATURE		T2	T3	T4	T5	T6	T6a		
FLOW				F4		F6	F6a	F7	
POWER									W8

MEAGER CREEK PROJECT
SEPARATOR-TURBINE TEST LOOP

FIGURE 8

line applied sufficient back pressure at the wellhead to choke the fluid flow from the bore. A bypass line leading directly to the silencer was installed in order to maintain wellhead pressures below a critical upper limit of approximately 350 kPa.

A report to EPRI on the results of the test is under separate cover (Ref. 34).

SECTION 4.0 - DISCUSSION

The collection of new data and the reinterpretation of existing data during the maintenance and testing program, which extended from 1983 to 1985, have provided information on reservoir characteristics.

Naturally, most of the work was concentrated on well MC-1 because of its capabilities as a geothermal producing well. The well was targeted to intercept a hypothesized, permeable volcanic breccia at a depth of 3000 to 3500 m. However, drilling complications stalled MC-1 short of this goal. Although the rock was characterized by low overall permeability, a number of shear zones and dykes associated with the Meager Creek Fault were encountered. The steeply northward dipping normal fault zone is considered to be associated with Meager Volcanic Complex eruptive activity and is a likely conduit for the movement of ascending geothermal fluids.

When first tested in 1981, MC-1 showed little potential, with comparatively low temperatures and permeabilities for a geothermal well. However, with flow testing and stimulation attempts, the well began to discharge a steam and water mixture under considerable pressure at the wellhead. Temperature surveys indicated that most of the fluid was entering the bore from the intersection with the Meager Creek Fault Zone at a depth of 1600 to 1800 m.

Continued production testing through October 1984 appeared to have improved the flow characteristics of MC-1. Recent surveys indicate that fluid temperatures continue to increase, and it may be inferred from pressure records that "production zone" permeability has increased since testing began. Although only a proper injection/pressure fall-off test could confirm it, production may have cleaned up the fault zone and enhanced the permeability substantially.

Testing has also shown that geothermal fluids in the Meager Creek system are heavily saturated with calcium carbonate and that scale control must be considered seriously in any future installation design. The corrosivity of the fluid is comparatively low by geothermal standards and the toxic element content is within workable limits.

Perhaps the most significant findings of the maintenance and testing program involved well MC-3. The 3500 m well was drilled westward, intercepting the "No-Good Zone", a near vertical fault structure running perpendicular to the Meager Creek Fault, at a depth of 3025 m. Several geochemical and geophysical surveys conducted in the vicinity had indicated that the No-Good Creek area showed considerable geothermal activity. During drilling, the structure proved sufficiently permeable to cause a total loss of circulation fluid.

SECTION 5.0 - REFERENCES

1. B.C. Hydro and Power Authority: "Proposed Aquatic Inventory and Impact Assessment Studies Relative to Meager Mountain Geothermal Development" Report No. ESS-44.21 pp. (1982a).

2. B.C. Hydro and Power Authority: "Preliminary Study of Aquatic Resources Relative to Meager Mountain Geothermal Development" Report No. ESS-53, 18 pp. plus appendices (1982b).

3. B.C. Hydro and Power Authority: "Meager Creek Geothermal Project - Summary Report for 1982/83". 36 pp. (1983).

4. Emslie, J.H. "Summary of Meager Creek Meteorological Data June 1979 - March 1982". Environmental and Socio-Economic Services, B.C. Hydro (1982).

5. Ghomshei, M.M., S.A.S. Croft and J.J. Stauder: "Geochemical Evidence of Chemical Equilibria in the South Meager Creek Geothermal System, British Columbia, Canada". Geothermics - 1985. International Journal of Geothermal Research (1985).

6. Hammerstrom, L.T. and T.H. Brown: "The Geochemistry of Thermal Waters from the Mount Meager Hot Springs Area, B.C." GSC Open File Report 77-IA 34 pp. (1977).

7. Hitchon, B. and I. Friedman: "Geochemistry and Origin of Formation Waters in the Western Canada Sedimentary Basin - I. Stable Isotopes of Hydrogen and Oxygen" Geochim. Cosmochim. Acta.33 pp. 1321-1349 (1969).

8. Kingston, Reynolds, Thom and Allardice Ltd.: "Meager Creek Geothermal Project Well Completion Report, MC-1". (unpublished) for B.C. Hydro and Power Authority. Report No. 144. 56 pp. (June 1982a).

9. Kingston, Reynolds, Thom and Allardice Ltd.: "Meager Creek Geothermal Project Well Completion Report, MC-2". (unpublished) for B.C. Hydro and Power Authority, Report No. 155. 63 pp. (September 1982b).

10. Kingston, Reynolds, Thom and Allardice Ltd.: "Meager Creek Geothermal Project Well Completion Report, MC-3" (unpublished) for B.C. Hydro and Power Authority, Report No. 167. 70 pp. (February 1983).

11. Kingston, Reynolds, Thom and Allardice Ltd.: "Report on Meager Creek Geothermal Project, 1981/82". Unpublished report to B.C. Hydro. Kingston, Reynolds, Thom and Allardice Ltd., Auckland, New Zealand. March 1983. 214 pp. (1983).

12. Lewis, T.J. and J.G. Souther: "Meager Mountain, B.C.: "A Possible Geothermal Energy Resource" EMR, Earth Physics Branch. Geothermal Series No. 9 Ottawa 17 pp. (1978).

13. Lewis, John F.: "Preliminary Field Report of Drilling Near Mount Meager and Mount Cayley Volcanic Centers". EMR, Earth Physics Branch Open File Report 12 pp. (1977).

14. Michel, F.A. and P. Fritz: "Isotope Hydrology of the Meager Creek Thermal Waters" Final Report for EMR 11 pp. (1979).

15. Moore, J.N., M.C. Adams and J.J. Stauder: "Geochemistry of the Meager Creek Geothermal System". Transaction Vol. 7 Geothermal Resources Council. (1983).

16. Moore, J.N., M.C. Adams and J.J. Stauder: "Geologic and Geochemical Investigations of the Meager Creek Geothermal System, British Columbia, Canada". Transactions Stanford University Geothermal Workshop. (1985).

17. Nevin, Andrew E. and J. Stauder: Canada - "Early Stages of Geothermal Investigation in British Columbia". Proceedings of the Second United Nations Symposium on the Development of Use of Geothermal Resources. San Francisco, May 1975. pp. 1161-1165. (1976).

18. Nevin Sadlier-Brown Goodbrand Ltd.: "Report on Investigation of Geothermal Resources in Southwestern British Columbia". (unpublished) to B.C. Hydro and Power Authority. 24 pp. (1974).

19. Nevin Sadlier-Brown Goodbrand Ltd.: "Report on Detailed Geothermal Investigation at Meager Creek". (unpublished) to B.C. Hydro and Power Authority 18 pp. (1975).

20. Nevin Sadlier-Brown Goodbrand Ltd.: "Report on 1978 Field Work, Meager Creek Geothermal Area, Upper Lillooet River, British Columbia". (unpublished) to B.C. Hydro and Power Authority. 82 pp. (1979).

21. Nevin Sadlier-Brown Goodbrand Ltd.: "Report on 1979 Drilling and Exploration Program Meager Creek Geothermal Area, Upper Lillooet River, British Columbia". (unpublished) to B.C. Hydro and Power Authority. 57 pp. (1980).

22. Nevin Sadlier-Brown Goodbrand Ltd.: "Report on 1980 Drilling and Exploration Program, Meager Creek Geothermal Area, Lillooet River, British Columbia", (unpublished) to B.C. Hydro and Power Authority. 123 pp. (1981).

23. Nevin-Sadlier-Brown Goodbrand Ltd.: "Report on 1981 Drilling and Exploration Program, Meager Creek Geothermal Area, Upper Lillooet River, British Columbia". (unpublished) to B.C. Hydro and Power Authority. 93 pp. (1982a).

24. Nevin-Sadlier-Brown Goodbrand Ltd.: "Meager Creek Geothermal Area, Slim Hole Drilling Summary". for B.C. Hydro and Power Authority. (1982b).

25. Nevin-Sadlier-Brown Goodbrand Ltd.: "Meager Creek Geothermal Area, MC-1 Geological Summary, July 1981 - October 1981". (unpublished) for B.C. Hydro and Power Authority (1982c).

26. Nevin Sadlier-Brown Goodbrand Ltd.: "Meager Creek Geothermal Area, MC-2 Geological Summary, November 1981 - March 1982". (unpublished) for B.C. Hydro and Power Authority (1982d).

27. Nevin Sadlier-Brown Goodbrand Ltd.: "Meager Creek Geothermal Area, MC-3 Geological Summary, April 1982 - July 1982". (unpublished) for B.C. Hydro and Power Authority (1982e).

28. Nevin Sadlier-Brown Goodbrand Ltd.: "Report on 1982 Drilling and Exploration Program, Meager Creek Geothermal Area, Upper Lillooet River, British Columbia". (unpublished) to B.C. Hydro and Power Authority. (1983).

29. Read, P.B.: "Geology, Meager Creek Geothermal Area, British Columbia" GSC Open File 603, map, legend and descriptive notes. (1979).

30. Reid, Crowther and Partners Ltd.: "Meager Mountain Geothermal Project, Status of Environmental Studies, Baseline Data, Collection Program". (unpublished) prepared for B.C. Hydro and Power Authority 55 pp. (1981).

31. Reid, Crowther and Partners Ltd.: "Meager Creek Geothermal Project, Detailed Environmental Studies, Terms of Reference", (unpublished) prepared for B.C. Hydro and Power Authority. 78 pp. (1982).

32. Reid, Crowther and Partners Ltd.: "Environmental Reconnaissance Report, Meager Creek Geothermal Area", prepared for B.C. Hydro by Reid, Crowther and Partners Ltd. in association with VTN Consolidated Inc. 124 pp. plus appendices. (1979).

33. Stauder, J.J., J.M. Menzies, C.C. Harvey and T.M. Leach.: "Meager Creek Geothermal Project - Preliminary Resource Evaluation". Proceedings of the 7th Annual EPRI Geothermal Conference and Workshop. (1983).

34. Stauder, J.J.: "Meager Creek Project Resource Characteristics and 230 kW Wellhead Turbine and Separator Testing". B.C. Hydro Report. Prepared for EPRI. (1985).