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THE CIRCULATING WATER AND GAS EXTRACTION SYSTEMS FOR OHAAKI POWER STATION

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ABSTRACT

The paper provides discussion on two of the key systems installed at Ohaaki Power Station: the circulating water and gas extraction systems. The authors briefly consider the constraints placed on these systems by the environment, operating requirements and the optimisation process before continuing to discuss the design decisions that led to the final design. The systems, in terms of both equipment and operation, are also described.

INTRODUCTION

The development of Ohaaki during the 1980's, a time of increasing concern as to the effects of power developments on the environment, resulted in steamfield and power station systems designed with the environment in mind.

This paper addresses two of the power station systems that have been influenced by environmental considerations - the circulating water (CW) system, which provides cooling water for the intermediate pressure (IP) turbo-generator condensers, and the gas extraction system, which removes non-condensable gases from the condenser. The approach used to meet the environmental constraints differs between the two systems - the CW system by either avoiding discharge or using reinjection, and the gas extraction system by encouraging the widest possible dispersal of the discharge.

The paper also provides a brief insight into the key design decisions and a description of the systems and plant installed.

OPERATIONAL REQUIREMENTS

Before considering the design decisions made, it is necessary to review the other influences on them. The first of these is the operational requirements imposed by both the geothermal resource and the electricity demand. The impracticality of using a geothermal resource to supply vastly varying quantities of steam and the requirement for cheap continuous power to supplant more expensive generation dictated that Ohaaki would be a base load station.

Ohaaki is also relatively close to Wairakei Power Station and the economics of operating it as a stand alone power station were unattractive when compared with making Ohaaki a satellite operation from Wairakei. A simple step from the concept of satellite operation was that of unmanned operation, a philosophy which had a significant effect on the design of the systems.

OPTIMISATION

The second major influence on the systems being considered is the optimisation process required to ensure that minimum costs and maximum revenue are achieved.

The circulating water and gas extraction systems are not only capital and energy intensive in themselves but also have a significant effect on the performance of the turbo-generator and hence power station efficiency and output. Optimisation procedures are therefore necessary to determine the best solution based on the large number of often apparently conflicting variables.

The optimisation process for Ohaaki considered the turbine in association with the key components of the two systems. Traditionally such processes would consider a single design point based on the limited meteorological data available; the key parameters for the process being wet and dry bulb temperatures and atmospheric pressure. In the Ohaaki case, four years of on-site climate data was available and therefore a computer programme was developed to make use of this data and carry out the optimisation over the full range of anticipated conditions.

The complex model, previously described by Pearce (1981), combined the effects of capital and operating costs of the major plant items (turbines, condensers, CW pumps, gas exhausters, etc), their predicted performance data and predicted operating regime and the climatic data to determine the net station value, this value being the difference between the capitalised value of the power generated and the total cost of the plant.

By maximising the net station value, the optimum key parameters of CW flow, cooling tower design point, condenser pressure range, etc. can be determined. Optimising over a range of conditions results in plant sizing for the optimum and not necessarily the maximum duty point, the effects of which will be discussed later.

DESIGN DECISIONS

A number of design decisions were made at a very early stage based on anticipated environmental considerations (Canvin (1989)). Others flowed from the optimisation process discussed above. All decisions had ultimately to be made on a sound engineering basis with due weight to operational factors and the availability of proven hardware. Some of these aspects are discussed in more detail by Tokeley (1989).

a) Plant Operation

As previously discussed, Ohaaki was required to be a satellite of Wairakei. This led to the further decision to make it unmanned.

b) CW System

Concern for the environment led to a decision not to apply for water rights to obtain cooling water from the Waikato River and therefore a closed cooling system with cooling tower(s) was adopted.

c) Condenser Type

The use of direct contact condensers, almost standard practice in the geothermal industry, was an early decision. The choice of condenser type, between barometric leg and pumped extraction types, was eventually decided in favour of the former primarily due to its inherent safety from flooding, particularly important for an unmanned station.

d) Cooling Tower Type

The economics did not produce a clear advantage between natural draft or mechanical draft cooling towers. The decision in favour of the single natural draft tower installed was therefore based largely on environmental considerations. The Waikato River valley at Broadlands is subject to fogs which would be made worse by low level discharge from mechanical draft cooling towers. Additionally the natural draft tower could be used to aid non-condensable gas dispersion.

e) Gas Extraction

The choice between rotary gas exhausters and steam ejectors was made in favour of the former on the basis of pure economics when relatively high percentages of gas have to be removed.

CIRCULATING WATER SYSTEM

This section provides a description of the various components of the CW system. ,Figures 1 & 2 indicate the extent of the system. A number of aspects are however common to all or most of the components.

a) Materials

The nature of the fluids present in various parts of the CW system, due to the H_2S and CO_2 dissolved in the condensate lead to a careful selection of materials to ensure long-life.

Materials actually used in the system fall into two categories; metallic and non metallic. All metallic components in contact with the circulating water are manufactured from 316 stainless steel. This includes the condensers, which for economic reasons are fabricated from clad stainless steel plate, being 3mm of 316 SS backed by 20mm of carbon steel for structural strength.

A variety of non metallic materials are used, the major ones being fibre reinforced plastic (FRP) and high density polyethylene (HDPE). FRP is used for the barometric legs, the buried culvert and CW pump discharge pipeline and HDPE for the cooling tower pack and the smaller auxiliary cooling water supply lines.

b) Failsafe

The power station will operate unattended and therefore extra safeguards have to be built into the system to ensure that it reverts to a safe condition in the event of trips etc. A key factor in determining the required extent of these safeguards was the power station location at the top of a hill overlooking a number of environmentally sensitive areas along the Waikato River. The possibility of a large scale overflow into the Waikato River had to be minimised.

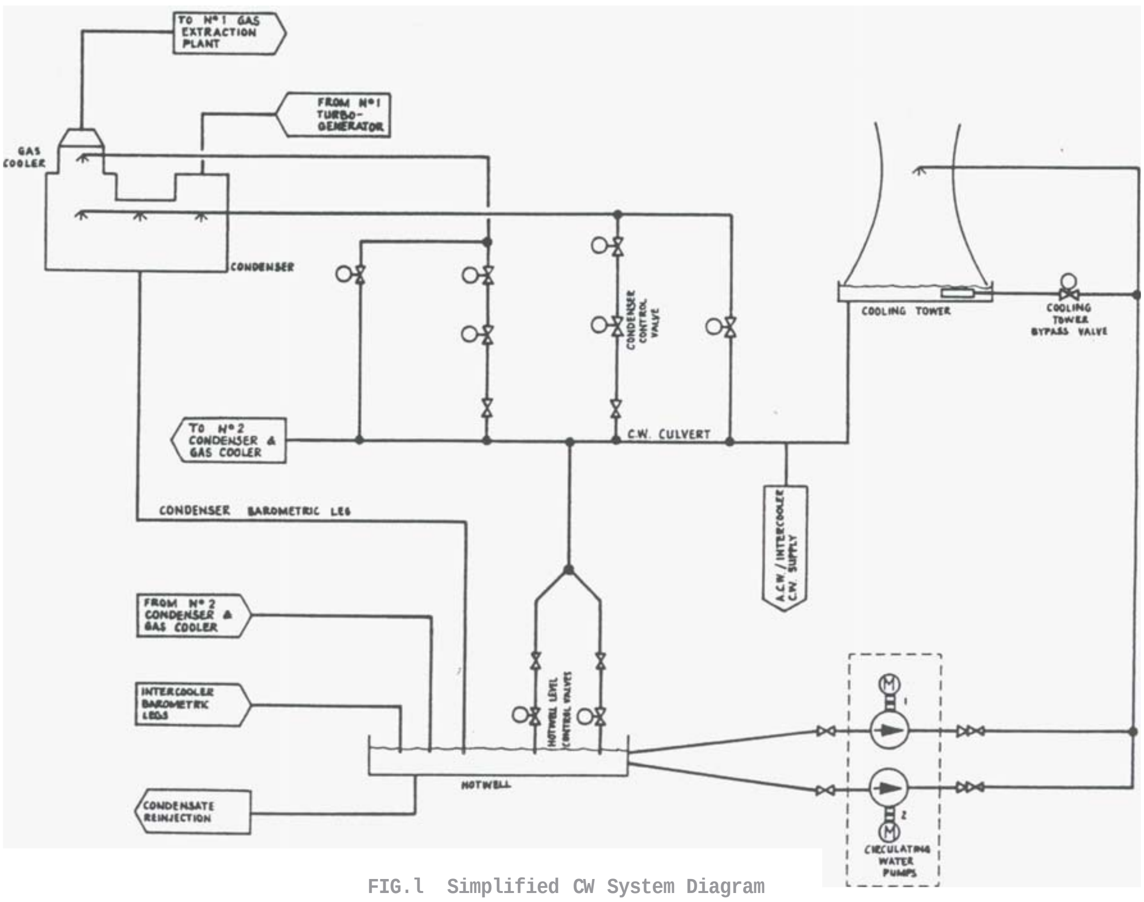

FIG.1 Simplified CW System Diagram

This was achieved by two means. Firstly the hotwell, as the lowest point in the system, includes a substantial overflow chamber which can collect all the water discharged from the condenser barometric legs following an emergency trip caused by a major electrical power loss. In the unlikely event that there is insufficient capacity in the overflow chamber, the excess water will flow over a weir in the hotwell wall into a large bunded overflow channel/reservoir.

Secondly, vital valves have been duplicated with a second valve in series and/or provided with a stored energy system (e.g. nitrogen gas or hydraulic accumulator) to provide operation in the event of power failure.

CONDENSERS. GAS COOLERS AND INTERCOOLERS

Condenser design is critical to both the power output of the power station and the resultant water chemistry in the CW system itself. Poor control of the CW chemistry may lead to corrosion or slime problems. A pilot plant was used at Ohaaki to investigate the best method of controlling the absorption of H_2S and CO_2 into the CW within the condenser and gas cooler. The results of these pilot studies were made available to the manufacturer's condenser designers for use in the condenser design.

The condenser itself is divided into four sections, designated according to the relationship between steam and water spray flow directions or function. The co-current section directly below the turbine exhaust, the cross-current section (a horizontal portion which passes out through the turbine hall wall) and the counter-current section with the separate gas cooler section mounted on top. Water boxes and nozzles are installed in each section to provide the correct distribution of water spray.

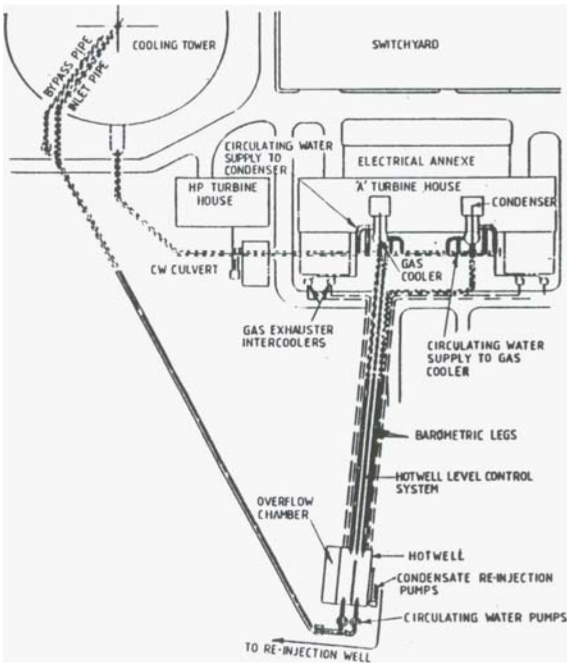

FIG.2 Plant Layout showing major components of the Circulating Water and Gas Extraction Systems.

Water supply to the first three sections of the condenser is controlled by the butterfly condenser control valves, with a separately controlled supply used for the gas cooler section. This reflects the findings of the pilot plant work and will allow for the possibility of some control of CW chemistry. A second control valve is installed in parallel to the main ones to be used whilst they are out of service for maintenance etc.

Both the condenser control valves and their isolation valves are fitted with nitrogen powered pneumatic motors for emergency use.

The barometric leg discharge from the condenser leaves from below the counter-current section.

An intercooler is fitted between stages of each gas exhauster in the gas extraction system. These direct contact heat exchangers are used to reduce the gas temperature part way through the gas compression cycle of the gas exhausters thereby reducing power requirements and water vapour carry-over. CW flow into the intercoolers is controlled by butterfly valves and is discharged to the hotwell via separate barometric legs.

HOTWELL LEVEL CONTROL SYSTEM

The hotwell level control system bypasses CW from the CW culvert directly into the hotwell. Its purpose is to maintain a constant water level in the hotwell by compensating for variations in the flow from the condensers.

The system has two parallel legs each with a motorised control valve, discharging below water level in the hotwell, and an isolating butterfly valve. The control valves are located at the hotwell to minimise the delay between demand for more flow and that flow becoming available. The bypass system is designed to pass flows of 3.6 cumecs during start-up with lower quantities modulated during operation.

The valves are normally operated electrically but air motors are provided to give emergency closing from a nitrogen bottle supply if the electrical supply is unavailable when the valves are asked to close by the trip system.

HOTWELL AND CW PUMPS

The hotwell consists of two chambers - operating and overflow (Fig 3). The decision to use only two 50% CW pumps, a result of the optimisation process, allowed the relatively simple shape of the hotwell to be adopted. The total capacity of both chambers of the hotwell is designed to accept the total volume of condensate that can enter it in the event of a plant trip.

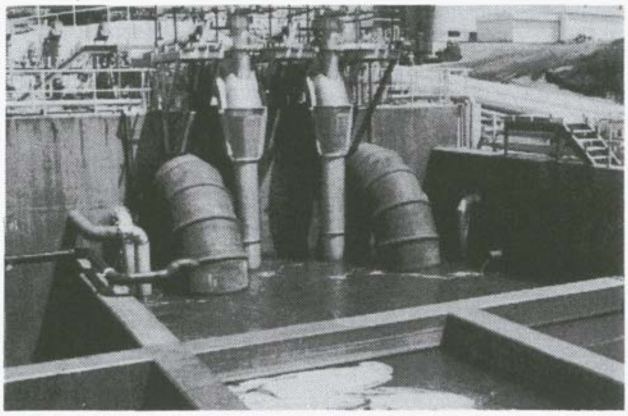

FIG.3 Hotwell showing level control valves and barometric legs entering the operating chamber.

Model testing was used to determine the hotwell arrangement. This was considered necessary as the flow entering the hotwell from the barometric legs is turbulent. Classical long flow channels were required to prevent suction problems for the CW pumps, separate channels with baffles being run to each CW pump.

The CW pumps are of a split casing horizontal type which facilitates their dismantling without the need to disturb the adjacent piping and valves. Shaft sealing is provided by mechanical seals.

Combined isolation and non return valves, of the butterfly type, are provided on both the suction and discharge sides of the pumps. These valves have to close in trip situations to prevent the flooding of the hotwell and are therefore provided with large counter weights to ensure closing in the event of power loss. The valves are opened using a centralised hydraulic system.

COOLING TOWER

The 105 m tall 70 m diameter natural draft cooling tower is the most obvious feature of the Ohaaki skyline (Fig 4). It is used for both circulating water cooling and non-condensable gas dispersal.

Circulating water, from the hotwell, is pumped to the cooling tower via the 1800 mm discharge line. A central vertical riser within the tower carries the water to the diametrical distribution culvert. This large rectangular duct feeds the PVC distribution network.

The water sprayed downwards from the distribution network drops onto the pack. The pack consists of 110,200 grids, held in 25 different layers. The grid assists in the heat transfer from the water to the airflow. Moisture eliminators are provided above the spray system and pack to reduce the amount of moisture becoming entrained in the rising air column.

Isolation gates are fitted to the distribution culvert and these along with a number of distribution network isolation valves, permit the division of the tower into halves as part of the ice-up protection. Icing of the pack (and its collapse from the extra weight) is a problem in many countries and may be a problem at Ohaaki, particularly during winter start-ups. Water distribution over half the pack at times of low ambient temperature reduces the risk. Constraints on operation have also been incorporated into the control logic which will not allow the station to operate if there is danger of the pack icing up.

A cooling tower bypass is also fitted to the system. This valve allows the flow from one CW pump to be directed to the tower pond without passing through the tower pack. This enables the plant to be started up under cold weather conditions without causing icing problems in the tower.

CW SYSTEM DOSING

The CW system, initially filled with river water, is progressively diluted with condensate during operation. A dosing system was installed in order to provide for control of pH and organic growth within the CW circuit. This was considered to be particularly important in order to avoid heat exchanger fouling and reduced pump efficiency.

AUXILIARY COOLING WATER SYSTEM

While the CW system supplies cooling water for the condenser cooling, the ACW is used for other cooling throughout the IP station.

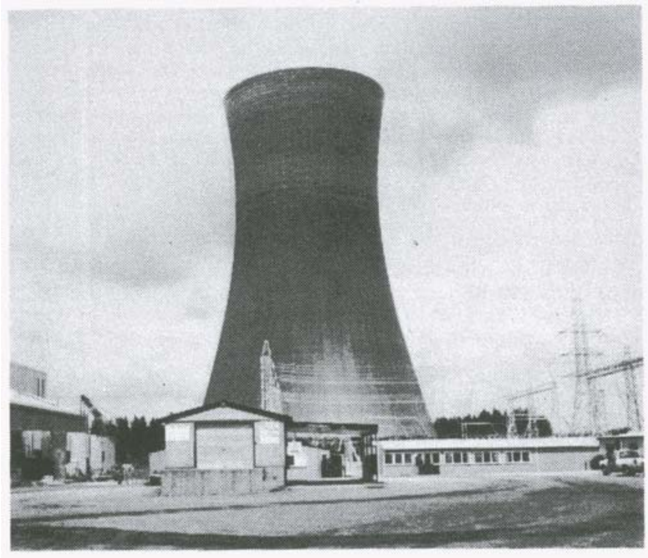

FIG.4 Cooling Tower.

Two ACW centrifugal pumps, one 100% duty and one standby, are used for each turbo-generator. Key items such as CW pump motors can be supplied with cooling water from either turbo-generator's system.

Areas of stagnation likely to cause corrosion problems are avoided by providing back flow bleeds in standby coolers, pumps etc.

CW SYSTEM OPERATION

Circulating Water in the cooling tower pond (recooled water) flows to the CW culvert from where it is drawn by the condenser vacuum into the direct contact condensing plant (including gas coolers and gas exhauster intercoolers) and discharges via the barometric legs to the hotwell. Under normal operation each condenser's recooled water requirement is controlled by a Condenser Control Valve. The recooled water requirement for the gas coolers and gas exhauster intercoolers are separately controlled.

Two CW pumps, arranged in parallel, draw CW (at a constant rate of 2.85 cubic metres/second each) from the hotwell and discharge it via a common discharge line to the cooling tower. For normal operation, the number of pumps running matches the number of turbo-generators running.

The outflow from the hotwell will normally exceed inflow and therefore to avoid the depletion of hotwell water which would result, a flow of recooled water is bypassed around the condensing plant, directly from the culvert into the hotwell via the hotwell level control valves. The optimisation process in fact resulted in the CW pumps being sized smaller than required for maximum condenser demand and in these circumstances the water level in the hotwell is controlled by the condenser control valves (about *20%* of the time), with the hotwell level control valves closed.

The CW system continually gains water as steam/water vapour is condensed in the direct contact condensers and from various pipework drains, and loses water in the natural draught cooling tower by evaporation and drift. The gains exceed the losses and with the hotwell level control valves maintaining hotwell level, the resulting excess accumulates in the cooling tower pond. The condensate reinjection (CR) system is provided to extract water from the hotwell and inject it into the reinjection wells to maintain cooling tower pond level.

Three pumps (nominally two duty, one standby) are installed in the CR system, automatically starting/stopping on high/low levels in the cooling tower pond. During periods when the pumps are not required, a bypass line around the pumps is open allowing an unassisted and thus lower reinjection rate.

GAS EXTRACTION SYSTEM

The gas extraction system is in fact two separate identical sub-systems, one for each of the IP turbo-generators (Fig 5 & 6).

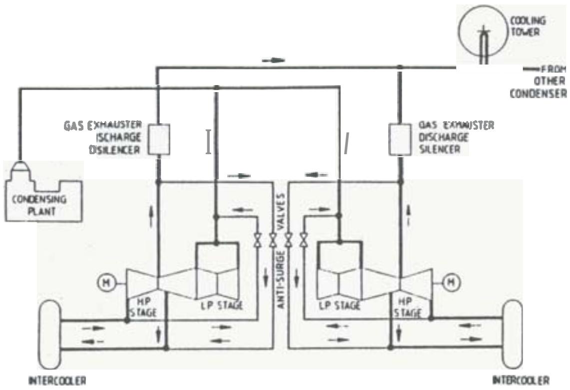

FIG.5 Simplified Gas Extraction System Diagram.

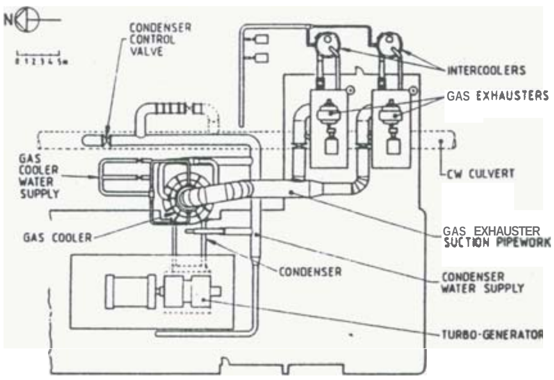

FIG.6 Condenser and Gas Extraction Plant Layout.

Parts of the gas extraction system have already been mentioned in the previous sections. This section provides a more detailed description of the system used. In common with the CW system it makes use of 316 SS and FRP for the majority of its components.

GAS EXHAUSTERS

Two 50% duty motor-driven gas exhausters are installed for each turbo-generator to extract non-condensable gas from its condenser. The gas is drawn from the top of the gas cooler section of the condenser via a single 2000 mm diameter gas duct which bifurcates to supply the individual exhausters.

High speed (7800 rpm) industrial type rotary gas exhausters are used. Each is driven through a large gearbox by an 1150 kW electric motor rotating at 1490 rpm.

Gas compression is carried out in stages with the gas being passed out to the direct contact intercoolers (one per exhauster) between the high pressure (HP) and low pressure (LP) sections. Cooling of the gas part way through the compression cycle provides considerable savings in motor power consumption and reduces water vapour carry-over.

Noise generation is a problem with plant of this type. Pipework directly underneath the gas exhausters, including the anti-surge system, is contained in an acoustic enclosure, whilst other pipework is individually insulated. The gas exhausters themselves are not treated.

ANTI-SURGE SYSTEM

An anti-surge system fitted to the gas exhausters ensures stable operation at low gas flows. To enable stable and efficient operation, gas exhausters normally require a relatively constant flow through them.

Individual anti-surge systems are fitted to each gas exhauster and provide two separate recycling paths for the gas to prevent surges which occur when the geothermal gas flow is less than that required for stable operation. These paths, around the LP and HP sections, respectively connect the intercooler outlet to the gas exhauster suction and the gas exhauster outlet to the intercooler inlet.

Each anti-surge path contains an hydraulically powered butterfly valve which is operated by a controller sensing gas flow, temperature and pressure.

GAS DISCHARGE DUCTWORK

The vapour and non-condensable gases extracted from the condenser are discharged into the cooling tower plume for dispersal. FRP ducts are used to carry the gas from the gas exhausters to the discharge nozzles located above the moisture eliminators in the cooling tower, one duct being used for each pair of gas exhausters (sub-system).

A gas silencer is installed between the gas exhauster and the duct. The silencer is used to avoid significant noise generation from the ducts and cooling tower.

GAS EXTRACTION SYSTEM OPERATION

Operation of the sub-system may require one or both gas exhausters to operate depending on gas quantity, which is likely to vary during the operation and exploitation of the field.

At start-up of a turbo-generator, the condenser vacuum cannot be drawn dom from atmospheric pressure by the gas exhauster as this would overload the gas exhauster motor. A steam driven start-up ejector is therefore used to draw the initial vacuum prior to gas exhauster start-up.

The gas exhauster motor is heavily loaded during start-up sequence due to the high inertia load of the exhauster and the gearing. Start-up of the exhausters will therefore take longer than could normally be expected for motors of this size. There are therefore limitations placed on how frequently the motors can be started.

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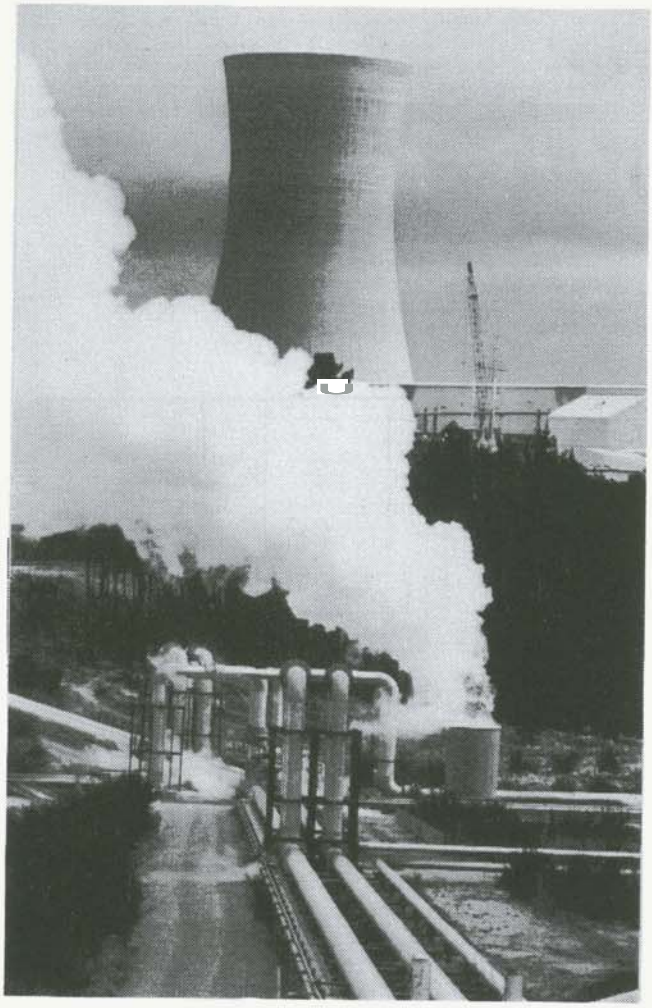

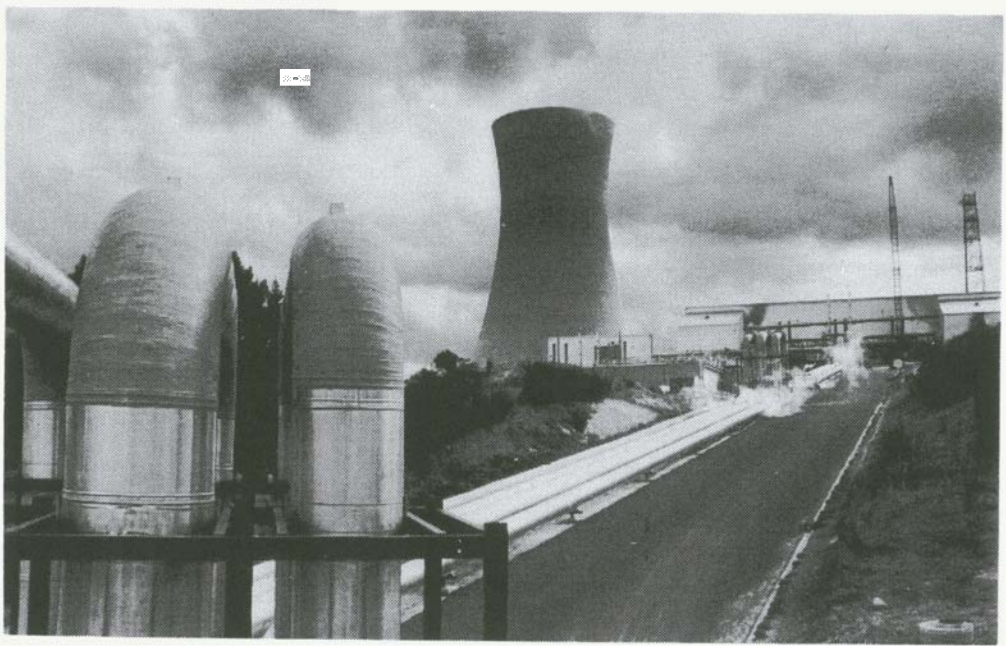

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