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TARAPUR ATOMIC POWER STATION

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Tarapur Atomic Power Project

ABSTRACT

This paper gives an account of the Tarapur Atomic Power Project. The station is located about 62 miles north of Bombay and will feed power into the power systems of Western India serving industrial areas around Bombay and in Gujarat. The reasons for adopting the dual reactor design and the choice of the output of the station are dealt with. The choice of the reactor type and the constructor was made from amongst seven proposals received from four countries submitted in response to a global invitation to bid which included detailed performance requirements and also standards for design and workmanship. The station will consist of two boiling water reactors using forced circulation with internal steam separation and pressure suppression containment is adopted. The paper discusses the philosophy of the layout and the basis of design of the systems and components and how this has been influenced by conditions at the site, characteristics of the power system into which the station will be feeding power and the fact that two identical reactors are housed together. The paper also deals with the conservatism in design and the potential for exploiting this conservatism. The reasons that led to the choice of the core design which consists of slightly enriched uranium oxide pellets clad in Zircaloy-2 arranged in a 6 x 6 matrix is dealt with. Information about the cost of the station and power costs is also presented.

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1. Introduction

1.1 India's first atomic power station is being built at Tarapur about 62 miles north of Bombay and will feed the power systems of western India serving areas around Bombay and in Gujarat. The station will have a net output of 380,000 kw and consist of two reactors each connected to a turbine generator system.

1.2 The west coast region of India around Bombay and in Gujarat is one of the highly industrialised parts of the country and the demand for power is growing very rapidly. At present, the power needs in this region are being met from a number of hydro electric stations and also coal fired power stations. There are also a number of isolated small thermal power stations some using coal and others using diesel oil; progressively the areas served by the isolated sets will be linked up with the organised net work so that power could be supplied in a more efficient manner. Coal for this region, however, has to be transported over distance of 700-1000 miles and the present cost of coal is Rs. 2.60 to 2.90/million BTU (or 54 to 61 U.S. cents/million BTU). Since the more readily exploitable hydro resources in the region have already been tapped, further generation capacity in this region can only be from coal fired stations using high cost coal or from atomic power stations. Conventional thermal power stations using oil cannot be considered as already the country is importing large quantities of oil and large scale generation of power using oil would mean further importation of oil thus aggravating the already difficult balance of payments situation. At the time the decision to construct an atomic power station in this part of India was taken, our studies indicated that the cost of power from such a station would compare favourably with that from an alternative coal fired station and in fact as will be seen from a later discussion on the cost of power from the proposed station, the forecasts were more than justified. Installation of an atomic power station also has the advantage that the pressure on the railways, which handle the coal traffic, would be relieved to a considerable extent. It may be mentioned in passing that the Indian Railways have been under great pressure to meet the rapidly increasing traffic demands and a relief of about 1.2 million tonnes of coal required to support a 380 MW station is of considerable significance. When the decision to install the atomic power station was taken it was also realised that the capital cost of such a station would be higher than for a conventional thermal station. Nevertheless, when the economy of the country as a whole was looked at and investments required for transport and mining of the additional coal taken into account, the gap was narrowed down.

1.3 The west coast region of India is served by two power systems which at present have installed capacities of about 850 MW and 3888 MW, the peak loads being 637 MW and 290 MW respectively; the two systems will be interconnected by a 220 KV double circuit transmission line. A study of the demand pattern on the two systems indicated that by 1967-68 the peak loads would be 1224 MW and 721 MW; the corresponding figures for 1968-69 would be 1372 MW and 820 MW and for 1970-71, 168 MW and 1050 MW. The Tarapur station with an output of 380 MW, which will be in full power operation in 1968, will be fully utilised from the moment it is available to the system and considerable additional capacity will also have to be provided to meet the growing needs.

2. <u>Selection of Unit Size</u> :

2.1 One of the early decisions that had to be taken was whether to install a large single reactor station or to have a twin reactor station. The effective capacity of the combined system in 1967-68 excluding the contribution of the atomic power station will be about 1500 MW and it was therefore felt that from the point of view of forced outage and also system standby capacity for routine maintenance, single units in excess of about 150 MW would not fit in. The original decision was in favour of a 300 MW station with two reactors each of 150 MW. At the time the final decision was taken, it was found that the incremental cost in going from 300 MW to say 400 MW was quite low and further that higher system capacities than estimated earlier were being planned; both these circumstances favoured an increase in the size from 300 MW to 380 MW using reactors each of 190 MW capacity.

2.2 The annual load factors on the two systems to which the atomic power station will be feeding are about 68% and 63% (Bombay and Gujarat respectively). The combined system will have about 850 MW of hydro capacity by 1968-69, all from storage schemes. The energy available in the hydro system is limited by water availability and present indications are that the installed capacity can only work at an average plant factor of less than 50%. The mode of operation foreseen is that the nuclear and the newer conventional power stations would take the baseload in the system and that the hydro stations would supply the peak loads. The scheme of operation of the atomic power station has been examined carefully and there should be no difficulty in achieving a load factor of 80%. When the atomic power station is commissioned it will constitute a little less than 20% of the effective capacity in the system and supply about 30% of the energy requirements. However, the fact that this nuclear contribution is made from two units rather than one means that the requirements of spinning reserve and hot standby in the system will not be excessive.

3. Selection of Site :

3.1 A number of alternative sites in the west coast region of India were looked at to determine the best location for the proposed atomic power station. Cooling water requirements dictated a coastal location as even the major rivers of the region, Narbada and Tapi, which carry very large quantities of flow in the flood season have rather low dry weather flows. Hydrographic surveys were conducted at the alternative coastal sites to determine offshore conditions, stability of coastal regime and other factors having a bearing on construction of suitable intake works. Exploratory bore-hole drillings were also taken to determine the subsoil and foundation conditions. A detailed examination of the health and safety aspects of locating the power station at the alternative sites was made and the likely radiological hazards both during normal operation and accident conditions assessed. The power flow pattern into the two systems was studied to determine the influence of location on losses in the transmission of power to the load centres. Other factors such as access to site, availability of construction materials, fresh water, etc. were also looked into. An analysis of these factors indicated that the site at Tarapur was the best site for installing the atomic power station.

4. Tender Enquiry :

4.1 An invitation to tender for constructing the station on a prime contract basis covering design, manufacture, supply, erection, setting to work and commissioning of the entire station was issued in October 1960. No restriction was placed on the type of reactor. The enquiry specifications stipulated performance requirements of the station as a whole and its components and laid down standards for design and workmanship. The method of operation of the station in the power system was specified and the plant parameters required to ensure that the station fitted properly into the power system such as short circuit ratio and power factor of generators, system fault levels, etc. were laid down. The scope of work and standards of design and construction, testing and workmanship were also specified in detail.

4.2 So far as the reactor system was concerned, the specifications were prepared in such a way that they applied generally to all systems. Fairly detailed requirements regarding radiation levels, access control and radiation shielding were laid down. Similarly, requirements regarding reactivity control and reactor operating characteristics were specified. So far as the conventional part of the station was concerned, utility practices adopted in India were particularly kept in mind. The specifications also laid down requirements in regard to installed spare equipment notably cooling water pumps, feed pumps, etc. Similarly, the extent of services such as the capacity of the irradiated fuel store and fresh fuel store which are determined by the method of fuel management were also laid down. In framing the specifications, care was however taken to ensure that the freedom of the designer was not hampered in any way.

4.3 Since the invitation to tender called for fixed price including civil construction at site, it was necessary to include complete information on the site conditions. Thus detailed contour surveys, extensive bore-hole data, detailed hydrographic surveys, tidal current data, silt content of sea water, sea water temperatures, meteorological data, etc. were provided. Apart from a firm price for the construction of the station, the enquiry specifications also called for a firm commitment on the Indian content of the price. The tenderers were particularly asked to investigate the equipment and services that could be procured in India so that the foreign exchange portion of the price would be kept low. Considerable assistance in this respect was furnished to the prospective tenderers.

5. Tender Selection :

5.1 Seven tenders were received from four countries namely Canada, France, U.K. and U.S.A., in response to the invitation to tender. Two tenders from U.K. and one from France were for stations adopting natural uranium graphite gas cooled reactors and two from the U.S. were for stations adopting slightly enriched uranium light water reactors, one using the boiling water concept and the other using the pressurised water concept. The other two proposals, one from Canada using the CANDU System and the other from the U.S. using the heavy water moderator organic cooled system were not in the nature of tenders as they did not include firm prices and were more in the nature of proposals for collaborative investigations. The three tenders from France and U.K., and the two from U.S. were found to be technically sound and could be considered seriously. During the evaluation, it was found that practically in all these cases, it was possible to increase the output of the station by only marginal changes to the plant.

5.2 The cost of stations using natural uranium graphite reactors was more than that of stations using light water enriched uranium reactors. Since adoptation of the latter system meant continuous importation of fuel (natural uranium is being produced indigenously), detailed calculations were made for the different proposals of the power costs including the foreign exchange component over an assumed life of 20 years. Taking these and the relevant technical and cost factors into consideration, it was found that the tender submitted by M/s. International General Electric Company based on boiling water reactors was the best amongst all the tenders received. Accordingly a letter of intent was placed with this company in September 1962. An

Agreement for Cooperation concerning the station and also supply of enriched uranium was concluded with the United States government in August 1963. Financing arrangements with the Agency for International Development of the U.S. government were concluded in December 1963. An authorisation for IGE to commence work on the project was issued in April 1964.

6. Station Design :

6.1 A layout of the station is shown in Figure 1. As will be seen therefrom, a common reactor building housing both the reactors is flanked by a service building which contains the services and the central control room, and adjacent to it is the turbine building. A canal extending to about 2300 ft. into the sea from the high water line and protected by two breakwaters provides the intake for the cooling water. The discharge is also through another canal. One of the prime reasons for adopting this type of intake is the transport requirement of the bulky and heavy components such as reactor pressure vessels, generator stators, main transformers, etc. The intake canal is designed to carry sufficient cooling water for an additional 400 MW station which may be built in future. Figure 2 shows the flow diagram for each reactor unit.

6.2 The reactors employ the dual cycle principle and have two primary loops per reactor. Internal steam separation and pressure suppression containment are adopted. The dual cycle arrangement was preferred as the reactor will be capable of following load automatically over a certain range. Although the Tarapur station will be operated at baseload, it was felt that this feature was a distinct advantage keeping in mind the characteristics of the power system. Being housed in a common building, the reactors share a common spent fuel storage pool and also a common refuelling platform. However, the design is such that even if one of the reactors has experienced a maximum credible accident, the other reactor can still continue to operate. Thus each reactor and its accessories are enclosed in a separate dry well which vents into its own pressure suppression chamber.

6.3 Since plant availability is a very important factor, special care has been given to the question of installed standby and spare capacity. Thus each reactor has two half capacity primary feed pumps and one full capacity secondary feed pump during normal operation. In addition, one half capacity primary feed pump and one full capacity secondary feed pump are provided as installed spare equipment which can be coupled to either reactor circuit as required; suitable provisions are made to positively ensure that the two reactor streams cannot mix inadvertantly. Care has similarly been exercised in the case of other auxiliary plant items such as condensate extraction pumps, air ejectors, cooling water pumps, etc. to ensure that availability of plant is not affected by malfunctioning of some of these auxiliary plant items. It may be of interest to mention that the reactors can be operated safely even with one secondary steam generator or one recirculating pump out of service, the output available from the particular reactor being 82% and 60% respectively.

6.4 The internal diameter of the reactor vessel is about 12 ft. and there are provisions for inserting 368 fuel assemblies and 89 control rods. Each fuel assembly consists of a square matrix of fuel rods enclosed in a zircaloy channel with outside dimension of 4.469". A number of alternative core loadings were examined before it was decided to adopt zircaloy clad fuel with a 6 x 6 matrix and 284 assemblies. In this type of reactor, considerable flexibility is possible in terms of the number of assemblies, rod diameter (or number of rods per fuel assembly) and cladding material. Although zircaloy clad fuel has a higher unit fabrication cost than stainless steel clad fuel, there is a compensating effect due to the lower initial enrichment and better neutron economy. The total foreign exchange required for refuelling purposes, however, gets reduced by using zircaloy clad fuel as we are planning to fabricate the reload fuel in India using imported enriched uranium. (The total of the rupee and foreign currency costs may however not be affected appreciably). Having decided on zircaloy cladding, there was still considerable flexibility in the choice of the core loading. Thus use of smaller diameter rods and higher power densities would mean a lower investment in enriched uranium which would be offset by higher fabrication cost of smaller diameter rods. A number of fuel assemblies using 6 x 6, 7 x 7 and 8 x 8 matrices with rod diameters of 0.541", 0.464" and 0.406" respectively were studied and it was found that on the basis of current economic data applicable to Indian conditions, it would be best to adopt 6 x 6 matrix using 284 fuel assemblies. Some of the salient station and core design parameters are shown in Table I.

7. Conservatism in Design :

7.1 A preliminary assessment of the potential for increasing the output of the reactors has been made. As has been mentioned earlier, although the reactor is designed for accommodating a fuel loading of 368 assemblies, the initial core load to give full output will only be 284 assemblies. One direct manner in which the reactor output can be increased will be to increase the fuel loading. The steam separators and the capacity of the recirculation loops would limit the extent to which the output could be increased. The steam lines from the reactors appear to have enough capacity to accommodate some increase. It would appear that with marginal changes in the plant, some increase in the output of the station can be accomplished. So far as the reactor itself is concerned, significant increase in output would be possible if the power densities were allowed to be higher. The very large core volume available ensures that the choice of the reload cores could be optimised to give the best economic result without any hindrance.

8. <u>Costs</u> :

8.1 The value of the contract placed with M/s. International General Electric Company is $ 84.3 million and this includes, as has been mentioned earlier, design, manufacture, procurement, erection, commissioning and setting to work of the station and the construction of all civil and building works in the station proper including the administration building, workshop and warehouse. Also included in the price is the customs duty to be paid on all equipment and components imported to India. The cost per kw sent out on the basis of the contract price works out to $ 222. In addition to this, an allowance of about $ 45/kw has been made for site preparation (i.e. land, access road, water supply arrangements, staff colony, etc.), capital spares, administration costs, consultancy, training of personnel, escalation and contingencies. The total outlay on the station is reckoned at $ 267/kw.

8.2 The fuelling cost is estimated to be 2.62 mills/kwh based on the U235-U238 cycle using zircaloy clad fuel and on the basis of current U.S. unit costs for fabrication and reprocessing (transport costs have been allowed for). The total cost of power assuming 75% load factor, 20 year plant life and interest rate of 5%, as is common practice in India, comes to 6.42 mills/kwh; making an allowance for interest during construction, the cost comes to 6.76 mills/kwh. The comparable figure for power from a coal fired station is 7.9 to 8.5 mills/kwh; it may be borne in mind that the cost of coal is 54 to 61 cents per million BTU.

8.3 An oil fired station located in the same region would generate power at 6.63 mills/kwh assuming that no duty and taxes are levied on oil. The cost of oil is about 42.5 cents/million BTU excluding duty and taxes and is 74.5 cents/million BTU including duty and taxes. Even if the comparison is confined to oil prices without duty and taxes, it has been estimated that the foreign exchange requirement on an average to refuel the Tarapur station would be about 40% of that required for an oil fired station based on imported oil.

8.4 It will thus be seen that cost of power from Tarapur will be cheaper than from an alternative coal fired station located in the same area and of the same order as from an oil fired station with the advantage that the foreign exchange cost of refuelling the station is considerably less. It may be mentioned that the life has been assumed to be 20 years in the case of Tarapur as compared with 25 years for the conventional station, though there is no reason why the atomic power station should not have a life of 25 years. Furthermore, in computing the fuelling cost, the current U.S. fabrication and reprocessing costs have been assumed although it is proposed to carry out these operations in India. Experience in India with fabrication of natural uranium fuel elements for the large research reactor indicates that fabrication costs in India could be lower due largely to the lower labour costs in the country. Similar arguments would apply to the reprocessing costs also. These factors should reduce the cost of power from Tarapur to about 6 mills/kwh. It is also possible that the price of enriched uranium may go down in future and this would reduce the cost of power from the Tarapur station. Further reductions will be possible when the capability for uprating the reactor output is utilised fully.

9. Conclusion :

9.1 The experience with the Tarapur station has confirmed the prognastications of the Indian Atomic Energy Commission that it is already economic to construct large nuclear power stations in parts of India which are remote from coal fields and where the demand for power is rising. Consideration is now being given to constructing nuclear power stations in other parts of India and work has already commenced on the second station of the heavy water type in collaboration with Canada in Rajasthan. Planning work is also being taken up on a third station to be built in South India.

TABLE I

STATION DATA (for each of the two reactors) :

Thermal power output, MWt	660.9
Gross electric power output MWe	200
Net electric power output, MWe	190
Primary (saturated) steam flow, lbs/hr	1.913×10^{6}
Primary steam pressure, psia	1015
Secondary (saturated) steam flow, lbs/hr	0.792×10^{6}
Secondary steam pressure, psia	500
Core recirculation flow, lbs/hr	23×10^{6}
Core inlet sub-cooling, btu/lb	42.9
Number of recirculation loops	Two
Turbine capability at rated steam flow, MWe	200
Exhaust pressure, inch. Hg. abs.	2.5
Generator rating at 50 cps, 0.85 p.f., KVA	235,000
Voltage, V	12,000 ± 10%

Containment:

Type	..	Steel drywell
Diameter, ft.	..	Sphere, 65, neck, 23
Total height, ft.	..	96.5

Reactor Pressure Vessel and Primary Circuit :

Material of pressure vessel	..	Low alloy steel clad with S.S.
Diameter (internal), ft.	..	12
Height, ft.	..	53.9
Wall thickness, in.	..	5.375

Core :

Weight of uranium in core, lbs.	87,870
Fuel lattice	Square, 6 x 6
Fuel rod diameter (outer) in.	0.541
Sheath material and thickness, mills	Zr.2, 28
Active fuel length, ft.	12
Fuel average enrichment (initial core) %	2.23
Fuel average enrichment (reload core) %	2.09
Core power density, kw/litre	39.43
Heat transfer area, ft^2	17,377
Maximum heat flux, btu/hr, ft^2	4.35×10^{5}
Core exit steam quality, %	8.3
Number of control rods in the core	69
Emergency control (manual)	Sodium pentaborate solution
Total core excess reactivity, (initial core), Δk	0.282
Total core excess reactivity, (equilibrium core), Δk	0.126

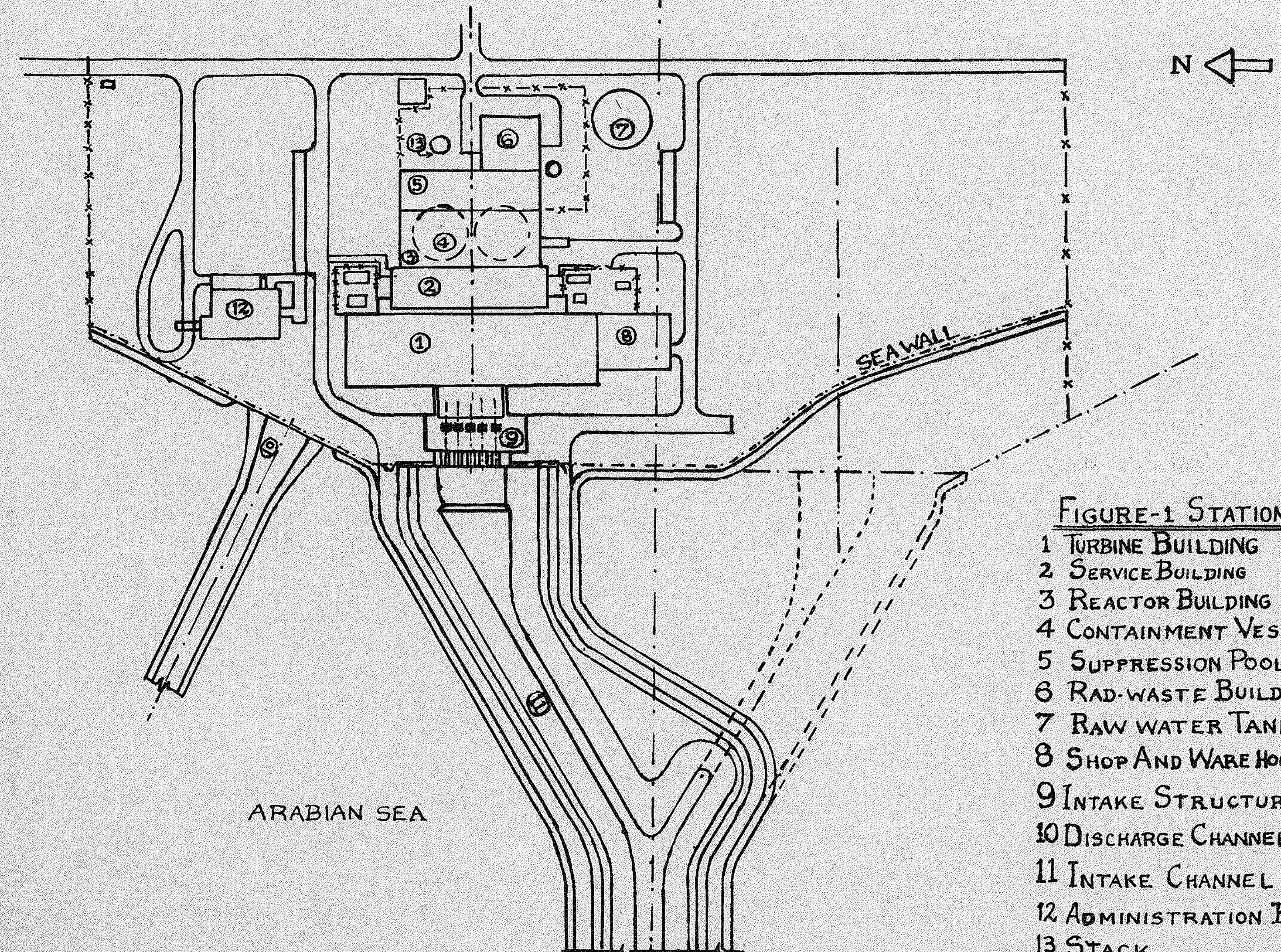
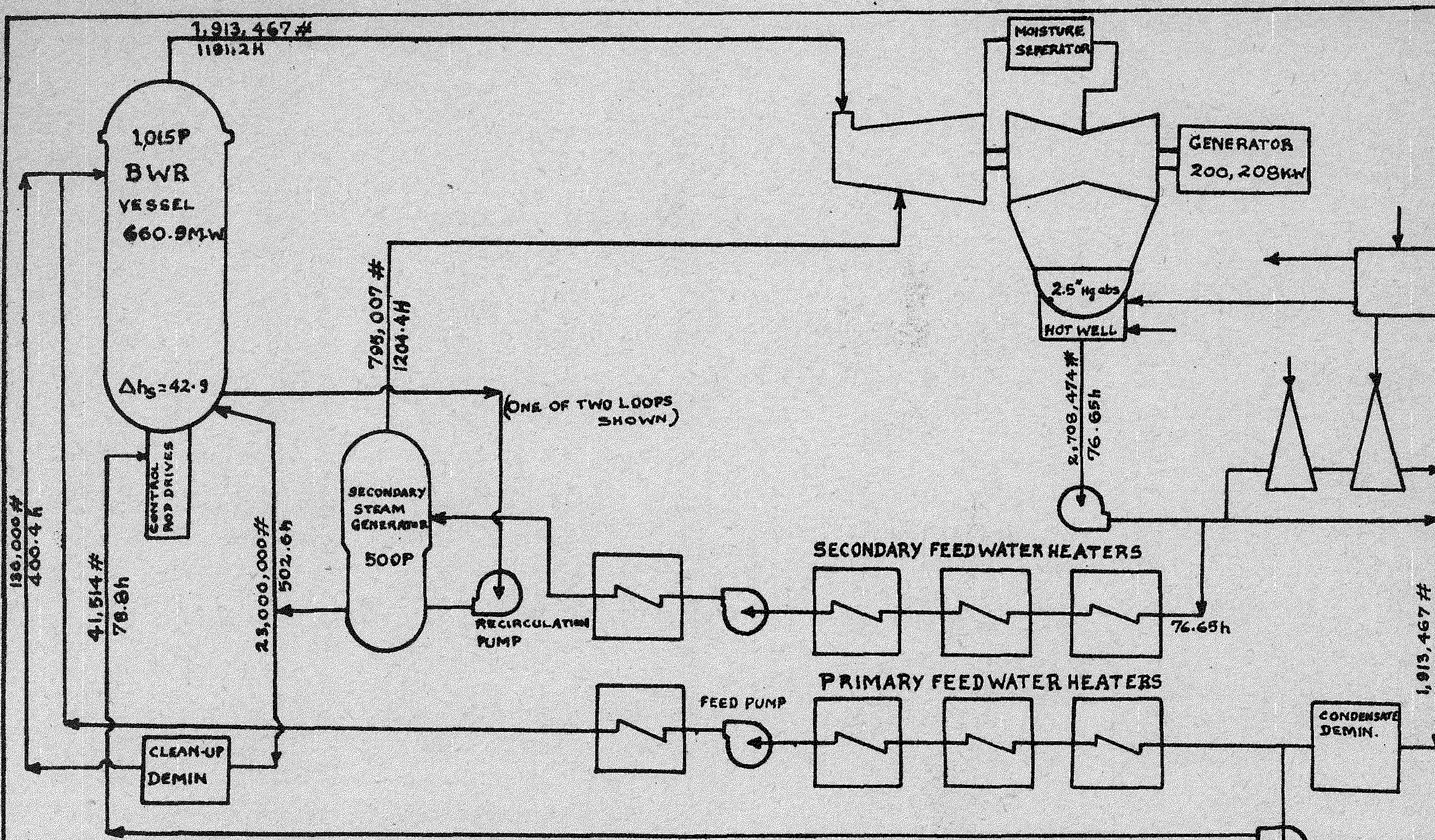


FIGURE-1 STATION LAY-OUT

1 TURBINE BUILDING
2 SERVICE BUILDING
3 REACTOR BUILDING
4 CONTAINMENT VESSEL
5 SUPPRESSION POOL
6 RAD-WASTE BUILDING
7 RAW WATER TANK
8 SHOP AND WARE HOUSE
9 INTAKE STRUCTURE
10 DISCHARGE CHANNEL
11 INTAKE CHANNEL
12 ADMINISTRATION BUILDING
13 STACK



LEGEND

# = Flow, LBS/HR
P = Pressure, PSIA
° = Temperature, °F
H, h = Enthalpy, BTU/LB

ESTIMATED GROSS UNIT HEATRATE = 11,265 BTU/KW-HR
ESTIMATED AUX. POWER = 10,000 K.W
ESTIMATED NETT UNIT HEAT RATE = 11,860 BTU/KW-HR

FIGURE - 2
FLOW DIAGRAM