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INTRODUCTION

The study conducted by the TBR group has never been reproduced in the form of a final report, but it was agreed that the study of the turbine-generator plant should be recorded for use in the preparation of subsequent reports.

At the time this study was started, only meager data that required revision were available. The data presented herein are more complete and include the required revisions. It should be kept in mind that the cost index used in this report may vary from year to year for the various Federal Power Commission account numbers and should be applied accordingly. It is also anticipated that changes in technology may affect the cost of the various components and decisions as to whether they should be used.

DESIGN CHARACTERISTICS

Steam Cycle

Although the trend in public utilities has been toward high-pressure, high-temperature steam cycles, either straight or reheat, present reactor design characteristics required an adjustment of thinking.

The operating characteristics of present-day reactors indicated the use of saturated cycles, and they were subsequently selected for this study. No detailed analysis was made for cycles over 700 psia because of the excessive end-point moisture and questions as to the validity of the moisture correction factors.

The addition of superheat at the throttle, by reducing the steam pressure, is desirable only if it is coupled with a parallel increase in the throttle temperature. With a given maximum throttle temperature (limited by the nuclear reactor characteristics), superheating at constant temperature at the expense of throttle pressure is detrimental to cycle efficiency. Although no economic evaluation is presented, it is the opinion of Beldecos and Smith⁽¹⁾ that the superheat-cycle costs, resulting from increased heat exchanger surface, piping, radiation shielding, and reactor cost, will exceed the cost of the moisture-separator installation, thus requiring a still higher throttle temperature to be competitive.

If reheater and moisture-separator installations are compared on the basis of identical thermodynamic conditions, with both cycles drying the steam to a moisture content of 1%, the separator is the choice for reasons of lower cost and higher efficiency. If it is possible to reheat the steam to the initial throttle temperature, the reheater assumes the thermodynamic advantage. This results from the fact that the moisture separator can only dry the steam up to the saturation line as the ideal limit. An increased cost of reheater installation results from increases in reactor shielding, primary coolant holdup, reheater surface requirements, valves, and piping. These costs, in addition to consideration of space, weight, and complexity, are of such magnitude that the steam reheater cannot be justified. Reheat cycles were also dropped from the studies of Project Dynamo (Declassified Section May 25, 1954, AECD-3659) when it became apparent that they would be applicable over only a very narrow range of initial steam conditions and on the basis of assurances from both Westinghouse and General Electric engineers that moisture separation is entirely practical. After consideration of the points outlined above and the fact that moisture separation was the decision of the PWR group, further investigation of reheat cycles was discontinued. A valid comparison of the two installations requires an economic evaluation to determine whether the higher efficiency is sufficient to offset the cost differential between the separator and reheater installations.

Based on the optimization study conducted by the TBR group, a 370-psia, 437°F, dry-and-saturated cycle was chosen for this particular design.

(1) N. A. Beldecos and A. K. Smith, "Comparative Performance of Turbine Generator Units in Saturated Steam Cycles," WLAP-P-1.

Heat Balance and Station Flowsheet

The heat balance for the basic cycle is shown in Appendix I. The turbine plant flow diagram is shown in Appendix II. Three stages of feed-water heating and one stage of moisture separation are employed. All flows are based on a total generator output of 106,000 kw. The calculated auxiliary load for both the reactor plant and the turbine plant is approximately 6000 kw.

It is apparent that various regions of the turbogenerator plant could be more efficiently utilized. It must be kept in mind that many variations in the design, layout, and mockup of a particular plant are possible, due to the concepts of the design engineers or the operating preferences and procedures of the utility company. The cycle presented herein is a simplified version for this reason. No attempt was made on either the plant layout or flow diagrams to include all the miscellaneous steam, drain, air, or water lines. However, it should be noted that since the piping cost estimates are based on appropriate portions of actual plant installations, these miscellaneous items are included in this study.

Turbine-Generator

A 100,000-kw tandem compounded, double-flow turbine, with hydrogen-cooled generator and attached exciter, was selected. Throttle steam will be at 335 psia, dry and saturated, and the exhaust pressure at 1-1/2 in. Hg abs. Three extraction points will be provided for feed-water heating. The turbine-generator is to be provided with one moisture separator; turbine oil reservoir; miscellaneous oil, water, and steam piping, and necessary instruments and gages. The estimated cost will be approximately \$3,100,000.

Condenser

The surface condenser contemplated will be a two-pass deaerating type. The approximate cost, based on published data by condenser manufacturers, is \$910,000. This figure includes shells, tubes, two one-half-capacity circulating water pumps, two full-capacity condensate pumps, air-removal equipment, and erection supervision. Typical manufacturers of such equipment are Allis-Chalmers, Westinghouse, Worthington, and Ingersoll Rand.

Condensate Pump, Circulating Water, Pump, and Air Ejector

These items are normally included with the condenser contract.

For this particular case, we have specified two multistage condensate pumps (2500-gpm, 220-ft total head, 3-ft NPSH (net positive suction head) vertical-pit type), each driven through a solid flange coupling by a 200-hp motor, 1160 rpm. Cost for the two, including the motors, is approximately \$22,000.

Two circulating pumps (70,000-gpm, 40-ft total head, vertical-mix flow, removable type) with suitable motor drive, are specified. The cost of these pumps, including motors, is approximately \$95,000.

Air-removal equipment considered includes a twin-element, two-stage steam jet ejector, mounted on a combined-shell surface-type inter and after condenser, and will include a set of connecting steam piping, stop valves, steam strainer, and manual throttling valve (flow control), inter-condenser drain loop, and air meter. The cost of this equipment is estimated at approximately \$4,000.

Feed-Water Heaters

This cycle includes three feed-water heaters (two-pass floating-head, shell-and-tube type), which for purposes of identification, will be referred to as low-, intermediate-, and high-pressure heaters. The heaters will utilize extraction of steam from the third, second, and first bleed points of the tandem compound turbine-generator unit, as indicated in Fig. 2 (Appendix I).

The costs were developed from unit costs obtained from heater manufacturers from other particular projects.

Low-pressure heater	\$24,400
Intermediate-pressure heater	22,800
High-pressure heater	32,900
<hr/>	
Total for the station	\$80,100

Boiler Feed Pumps

We anticipate the use of two 100% capacity feed pumps for this particular cycle. These pumps will each handle 2960 gpm at a TDH (total developed head) of 1039 ft. They will be three-stage, 8-in. (discharge) pumps, driven by 900-hp 3600-rpm motors through fluid couplings. Based on cost information from pump manufacturers, the approximate breakdown is as follows:

Pump (standard materials)	\$9,000
Extra for fluid-drive base	600
Fluid drive	14,500
Motor	13,000
<hr/>	
	\$37,100

Total for one unit of three-unit station \$74,200

Typical manufacturers of such equipment are Ingersoll Rand, Byron Jackson and Worthington.

Moisture Separator

It is intended to use a centrifugal-type moisture separator. The unit will be approximately 8 ft in diameter by 17 ft long. The inlet connection will be approximately 40 in. A rough estimate of the cost of this separator is \$200,000, based on \$2 per kilowatt. There is little information available on performance and design for a separator of this size. An additional investigation is necessary to determine the feasibility of using a bank of smaller separators, possibly three or four.

Traveling Screens

The over-all cost of the screen house will be approximately \$376,000. Of this total, the traveling screens account for about \$40,000. This basic design calls for the chlorinating system, circulating water, cooling water, and cooling-water pump to be located in the screen house.

Screen Wash Pumps

Included with the screen is a 35- to 70-gpm pump, at an approximate cost of \$50. Screen washing can also be accomplished with a source from the cooling-water pumps.

Makeup Equipment

In lieu of the use of evaporators for makeup, it is intended to use ion-exchange equipment. Two mixed-bed units with a capacity of 100 gpm each are proposed. The tanks will be approximately 4 ft 6 in. in diameter by 7 ft long, with an over-all length of 10 ft. Each unit will provide 36,000 gal of treated water (using Clinch River water) between regenerations.

Approximately 135 lb of sulfuric acid (H_2SO_4) and 243 lb of caustic soda (NaOH) are required per regeneration. Regeneration cycle will be about every 6 hr per unit.

Based on data from the manufacturer, the approximate cost, with automatic regeneration, is \$34,000.

Typical manufacturers of this type of equipment are Permutit and Rohm-Haas.

Reactor Drain Pumps

A drain pump will be required for both the low-pressure and intermediate-pressure heaters.

The low-pressure-heater drain pump will handle 196 gpm of 180°F drains at an assumed 4-ft NPSH and a total head of 100 ft; it will be a horizontal two-stage pump with a 10-hp motor. The approximate cost, based on data from pump manufacturers, is about \$1500.

The intermediate-pressure-heater drains pump will handle about 890 gpm of 254°F drains at an assumed 4-ft NPSH and a total head of 70 ft. A horizontal two-stage pump with a 30-hp motor is proposed. Based on information from pump manufacturers, the equipment costs about \$3000.

Typical manufacturers of such pumps are Ingersoll Rand, Worthington, and Economy Pumps, Inc.

Cooling-Water Pump (Service Water)

It is proposed to use one 500-gpm pump, with strainers, at a discharge head of 250 ft. This pump will discharge to a head tank with takeoffs to the various pieces of plant equipment. The approximate cost will be about \$5000.

Piping Specifications

The general specifications for the piping associated with the turbine plant are given in the following paragraphs.

Main Steam Line

The main steam line is to be 24-in. Schedule 30 (ASTM specification A-105, grade B) downstream of the holdup drum. Approximately 180 ft of this pipe will be required. Upstream of the holdup drum, 20-in. Schedule 80 (ASTM specification A-106, grade B) will be used. Approximately 120 ft of this pipe will be required for the core heat exchanger, and 100 ft of 10-in. Schedule 80 (ASTM specification A-106, grade B) will be required for the blanket heat exchanger, to tie into a 24-in. Schedule 80 header (5 ft long) upstream of the holdup drum.

Boiler Feed Discharge

It is proposed to use 10-in. Schedule 40 (ASTM specification A-106, grade B) piping for the boiler feed discharge. Approximately 100 ft will be required.

Other Station Piping

Bleeder piping, boiler feed suction, condensate, auxiliary, stress, heater drains, vent piping, makeup piping, cooling (service) water piping, and miscellaneous stress, water, and air piping shall be ASTM specification A-105, grade A, standard-weight pipe.

All welds which will be inside the hot cell shall be radiographed. All piping that is to be within the hot cell shall have been inspected by a suitable means (i.e., ultrasonic, Magnaflux, or equal) to determine the quality of the pipe. This shall also apply to all valves that will be used in this piping.

Radioactive-Fluid-Intercept System

In the event of a leak of radioactive fluids from the fuel or blanket side of a heat exchanger to the steam side, it is desirable to provide a quick-action closure to prevent contamination of the turbogenerator. The system specified for this purpose is shown in Appendix II. (Figure 4).

The holdup drum is 6 ft in outside diameter and 64 ft in length. It will be designed for 400 psi working pressure with provisions for two safety valves which will relieve into the hot cell in the event of excessive pressure buildup. The drum is sized for a 3-sec holdup, which gives a reasonable safety factor based on a main turbine stop-valve closing time of 0.5 sec. It is believed that a high degree of safety should be maintained to compensate for a possible time delay in the receiving and transmitting signals of the monitored control equipment.

The main turbine stop valve will be used as the rapid shutoff (0.3 to 0.5 sec). In addition, a motor-operated gate valve will be provided upstream of the holdup drum to act as an isolating valve. It is possible, with the valve at this location, to make substantial savings in cost of the holdup drum and piping downstream of it. All parts of the system upstream of this isolating valve are designed for an equalization pressure of 1250 psi. The holdup drum and piping downstream of the isolating valve can be designed for 400 psi.

Since the motor-operated gate has a closing time of 5 to 10 sec, the contaminated steam can enter the holdup drum. It appeared to be advisable to provide another motor-operated gate valve outside the hot cell, in the event there is any leakage through the turbine stop valve, to prevent any radioactive fluids from seeping into the turbine.

The holdup drum will be equipped with safety valves to relieve to the waste disposal system in the case of an excessive buildup in pressure.

The monitoring system is designed to actuate simultaneously the turbine stop valve, the two steam-line motor-operated gate valves and a motor-operated gate valve in the feed-water inlet line.

A motor-operated gate valve with a 5- to 10-sec closing time will be provided as the isolating valve. The valve (a 600-lb 24-in. cast steel, pressure-sealed-type bonnet valve) with geared electric-motor operator and necessary controls will cost about \$14,300.

The motor-operated gate valve to be used as the safety block valve will be a 300-lb 24-in. cast-steel valve with geared electric-motor operator and necessary controls. Closing time of this valve will also be 5 to 10 sec. The estimated cost of the complete unit will be \$5500.

A motor-operated gate valve similar to the isolating valve will also be provided on the feed line, adjacent to the heat exchangers. This valve will be a 600-lb 10-in. cast-steel, pressure-sealed-type bonnet valve, with geared electric-motor operator and controls. The estimated cost of this valve with the accessories will be \$2500.

MAJOR PLANT SERVICES

Plant Heating

Plant heating would be accomplished with low-pressure steam, say 2 to 5 lb, with the use of unit heaters strategically placed at the basement, mezzanine, and operating floor levels. This steam can be obtained from the extraction

line to the intermediate-pressure heater or from the main steam line via proper reducing valves. Drains would be returned to a condensate return unit and returned to the condensate system. The approximate cost would be \$17,000 per unit or \$51,000 for the three-unit station.

Sanitary System

With the use of standard plumbing fixtures and a septic tank with subsurface disposal field and with 76 men for the three-unit plant, the approximate cost will be \$114,000, or \$38,000 per unit.

Plant Lighting

For plant lighting, with low bay lighting fixtures below the turbine operating floor and high bay lighting fixtures above the operating floor, the approximate cost will be \$50,400, or \$16,800 per unit.

Consolidated Cost Estimate

The Federal Power Commission (FPC) system of accounts has been maintained for reasons of ready comparison of previous reports. Overhead and indirect-cost figures at 13% of the direct cost of the turbine plant have been apportioned to the various accounts. Where necessary, the accounts have been corrected to reflect the changes in the January 1, 1955, Handy Whitman Index of Public Utility Construction Costs, published bi-yearly by Whitman, Requaardt and Associates.

Account No. 310 - Land and Land Rights

An allowance of \$2 per kilowatt has been made and includes land cost, taxes, permits, etc.

Account No. 311 - Structures and Improvements

Included in this account are the turbine plant building, screen house, land improvements, and railway facilities. Based on the current turbine plant building design and anticipated screen house, this amounts to \$21 per kilowatt.

Account No. 312 - Boiler Feed System

All piping and equipment associated with the turbine plant is covered by this account and includes feed-water heaters, feed pumps, piping, miscellaneous level controls, water-purification equipment, service water system, and all other station piping, insulation, and supports. The charge for this account amounts to \$9 per kilowatt.

Account No. 314 - Turbine-Generator and Accessories

This account includes a 100-Mw tandem compound, double-flow turbine-generator; oil reservoir; miscellaneous turbine oil, water, and steam piping; miscellaneous tests and instruments; erection labor; concrete turbine support; condenser; condenser tubes; two one-half-capacity circulating water pumps; two

full-capacity pit-type condensate pumps; and a twin-element, two-stage air ejector on inter and after condensers with loop seal piping. "All other" costs include a 66-in. circulating-water pipe line from the screen house to the turbine room, intake and discharge equipment, and miscellaneous turbine-room piping.

Miscellaneous control equipment, control panels, and devices which can be charged to the turbine plant, as well as the painting, are also included.

The total charge for this account is \$54 per kilowatt.

Account No. 315 - Accessory Electrical Equipment

The accessory electrical equipment is that associated with the turbine plant and includes station control excitation system, main generator connection, 2300- and 440-volt station auxiliary system, main load structure, and miscellaneous equipment. The charge against this account amounts to \$9 per kilowatt.

Account No. 316 - Miscellaneous Equipment

This includes the turbine-room crane, telephone and signal system, fire-extinguishing system, compressed-air system, miscellaneous tanks and pumps, office, stores, and shop and laboratory equipment. This cost amounts to \$2 per kilowatt.

Account No. 342-343 - Substation Equipment

These accounts include the control, feeders, high side breakers, main transformer, and supporting structures. The total for both accounts is estimated at \$9 per kilowatt.

SUMMARY OF COST ESTIMATE
TER TURBINE PLANT

11.

FPC Account No.

\$/kw*

310	Land and Land Rights	\$150,000		
	Total Account 1310	\$150,000		\$1.69
311	Structures and Improvements			
	A. Turbine Plant Bldg.	1,159,400		
	B. Screenhouse Bldg.	398,900		
	L. Land Improvements	185,600		
	X. Railways	<u>106,100</u>		
		1,850,000		20.90
312	Boiler and Accessories			
	N. Boiler Feed System	183,600		
	P Water Purification	34,700		
	R Service (Cooling) Water System	25,500		
	S Station Piping	<u>545,700</u>		
	Total Account 312	789,500		8.92
314	Turbine Generator and Accessories			
	J Turbine Generator and Extras	3,100,000		
	Erection Labor	150,000		
	Turbine Support	85,000		
	K Condenser and Auxiliaries	910,000		
	All Others	472,000		
	L Miscellaneous Equipment Work	<u>60,000</u>		
	Total Account 314	4,777,000		53.98
315	Accessory Electrical Equipment	816,200		
	Total Account	816,200		9.22
316	Miscellaneous Power Plant Equip.	210,000		
	Total Account 316	210,000		2.37
342 and 343	Substation Equipment	800,000		
	Total Account 342 and 343	800,000		9.04
	TOTAL	\$9,392,700		\$106.12

* Includes indirect costs and overhead

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APPENDIX I

APPENDIX I

Heat Balance, TBR Steam System

Assume 370 psia at heat exchanger
 335 psia at stop valve (assuming $\approx 10\%$ drop)
 320 psia at steam chest (assuming $\approx 4\%$ drop thru stop and throttle valves)

For H.P. Turbine Section

335 psia $h = 1203.6$ $s = 1.5006$

Set separator at 10% of throttle press Say 26 psia

Expand isentropically 335 to 26

at 26 psia $h_g = 1014$

Base internal eff. for H.P. & I.P. turbine section

$$\eta = 83.9\% = .839 \text{ (from West. curve)}$$

Apply moisture correction of 1.2% to assumed 11.2% moisture

$$C_M = \left[1 - \left(\frac{11.2}{2} + 1.2 \right) \right] = 93.2\% = .932$$

Correct base efficiency

$$\eta_B \times .932 = \eta_c$$

$$.839 \times .932 = .782 = 78.2\%$$

Using corrected internal eff. (335 psia to 35 psia)

$$\frac{1203.6}{1014.0}$$

189.6 Δh_g (isentropic)

$$189.6 \times .782 = 147.8 \text{ Btu to work}$$

$$1203.6 - 147.8 = 1055.8 \text{ hg @ 11.2\% moisture}$$

For L.P. Turbine Section - (Double Flow Unit)

For moisture separator - Assume 5% drop to obtain 1% moisture

$$\left. \begin{array}{l} 26 \text{ psia} \times .95 = 24.7 \\ \text{hg} = 1150.6 \\ s = 1.702 \end{array} \right\}$$

* Symbols used are those appearing in "Thermodynamic Properties of Steam" by J. H. Keen and F. G. Keyes, Wiley, New York.

Base internal eff. for L.P. Turbine Section

$$\eta = 88.7\% = .887 \text{ (From WIAP-P-1 Fig. 16)}$$

Apply moisture correction of 1.2% to assumed 11.2% moisture

$$C_M = \left[1 - \left(\frac{11.2}{2} + 1.2 \right) \right] = 93.2\% = .932$$

Corrected base efficiency

$$\eta_B \times .932 = \eta_c$$

$$.887 \times .932 = .827 = 82.7\%$$

Using corrected internal eff. (24.7 to 1-1/2 Hg Abs.)

$$1150.6$$

$$\underline{935.3}$$

$$215.3 \Delta \text{ hg (isentropic)}$$

$$215.3 \times .827 = 178.0 \text{ Btu to work}$$

$$1150.6 - 178.0 = 972.6 \text{ hg (SLEP)}$$

$$\text{Assume Exh. loss } \underline{13.0 \text{ Btu}}$$

$$985.6 \text{ hg Actual end point} \\ @ 11.2\% \text{ moisture}$$

Set final feed temp.

Assume 25% of throttle pressure

$$335 \times .25 = 84 \text{ psia} = 315^{\circ}\text{F Sat.} \\ \frac{5^{\circ} \Delta T}{320^{\circ}\text{F}} = 90 \text{ psia Sat.}$$

Assume 5% drop to heater

$$90 \times 1.05 = 94 \text{ psia}$$

No. 1 Extraction

$$94 \text{ psia } @ 1121.5 \text{ hg}$$

No. 2 Extraction

$$26 \text{ psia } @ 1055.8 \text{ hg}$$

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Fig 1. Turbine State Line.

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No. 3 Extraction

6.5 psia @ 1072.0 hg (arbitrarily set at 6.5 psia)
Say between 6 to 10 psia

Assume 5% drop to all heaters

Let G represent throttle flow

Extraction No. 1 $\rightarrow E_1$

$$80.86G = 831.2 E_1$$

$$E_1 = \frac{80.86}{831.2} = \underline{.09721 G}$$

Extraction No. 3 $\rightarrow E_3$

Assume .711 Exhaust flow

$$.708 G \times 74.6 = 932.8 E_3$$

$$E_3 = \frac{52.80}{932.8} = \underline{.05660 G}$$

Extraction No. 2 $\rightarrow E_2$

$$.708G \times 68.5 \quad .05660G \times 68.5 = .09721G \times 82.6 \quad E_2 \times 848.1$$

$$48.5 \quad 3.88 \quad = \quad 8.02G \quad 848.1 E_2$$

$$44.57 G = 828.1 E_2$$

$$E_2 = \frac{44.36 G}{848.1} = \underline{.05231 G}$$

Separator Drains $\rightarrow S_D$

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Fig. 2. Heat Balance Diagram.

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Flow thru separator	→	1.00000	1.00000
E ₁	-	<u>.09721</u>	<u>.09721</u>
		.90279	.90279
E ₂	-	<u>.05255</u>	<u>.05231</u>
		.85024	.85048

$$\frac{1150.6 \text{ hg}}{207.7} \quad \frac{1150.6 \text{ hg}}{1055.8}$$

$$\frac{942.9}{94.8}$$

$$s_D = \frac{94.8}{942.9} \times .85048 = .08551$$

Check exhaust flow - Assumed .711 G

E ₁	1.00000	E ₁	1.00000
	<u>.09721</u>		<u>.09721</u>
	.90279		.90279
E ₂	<u>.05255</u>	E ₂	<u>.05231</u>
	.85024		.85048
s _D	<u>.08548</u>	s _D	<u>.08551</u>
	.76576		.76497
E ₃	<u>.05682</u>	E ₃	<u>.05660</u>
	.70794		.70837

Say .708 & recheck →

Check Mix -

$$.708 \times 202.8 + .292 \times 207.7 =$$

$$143.58 + 60.65 = \underline{204.23 \text{ hr}}$$

Find Btu to work -

$$1.00000 \times (1203.6 - \overset{82.1}{1121.5}) = 82.1$$

$$.90279 \times (1121.5 - \overset{65.7}{1055.8}) = 59.3$$

$$.76497 \times (1150.6 - \overset{78.6}{1072.0}) = 60.1$$

$$.70837 \times (1072.0 - \overset{86.4}{985.6}) = 61.2$$

$$\underline{262.7}$$

Check heat added to & rejected from cycle

$$\text{Btu input} = 1203.6 - 285.1 = \underline{918.5}$$

$$\text{Btu rejected} = 918.5 - 262.7 = \underline{655.8}$$

$$\text{Check} - .708 (985.6 - 59.7) = \underline{655.5}$$

$$\eta_t = \frac{262.7}{918.5} = .286 \quad \text{Allow } 2.2\% \text{ for gen. \& mech. losses}$$

$$\eta_t = .978 \times .286 = .286 = .2797 = \underline{28.0\%}$$

$$\text{Heat rate} = \frac{3413}{.28} = \underline{12,189} \text{ Btu/KWHR}$$

$$\text{Steam rate} = \frac{12,189}{918.5} = \underline{13.27} \text{ \#/KWHR}$$

$$\text{Throttle flow} - \text{Allowing 6 Mw for Aux. power} = 1,406,620 \text{ \#/hr}$$

Find extraction and exhaust flow - \#/hr

$$E_1 = .09721 \times 1,406,620 = 136,740$$

$$E_2 = .05231 \times 1,406,620 = 73,580$$

$$S_D = .08551 \times 1,406,620 = 120,280$$

$$E_3 = .05660 \times 1,406,620 = \underline{79,610}$$

410,210

$$\text{Exhaust flow} = .708 \times 1,406,620 = 995,890$$

$$\text{Check} - 1,406,620 - 410,210 = 996,410$$

Check exhaust loss - Assumed 13 Btu

Use 33 D.F. End

$$\text{Exhaust Flow/end} = \underline{497,950}$$

$$\text{Specific Vol. @ } 1\text{-}1/2" \text{ Hg \& } 972.6 \text{ (SLEP)} = \underline{388}$$

$$\text{Volumetric Flow} = 497,950 \times 388 = \underline{193 \times 10^6}$$

From Exh. loss curve - 12.4 Btu

APPENDIX II

Fig 3 Turbine Plant Flow Diagram

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Fig 4 Schematic Diagram of Radioactive Fluid Intercept System

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APPENDIX III

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APPENDIX III

The curves presented herein are based on technical and cost data obtained from Westinghouse, General Electric, and Allis Chalmers through Pioneer Service and Engineering Company or directly by the writer. Unit costs, when necessary, have been corrected for today's costs by data from Handy Whitman Publication of Public Utility Construction Costs.

Figure 5 -- the curve of capital investment versus steam temperature -- includes the building for the turbine side of the plant; turbogenerator unit and ~~its~~ foundation; condenser, its auxiliaries and circulating water system; feed-water system including pumps, piping, and heaters; a proportionate part of all steam, water, and air piping which applies to the turbine side of the plant, as well as the auxiliary electrical equipment. Design considerations are based on dry-and-saturated cycles employing 1800-rpm turbogenerators. The curve presented is similar to the one presented for standard-cycle turbine plants using superheated steam in the Foster-Wheeler Corporation - Pioneer Service and Engineering Company study NEA-5301.

Figure 6 -- the curve of turbine cycle efficiency versus steam temperature -- is based on turbine throttle flows and heat-balance data for various dry-and-saturated steam cycles including moisture separation, which were obtained from turbine manufacturers. The turbine-generators are 1800-rpm units exhausting at 1-1/2 in. Hg abs, utilizing three stages of regenerative feed-water heating. The curve has not been penalized for pumping power. In consideration of 100- to 150-Mw units it is reasonable to multiply values obtained from the curve by 0.94 to get the net efficiency. The limitation of practical low end annulus and inherent exhaust loss directly affects the overall turbine cycle efficiency. In the examination of this curve, it should be remembered that these are 1800-rpm turbogenerators operating on straight dry-and-saturated cycles with no superheat and no reheat at the throttle.

Figure 7 includes power necessary for feed pumps, circulating water pumps, condensate pumps, heater and separator drain, and makeup pumping power.

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Fig. 5. Turbine Plant Cost vs. Steam Temperature.

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Fig. 6. Turbine Cycle Efficiency vs. Steam Temperature.

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Fig. 7. Turbine Plant Auxiliary Power Requirements vs. Temperature.