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A COST COMPARISON

OF

VERY HIGH TEMPERATURE NUCLEAR REACTORS

FOR

PROCESS HEAT APPLICATIONS

PREPARED FOR THE

UNITED STATES ATOMIC ENERGY COMMISSION

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DISCLAIMER

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Chapter 1

INTRODUCTION

1.1 SCOPE

In April 1974, the United States Atomic Energy Commission (USAEC) authorized General Atomic Company, General Electric Company and Westinghouse Astronuclear Laboratory to assess the available technology for producing process heat utilizing very high temperature nuclear reactors. General Electric and Westinghouse produced concepts for the entire nuclear system, including the balance of plant. The General Atomic assessment includes only the nuclear reactor portion of the nuclear plant. Draft reports of this work were submitted to the USAEC in September 1974 (References 1, 2 and 3).

United Engineers & Constructors Inc. (UE&C) was requested by the USAEC in November 1974 to prepare an economic comparison of the three conceptual plants under contract number AT(11-1)-2477. The comparison is divided into three tasks:

- Develop a balance of plant conceptual design to be combined with the General Atomic concept as a basis for comparison, and estimate the cost of the General Atomic/UE&C concept in July 1974 dollars.
- Normalize the overall plant costs for the General Atomic/UE&C, General Electric and Westinghouse concepts, compare the costs, and identify significant differences between the concepts.
- Estimate the operation and maintenance costs for the General Atomic/UE&C plant and compare with the other concepts.

The results of these tasks are discussed in Chapters 2, 3 and 4 of this report. Chapter 2 describes the balance of plant which supplements the General Atomic Nuclear Steam Supply System. The General Electric and Westinghouse plants and the normalization of the plant costs are described in Chapter 3. Chapter 4 compares the plant costs and identifies major differences between the plants. Appendix A identifies the interfaces between the nuclear process heat plant and the chemical plant. The chemical plant is not costed.

1.2 UE&C COST ESTIMATION METHODS

The total investment cost of a power plant consists of equipment, materials, labor, engineering, construction management, miscellaneous construction expenses, contingency (effects of uncertainty), and the financial costs associated with allocation and disbursement of these funds, which include escalation and interest during construction. The base investment cost of a power plant is defined as the part of the total plant cost that includes the equipment, materials, labor, engineering, construction management and miscellaneous construction expenses only. This report addresses the base investment cost only. Financial costs are not estimated because the parameters associated with them are too speculative to predict over long periods of time in a highly unpredictable and volatile economy. The effect of the financial costs on the total plant cost is very significant, and may exceed 40 percent of the total plant cost depending upon the magnitude of the parameters and the length of the project schedule.

The basis for this cost estimate is the USAEC Report WASH-1230, An Investment Cost Study for a 770 MWe HTGR (Reference 4). The costs contained in that study are based on January 1973 prices. The unit costs of equipment, labor, and materials for this report are adjusted for inflation to July 1, 1974, using the following escalation factors:

Equipment	20%
Labor	12.5%
Materials	20%

The cost of the equipment, labor, and materials required are adjusted by analyzing the physical sizes, capacities, and temperature requirements of the equipment and structures, and adjusting the costs contained in Reference 4. New estimates are prepared for items which are significantly different from those in Reference 4.

In developing the cost estimates, the following ground rules were observed:

- The General Atomic reference design in Reference 1, supplemented by the system descriptions in Reference 4, is the basis for the conceptual design of the balance of plant.
- Changes to the Gulf General Atomic reference design were kept to a minimum.
- Cost data was based on July 1974 prices.

  A full complement of licensing and design criteria circa 1974 was utilized.
- The base cost estimate was developed for Middletown, U.S.A. site conditions.
- The cost estimate was developed for a single unit.
- The base cost was developed in accordance with Appendix B (Estimator's Check List for Plant Capital Investment) of <u>Guide for Economic Evaluation of Nuclear Reactor Plant Designs</u>, USAEC Report NUS-531 (Reference 5).
- Recent design experience on similar sized HTGR plants is used wherever applicable.

This cost study is based on preliminary, conceptual designs. The costs which are presented may change as a result of further research and development and of more detailed design.

1.3 GENERAL ATOMIC/UE&C PLANT DESCRIPTION AND COST SUMMARY

The nuclear process heat plant which is described and costed in this report is based on a General Atomic 3000 MWt High Temperature Gas-Cooled Reactor (HTGR), similar in size and content to the 1160 MWe HTGR power plants which are currently being constructed. In the base case, the nuclear reactor systems are modified by General Atomic to include a reformer in the primary coolant loop. This reformer converts a steam-methane mixture to hydrogen and carbon dioxide, with a peak temperature of 1600°F.

The nuclear process heat Balance of Plant (BOP) is essentially the same as the supporting systems and structures for the 1160 MWe HTGR except that electric generation systems are not included. The Investment Cost Study for the 770 MWe HTGR (Reference 4) is the basis for definition of the BOP systems, with modifications and additions incorporated as a result of the latest experience with current power plant designs and with recent escalations in labor and materials costs.

The Base Plant is thus defined as a nuclear reactor (with the necessary BOP supporting systems and structures) which provides heat to a chemical process in the forms of steam and helium. All electrical needs of the plant are supplied from outside the plant. The costs of the Base Plant are summarized in Table 1.1. The chemical plant is not a part of this estimate.

To better isolate the process from the primary coolant, an intermediate helium loop (IHL) is estimated as an addition to the cost of the Base Plant. This loop minimizes migration of tritium from the primary coolant to the process gas and of hydrogen to the primary coolant. It also relocates the reformers out of the containment building, thereby removing the danger of hydrogen explosions which might affect safety-related systems.

Two electric generation adders are also considered. Generation of 40 MWe provides enough power for the nuclear plant equipment plus an allowance for the demand from the chemical processing plant. The generation of 100 MWe permits external sale of power.

The costs of plants with all of these options are summarized in Table 1.2.

1.4 COMPARISON SUMMARY

The costs and scopes of supply are compared in Chapter 4 for the General Atomic/UE&C, General Electric and Westinghouse plants. The costs presented are not directly comparable because of significant differences in the scopes of supply. Table 1.3 summarizes the costs and Table 1.4 summarizes the descriptions of these plants.

The General Electric plant costs, $620 million, are similar to those for the General Atomic/UE&C plant, but the General Electric scope includes fewer structures. The small cost difference between the two concepts is not significant, given the uncertainties involved.

The Westinghouse plant costs, $326 million, are consistently lower than either of the other estimates. Although differences in some accounts can be explained by different scopes or different structure sizes, Westinghouse estimates of equipment, labor and material costs for the Reactor Containment Building, Administration Building, and Heat Transfer System are lower than would be expected if comparable base costs were used.

1.5 INTERFACES WITH THE CHEMICAL PLANT

The design of the chemical processing portions of the overall plant requires further definition of the interfaces with the nuclear part of the plant. As a result, UE&C assumed that:

- All steam generation by the nuclear plant will be used in the chemical plant.
- All boiler feedwater will be supplied by the chemical plant.
- All makeup water and water conditioning equipment for the steam systems will be supplied by the chemical plant.
- If a turbine-generator is used, the exhaust system will be used by the chemical plant.
- The heat sink for the steam cycle, if required, will be supplied by the chemical plant.
- The electrical demand of the chemical plant is 30 MWe.

Details of the interfaces between the nuclear and chemical plants are discussed in Appendix A.

1.6 GENERAL COMMENTS

As a result of this review, several items have been identified which should be investigated in more detail:

1.6.1 Plant Size

The output of this plant appears to be greater than the demand required by most single potential users. Although it is likely that energy use will become more concentrated in the future as energy production becomes concentrated, still the early generation of process heat plants will probably serve several customers. It is also possible that smaller nuclear heat sources will be applied sooner and more widely than the 3000 MWt size. Accordingly, the costs and economic potential should be investigated for plants in the 500 to 2000 MWt range.

1.6.2 Power Generation

The incomplete design of the process plant prevents analysis of the amount of energy available for generation of electricity. When the energy demands of the process plans are more clearly defined, a new estimate of electric generation costs should be made.

1.6.3 Plant Configuration

The nuclear process heat plant described in this report is not an optimum plant. The costs and advantages of different primary/intermediate loop configuration strongly affect the cost of the plant (Table 1.2). If the intermediate loop is required, significant cost savings in PCRV and containment building costs can be realized if the steam generators are located only in the intermediate loop. However, reactor control should then be very carefully investigated.

1.6.4 Nuclear Plant Control

Although Instrumentation and Control systems are included in the three conceptual designs, the full scope and complexity of the systems are not documented. Since the problems of nuclear plant control are expected to be extensive, a full investigation of this area should be initiated at an early time.

1.6.5 Interaction Between Nuclear and Chemical Plants

The nuclear and chemical plants will be highly dependent on each other for electricity, steam, heat, feedwater, cooling water, and other services which are still undefined. To assure safe operation of the nuclear plant, administrative and technical coordination and interaction must be thoroughly investigated.

TABLE 1.1

SUMMARY OF COSTS FOR GA/UE&C BASE PLANT
(Without Power Generation or Intermediate Loop)

ACCOUNT	DESCRIPTION	Costs (Thousands of Dollars) BOP TOTAL	NSSS TOTAL	TOTAL
20	Land and Land Rights	1,000	-	1,000
21	Structure and Improvements	68,872	-	68,872
22	Reactor Plant Equipment	25,322	241,879	267,201
24	Electric Plant Equipment	26,597	-	26,597
25	Miscellaneous Plant Equipment	8,774	-	8,774
26	Special Materials	274	271	545
91	Engineering and Construction	89,083	-	89,083
99	Other Costs	7,874	24,939	32,813
	TOTAL PLANT COST	227,796	267,089	494,885

This Table is Derived From Table 2.2

Table 1.2

GENERAL ATOMIC/UE&C PLANT COST WITH OPTIONS
(July, 1974)

Account	Engineering and Construction	Base	Base With 40 MWe	Base With 100 MWe	Base With IHL (1) (2)	Base With IHL & 40MWe	Base With IHL & 100MWe
		Total Cost (Thousands of Dollars)					
20	Land and Land Rights	1,000	1,000	1,000	1,000	1,000	1,000
21	Structures and Improvements	68,872	69,247	69,555	75,579	75,954	76,282
22	Reactor Plant Equipment	267,201	267,201	267,201	~~349,423~~ 336,327	~~349,423~~ 336,327	~~349,423~~ 336,327
23	Turbine Plant Equipment	--	2,700	5,388	--	2,700	5,388
24	Electric Plant Equipment	26,597	26,933	27,118	27,047	27,383	27,568
25	Misc. Plant Equipment	8,774	8,868	8,945	9,174	9,268	9,345
26	Special Materials	545	545	545	961	961	961
91	Engineering and Construction	89,083	89,969	90,809	107,138	108,024	108,864
99	Other Costs	32,813	32,892	32,971	34,294	34,373	34,452
	Total	494,885	499,355	503,532	~~604,616~~ 591,520	~~609,086~~ 595,990	~~613,283~~ 600,187

Note:

(1) Intermediate Helium Loop
(2) This combination is the basis for comparison with the General Electric and Westinghouse plants.
(3) This Table is derived from Tables 2.2, 2.3, 2.4, and 2.5.

TABLE 1.3

SUMMARY OF COMPARISON
(July, 1974)

Account	Description	Total Costs (Thousands of Dollars) GA/UE&C	General Electric	Westinghouse
20	Land and Land Rights	1,000	2,000	800
21	Structures and Site Facilities	75,579	68,986	47,551
22	Reactor Plant Equipment	~~349,423~~ 336,327	369,742	149,228
24	Electric Plant Equipment	26,597	21,521	16,206
25	Miscellaneous Plant Equipment	8,774	9,675	6,421
26	Special Materials	961	840	250
Subtotal	(Accounts 21 through 26)	~~462,334~~ 449,238	470,764	219,656
91	Engineering & Construction Costs	107,138	64,134	57,268
99	Other Costs	34,294	82,745	47,820
Total Costs		~~604,616~~ 591,520	619,643	325,544
Annual Operation and Maintenance Costs (3)		8,995 to 11,155	3,388	5,996

Notes: (1) Base Plant with Intermediate Loop, but without Power Generation
(2) This table is derived from Table 4.1
(3) Costs represent different scopes of supply. Direct costs only.

TABLE 1.4

COMPARISON OF CONCEPTUAL DESIGNS

ITEM	GENERAL ATOMIC/UE&C[1] (Comparison Plant)	General Electric[2]	Westinghouse[3]
Reference Process	Hydrogen Production By Methane Reforming	Hydrogen Production By Methane Reforming	Hydrogen Production By Proprietary Steam - Electric Process
Maximum Average Process Temperature	1400°F	1400°F	1400°F
Nuclear Reactor Type	3000 MWt VHTR[4] (Modified HTGR)	3000 MWt VHTR[4] (Similar to German THTR)	3000 MWt VHTR[4] (Based on Nuclear Rocket Technology)
Reactor Core Type	Hexagonal Blocks, Solid Fuel Rods, 93 w/o U-235	Pebble Bed, Low Enriched	Hexagonal Blocks, Hollow Cylindrical Fuel Rods, 93 w/o U-235
Reactor Coolant	Helium	Helium	Helium
Reactor Vessel	PCRV[5]	PCRV[5]	PCIV[6]
Intermediate Loop (IHL)	Yes	Yes	Yes
IHL Coolant	Helium	Helium	Helium
Electric Generation	No	No	Yes

Notes:
(1) See Table 2.7 for plant costs.
(2) See Table 3.1 for plant costs.
(3) See Table 3.2 for plant costs.
(4) Very High Temperature Reactor
(5) Prestressed Concrete Reactor Vessel
(6) Prestressed Cast Iron Reactor Vessel

Chapter 2

DESCRIPTION AND COST OF GENERAL ATOMIC/UE&C PLANT

2.1 INTRODUCTION

The General Atomic/UE&C nuclear process heat plant is costed as a Base Plant with adders for an intermediate heat transfer loop and two electric generation options. Sections 2.2, 2.3, and 2.4 describe the plant and the modifications required for the options.

A chemical plant is associated with the nuclear plant, but is not within the scope of this study. Steam is generated by the nuclear plant and supplied to the chemical plant, where it is mixed with methane. The steam-methane mixture is heated in a reformer by helium from the nuclear plant to produce a mixture of steam, hydrogen, and carbon dioxide. This is processed by the chemical plant into hydrogen. A flow diagram of a conceptual chemical plant is illustrated in Figure 4.3 of Reference 1.

The estimated Operation and Maintenance cost of the nuclear plant is described in Section 2.5.

2.2 BASE PLANT

2.2.1 Site

The nuclear process heat plant is assumed to be located at the 'Middletown' standard site described in Appendix A of USAEC Report NUS-531, Guide for Economic Evaluation of Nuclear Reactor Plant Designs (Reference 5). The site was modified for the 770 MWe HTGR investment cost study, and is described in Reference 4. The site is on a flood plain next to a river, and about 25 miles from the nearest large city. The site description also includes water, gas, and electric supplies; air, railroad, road, and water access routes; topography, geology, and seismology; meteorological conditions; and waste disposal regulations.

2.2.2 Nuclear Steam Supply System

The nuclear steam supply system (NSSS) is a 3000 MWe HTGR supplied by General Atomic Company. The NSSS consists of the nuclear reactor, control and safety equipment, the prestressed concrete reactor vessel (PCRV), helium circulators, and the steam generators. For the nuclear process heat plant, the NSSS also includes a methane-to-hydrogen reformer in the primary coolant loop within this PCRV. Other modifications are made to some systems in order to accommodate the temperatures required, which are several hundred degrees hotter than the comparable electric HTGR plant.

General Atomic has investigated the materials and operating problems of the nuclear process heat plant, estimated the cost of a typical NSSS for process heat, and recommended a research and development program. The results and the NSSS description are reported in Reference 1. Process options are discussed, with peak process temperatures from 1200°F to 2000°F. The 1600°F case was chosen as the NSSS for definition of the Base Plant balance of plant, because it appears to be the most efficient operating temperature. Serious materials problems exist at higher temperatures.

A heat balance diagram of the primary cooling system of the Base Plant is shown in Figure 2.1. The helium is heated in the reactor core and enters the methane reformer at 1800°F (average). It passes through the reformer and a steam generator and is then compressed before it reenters the core. Steam generated by the cycle drives the helium circulators and is then used by the chemical process plant, which returns feed water to the system. (Appendix A of this report discusses interfaces with the process plant.)

General Atomic quotes their estimate of NSSS costs as adders to their public bid to the Los Angeles Department of Water and Power (LADWP), which was a single-price bid of $169,358,000. To bring prices to July

1974 dollars, General Atomic escalated this estimate to $178,503,300. In order to compare costs of the plants estimated by General Atomic, General Electric, and Westinghouse (Section 4), UE&C prorated the General Atomic LADWP bid based on the relative values of the appropriate accounts in Reference 4 with modifications and additions resulting from the latest experience with current power plant design, as shown in Table 2.1. This division of the costs probably does not represent the current cost breakdown from the General Atomic NSSS, but it is the best estimate which can be made without a detailed design and estimate for the NSSS system.

2.2.3 Balance of Plant Conceptual Design

The conceptual design of the balance of plant is developed from the investment cost summary for the 770 MWe HTGR (Reference 4), current experience with similar nuclear power plants, and the General Atomic scope of supply for the NSSS (Reference 1, pages 4-19 to 4-42). The plant costs, including the General Atomic costs, are shown in Table 2.2.

The layout of the plant site, will all significant structures, is shown in Figure 2.6. Sections through the main structures, in Figures 2.7 through 2.10, show the locations of the main systems. The most significant differences between this plant and the one described in Reference 4 are:

- Size (3000 MWt instead of 2000 MWt)
- Mixed mean coolant temperature at core outlet (1800°F vs. 1434°F)
- PCRV contains reformers
- No electric generation equipment, supporting systems, or structures

The following sections briefly describe the differences between the nuclear process heat balance of plant and the comparable accounts in Reference 4. Where an account is not discussed, the systems are essentially the same as the comparable systems in the 770 MWe plant, expanded to 1160 MWe.

212. Reactor Containment Building

The containment building and annulus diameters are larger than the comparable structures in Reference 4 because the PCRV diameter is larger. There is sufficient clearance for the removal of the reformers from the PCRV for servicing.

213. Turbine-Generator Building

This building is not a part of the Base Plant. (See Section 2.4).

214. Water Intake Structures

The circulating water intake structure is not a part of the nuclear process heat plant, because waste heat dissipation is the responsibility of the chemical plant.

The service water intake structure is scaled up from Reference 4.

215. Reactor Service Building

The services provided are the same as in Reference 4, but the building size is slightly increased. The cost estimate in Reference 4 was for a reactor service building which serves two reactor units, so this building would be smaller. However, recent comparable structure designs are considerably larger than the one in Reference 4, so the net effect is a larger building.

Storage space is provided for 40 percent of the reactor core, which is appropriate for the 3-year fuel cycle. Because of the more demanding fuel service, it may be desirable to provide storage for the entire core plus a recently discharged batch (140 percent of core). This option was not estimated.

Major repairs to the steam generators and reformers will be performed off-site. The equipment hatch was enlarged to allow removal of these components by rail to a repair facility.

218A. Control Building

The control building is similar in size and function to the control building for the 1160 MWe HTGR. The space allocated in an 1160 MWe plant to electrical generation and distribution equipment will be available for process instrumentation.

218C. Administration Building

The administration building is the same size as the building for an 1160 MWe HTGR single unit plant. A warehouse and a shop area are included.

218D. Auxiliaries Building

The auxiliaries building houses the auxiliary boilers, water treatment equipment, and associated electrical and instrumentation and control equipment.

222. Main Heat Transfer and Transport Systems

Installation of the reformers is added to this account. (Reformer Equipment cost is an NSSS cost.)

226. Other Reactor Plant Equipment

A containment inerting system is required to prevent hydrogen explosions which might result from reformer leaks. The cost of this equipment was taken from Reference 1, page 5-49.

24. <u>Electric Plant Equipment</u>

The auxiliary power system is comparable to that for a 1160 MWe HTGR steam generating station. The safety-related (Class IE) systems are identical. Equipment types in the nuclear process heat plant are similar to those in Reference 4 with the exception of generator related equipment (i.e., switchgear, protective relay panel and isolated phase bus duct). All auxiliary transformers are connected to the offsite power supply (grid) because there is no onsite generation.

The substation and incoming power lines are not included in this estimated.

25. <u>Miscellaneous Plant Equipment</u>

This account contains essentially the same equipment as in Reference 4, except that no turbine-generator crane is required. In order to handle a reformer in a shipping cask, the reactor service building crane was increased in size from 100 to 200 tons.

263. <u>Reactor Coolant</u>

This account covers the cost of the initial helium inventory in the reactor, and was not estimated in Reference 1.

910. <u>Engineering Construction Management, and Field Supervision</u>

This account is substantially increased relative to Reference 4 because of the recent increases in quality assurance requirements (10 CFR 50, Appendix B) and because of anticipated licensing costs for the process heat plant. Quality Assurance is assumed to be proportional to the plant size, and is estimated to involve a

20 percent greater scope. Licensing costs are estimated to be 30 percent higher than for an electric power plant of comparable thermal power.

2.3 INTERMEDIATE HEAT TRANSFER LOOP

2.3.1 Summary

This portion of the study was performed because safety and licensing considerations (See References 2 and 3) may require that an intermediate helium loop (IHL) be inserted between the primary coolant and the process gas. This loop would provide additional isolation between the reactor fission products and the products of the reformer. Although evidence has been found in nuclear explosion experiments which implies that the product gas will not be significantly contaminated, this experience is not directly comparable to the nuclear process heat reactor components. The IHL will reduce the possibility that the public will be exposed to radioactive materials. As a result, a conceptual design was prepared and costs estimated for an intermediate loop. Table 2.3 shows changes to the costs of the Base Plant which are required for the installation of an intermediate loop.

The nuclear reactor portion of the plant is essentilly unchanged by the addition of an intermediate loop. The peak coolant temperature is about 1800°F in each case. When the IHL is added, the reformers are removed from the PCRV and are replaced by helium-to-helium heat exchangers. As shown in Figure 2.3, the IHL directs helium flow from the PCRV and the containment building to the two intermediate loop buildings, and then through the reformers, secondary steam generators, steam driven circulators, and finally back to the PCRV. In conceptual design, the plant has four parallel intermediate loops.

The helium is transferred through internally insulated pipes. This insulation is similar to the insulation described in Reference 1 for the hot ducts within the PCRV. Pressure vessels are provided in the intermediate loop buildings for the reformers, steam generators, and circulators. A redundant helium purification system assures that the loop is free of any fission products that may have leaked or migrated through the heat exchangers from the primary coolant loop.

The two intermediate loop buildings are located adjacent to the containment building annulus, as shown in Figure 2.11. Details of the buildings are shown in Figures 2.12 and 2.13.

2.3.2 Intermediate Loop Conceptual Design

The following paragraphs describe the conceptual design of the intermediate loop.

211. Yard Work

Railroad tracks are extended to provide access to both intermediate helium loop buildings in order to facilitate installation, removal, and transport of equipment in loop buildings, such as the reformer, the steam generator, the helium circulator, reformer feed effluent heat exchanger, and other components. Approximately 1,100 feet of additional railroad tracks are provided from the base plant spur to the intermediate loop buildings.

212D. Intermediate Loop Buildings

The two intermediate loop buildings are located adjacent to, and at diametrically opposing positions of, the containment annulus. Each building houses two reformers, two steam generators, and intermediate loop support equipment. Although they are considered part of the containment building, they are structurally independent. Each is 125' x 95' x 140' high. Both have structural steel frames supported on foundations mats and are enclosed by insulated metal siding, metal roof deck and built-up roofing. The below-grade portion of the structures is a basement mat floor with concrete walls up to grade.

Above grade, the buildings are framed with structural steel and interior structural steel is provided to support the reformers, steam generators, helium circulators, pressure vessels and the reformer feed effluent heat exchangers housed in the buildings. The integrated heavy interior steel framing is also used to support the intermediate helium loop and associated piping. Interior walls are concrete block and the floors are concrete slabs supported on steel framing. The building also houses helium purification equipment, switchgear and intermediate loop instrumentation.

Railroad bays for transport of components are located at the ends of the buildings farthest from the annulus. Overhead traveling cranes (85/15 ton) located at the top of the buildings serve the railroad bays as well as the operating floor. The buildings are shown in Figures 2.12 and 2.13.

218E. Helium Storage Building

The helium storage facilities for the intermediate helium loop are housed in an extension to the primary loop helium storage building. The enlarged size of the helium storage building was designed to accommodate required added storage capacity. Labor material costs were scaled from the helium storage buildings costs in Reference 4.

221. Reactor Equipment

The steam generators and intermediate heat exchangers for the primary loop are smaller than the steam generators and reformers in the base plant. As a result, the sizes of the PCRV and the containment building are slightly reduced.

222B. Intermediate Heat Transfer Loop

The intermediate heat exchanger is described and estimated in Reference 1. Installation costs are assumed to be equivalent to the reformer installation costs for the Base Plant.

The steam generators for the intermediate loop are similar in material and design, but smaller than the steam generators in the Base Plant. The steam generator costs were assumed to be proportional to the surface area of the equipment.

The reformers are similar to those described in Reference 1 for the 1600°F case, but larger in diameter to accommodate the larger catalyst surface area which is required at the lower operating temperature of 1400°F. The equipment cost is from Reference 1, page 5-49. Labor and material costs are assumed to be no different than the Base Plant.

The intermediate loop circulators are described in Reference 1. Equipment costs are taken from Reference 1, page 5-49. Labor and material costs are assumed the same as the circulators for the Base Plant.

Pressure vessels are used in the intermediate loop to house the reformer and the steam generator-circulator assemblies. They provide strength to resist the hoop and axial stresses that the PCRV provides in the Base Plant. Costs of the pressure vessels are calculated from a sample design.

Intermediate loop piping is similar to that described for PCRV hot duct piping in Reference 1. The 2¼ Cr-1 Mo (Type A-335 P11) pipe is suitable for the application and is used as the reference design. Costs for piping are computed on a unit cost basis. The internal insulation methods, materials and costs for the conceputal design are described in Reference 1. It has been found that exterior insulation is unnecessary. A cross section of the hot leg is shown in Figure 2.14.

In the conceptual design, 16 isolation valves are necessary. The conceptual design of the valves uses a valve body outer material of 2¼ Cr-1 Mo (A-217 WC-6) and inner material of Incoloy 800, with compatible seat and stem materials and insulation similar to that used in the piping design. Costs are derived from valve cost data for valves in similar applications.

Hanger and support costs are based on current cost data, as are expansion joints and penetrations.

226. Other Reactor Plant Equipment

Containment Inerting Equipment

Because the reformers are not located in the containment building, hydrogen leakage does not endanger the integrity of safety-related equipment. The cost of the containment inerting equipment is thus deleted from the account. The equipment cost is taken from Reference 1, page 5-49.

Helium Storage and Make-up

The helium storage capacity is assumed equal to the helium contained in the entire intermediate loop. Costs are based on this capacity, although the helium storage and make-up system is housed in a common storage building; this system is completely independent of the primary loop storage and make-up system.

Helium Purification Systems

The helium purification systems are similar to those described in Reference 4. The equipment, however, is assumed to be smaller than comparable primary loop equipment because the fission product concentration will be, at most, equal to one-tenth of the concentration of the primary loop.

There are two independent helium purification trains which tie into a single hydrogen removal module. Waste products are vented to the primary loop radioactive waste systems.

227. Instrumentation and Control

Instrumentation and control is assumed similar to the Reference 4 primary loop controls.

241. Switchgear

It is assumed that four 5 kv feeder breakers and four 480 V motor control centers are needed for the intermediate loop power train. Costs are based on current data.

245. Electrical Structure and Wiring Containers

Costs for cable trays and conduit for the intermediate loop equipment are based on current unit cost data.

246. Power and Control Wiring

Costs for low voltage (under 5 kV) and instrument cables are based on estimated quantities and current unit costs.

251. Transportation and Lifting Equipment

An 85/15 ton overhead traveling crane is required in each intermediate loop building for removal of reformers and steam generators.

264. Intermediate Coolant Inventory

The initial helium inventory is assumed equal to the intermediate loop working inventory plus initial storage equal to the working inventory.

91 & 99. Indirect Costs

Accounts numbers 91 and 99 are assumed to be proportional to the direct total cost of the system.

2.4 POWER GENERATION

2.4.1 Summary

The Base Plant is designed to operate entirely from off-site power with no internal generation (other than emergency) in order to provide a more direct comparison of the costs of supplying process heat.

Additional costs of generating electricity on-site are estimated for two cases. In one, generation is sufficient for internal use only, while in the other there is excess generation to permit some sale of power. These costs are summarized in Tables 2.4 and 2.5. The first case is for the generation of 40 MWe, which is enough to supply power for the nuclear process heat plant with about 30 MWe remaining for the chemical process plant. The other case is arbitrarily chosen as 100 MWe, which is sufficient to supply the nuclear and chemical plant needs, with about 60 MWe remaining to sell. Incremental generation costs in this range, from 40 MWe to 100 MWe, are approximately proportional to the incremental power.

The power turbine plant is essentially an additional piece of equipment which draws steam from the main steam supply and exhausts it back to the chemical plant. Figures 2.4 and 2.5 show the inlet, outlet, and main steam conditions for each case. The changes in the plant systems to accommodate power generation all occur in the chemical process plant rather than the nuclear plant. Figures 2.15 and 2.16 show the location of the Turbine Building on the plant site.

The chemical plant is expected to supply steam to the turbine and to use the turbine effluent. Support systems necessary for the operation of the turbine are included in this estimate. Because the conditions and equipment of the chemical plant are not yet defined, costs are not estimated for circulating water and water purification systems, condensate and feedwater systems, water intake and outlet structures, and steam piping.

The total cost of generating electricity is thus not included in these estimates, but the additional systems costs will depend on the chemical plant conceptual design.

2.4.2 Power Generation Plant Conceptual Design

The systems and structures required for the power generation are described below by account.

213. Turbine-Generator Building

This building is similar in design and construction to the turbine-generator building described in Reference 4 with the exception that upper floors, walls, and platforms are not required for condensate and feedwater systems, which will be located in the chemical plant.

231. Turbine-Generator

The turbine-generator account includes the turbine-generator, foundation mat, CO_2 purge gas system, hydrogen cooling gas system, and the lubricating oil system.

24. Electric Plant Equipment

This account includes the generator switchgear and the generator bus duct to the main plant switchgear. The 100 MWe case also includes a generator protective relay panel.

251. Transportation and Lifting Equipment

The Turbine Building is supplied with a 40 ton crane for the 40 MWe case and a 75 ton crane for the 100 MWe case.

91 & 99. Indirect Costs

Accounts 91 and 99 are proportional to the total plant cost.

2.5 OPERATION AND MAINTENANCE

The annual operation and maintenance (O&M) charges for the NPH plant estimated by GA in Reference 1 are in general agreement with the O&M costs for similar sized power reactor plants. Table 2.6 shows the O&M costs estimated by UE&C for plants with and without an intermediate loop and with and without power generation.

The GA fixed maintenance charges seem unusually low when compared with power reactors. Fixed maintenance is defined as mechanical equipment servicing and building maintenance. Power industry experience for these costs ranges between 1.5 and 2.5 million dollars per year. The majority of this expense is incurred in heat exchanger maintenance.

The base NPH plant has four steam generators and four reformers, which represents a total of two more heat exchangers than in an 1160 MWe HTGR. When the intermediate loop is added, there are eight steam generators, four reformers, and four intermediate heat exchangers which represents ten more heat exchangers than in a comparable electric plant. In addition, the reformers and intermediate heat exchangers operate at higher temperatures than standard steam generators, and are thus expected to required more maintenance. Additional maintenance will be necessary if the systems are not kept free of dust and impurities, which cause hot spots in the heat exchangers.

The fixed maintenance costs for the NPH plant are thus likely to be about 1.5 to 2.5 million dollars per year, which is in the same range as for a comparable power plant. These costs will be increased by about 1.0 to 1.5 million dollars if an intermediate loop is added.

2.6 COMPARISON PLANT

The Comparison Plant is the combination of the Base Plant (Section 2.2) and the Intermediate Loop (Section 2.3). It is the basis for comparing the General Atomic/UE&C conceptual design and cost estimate with the estimates provided by General Electric and Westinghouse (Chapter 3). Chapter 4 compares these estimates.

As shown in Figure 2.11, the Comparison Plant is essentially the same as the Base Plant, except that additional facilities have been added to house and service the Intermediate Loop. Table 2.7 combines the costs which will be compared with the other estimates.

TABLE 2.1

NSSS COST ESTIMATED BY GENERAL ATOMIC
(July, 1974)

Account	Description	Cost (Thousands of Dollars) LADWP[1] BID	NPH[2] ADDER	TOTAL
221	Reactor Equipment	107,594	20,323	127,917
222	Main Heat Transfer Loop	39,269	39,054	78,323
223	Safeguards Cooling System	7,258	12	7,270
224	Radioactive Waste Treatment and Disposal	3,822	718	4,540
225	Nuclear Fuel Handling and Storage	13,826	516	14,342
226	Other Reactor Plant Equipment	2,973	2,700	5,673
227	Instrumentation and Control	3,761	53	3,814
269	Initial Catalyst Filling	0	271	271
99	Other Costs	0	939	939
995	Contingency	0	24,000	24,000
	Total	178,503	88,586	267,089

NOTES:

(1) Total bid by GA to Los Angeles Department of Water and Power (LADWP), escalated by GA to July 1974, and divided into accounts according to recent estimates and the appropriate costs in Reference 4.

(2) Adders for NPH plant from Reference 1, Section 8, with contingency costs removed to separate accounts, in proportion to the size of each account.

(3) For discussion, see Section 2.2.2.

TABLE 2.2

COST OF BASE PLANT WITH GENERAL ATOMIC REACTOR
NO INTERMEDIATE LOOP, NO POWER GENERATION
(July, 1974)

Account	Description	BOP Materials and Equipment	BOP Labor	GA Adder[1]	Total
		Costs (Thousands of Dollars)			
20	Land and Land Rights				
201	Land and Privilege Acquisition	1,000	--	--	1,000
Total 20		1,000	--	--	1,000
21	Structures and Improvements				
211	Yard Work	1,203	1,424	--	2,627
212	Reactor Containment Building	12,247	21,564	--	33,811
214	Intake Structure	285	127	--	412
215	Reactor Service Building	6,000	11,255	--	17,255
218A	Control Building	1,900	4,146	--	6,046
218B	Diesel Generator Building	1,628	3,512	--	5,140
218C	Administration Building	1,200	1,372	--	2,572
218D	Auxiliaries Building	363	485	--	848
218E	Helium Storage Building	90	71	--	161
Total 21		24,916	43,956	--	68,872
22	Reactor Plant Equipment				
221	Reactor Equipment	104	578	127,917	128,599
222	Main Heat Transfer Loop	318	1,146	78,323	79,787
223	Safeguards Cooling System	409	259	7,270	7,938
224	Radioactive Waste Treatment and Disposal	239	884	4,540	5,663
225	Nuclear Fuel Handling and Storage	254	640	14,342	15,236
226	Other Reactor Plant Equipment	9,968	6,998	5,673	22,639
227	Instrumentation and Control	2,356	1,169	3,814	7,339
Total 22		13,648	11,674	241,879	267,201

TABLE 2.2 (Page 2 of 3)

Account	Description	BOP Materials and Equipment	BOP Labor	CA Adder	Total
		Base Plant Costs (Thousands of Dollars)			
24	Electric Plant Equipment				
241	Switchgear	2,131	381	--	2,512
242	Station Service Equipment	4,484	808	--	5,292
243	Switchboards	361	146	--	507
244	Protective Equipment	190	328	--	518
245	Electrical Structures and Wiring Containers	1,429	5,615	--	7,044
246	Power and Control Wiring	4,886	5,838	--	10,724
Total 24		13,481	13,116	--	26,597
25	Miscellaneous Plant Equipment				
251	Transportation and Lifting Equipment	1,121	278	--	1,399
252	Air, Hydraulic, Water and Steam Service Systems	3,165	3,643	--	6,808
253	Communications Equipment	74	107	--	181
254	Furnishings and Fixtures	345	41	--	386
Total 25		4,705	4,069		8,774
26	Special Materials				
263	Reactor Coolant (and initial storage)	254	--	--	254
269	Initial Catalyst Filling	0	20	271	291
Total 26		254	20	271	545
Total 21, 22, 23, 24, 25, & 26		57,004	72,835	242,150	371,989

TABLE 2.2 (Page 3 of 3)

Account	Description	BOP Materials and Equipment	BOP Labor	GA Adder	Total
		Base Plant Costs (Thousands of Dollars)			
91	Engineering and Construction Costs				
910A	Engineering Services and Construction Management	--	63,898	(2)	63,898
911	Temporary Facilities	1,800	3,375	--	5,175
912	Construction Equipment	8,400	900	--	9,300
913	Construction Services	5,760	4,950	--	10,710
Total 91		15,960	73,123		89,083
99	Other Costs				
	GA Other Costs	--	--	939	939
991	Operator Training	1,330	--	--	1,330
992	Spare Parts	1,756	--	--	1,756
993	Preliminary Operations and Testing	--	(Not included in Estimate)		--
994	Miscellaneous Costs	4,788	--		4,788
995	Contingency	--	--	24,000	24,000
Total 99		7,874		24,939	32,813
Total 91 & 99		23,834	73,123	24,939	121,896
Total Plant Costs		81,838	145,958	267,089	494,885

Notes: (1) GA Adders are from Reference 2, Section 8. Contingency costs were separated in proportion to the size of each account. The GA bid for LADWP is taken from Table 2.1.

(2) GA added costs were distributed by GA among other accounts.

(3) For discussion, see Section 2.2.

TABLE 2.3

COST ADJUSTMENTS FOR INTERMEDIATE LOOP
(July, 1974)

Account	Description	Cost (Thousands of Dollars) Equipment & Material	Labor	Total
211	Yard Work	29	16	45
	Railroads			
212D	Intermediate Loop Building	3,091	3,502	6,593
218E	Helium Storage Building	30	39	69
221	Reactor Equipment	(513)	(823)	(1,336)
222B	Intermediate Heat Transfer Loop	~~72,626~~ 59,530	~~10,186~~ 9,736	~~82,812~~ 69,266
	Intermediate Heat Exchanger Steam Generators Reformers Circulators Pressure Vessels Piping and Valves			
226	Other Reactor Plant Equipment	24	(17)	7
	Containment Inerting Equipment Helium Storage and Make-up Helium Purification Systems			
227	Instrumentation and Control	628	111	739
241	Switchgear	113	23	136
245	Electrical Structures and Wiring Containers	45	197	242
246	Power and Control Wiring	25	47	72
251	Transportation and Lifting Equipment	310	90	400
264	Intermediate Coolant Inventory (Including initial storage)	89	--	89
269	IHL Initial Catalyst Filling	307	20	327

TABLE 2.3 (Page 2 of 2)

		Cost (Thousands of Dollars)		
Account	Description	Equipment & Material	Labor	Total
910	Engineering Services and Construction Management	--	15,463	15,463
913	Construction Services	1,394	1,198	2,592
991	Operator Training	322	--	322
994	Miscellaneous Costs	1,159	--	1,159
	Total	~~79,679~~ 66,583	~~30,052~~ 29,602	~~109,731~~ 96,185

NOTE: For discussion, see Section 2.3.

TABLE 2.4

COST ADJUSTMENTS FOR POWER GENERATION
(July, 1974)
40 MWe CASE

ACCOUNT	DESCRIPTION	COST (THOUSANDS OF DOLLARS)		
		EQUIPMENT & MATERIAL	LABOR	TOTAL
213	Turbine-Generator Building	140	235	375
231	Turbine-Generator	2,434	266	2,700
241	Switchgear	65	10	75
242	Station Service Equipment	(30)	0	(30)
246	Power and Control Wiring	201	90	291
251	Transportation and Lifting Equipment	73	21	94
91	Engineering and Construction	-	886	886
99	Other Costs	79	-	79
	TOTAL	2,962	1,508	4,470

NOTE: For discussion, see Section 2.4.

TABLE 2.5

COST ADJUSTMENTS FOR POWER GENERATION
(July, 1974)
100 MWe CASE

ACCOUNT	DESCRIPTION	COST (THOUSANDS OF DOLLARS)		
		EQUIPMENT & MATERIAL	LABOR	TOTAL
213	Turbine-Generator Building	262	441	703
231	Turbine-Generator	4,854	534	5,388
241	Switchgear	73	10	83
242	Station Service Equipment	(30)	0	(30)
243	Switchboards	71	14	85
246	Power and Control Wiring	265	118	383
251	Transportation and Lifting Equipment	136	35	171
91	Engineering and Construction	-	1,726	1,726
99	Other Costs	158	-	158
	TOTAL	5,789	2,878	8,667

NOTE: For discussion, see Section 2.4.

TABLE 2.6

ANNUAL OPERATION AND MAINTENANCE COSTS

(Thousands of Dollars)

(JULY 1974)

Item	Base Plant	Base Plant + Intermediate Loop[1]	Base Plant + Power Generation	Base Plant + Power Generation + Intermediate Loop
Station Staffing	1,800	1,960	1,880	2,040
Fixed Maintenance	1,500 - 2,500	2,500 - 4,000	1,500 - 2,500	2,500 - 4,000
Variable Maintenance (Including Catalyst Costs)	960	1,320	960	1,320
Supplies and Expenses	140 - 800	160 - 820	150 - 810	170 - 830
Coolant Make-Up Purchase	65	125	65	125
Electric Power Purchased	2,080	2,080	0	0
Insurance	390	390	390	390
Annual License Fee	200	200	200	200
Administrative & General	260	260	260	260
TOTAL	7,395 - 9,055	8,995 - 11,155	5,405 - 7,065	7,005 - 9,165

NOTE: (1) This plant is the basis for comparison with the General Electric and Westinghouse plants.

TABLE 2.7

COMPARISON PLANT COSTS - GENERAL ATOMIC/UE&C
(July, 1974)

Account	Description	COSTS (THOUSANDS OF DOLLARS) Base Plant	IHL Adder	Total
20	LAND AND LAND RIGHTS			
201	Land and Priv. Acq.	1,000	-	1,000
	Account 20 - Total	1,000		1,000
21	STRUCTURES AND IMPROVEMENTS			
211	Yard Work	2,627	45	2,672
212	React. Contain. Bldg.	33,811	-	33,811
212D	Intermediate Loop Bldg.	-	6,593	6,593
214	Intake Structures	412	-	412
215	React. Service Bldg.	17,255	-	17,255
217	Fuel Storage Building (3)	-	-	-
218A	Control Building	6,046	-	6,046
218B	Diesel Gen. Building	5,140	-	5,140
218C	Admin. Building	2,572	-	2,572
218D	Auxiliaries Building	848	-	848
218E	Helium Storage Bldg.	161	69	230
	Account 21 - Total	68,872	6,707	75,579
22	REACTOR PLANT EQUIPMENT			
221	Reactor Equipment	128,599	(1,336)	127,263
222	Heat Transfer System	79,787	69,266 ~~82,812~~	~~162,599~~ 149,053
223	Safeguards Cool. System	7,938	-	7,938
224	Rad. Waste Treatment & Disp.	5,663	-	5,663
225	Nuclear Fuel Hdlg. & Storage	15,236	-	15,236
226	Other	22,639	7	22,646
227	I&C	7,339	739	8,078
	Account 22 - Total	267,201	~~82,222~~ 68,676	~~349,423~~ 335,877

TABLE 2.7 (Page 2 of 3)

Account	Description	Base Plant	IHL Adder	Total
		COSTS (THOUSANDS OF DOLLARS)		
24	ELECTRIC PLANT EQUIPMENT			
241	Switchgear	2,512	136	2,648
242	Sta. Service Equip.	5,292	-	5,292
243	Switchboards	507	-	507
244	Protective Equipment	518	-	518
245	El. Struct. & Wiring Contain.	7,044	242	7,286
246	Power & Control Wiring	10,724	72	10,796
	Account 24 - Total	26,597	450	27,047
25	MISCELLANEOUS PLANT EQUIPMENT			
251	Trans. & Lifting	1,399	400	1,799
252	Air, Hyd., Water & Steam	6,808	-	6,808
253	Communications	181	-	181
254	Furnishings & Fixtures	386	-	386
	Account 25 - Total	8,774	400	9,174
26	SPECIAL MATERIALS			
263	Reactor Coolant (2)	254	-	254
264	Intermediate Coolant (2)	-	89	89
269	Initial, Catalyst Filling	291	327	618
	Account 26 - Total	545	416	961
	Subtotal (Accounts 21 through 26)	371,989	~~90,195~~ 76,649	~~462,184~~ 448,638
91	ENGINEERING & CONSTR. COSTS			
910	Engineering Services and Construction Management	63,898	15,463	79,361
911	Temporary Facilities	5,175	-	5,175
912	Construction Equipment	9,300	-	9,300
913	Construction Services	10,710	2,592	13,302
	Account 91 - Total	89,083	18,055	107,138

TABLE 2.7 (Page 3 of 3)

Account	Description	Base Plant	IHL Adder	Total
		COSTS (THOUSANDS OF DOLLARS)		
99	OTHER COSTS			
991	Operator Training	1,330	332	1,652
992	Spare Parts	1,756	--	1,756
993	Prelim. Oper. & Testing(1)			
994	Misc. Costs	4,788	1,159	5,947
995	Contingency	24,000		24,000
996	IDC (1)		--	
997	GA-Other Costs (Undistr.)	939		939
	Account 99 - Total	32,813	1,481	34,294
	TOTALS OF ALL COSTS	494,885	~~109,731~~ 96,185	~~604,616~~ 591,070

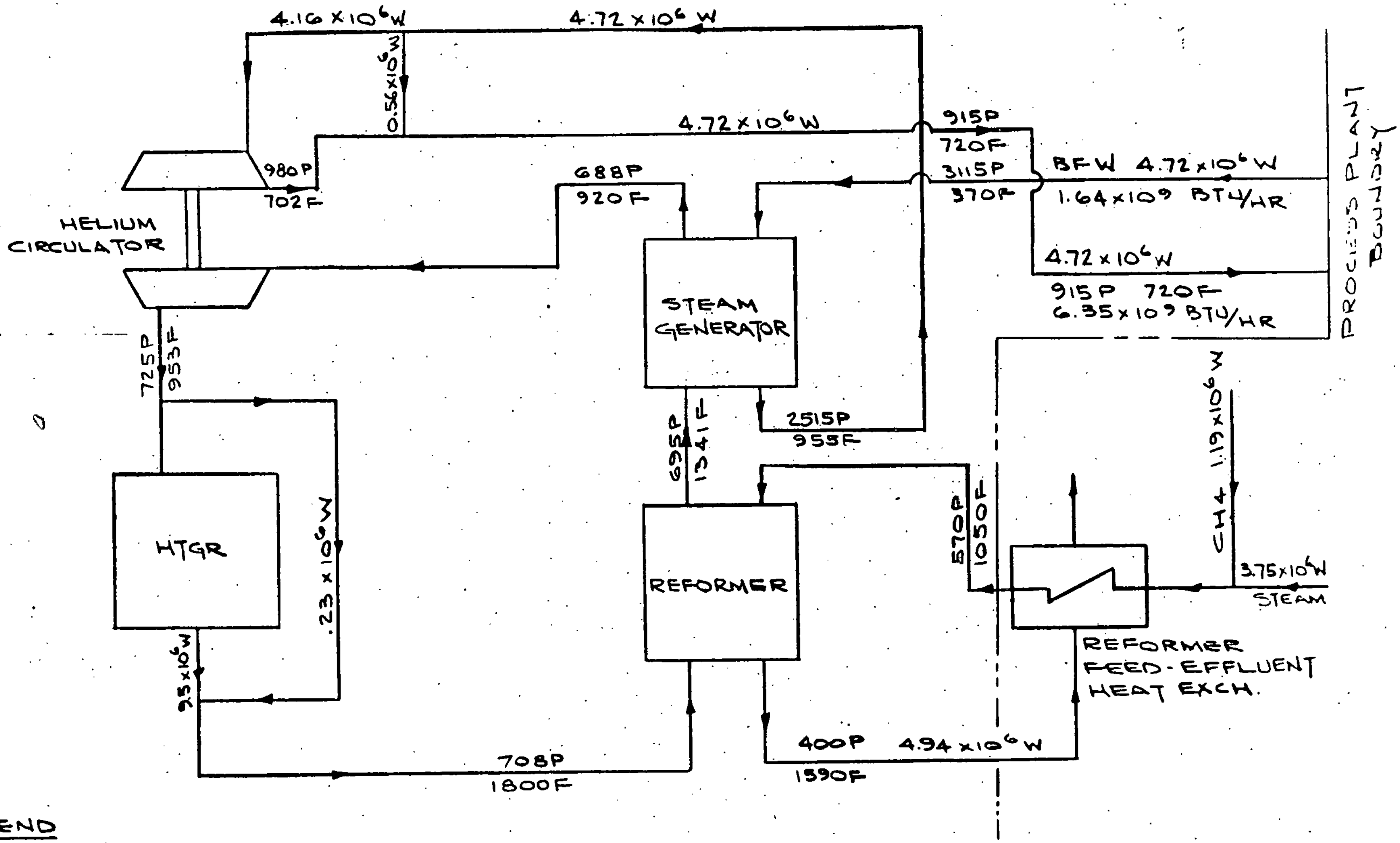
NOTES:

(1) - Not Estimated.

(2) - Includes 100% Reserve in Storage.

(3) - Functions Included in Reactor Service Building (Account No. 215).

(4) - This table is derived from Tables 2.2 and 2.3.

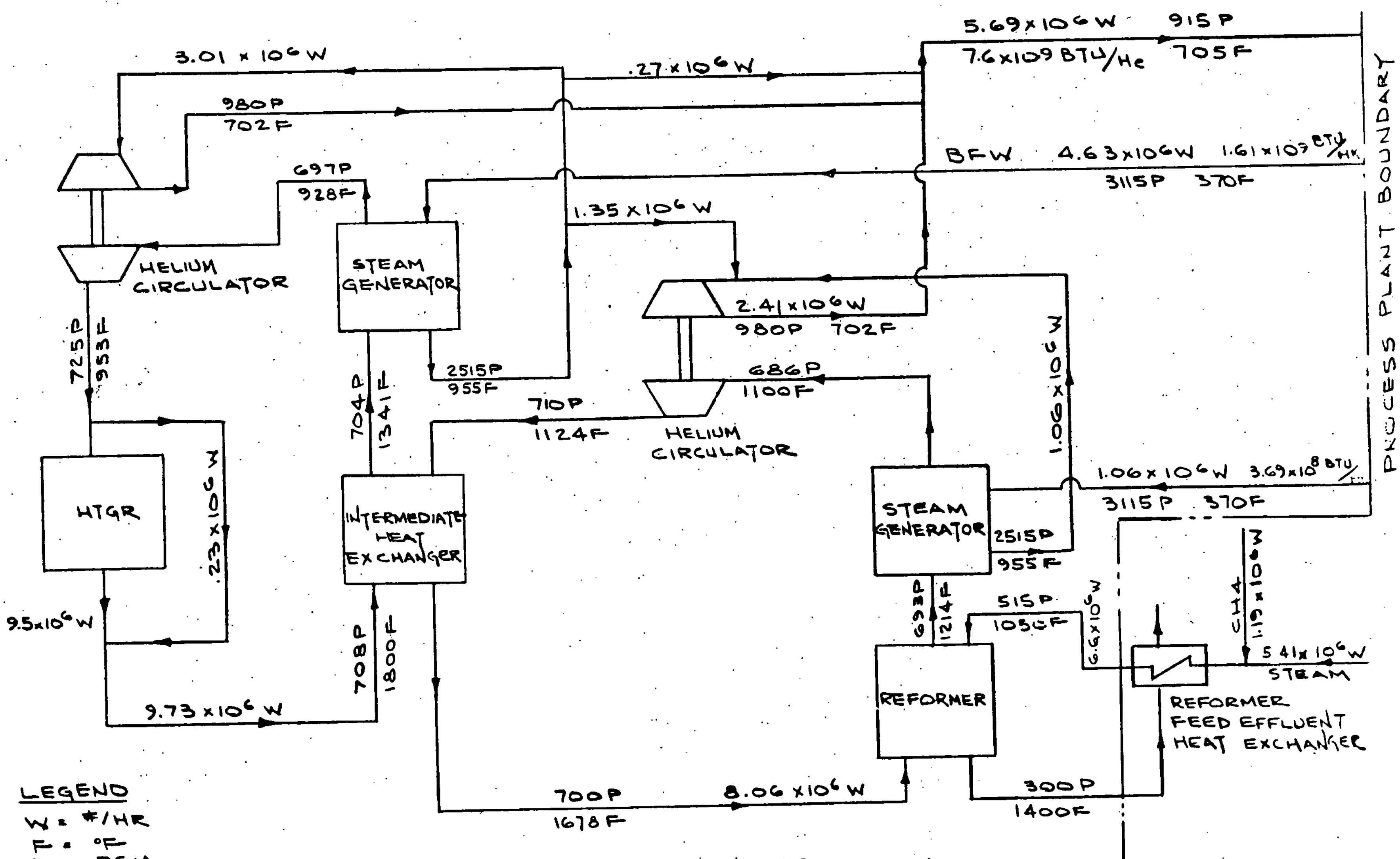


LEGEND
W = #/HR
F = °F
P = PSIA

HEAT BALANCE DIAGRAM

NUCLEAR PROCESS HEAT REACTOR WITH REFORMER IN PCRV

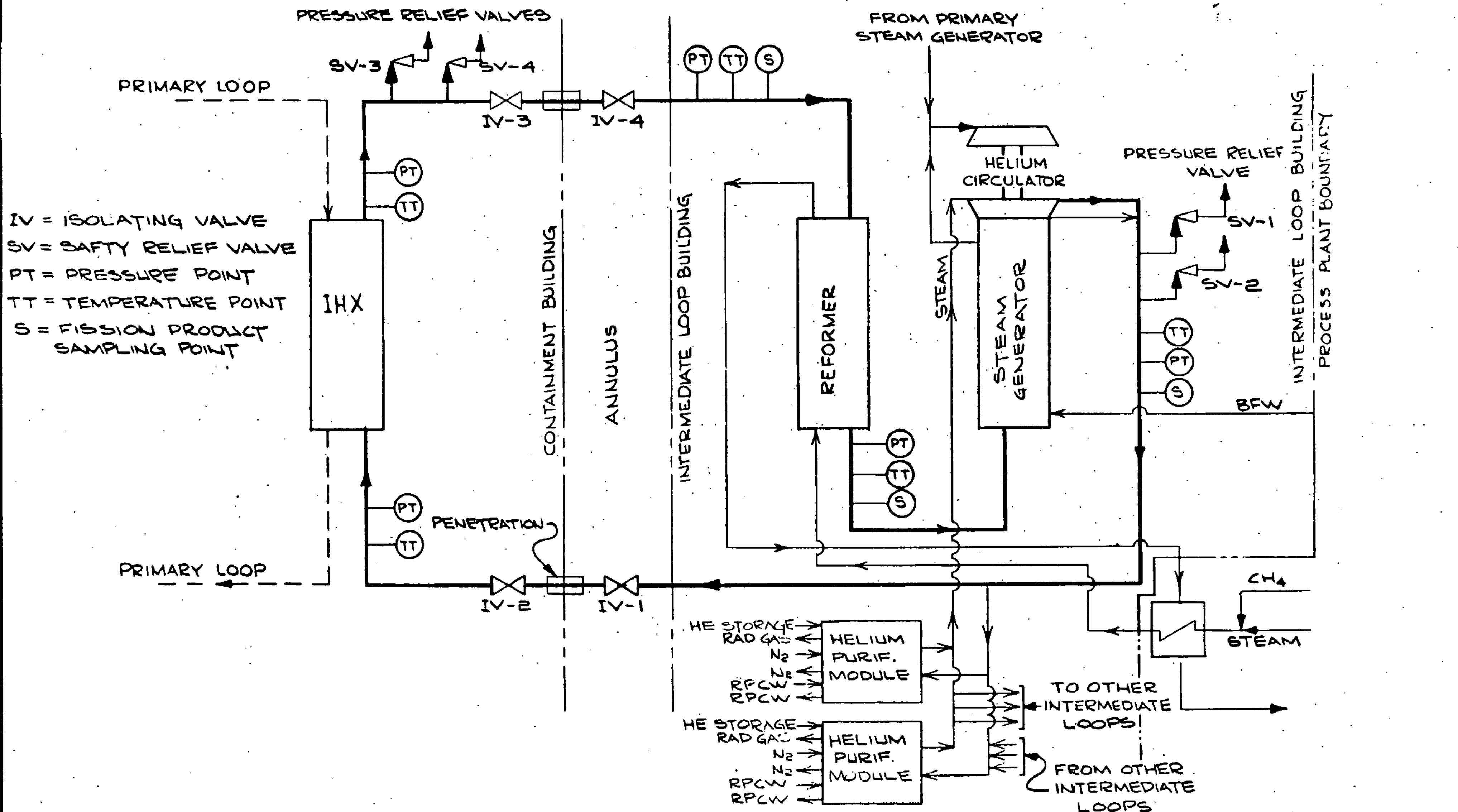
FIGURE 2.1



HEAT BALANCE DIAGRAM

NUCLEAR PROCESS HEAT REACTOR WITH INTERMEDIATE HELIUM LOOP

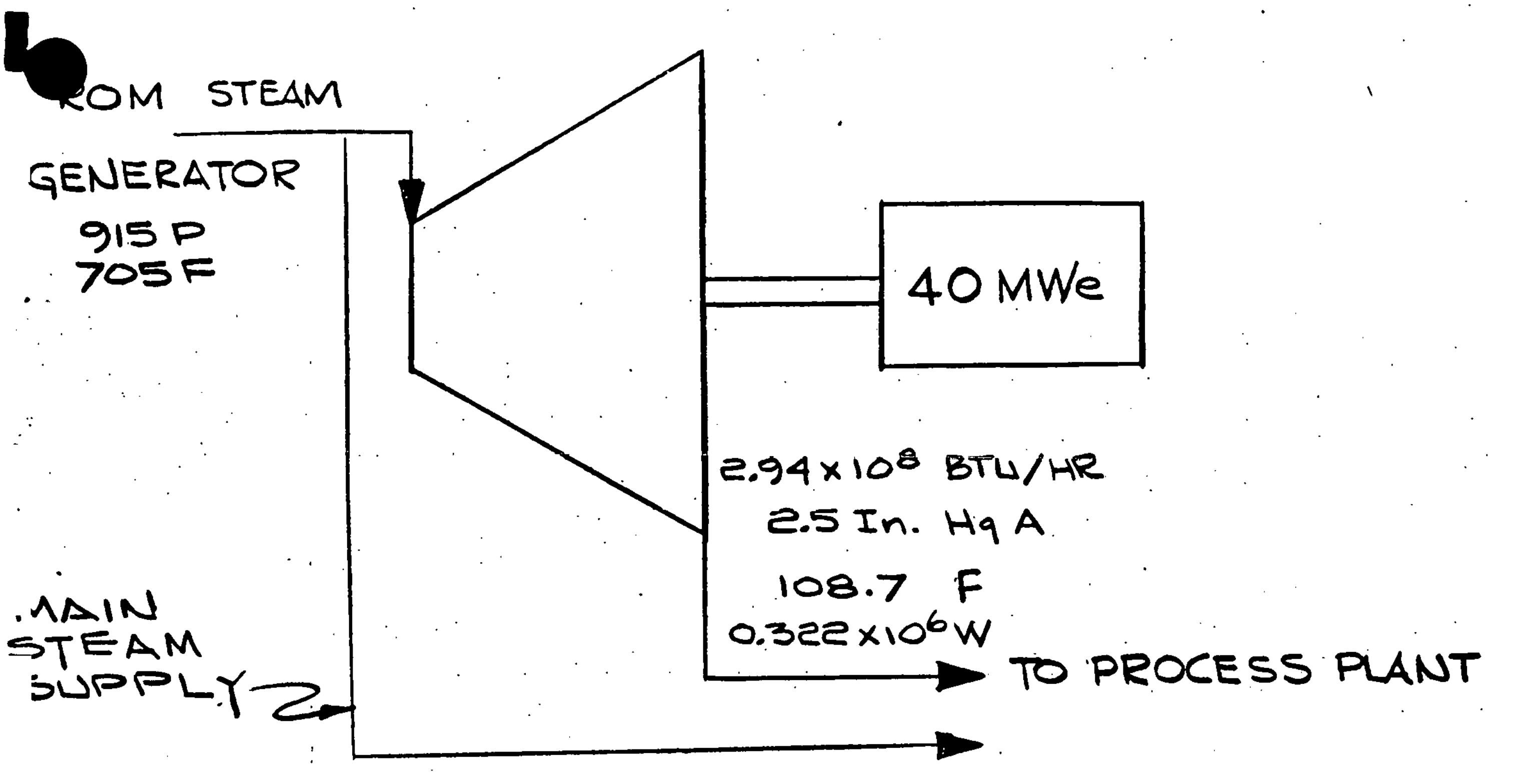
FIGURE 2.2



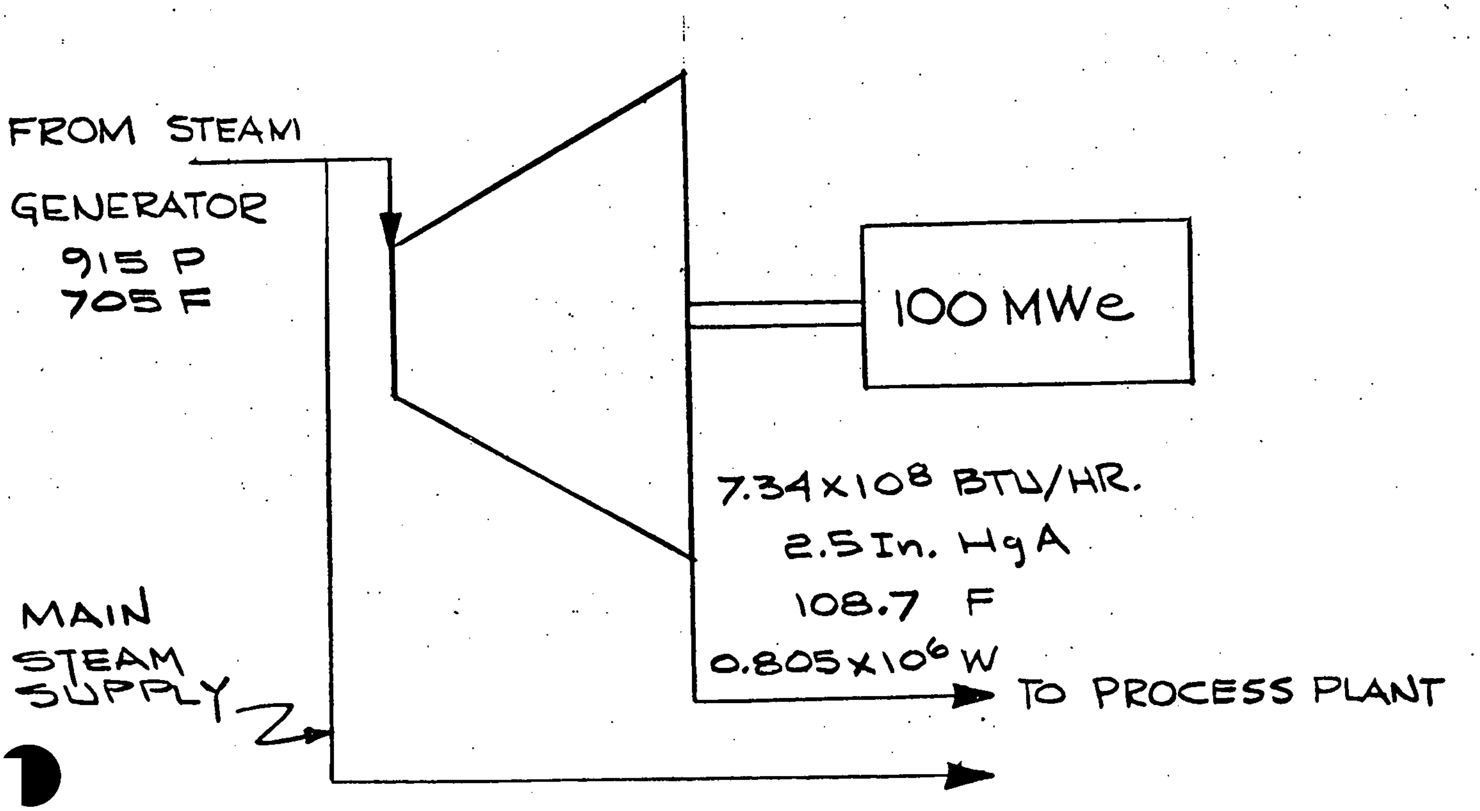
SCHEMATIC DIAGRAM

INTERMEDIATE HELIUM LOOP

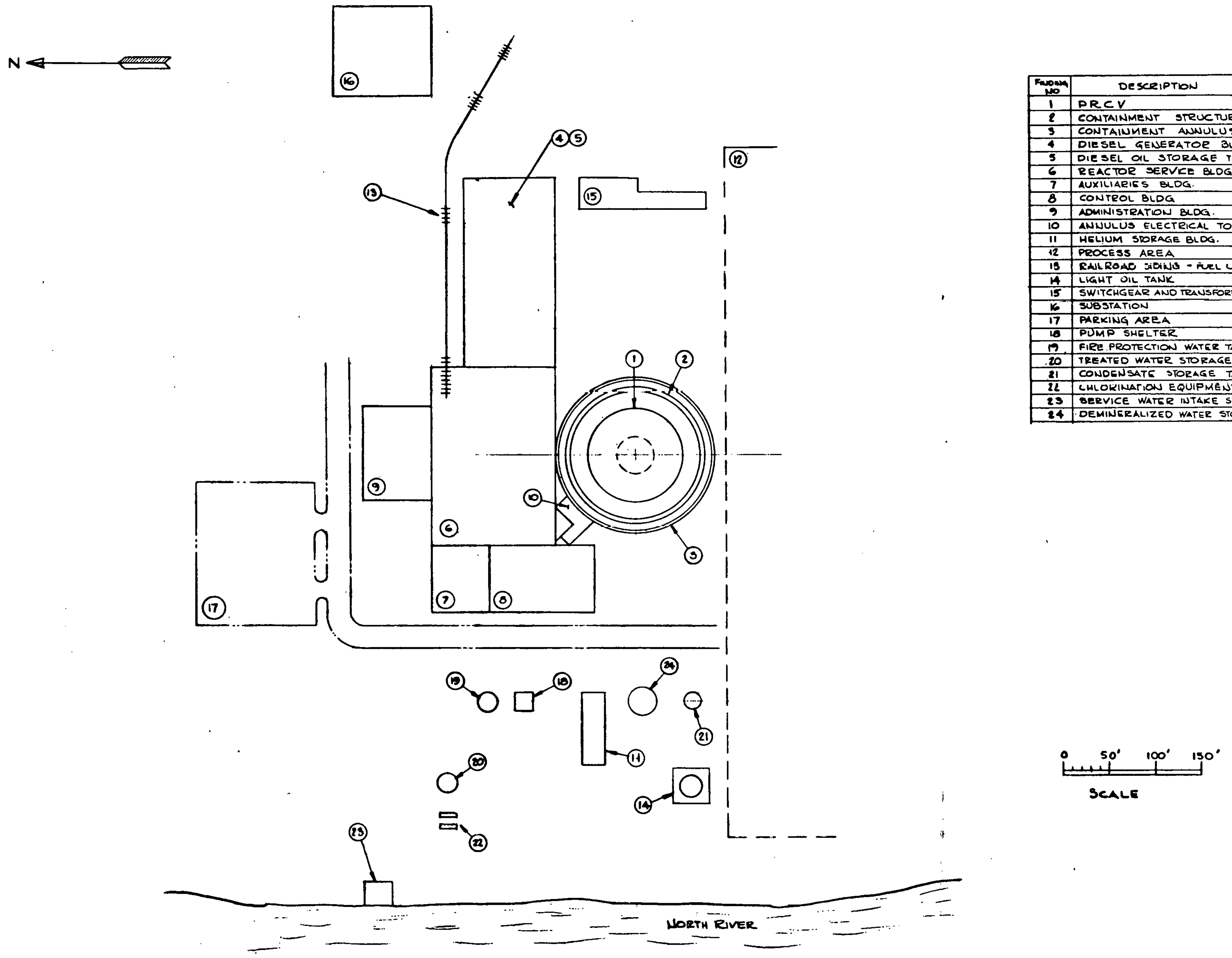
FIGURE 2.3



HEAT BALANCE DIAGRAM, 40 MWe TURBINE — FIGURE 2.4



HEAT BALANCE DIAGRAM, 100 MWe TURBINE — FIGURE 2.5



FIELD NO	DESCRIPTION
1	PRCV
2	CONTAINMENT STRUCTURE
3	CONTAINMENT ANNULUS
4	DIESEL GENERATOR BLDG
5	DIESEL OIL STORAGE TANKS
6	REACTOR SERVICE BLDG.
7	AUXILIARIES BLDG.
8	CONTROL BLDG
9	ADMINISTRATION BLDG.
10	ANNULUS ELECTRICAL TOWER
11	HELIUM STORAGE BLDG.
12	PROCESS AREA
13	RAILROAD SIDING - FUEL CAR
14	LIGHT OIL TANK
15	SWITCHGEAR AND TRANSFORMER AREA
16	SUBSTATION
17	PARKING AREA
18	PUMP SHELTER
19	FIRE PROTECTION WATER TANK
20	TREATED WATER STORAGE TANK
21	CONDENSATE STORAGE TANK
22	CHLORINATION EQUIPMENT
23	SERVICE WATER INTAKE STRUCTURE
24	DEMINERALIZED WATER STORAGE TANK

FIGURE 2.6

DATE	DESCRIPTION	ENGR.	SUP. ENG.
	FIRST ISSUE		

ENGINEER
STATE REG. NO.

PLOT PLAN
3000MW(t) HGTR (O-MWE)
FOR PROCESS HEAT
(MIDDLETOWN HYPOTHETICAL SITE)

united engineers & constructors inc.

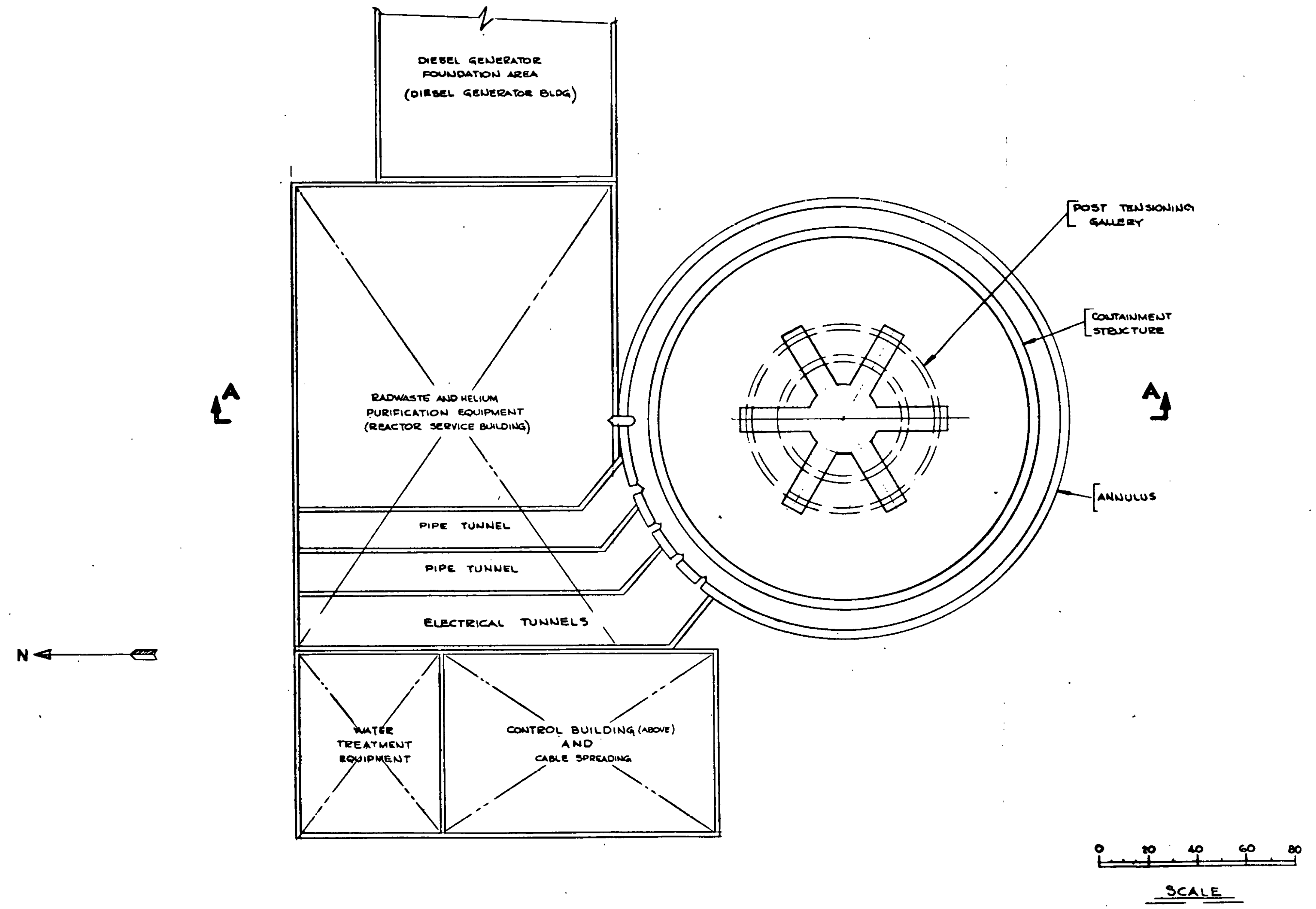


FIGURE 2.7

GENERAL ARRANGEMENT
PLAN VIEW AT ELEV 1'-0"
3000 MW(t) HTGR (0-MWE)
FOR PROCESS HEAT
(MIDDLETOWN HYPOTHETICAL SITE)

united engineers

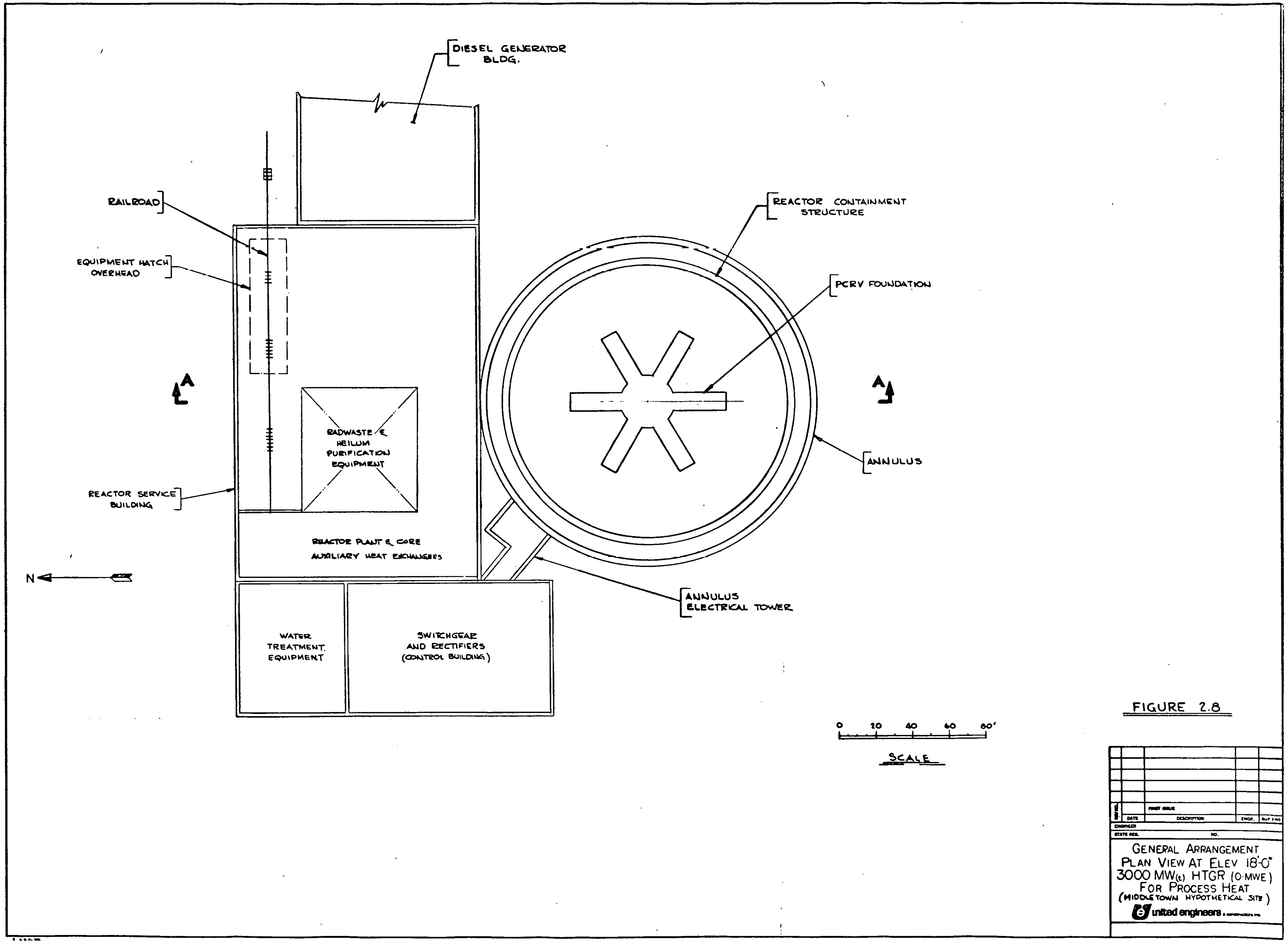
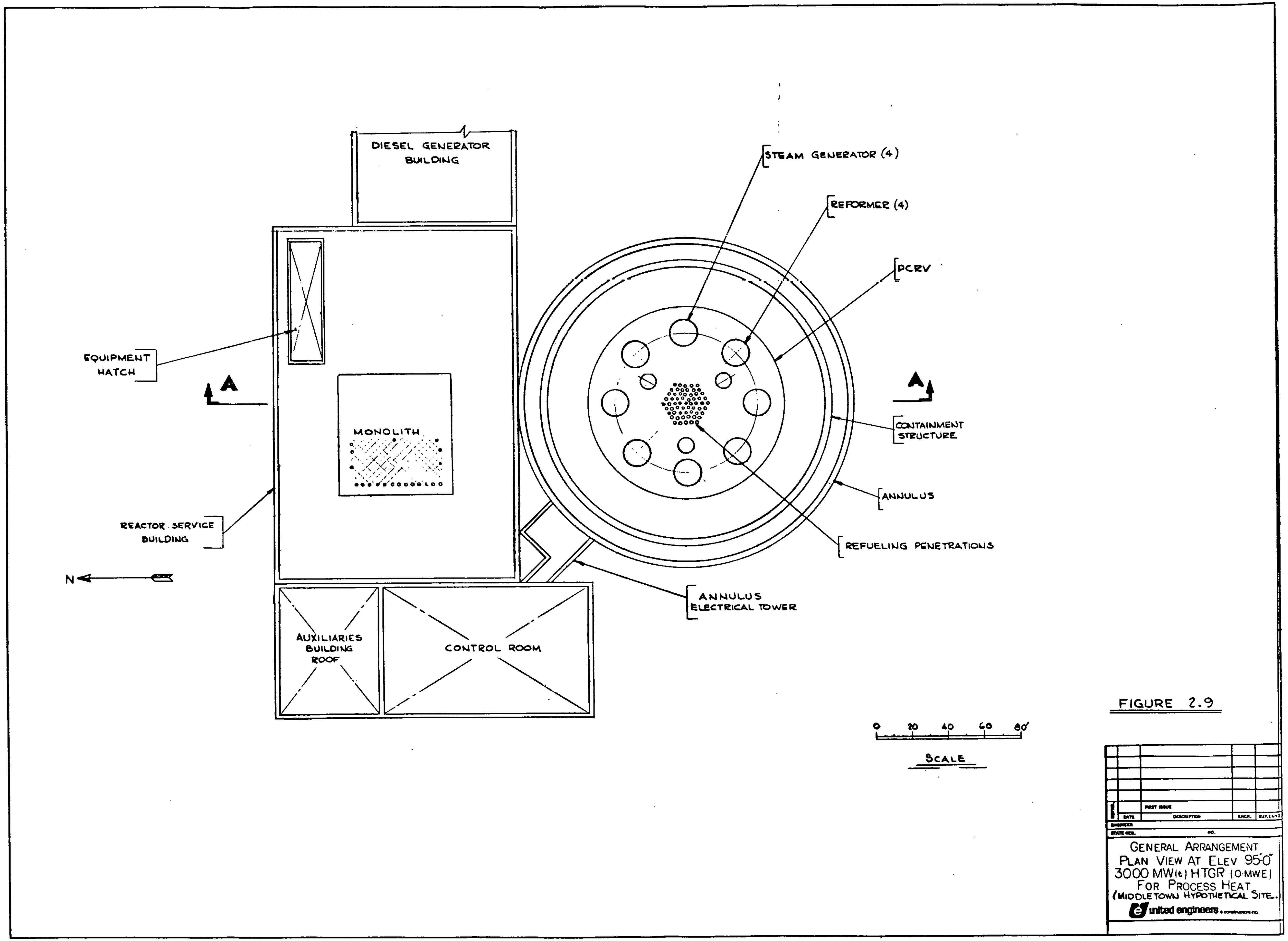
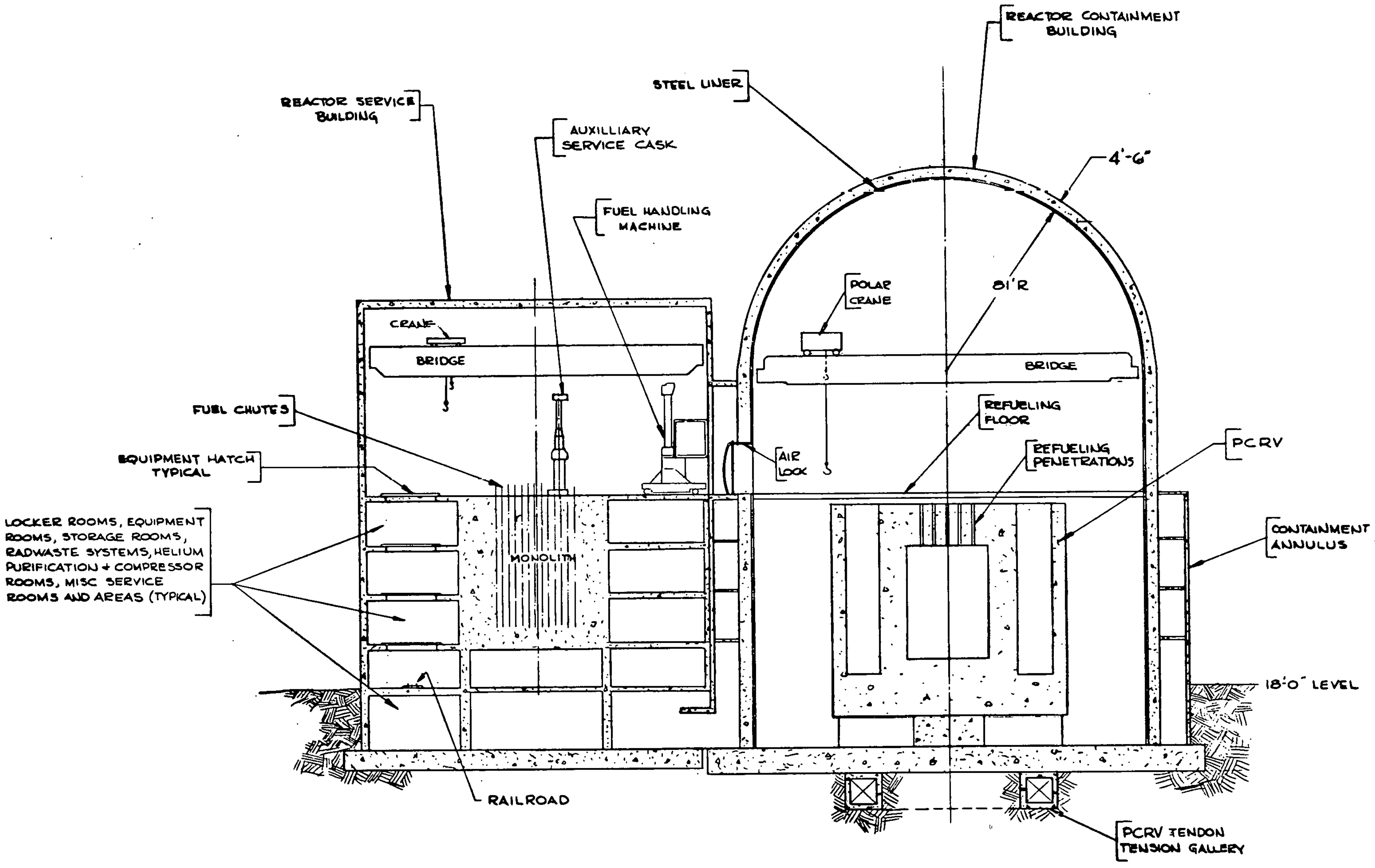

DIESEL GENERATOR BLDG.
RAILROAD
EQUIPMENT HATCH OVERHEAD
REACTOR CONTAINMENT STRUCTURE
PCRV FOUNDATION
A
A
RADWASTE & HEILUM PURIFICATION EQUIPMENT
ANNULUS
REACTOR SERVICE BUILDING
REACTOR PLANT & CORE AUXILIARY HEAT EXCHANGERS
N
ANNULUS ELECTRICAL TOWER
WATER TREATMENT EQUIPMENT
SWITCHGEAR AND RECTIFIERS (CONTROL BUILDING)
0 20 40 60 80'
SCALE
FIRST ISSUE
DATE
DESCRIPTION
GENERAL ARRANGEMENT
PLAN VIEW AT ELEV 18'-0"
3000 MW(t) HTGR (0-MWE)
FOR PROCESS HEAT
(MIDDLETOWN HYPOTHETICAL SITE)
united engineers

FIGURE 2.8



DIESEL GENERATOR BUILDING
STEAM GENERATOR (4)
REFORMER (4)
PCRV
EQUIPMENT HATCH
A
A
MONOLITH
CONTAINMENT STRUCTURE
ANNULUS
REACTOR SERVICE BUILDING
REFUELING PENETRATIONS
N
ANNULUS ELECTRICAL TOWER
AUXILIARIES BUILDING ROOF
CONTROL ROOM
0 20 40 60 80'
SCALE
FIRST ISSUE
DATE
DESCRIPTION
GENERAL ARRANGEMENT
PLAN VIEW AT ELEV 95'-0"
3000 MW(t) HTGR (O-MWE)
FOR PROCESS HEAT
(MIDDLETOWN HYPOTHETICAL SITE.)
united engineers & constructors inc.

FIGURE 2.9



SECTION **A - A**

0 20 40 60 80'

SCALE

FIGURE 2.10

REV. NO.		FIRST ISSUE		
	DATE	DESCRIPTION	ENGR.	SUP. ENG.

ENGINEER

STATE REG. NO.

GENERAL ARRANGEMENT
SECTION A-A
3000 MW(t) HGTR (0-MWe)
FOR PROCESS HEAT
(MIDDLETOWN HYPOTHETICAL SITE)

united engineers & constructors inc.

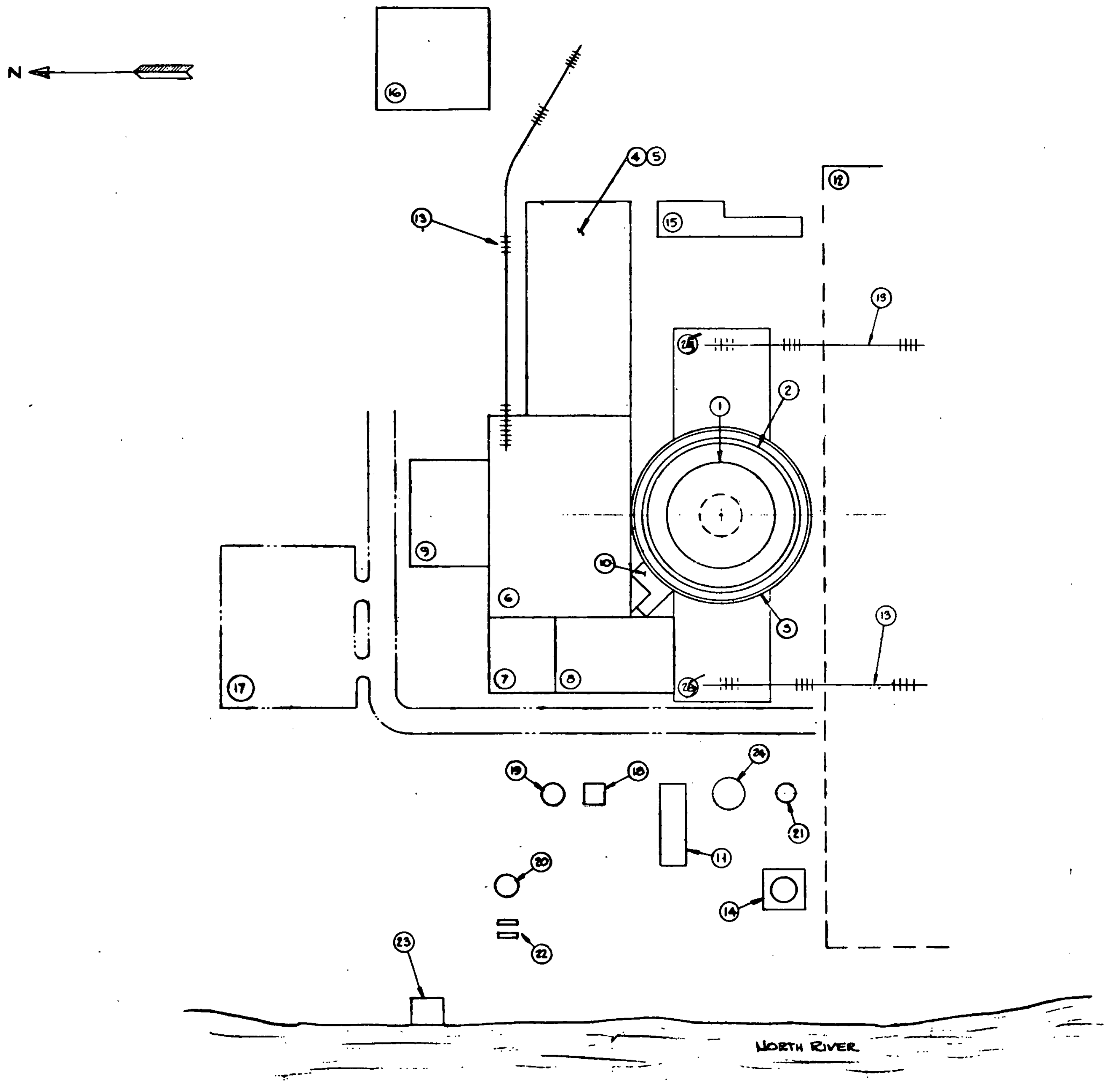


FIGURE NO	DESCRIPTION
1	PRCV
2	CONTAINMENT STRUCTURE
3	CONTAINMENT ANNULUS
4	DIESEL GENERATOR BLDG
5	DIESEL OIL STORAGE TANKS
6	REACTOR SERVICE BLDG.
7	AUXILIARIES BLDG.
8	CONTROL BLDG
9	ADMINISTRATION BLDG.
10	ANNULUS ELECTRICAL TOWER
11	HELIUM STORAGE BLDG.
12	PROCESS AREA
13	RAILROAD SIDING
14	LIGHT OIL TANK
15	SWITCHGEAR AND TRANSFORMER AREA
16	SUBSTATION
17	PARKING AREA
18	PUMP SHELTER
19	FIRE PROTECTION WATER TANK
20	TREATED WATER STORAGE TANK
21	CONDENSATE STORAGE TANK
22	CHLORINATION EQUIPMENT
23	SERVICE WATER INTAKE STRUCTURE
24	DEMINERALIZED WATER STORAGE TANK
25	INTERMEDIATE LOOP BLDG.

0 50' 100' 150'

SCALE

FIGURE 2.11

		FIRST ISSUE		
	DATE	DESCRIPTION	ENGR.	SUP. ENG.

ENGINEER

STATE REG. NO.

PLOT PLAN
3000MW(t) HGTR (0-MWE)
INTERMEDIATE LOOP BUILDING
(MIDDLETOWN HYPOTHETICAL SITE)

united engineers & constructors inc.

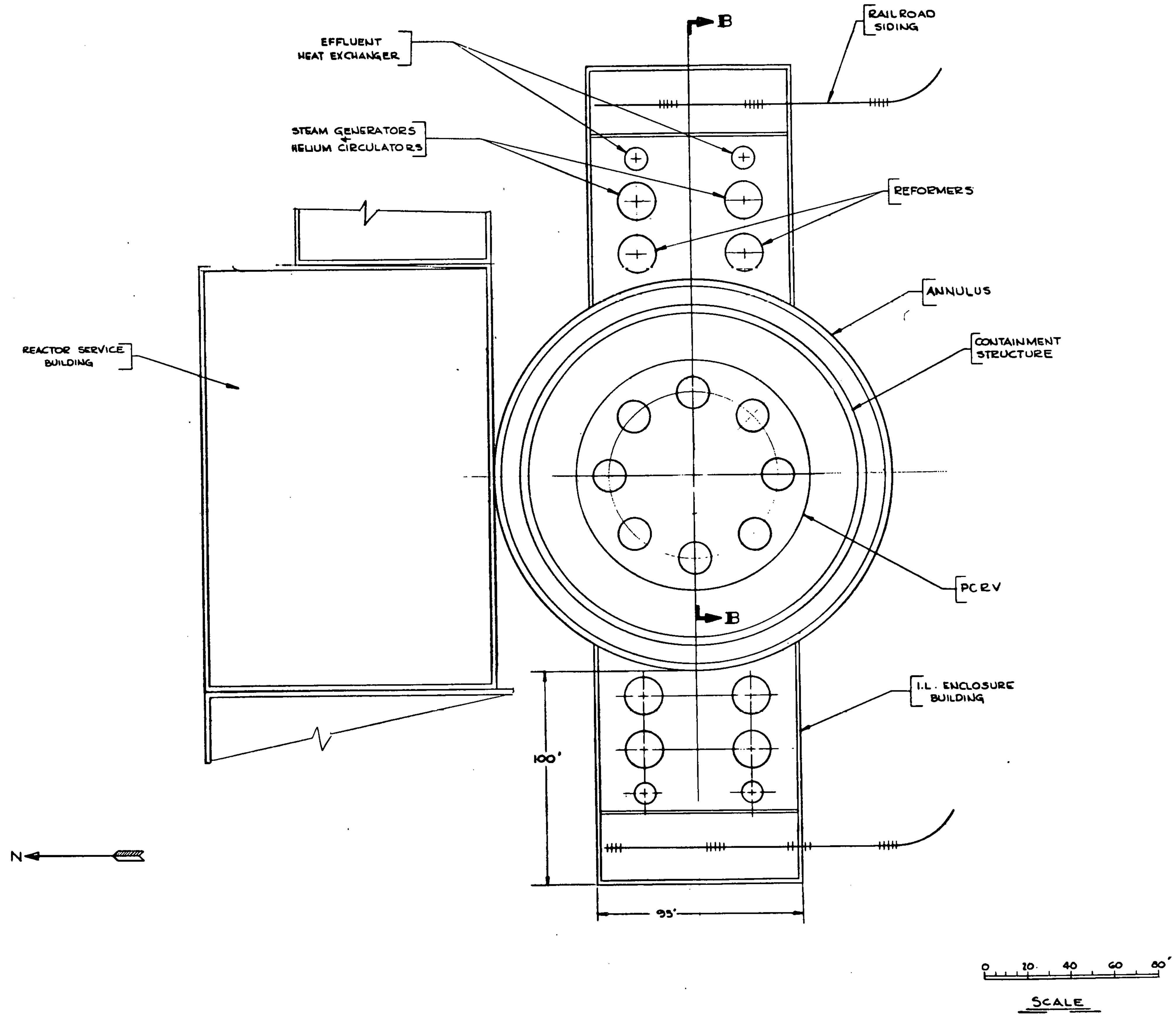


FIGURE 2.12

REV'D.	DATE	DESCRIPTION	ENGR.	SUP. ENG.
		FIRST ISSUE		

ENGINEER

STATE REG. NO.

GENERAL ARRANGEMENT
PLAN VIEW AT ELEV 18'-0"
3000 MW(t) HTGR (0-MWE)
INTERMEDIATE LOOP BUILDING
(MIDDLETOWN HYPOTHETICAL SITE)

united engineers & constructors inc.

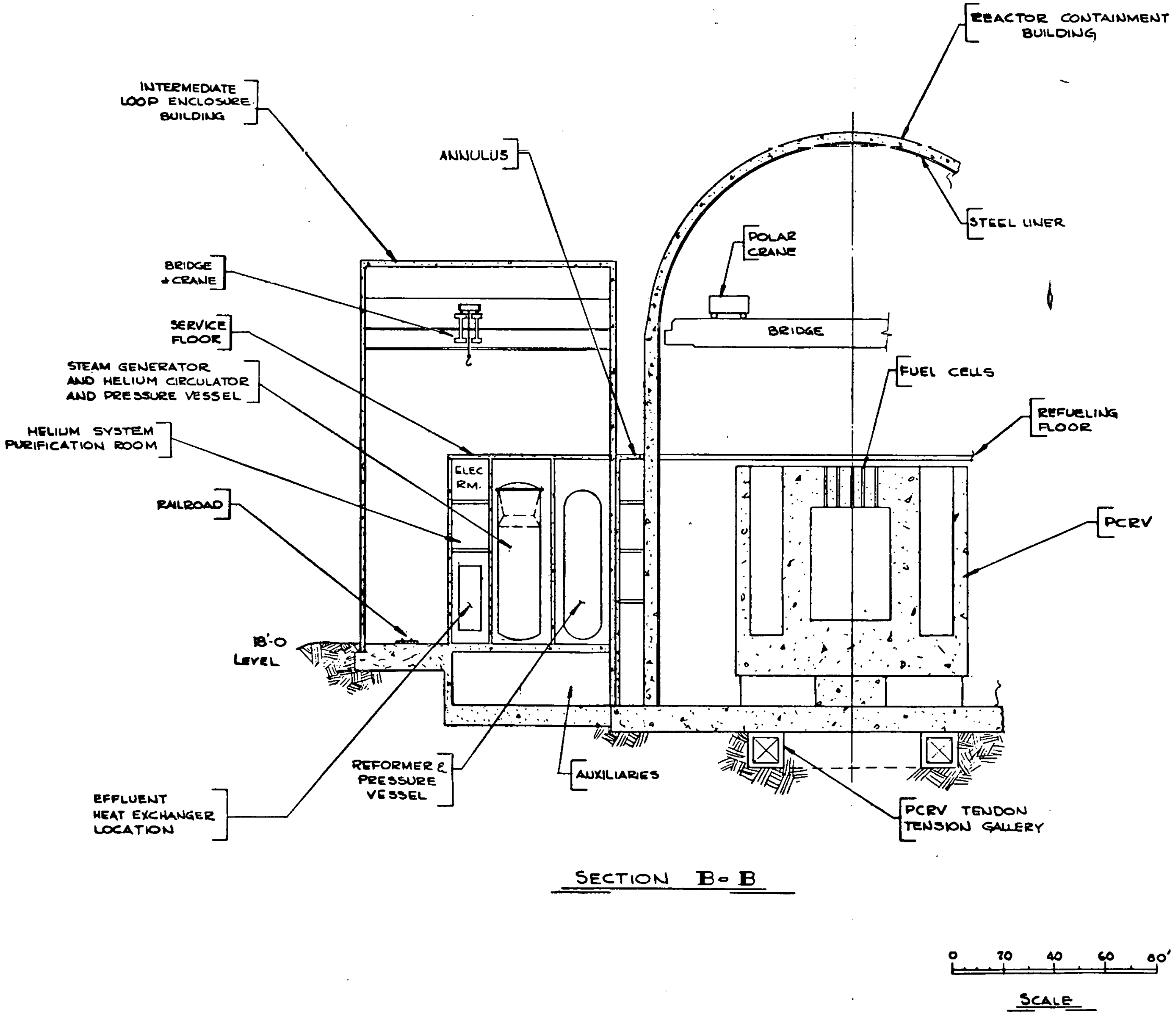
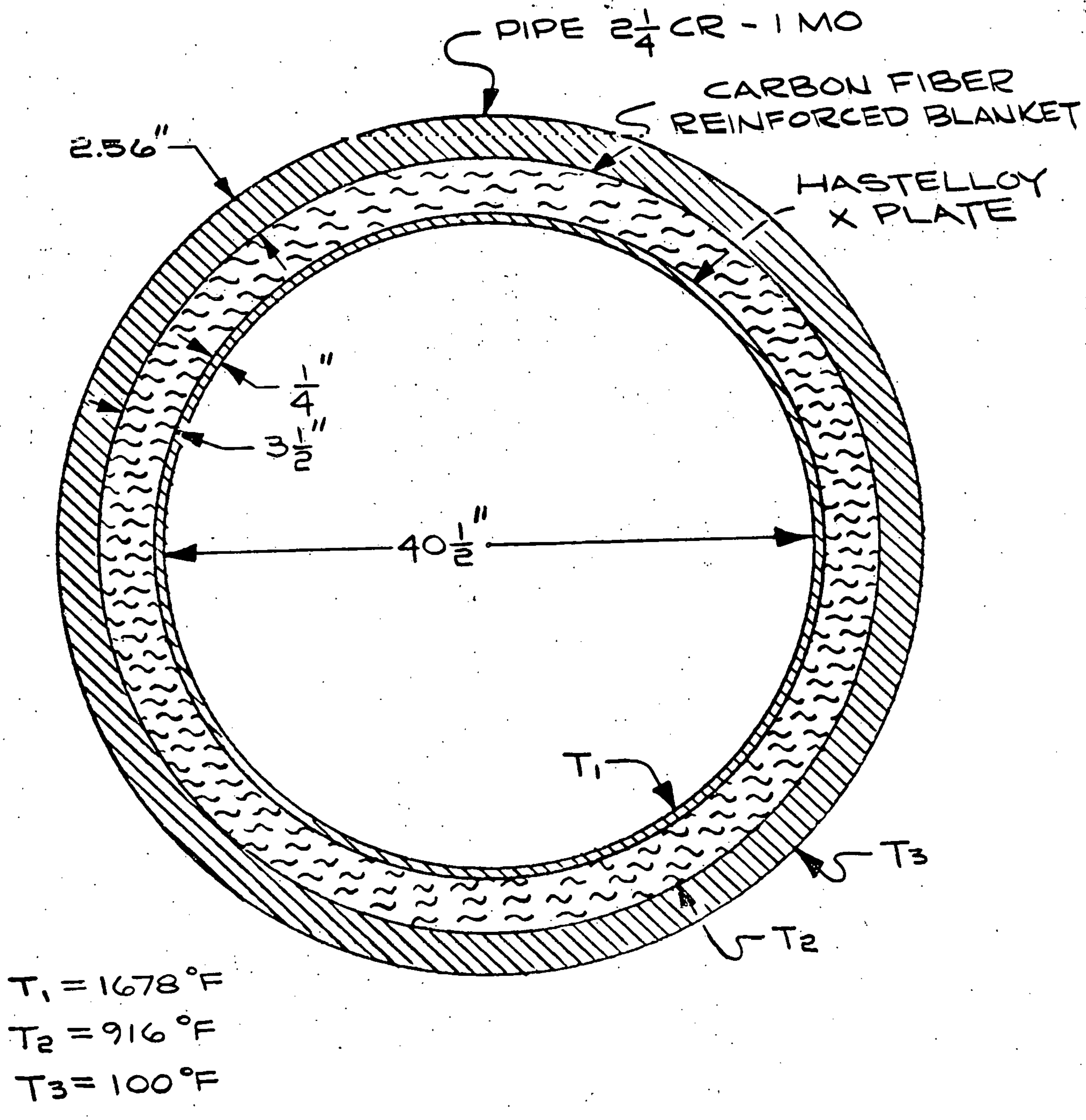


FIGURE 2.13

		FIRST ISSUE		
DATE		DESCRIPTION	ENGR.	SUP. ENG.

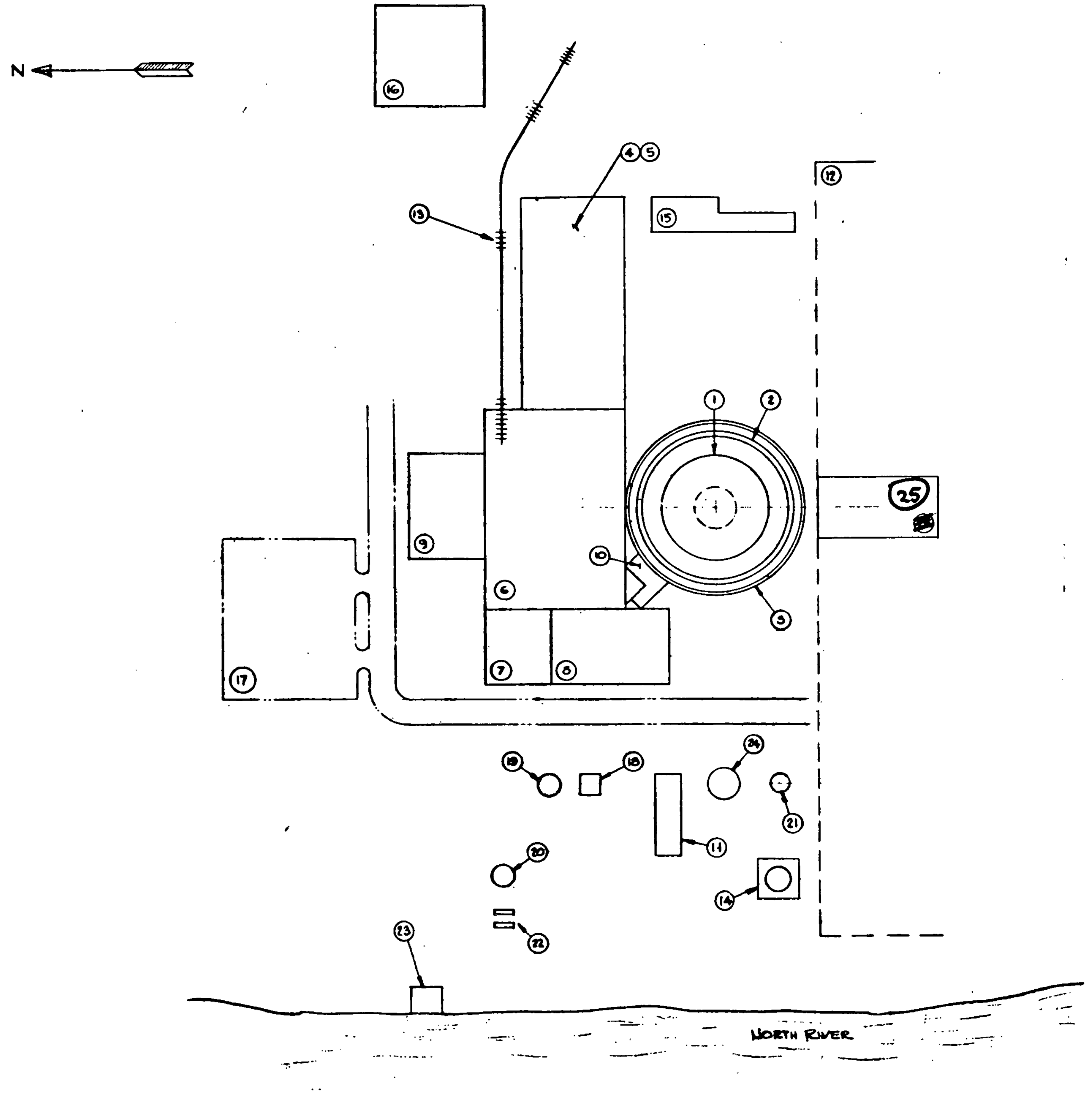
GENERAL ARRANGEMENT
SECTION B-B
3000 MW(t) HGTR WITH
INTERMEDIATE LOOP BUILDING
(MIDDLETOWN HYPOTHETICAL SITE)
United Engineers & Constructors Inc.



CROSS SECTION

INTERMEDIATE LOOP PIPING

FIGURE 2.14



FINDING NO	DESCRIPTION
1	PRCV
2	CONTAINMENT STRUCTURE
3	CONTAINMENT ANNULUS
4	DIESEL GENERATOR BLDG
5	DIESEL OIL STORAGE TANKS
6	REACTOR SERVICE BLDG.
7	AUXILIARIES BLDG.
8	CONTROL BLDG
9	ADMINISTRATION BLDG.
10	ANNULUS ELECTRICAL TOWER
11	HELIUM STORAGE BLDG.
12	PROCESS AREA
13	RAILROAD SIDING - FUEL CAR
14	LIGHT OIL TANK
15	SWITCHGEAR AND TRANSFORMER AREA
16	SUBSTATION
17	PARKING AREA
18	PUMP SHELTER
19	FIRE PROTECTION WATER TANK
20	TREATED WATER STORAGE TANK
21	CONDENSATE STORAGE TANK
22	CHLORINATION EQUIPMENT
23	SERVICE WATER INTAKE STRUCTURE
24	DEMINERALIZED WATER STORAGE TANK
25	TURBINE BLDG.

FIGURE 2.15

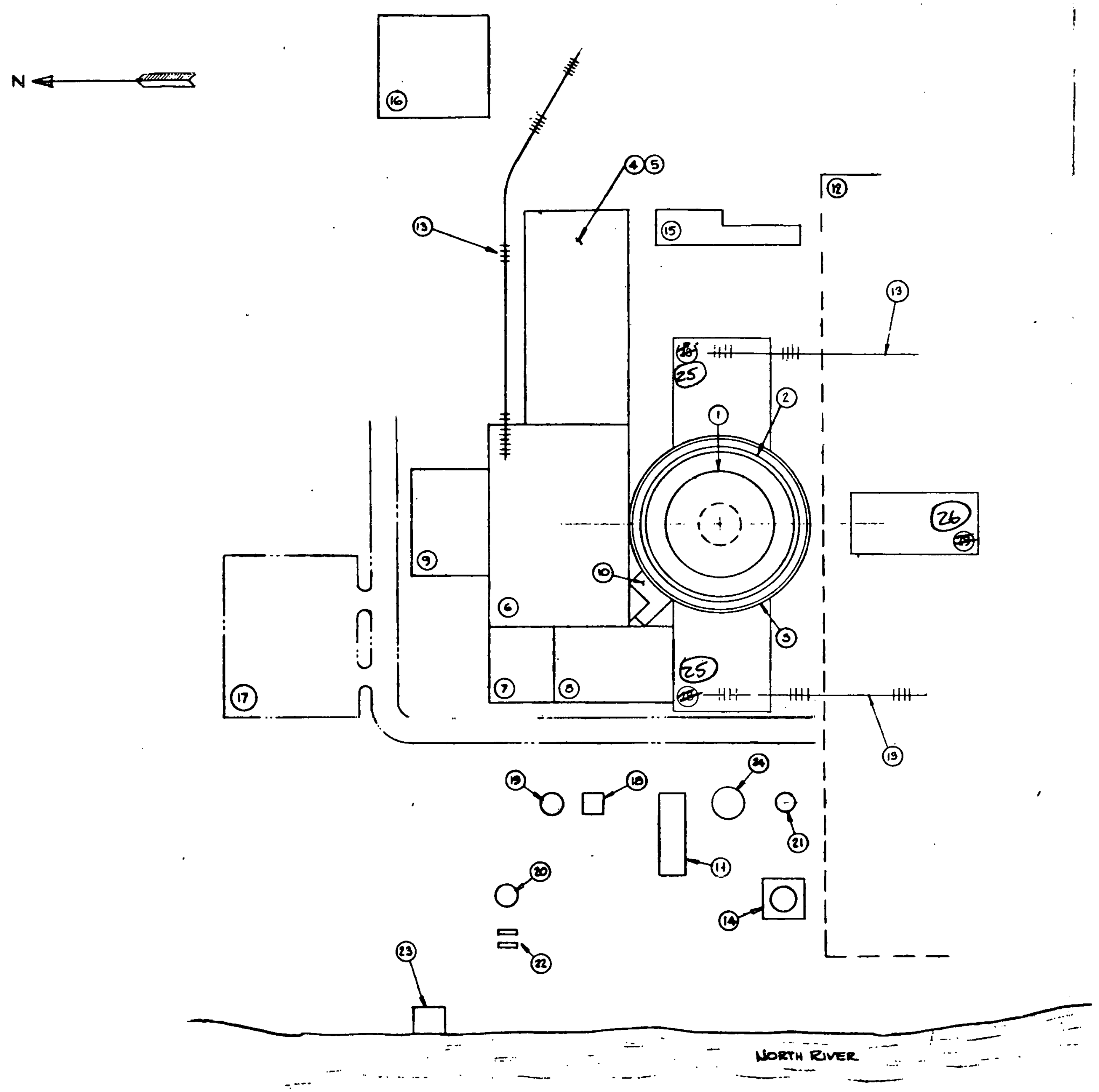
	DATE	DESCRIPTION	ENGR.	SUP. ENG.
		FIRST ISSUE		

ENGINEER

STATE REG. NO.

PLOT PLAN
3000MW(t) HGTR (O-MWE)
FOR PROCESS HEAT
WITH TURBINE
(MIDDLETOWN HYPOTHETICAL SITE)

united engineers & constructors inc.



FINDING NO	DESCRIPTION
1	PRCV
2	CONTAINMENT STRUCTURE
3	CONTAINMENT ANNULUS
4	DIESEL GENERATOR BLDG
5	DIESEL OIL STORAGE TANKS
6	REACTOR SERVICE BLDG.
7	AUXILIARIES BLDG.
8	CONTROL BLDG
9	ADMINISTRATION BLDG.
10	ANNULUS ELECTRICAL TOWER
11	HELIUM STORAGE BLDG.
12	PROCESS AREA
13	RAILROAD SIDING
14	LIGHT OIL TANK
15	SWITCHGEAR AND TRANSFORMER AREA
16	SUBSTATION
17	PARKING AREA
18	PUMP SHELTER
19	FIRE PROTECTION WATER TANK
20	TREATED WATER STORAGE TANK
21	CONDENSATE STORAGE TANK
22	CHLORINATION EQUIPMENT
23	SERVICE WATER INTAKE STRUCTURE
24	DEMINERALIZED WATER STORAGE TANK

25 INTERMEDIATE LOOP BLDG.
26 TURBINE BLDG.

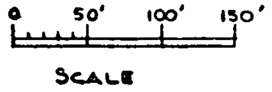


FIGURE 2.16

	DATE	DESCRIPTION	ENGR.	SUP. ENG.
		FIRST ISSUE		

ENGINEER

STATE REG. NO.

PLOT PLAN
3000MW(t) HGTR(O-MWE)
INTERMEDIATE LOOP BUILDING WITH TURBINE
(MIDDLETOWN HYPOTHETICAL SITE)
united engineers & constructors inc.

Chapter 3

DESCRIPTION AND COSTS OF GENERAL ELECTRIC AND WESTINGHOUSE PLANTS

General Electric and Westinghouse Astronuclear Laboratory each prepared a description and cost estimate for a nuclear hydrogen production facility. Each concept has significant unique features, and each cost estimate is quoted in a slightly different format. This section contains brief summaries of the conceptual plant designs and presents the General Electric and Westinghouse cost estimates in a consistent format.

3.1 GENERAL ELECTRIC DESCRIPTION AND COST

3.1.1 Plant Description

The General Electric conceptual design (Reference 2) used as a comparison plant in this report is a 3000 MWt Very High Temperature Reactor (VHTR) which employs the concept of an intermediate loop connecting the reactor and the hydrogen reformers. The reactor is a helium-cooled pebble bed reactor, developed by the German KFA*, delivering 3000 MWt. It provides a total of 900 MWt to five process loops each at 1400°F outlet temperature, 1640 MWt to five primary loop steam generators which can deliver up to 600 MWe of electric power, and 460 MWt to five intermediate loop steam generators as discussed in Section 2.1.1 of the Systems Concepts Topical Report of Reference 2.

The reactor is located in an integrated PCRV which contains all of the primary loop components. The five intermediate heat exchangers and five steam generators are located in separate cavities in the PCRV as discussed in Sections 2.1.1.4 and 2.1.1.5 of the Systems Concepts Topical Report of Reference 2.

The five independent primary loops transport the reactor coolant (helium) to intermediate heat exchangers and through transverse ducts to

*Institut fur Reaktorentwicklung Kernforschungsanlage, Julich.

the steam generators. The helium is then transported up along the wall of the steam generator cavities to the circulators, which return it to the reactor core. The primary loop helium ducting has internal insulation as discussed in Section 2.1.7 of Reference 2.

The high temperature secondary loop helium is transported from the intermediate heat exchangers to the reformers. The helium is then ducted to the nearby reheater and circulator, all located in bays adjacent to the process building. The secondary loop consists of five independent loops, one from each of the five intermediate heat exchangers to the five reformers. The secondary loop piping is internally insulated. The hot leg is four feet in diameter.

The General Electric conceptual design of the reformer is similar to the EVA design used by KFA. Each of the five reformers is housed in a single shell. The General Electric reference design is discussed in Section 2.1.9.1 and shown in Figure 2-16 of Systems Concepts, Reference 2.

The secondary loop coolant circulates on the shell side of the reformer unit, which reforms a methane and steam mixture into hydrogen. The product is then passed through a series of heat exchangers and a chemical converter to permit maximal recovery of sensible heat for input stream preheating. Of this process equipment, only the reformers are considered in the General Electric conceptual design scope and cost estimate.

The plant arrangement of the General Electric conceptual design is shown in Figure 6-4 of Reference 2, (Volume II). The PCRV is contained by a 156' diameter containment building which is surrounded by a penetration building 216' in diameter and 116' high. Around these central structures are located:

- reactor service building
- core auxiliary cooling systems building
- helium storage building
- control building
- process heat exchanger building (which houses the reformers)
- diesel generator building
- auxiliary boilers building
- administration building
- radwaste building
- a turbine building is shown in Figure 6-4, but the turbine building and turbine plant equipment are not included in the General Electric scope of design or cost estimate.

3.1.2 Costs

In Table 4-1 of Reference 2 (Volume I), General Electric presents the plant costs divided into descriptive categories, but without account numbers. This cost breakdown was slightly reorganized and assigned account numbers in accordance with the NUS-531 (Reference 5) system. The costs are shown, by account, in Table 3.1, and correspond fairly closely to the listing in Table 4-1 of Reference 2.

Account 20, Land and Land Rights, is taken from Table 4-5 of Reference 2.

To allow comparison of similar cases, the costs of Account 222, Heat Transfer Loops, were adjusted in accordance with Table 4-3 of Reference 2. The cost adjustments for the P14 (1400^{o}F Peak Average Process Gas Temperature) case were used. The adjustments total -2,760,000 dollars for the primary loop and +23,329,900 dollars for the intermediate loop.

3.2 WESTINGHOUSE DESCRIPTION AND COST

3.2.1 Plant Description

The Westinghouse conceptual plant (Reference 3) is a VHTR providing 3000 MWt of energy, in the form of electric power and heat, to a chemical process operating with a peak temperature of 1400°F. The reactor is a helium-cooled graphite moderated unit employing the high temperature fuel technology derived from the NERVA nuclear rocket program. The reactor is housed in a prestressed cast iron vessel (PCIV) in which are also located the helium circulators, turbomachinery, and high and low temperature intermediate heat exchangers. An intermediate heat transport loop isolates the reactor from the process and enhances the operability, maintainability, and licensibility of the nuclear heat source.

The reactor and its coolant loops are contained within a multi-cavity PCIV, whose design is based on work by the German firm Siempalkamp. Housed in cavities within the vessel walls are five high temperature heat exchangers and circulators, and five turbogenerators and low temperature intermediate heat exchangers. Reactor helium coolant enters and discharges from the cavities through coaxial piping at the upper end of the cavity, while the intermediate helium coolant is introduced and leaves through the bottom of the cavities. The function of the five parallel high temperature intermediate heat exchanger loops is to transfer heat from the reactor core to the high temperature process equipment.

The proprietary Westinghouse process uses steam and electricity to generate hydrogen. No process equipment is included in the cost estimate.

The Westinghouse arrangement of plant structures on the site is shown in Figure 2.1.1 of Reference 3. The major buildings are:

- reactor containment

- reactor auxiliary building
- control and electrical building
- diesel generator building
- administration service building
- helium storage building

3.2.2 Costs

For the most part, the plant costs given by Westinghouse in Table 3.2.2 of Reference 3 are in the format established for Table 3.1 of this report. These costs are shown in Table 3.2.

The only areas rearranged by UE&C are in the 90's accounts, where Westinghouse uses account number designations outside of the NUS-531 (Reference 5) system. Specifically, the Westinghouse Accounts 92 and 94 become Accounts 910A and 996, respectively, of Table 3.2, without change of description. Westinghouse Account 93, "Other Costs," becomes in Table 3.1, Account 994, "Miscellaneous Costs." One Westinghouse entry, Account 91, "Construction, Facilities, Equipment and Services," covers the scope of the following Table 3.2 entry listings, without any information to permit a distribution among them:

- Account 910B - Construction Management and Field Supervision
- Account 911 - Temporary Facilities
- Account 912 - Construction Equipment
- Account 913 - Construction Services

Spare Parts costs, entered in Table 3.2 as Account 992, represent a value accumulated from spare parts costs given individually under the following Westinghouse accounts:

- Account 22 - Reactor Plant Equipment
- Account 24 - Electric Plant Equipment
- Account 25 - Miscellaneous Plant Equipment

TABLE 3.1

INTERPRETED ACCOUNTS SUMMARY - GENERAL ELECTRIC

(JULY, 1974)

Account	Description	COSTS (THOUSANDS OF DOLLARS) Matl./Equip.	Labor	Total
20	LAND AND LAND RIGHTS			
201	Land and Privilege Acquisition			
	Account 20 - Total	2,000	---	2,000
21	STRUCTURES AND SITE FACILITIES			
211	Yard Work	2,000	3,000	5,000
212	Reactor Containment Building	13,250	26,242	39,492
213	Turbine Generator Building (1)			
214	Intake Structures (1)	3,048	7,839	10,887
215	Reactor Service Building			
217	Fuel Storage Building	1,608	2,745	4,353
218A	Control Building	1,689	4,566	6,245
218B	Diesel Generator Building	644	1,931	2,575
218C	Administration Building (1)			
218D	Auxiliaries Building (1)			
218E	Helium Storage Building	178	246	424
	Account 21 - Total	22,417	46,569	68,986
22	REACTOR PLANT EQUIPMENT			
221	Reactor Equipment	62,022	38,163	100,185
222A	Primary Heat Transfer System	24,445	8,468	32,913
222B	Intermediate Heat Transfer System	129,406	58,441	187,847
223	Safeguards Cooling Systems	1,977	248	2,225
224	Radioactive Waste Tmt. & Disp.	2,027	1,045	3,072
225	Nucl. Fuel Hdlg. & Stg.	10,409	1,561	11,970
226	Other Reactor Plant Equip.	12,821	6,971	19,792
227	Instrumentation and Control	9,767	1,971	11,738
	Account 22 - Total	252,874	116,868	369,742
23	TURBINE PLANT EQUIPMENT			
232	Heat Rejection Systems (1)			
	Account 23 - Total	---	---	---

Account	Description	COSTS (THOUSANDS OF DOLLARS) Matl./Equip.	Labor	Total
24	ELECTRIC PLANT EQUIPMENT			
241	Switchgear	732	175	907
242	Station Service Equip.	3,538	933	4,471
243	Switchboards	623	225	848
244	Protective Equip.	200	250	450
245	El. Struc. & Wiring Contain.	975	5,150	6,125
246	Power & Control Wiring	3,525	5,195	8,720
	Account 24 - Total	9,593	11,928	21,521
25	MISCELLANEOUS PLANT EQUIPMENT			
251	Trans. & Lifting	1,120	325	1,445
252	Air, Hyd., Water & Steam	3,659	3,796	7,455
253	Communications	104	154	258
254	Furnishings & Fixtures	457	59	516
	Account 25 - Total	5,340	4,335	9,675
26	SPECIAL MATERIALS			
263	Reactor Coolant (2)	240	---	240
264	Intermediate Coolant (2)			
269	Initial Catalyst Filling	600	---	600
	Account 26 - Total	840	---	840
	Sub-Total (Accounts 21 through 26)	291,064	179,700	470,764
91	ENGINEERING AND CONSTR. COSTS			
910	Engineering Services and Construction Management	---	42,830	42,830
911	Temporary Facilities	1,911	4,687	6,598
912	Construction Equipment	6,445	---	6,445
913	Construction Services	1,543	6,718	8,261
	Account 91 - Total	9,899	54,235	64,134

Account	Description	COSTS (THOUSANDS OF DOLLARS) Matl./Equip.	Labor	Total
99	OTHER COSTS			
991	Operator Training (1)			
992	Spare Parts (1)			
993	Prelim. Oper. & Testing	468	1,312	1,780
994	Misc. Costs (1)			
995	Contingency	44,758	36,207	80,965
	Account 99 - Total	45,226	37,519	82,745
	TOTALS OF ALL COSTS	348,189	271,454	619,643

NOTES:

(1) - Not Estimated.

(2) - Includes 100% Reserve in Storage.

TABLE 3.2

INTERPRETED ACCOUNTS SUMMARY - WESTINGHOUSE
(JULY, 1974)

Account	Description	Matl./Equip.	Labor	Total
		COSTS (THOUSANDS OF DOLLARS)		
20	LAND AND LAND RIGHTS			
201	Land and Privilege Acquisition	800	---	800
	Account 20 - Total	800	---	800
21	STRUCTURES AND SITE FACILITIES			
211	Yard Work	1,041	1,293	2,334
212	Reactor Containment Building	5,463	9,509	14,972
213	Turbine Generator Building (1)			
214	Intake Structures	183	551	734
215	Reactor Service Building	6,453	16,575	23,028
217	Fuel Storage Building (1)			
218A	Control Building	1,141	2,606	3,747
218B	Diesel Generator Building	486	1,293	1,779
218C	Administration Building	359	431	790
218D	Auxiliaries Building (1)			
218E	Helium Storage Building	73	94	167
	Account 21 - Total	15,199	32,352	47,551
22	REACTOR PLANT EQUIPMENT			
221	Reactor Equipment	46,218	6,797	53,015
222A	Prim. Heat Transf. Syst. (3)	54,272	1,585	55,857
222B	Intermed. Heat Transf. Syst.	2,769	2,800	5,569
223	Safeguards Cool. System	3,054	1,155	4,209
224	Rad. Waste Tmt. & Disp.	1,351	634	1,985
225	Nucl. Fuel Hdlg. & Stg.	10,140	859	10,999
226	Other Reactor Plant Equip.	7,547	2,659	10,206
227	Instrumentation & Control	6,084	1,304	7,388
	Account 22 - Total	131,435	17,793	149,228
23	TURBINE PLANT EQUIPMENT			
232	Heat Rejection Systems (1)			
	Account 23 - Total	---	---	---

Account	Description	COSTS (THOUSANDS OF DOLLARS) Matl./Equip.	Labor	Total
24	ELECTRIC PLANT EQUIPMENT			
241	Switchgear	1,121	173	1,294
242	Sta. Service Equip.	2,825	452	3,277
243	Switchboards	521	132	653
244	Protective Equipment	110	171	281
245	Elec. Struct. & Wiring Contain.	591	2,441	3,032
246	Power & Control Wiring	3,378	4,291	7,669
	Account 24 - Total	8,546	7,660	16,206
25	MISCELLANEOUS PLANT EQUIPMENT			
251	Trans. & Lifting	947	250	1,197
252	Air., Hyd., Water & Steam	2,128	2,614	4,742
253	Communications Equipment	60	97	157
254	Furnishings & Fixtures	288	37	325
	Account 25 - Total	3,423	2,998	6,421
26	SPECIAL MATERIALS			
263	Reactor Coolant (2)	250	---	250
264	Intermediate Coolant			
269	Initial Catalyst Filling (1)			
	Account 26 - Total	250	---	250
	Subtotal (Accounts 21 through 26)	158,853	60,803	219,656
91	ENGINEERING AND CONSTRUCTION COSTS			
910	Engineering Services and Construction Management	40,800	---	40,800
911	Temporary Facilities	16,468	---	16,468
912	Construction Equipment(1)	---	---	
913	Construction Services(1)	---	---	---
	Account 91 - Total	57,268	---	57,268

TABLE 3.2 (page 3 of 3)

Account	Description	COSTS (THOUSANDS OF DOLLARS) Matl./Equip.	Labor	Total
99	OTHER COSTS			
991	Operator Training (1)			
992	Spare Parts	1,391	---	1,391
993	Prelim. Oper. & Testing (1)			
994	Misc. Costs	12,700	---	12,700
995	Contingency	27,649	6,080	33,729
	Account 99 - Total	41,740	6,080	47,820
	TOTALS OF ALL COSTS	258,661	66,883	325,544

NOTES:

(1) - Not Estimated.

(2) - Includes 100% Reserve in Storage.

(3) - Includes Helium-Driven Internal Turbomachinery (Turbine - Generator).

Chapter 4

COMPARISON OF SCOPE AND COSTS OF GENERAL ATOMIC/UE&C, GENERAL ELECTRIC AND WESTINGHOUSE CONCEPTUAL DESIGNS

4.1 BASES FOR COMPARISON

Three conceptual designs have been estimated. A General Atomic NSSS with a UE&C BOP is described in Chapter 2, and summarized in Table 2.7. Summaries of the General Electric and Westinghouse plants are presented in Chapter 3, and shown in Tables 3.1 and 3.2. The costs are compared in Table 4.1, and technical parameters are shown in Table 4.2. Section 4.2 discusses the differences between the concepts in detail.

Operation and maintenance costs are compared in Section 4.3.

Several groundrules were established for the comparison:

- All costs are quoted in July, 1974 dollars.
- All finance charges (interest, IDC, cost of money, etc.) are ignored, because they are percentages of the capital cost of the plant.
- No electricity is generated (although turbine-generators are included in the Westinghouse estimate).
- Costs quoted in References 1, 2 and 3 are adjusted as described in Chapters 2 and 3, using adders from the references, to allow comparison of plants with similar operating conditions.
- Costs are stated in a consistent code of accounts.

4.2 PLANT COST AND SCOPE COMPARISON

4.2.1 Major Differences

There are significant differences among the three estimates compared in this report, both in scope of supply and in the types of equipment used. The costs for the three plants, shown in Table 4.1, are thus not directly comparable. Although gross differences in the scope can explain differences in cost, an evaluation of the accuracy of the cost estimates is not, in general, possible. Because the Westinghouse and General Electric designs are based on less developed technology, the uncertainty in their estimates is somewhat higher than that for the General Atomic/UE&C estimate.

The Prestressed Cast Iron Reactor Vessel (PCIV) proposed by Westinghouse is a significant, imaginative innovation. Potentially, the PCIV can cause reductions in construction time, reactor vessel cost, and BOP cost. However, the concept is still in early stages of development. Any estimate of costs and cost savings must be considered highly speculative.

The pebble bed reactor, which is the basis for the General Electric estimate, is presently being developed in Germany. A small prototype reactor (AVR) has operated for several years, and a large (300 MWe) demonstration plant is under construction. Fuel has been tested extensively, but not under commercial operating conditions. The pebble bed appears competitive with the General Atomic HTGR, but a detailed cost comparison is not possible with the data provided in References 1 and 2.

The fuel used in the Westinghouse reactor is similar to fuel which was studied early in the HTGR fuel development program. An extensive research, development and testing program is required. The Westinghouse fuel is the least developed, and thus the most uncertain of the three concepts.

4.2.2 Detailed Comparison

Table 4.1 presents superficially the comparison of the costs of the General Atomic/UE&C (GA/UE&C), General Electric (GE) and Westinghouse plants because the differences in scope of supply are not shown. Table 4.2 shows some of the technical characteristics of the plants. This section discusses the details of the differences in scopes and comments on obvious cost differences. The discussion is arranged by account:

212. Reactor Containment Building

The GA/UE&C plant includes the reactor containment, annulus, annulus electrical tower, and two intermediate loop buildings in Account 212.

General Electric has included a somewhat smaller reactor containment and a containment annulus. The process heat exchanger building of the GE conceptual design is analogous to the intermediate loop buildings of the GA/UE&C concept, but is not included in the GE cost estimate. If an allowance is included for the cost of the intermediate loop building, the GE estimate will be somewhat higher than the GA/UE&C estimate.

The containment structure of the Westinghouse concept is much smaller than the GA/UE&C or GE designs. This is due to the much smaller reactor vessel (PCIV) in the Westinghouse concept and results in a significant reduction in cost.

213. Turbine Generator Building

None of the conceptual designs includes a turbine-generator building in the base cost estimates. The GA/UE&C design shows this as an optional adder in Tables 2.4 and 2.5.

214. Intake Structures

A service water intake structure to provide plant and safety-related cooling water is costed by the GA/UE&C and Westinghouse estimates, but the GE concept does not include any cooling for those purposes. All these conceptual designs do not include a circulating water intake structure, because waste heat dissipation is the responsibility of the chemical plant.

215. Reactor Service Building

A reactor service building is included in all three concepts. The GE design of this building is somewhat smaller in size than the other two concepts, and is less costly.

217. Fuel Storage Building

A fuel storage building is costed only by GE, but no separate building appears on GE's plant arrangement drawing, Figure 2-4, Reference 2. General Atomic/UE&C and Westinghouse include fuel storage in the Reactor Service Building.

218A. Control Building

A control building is included in all three concepts. The Westinghouse concept describes a much smaller size building, resulting in much smaller cost.

218B. Diesel Generator Building

The diesel generator building of the GA/UE&C design is much larger in size and cost than GE or Westinghouse concepts due to recent licensing criteria stipulating that three diesel generators and three 30-day oil storage tanks must be provided.

218C. Administration Building

An administration building is not included in the GE estimate, Table 4-2, Reference 2; however, GA/UE&C and Westinghouse have included this structure. The Westinghouse estimate is considerably less than the GA/UE&C estimate, although the physical size and function are comparable. The GA/UE&C estimate is based on current UE&C experience.

218D. Auxiliaries Building

An auxiliaries building, which houses auxiliary boilers, water treatment equipment, and miscellaneous plant auxiliaries, is included in the GA/UE&C estimate. GE shows an auxiliary boiler building, and machine shop building on their plant arrangement drawing, Figure 2-4, Reference 2; but the costs of these buildings are not identified in Table 3.2-2 and Table A-9 of Reference 2. Westinghouse does not include an auxiliaries building or similar type structure in their design or estimate.

218E. Helium Storage Building

All three concepts, GA/UE&C, GE and Westinghouse include a helium storage building. However, the Westinghouse estimate is lower and the GE estimate is higher, both for no obvious reason.

221. Reactor Equipment

The PCRV sizes are essentially comparable, however the GA/UE&C PCRV incorporates eight major cavities and the GE PCRV incorporates ten. Costs quoted for the General Atomic PCRV are somewhat higher than for GE.

Due to the dramatically different PCIV design which Westinghouse incorporates, the estimated cost is considerably lower and contributes significantly to the difference in total plant cost.

222. Heat Transfer System

Physical data for the heat transfer systems appear in Table 4.2. The Westinghouse estimate includes intermediate loop equipment only within the containment building. It is not clear whether isolation valves (a considerable expense) are included. The large difference between GA/UE&C and GE heat transfer system costs seem to be due to a very high GE cost for intermediate loop piping. The layout of the GE intermediate loop requires 3,370 feet of intermediate loop piping, compared to 1,160 feet required for the GA/UE&C configuration.

223. Safeguards Cooling System

Differences in costs of the safeguards cooling system cannot be explained based on the information provided in References 1, 2 and 3. The heat loads on the systems are not likely to be significantly different.

224. Radwaste System

The low cost of radwaste systems in the Westinghouse estimate may be due to lower flow through the radwaste system because of smaller total helium loop inventory than the other designs. However, the low GE estimate cannot be supported by this reasoning.

225. Fuel Handing and Storage

The GA/UE&C cost is based on current UE&C experience and is higher than the Westinghouse estimate. Because of the different fuel concept, the GE estimate is not comparable.

226. <u>Other Reactor Plant Equipment</u>

The Westinghouse estimate is considerably lower than GE or GA/UE&C, in part because of smaller coolant storage and make-up, purification, and treatment systems required by the Westinghouse conceptual design. However, the higher GA/UE&C and GE estimates appear close to applicable recent experience.

227. <u>Instrumentation and Control</u>

Instrumentation and control requirements and costs are generally equivalent.

24. <u>Electric Plant Equipment</u>

The costs in these accounts are generally comparable. The higher costs in some accounts of the GA/UE&C estimate are caused by provisions in this account to supply 30 MWe from the grid to the chemical process plant.

251. <u>Miscellaneous Plant Equipment</u>

The costs for this account are comparable.

252. <u>Air, Water and Steam Services</u>

The Westinghouse estimate is slightly
probably due to smaller overall building sizes.

910-913. <u>Engineering and Construction Costs</u>

Engineering costs have risen significantly due to new quality assurance requirements affecting not only construction costs, but also engineering costs. The UE&C estimate is probably conservative.

4.2.3 Normalized Cost Comparison

In order to identify the largest differences between the GA/UE&C, General Electric and Westinghouse estimates, a normalized comparison of the estimates is presented in Table 4.3. This comparison is based on assumptions about the extent and detail of the General Electric and Westinghouse estimates and design. It should thus be used only for gross comparison of the estimates, and should not be considered precise.

Some structures, such as the Intake Structure, Diesel Generator Building, and the Auxiliaries Building, are essentially independent of the type of facility considered. The estimates prepared by UE&C for these structures are based on recent power plant experience and thus assigned to each of the three concepts. The General Electric Fuel Storage Building cost is combined with the cost of their Reactor Service Building.

The costs of an intermediate loop and associated equipment and structures are shown in Table 2.3. These costs are added to the appropriate accounts in the General Electric and Westinghouse estimates where it appears that the costs were not previously estimated.

The normalized comparison shows that the three cost estimates differ significantly in only three accounts. The Westinghouse estimate for the Containment Building cost is much lower than the GA/UE&C and General Electric costs, and appears to be based on a lower estimate of construction and material costs.

The Reactor Equipment account shows major differences between the estimates for the General Electric and Westinghouse concepts and the GA/UE&C plant which is based on the commercial HTGR. Past experience indicates that the costs of new technologies, such as the pebble bed reactor, PCIV, and NERVA-type fuel will increase considerably before they become commercial. The concept with the lowest cost (Westinghouse) is also the least developed and can thus be expected to increase the most.

The major difference between the GA/UE&C and the General Electric estimate for the Heat Transfer System account is the length of the IHL piping. The General Electric cost could probably be considerably reduced by building more than one IHL building and reducing the IHL piping length. The Westinghouse estimate for this account (Table 4.1) is apparently based on the costs of the intermediate heat exchanger, IHL piping within the containment building, and isolation valves, as well as the systems normally contained in this account for an HTGR (Reference 4). This estimate is unreasonably low.

4.3 COMPARISON OF OPERATION AND MAINTENANCE COSTS

Operation and Maintenance (O&M) costs were compiled from References 2 and 3 for the General Electric and Westinghouse plants and in Section 2.5 for the General Atomic/UE&C plant, and are presented in Table 4.4. Only direct O&M costs are included in the comparison; interest and finance charges are excluded because they are merely percentages of direct costs which are compared.

The total O&M costs given in Table 4.4 are not comparable because not all categories of O&M were estimated in each report. However, the costs for each category that is quoted in more than one estimate are essentially the same in each estimate. Thus, assuming that the items missing from estimates will also be comparable when included, it is reasonable to expect an annual direct O&M cost of about $10,000,000 for each of the concepts being compared.

The General Atomic/UE&C estimate for station staffing is higher than the other estimates. This difference is due to the additional staff required for the intermediate loop building and other structures not estimated for the other plants.

It is difficult to accurately estimate materials, supplies, and outside services without detailed design and operating experience. Within the accuracy of this comparison, the costs presented are not significantly different.

General Electric did not estimate the cost of electricity required to operate the plant. This cost is likely to be the same as the other estimates. Electricity costs are, of course, subject to rapid change in the present economy.

Fixed and variable maintenance are not estimated by General Electric or Westinghouse. Based on recent experience with high temperature heat exchangers (see Section 2.5), maintenance costs are expected to be high. The General Atomic/UE&C estimate is conservative, but the costs are likely to be similar for all plants. (Note: the General Atomic/UE&C estimate includes maintenance of the reformer, but no other process equipment.)

TABLE 4.1

COMPARISON OF COSTS OF VHTR NUCLEAR PROCESS HEAT PLANTS (1)

(JULY 1974)

Account	Description	TOTAL COSTS (THOUSANDS OF DOLLARS) GA/UE&C	GE	W
20	LAND AND LAND RIGHTS			
201	Land and Privilege Acquisition	1,000	2,000	800
	Account 20 - Total	1,000	2,000	800
21	STRUCTURES AND SITE FACILITIES			
211	Yard Work	2,672	5,000	2,334
212	Reactor Containment Building	40,404	39,492	14,972
214	Intake Structures	412	-	734
215	Reactor Service Building	17,255	10,887	23,028
217	Fuel Storage Building	-	4,353	-
218A	Control Building	6,046	6,245	3,747
218B	Diesel Generator Building	5,140	2,575	1,779
218C	Administration Building	2,572	-	790
218D	Auxiliaries Building	848	-	-
218E	Helium Storage Building	230	424	167
	Account 21 - Total	75,579	68,986	47,551
22	REACTOR PLANT EQUIPMENT			
221	Reactor Equipment	127,263	100,185	53,015
222	Heat Transfer System	~~162,599~~ 149,053	220,760	61,426
223	Safeguards Cooling System	7,938	2,225	4,209
224	Radioactive Waste System	5,663	3,072	1,985
225	Fuel Handling Systems	15,236	11,970	10,999
226	Other	22,646	19,792	10,206
227	Instrumentation & Control	8,078	11,738	7,388
	Account 22 - Total	~~349,423~~ 335,877	369,742	149,228

Account	Description	TOTAL COSTS (THOUSANDS OF DOLLARS) GA/UE&C	GE	W
24	ELECTRICAL PLANT EQUIPMENT			
241	Switchgear	2,512	907	1,294
242	Stations Service Equip.	5,292	4,471	3,277
243	Switchboards	507	848	653
244	Protective Equipment	518	450	281
245	Elec. Struct. & Wiring Containers	7,044	6,126	3,032
246	Power & Control Wiring	10,724	8,720	7,669
	Account 24 - Total	26,597	21,521	16,206
25	MISCELLANEOUS PLANT EQUIPMENT			
251	Trans. & Lifting	1,399	1,445	1,197
252	Air, Hyd., Water & Steam Service	6,808	7,455	4,742
253	Communications Equipment	181	258	157
254	Furnishings & Fixtures	386	516	325
	Account 25 - Total	8,774	9,675	6,421
26	SPECIAL MATERIALS			
263	Reactor Coolant	254	240	250
264	Intermediate Coolant	89	-	-
269	Initial Catalyst Filling	618	600	-
	Account 26 - Total	961	840	250
	Subtotal (Accounts 21 through 26)	~~462,334~~ 448,788	470,764	219,656

Account	Description	TOTAL COSTS (THOUSANDS OF DOLLARS) GA/UE&C	GE	W
91	ENGINEERING & CONSTRUCTION COSTS			
910	Engineering Services and Construction Management	79,361	42,830	40,800
911	Temporary Facilities	5,175	6,598	16,468
912	Construction Equipment	9,300	6,445	-
913	Construction Services	13,302	8,261	-
	Account 91 - Total	107,138	64,134	57,268
99	OTHER COSTS			
991	Operator Training	1,652	-	-
992	Spare Parts	1,756	-	1,391
993	Prelim. Operation & Testing	-	1,780	-
994	Miscellaneous Costs	5,947	-	12,700
995	Contingency	24,000	80,965	33,729
997	GA-Other Costs (Undistr.)	939	-	-
	Account 99 - Total	34,294	82,745	47,820
	TOTAL COSTS (1)	~~604,616~~ 591,070	619,643	325,544

NOTES:

(1) These costs represent different scopes of supply and are not completely comparable. Significant, identifiable differences are discussed in Chapter 4.

(2) This table is derived from Tables 2.7, 3.1, and 3.2.

TABLE 4.2

COMPARISON OF SIGNIFICANT DESIGN PARAMETERS

Item	General Atomic/UE&C	General Electric	Westinghouse
Building Sizes (Length x Width x Height, feet)			
Containment Building	152 D x 240 high	156 D x 188 high	110 D x 250 high
Intermediate Loop Bldg.	125 x 95 x 140	(1)	(1)
Reactor Service Bldg.	240 x 135 x 140	80 x 313 x 80	130 x 100 x 160 and 90 x 130 x 89
Control Building	110 x 50 x 130	80 x 150 x 125	80 x 160
Diesel Generator Bldg.	90 x 210	80 x 120	60 x 90
Administration Bldg.	134 x 170	60 x 150 (1)	50 x 100
Heat Transfer Systems			
Reactor Vessel			
Type	PCRV (3)	PCRV (3)	PCIV (4)
Dimensions	106 D x 84.3 H	116 D x 82 H	66 D x 110 H
Primary Steam Generators			
Number	4	5	0
Total Area, $ft.^2$	30,000	25,000	-
MWt	1374	1640	-

TABLE 4.2 (Page 2 of 2)

Item	General Atomic/UE&C	General Electric	Westinghouse
Intermediate Heat Exchrs.			
Number	4	5	5
Total Area, ft.^{2}	175,000	123,000	157,000
MWt	1626	1360	1555
Auxiliary Cooling Loops			
Number	3	2	2
Helium Turbine - Generators			
Number	-	-	5
IHL(5) Steam Generators			
Number	4	5	(1)
Total Area, ft.^{2}	7600	(2)	(1)
MWt	350	460	(1)
IHL Reformers			
Number	4	5	(1)
MWt	1276	900	(1)
Reference Report	CA-A13158 (Reference 1)	GEAP-14018 (Reference 2)	WANL-2445-1 (Reference 3)

NOTES:
(1) Not included in cost estimate.
(2) Not included in Reference 2.
(3) Prestressed Concrete Reactor Vessel
(4) Prestressed Cast Iron Reactor Vessel
(5) Intermediate Heat Transfer Loop

TABLE 4.3

NORMALIZED COST COMPARISON
(JULY 1974)

Account	Description	TOTAL COSTS (MILLIONS OF DOLLARS) (1) GA/UE&C	GE	W
20	LAND AND LAND RIGHTS			
201	Land and Privilege Acquisition	1.0	1.0	1.0
21	STRUCTURES AND SITE FACILITIES			
211	Yard Work	2.7	5.0	2.4
212	Reactor Containment Building	40.4	46.1	21.6
214	Intake Structures	.4	.4	.4
215	Reactor Service & Fuel Stor. Bldg.	17.2	15.2	23.0
218A	Control Building	6.0	6.2	3.7
218B	Diesel Generator Building	5.1	5.1	5.1
218C	Administration Building	2.6	2.6	.8
218D	Auxiliaries Building	.8	.8	.8
218E	Helium Storage Building	.2	.4	.2
	Account 21 - Total	75.4	81.8	58.0
22	REACTOR PLANT EQUIPMENT			
221	Reactor Equipment	127.3	100.2	53.0
222	Heat Transfer System	149.0 ~~162.6~~	220.8	102.8
223	Safeguards Cooling System	7.9	2.2	4.2
224	Radioactive Waste System	5.7	3.1	2.0
225	Fuel Handling Systems	15.2	12.0	11.0
226	Other	22.6	20.9	11.3
227	Instrumentation and Control	8.1	12.5	8.1
	Account 22 - Total	~~349.4~~ 335.8	371.7	192.4

TABLE 4.3 (PAGE 2 of 2)

Account	Description	TOTAL COSTS (MILLIONS OF DOLLARS) GA/UE&C	GE	W
24	ELECTRICAL PLANT EQUIPMENT			
	Undistributed Cost	-	.4	.4
241	Switchgear	2.5	.9	1.3
242	Station Service Equip.	5.3	4.5	3.3
243	Switchboards	.5	.8	.7
244	Protective Equipment	.5	.5	.3
245	Elec. Struct. & Wiring Containers	7.0	6.1	3.0
246	Power & Control Wiring	10.7	8.7	7.7
	Account 24 - Total	26.5	21.9	16.7
25	MISCELLANEOUS PLANT EQUIPMENT			
251	Trans. & Lifting	1.4	1.8	1.6
252	Air, Hyd., Water & Steam Service	6.8	7.5	4.7
253	Communications Equipment	.2	.3	.2
254	Furnishings and Fixtures	.4	.5	.3
	Account 25 - Total	8.8	10.1	6.8
26	SPECIAL MATERIALS			
263	Reactor Coolant	.3	.3	.3
264	Intermediate Coolant	.1	.3	.1
269	Initial Catalyst Filling	.6	.6	.6
	Account 26 - Total	1.0	1.2	1.0
995	Contingency	24.0	81.0	33.7
	Total Normalized Costs (2)	~~485.1~~ 471.5	568.7	309.6

NOTES:

(1) Totals may differ from Table 4.1 due to normalizing or rounding off.
(2) Excluding Engineering, Construction, and Other Costs.
(3) This table is derived from Table 4.1.

TABLE 4.4

COMPARISON OF ANNUAL DIRECT OPERATION AND MAINTENANCE COSTS

(Without Electrical Generation)
(July, 1974)

ITEM	ANNUAL DIRECT COSTS (DOLLARS)		
	GA/UE&C	GENERAL ELECTRIC	WESTINGHOUSE
Station Staffing	1,960,000	1,544,000	1,698,400
Materials, Supplies & Outside Services	160,000 to 820,000	1,160,000	520,000
Coolant Make-up Purchases	125,000	120,000	135,000
Electric Power Purchases	2,080,000	---	2,920,000
Fixed Maintenance	2,500,000 to 4,000,000	---	---
Variable Maintenance (Including Catalyst Costs)	1,320,000	---	---
General & Administrative	260,000	174,000	332,760
Nuclear Liability Insurance (Including Comml. & Govt.)	390,000	390,000	390,000
Annual License Fee	200,000	---	---
TOTAL ANNUAL COSTS (1)	8,995,000 To 11,155,000	3,388,000	5,996,160

NOTE: (1) The total costs are not comparable without allowances for items not estimated.

Appendix A

PROCESS PLANT INTERFACES

This appendix defines the detailed thermal, mechanical, and electrical interfaces between the General Atomic/UE&C conceptual nuclear plant and the chemical process plant.

A.1 THERMAL INTERFACES

The nuclear plant supplies steam to the process plant in return for boiler feed water at required conditions. Steam and methane are supplied by the process plant to the reformer in the nuclear plant, and the reformer effluent is returned. Conditions for these interfaces are shown in Table A.1.

In the 40 MWe turbine plant option, 0.322×10^6 lbs./hr. of steam in the process plant are directed to the turbine and returned at 2.5 in HgA, 108.7°F, 2.94×10^8 BTU/hr. The heat balance diagram is shown in Figure 2.4.

In the 100 MWe turbine plant option, 0.805×10^6 lbs./hr. of steam in the process plant are directed to the turbine and returned at 2.5 in. HgA, 108.7°F, 7.34×10^8 BTU/hr. The heat balance diagram for this case is shown in Figure 2.5.

A.2 MECHANICAL INTERFACES

A.2.1 Equipment

As discussed in Section 2.2, the reformer and all other primary coolant and auxiliary equipment are considered within the scope of the nuclear plant. All process equipment, excluding the reformers, but including the reformer feed effluent heat exchangers located within the intermediate loop buildings, is included in the scope of the process plant.

All process plant support equipment is included with the process plant scope:

- Cooling water equipment & cooling water make-up equipment;
- lubricating oil equipment;
- station air equipment;
- instrument air equipment;
- turbine effluent conditioning equipment (if required);
- feedwater equipment.

A.2.2 Piping

Process piping is the responsibility of the process plant from the containment building outer wall. In the intermediate loop case, process piping will start at the reformer inlets and outlets, and the steam generator inlets.

A.2.3 Space

Control board space is provided in the control building for process plant control which is equal to the space allocated for turbine-generator controls in an 1160 MWe HTGR.

A.3 ELECTRICAL INTERFACES

The switchgear, power cable and wire to the switchgear of the process plant, and 30 MWe power are provided to the process plant by the nuclear plant. The process plant will supply all instrumentation and control wire and equipment for the process systems and interfaces with nuclear plant systems.

Additional electric power over 30 MWe must be provided by the process plant.

TABLE A.1

THERMAL INTERFACES

NUCLEAR PLANT CONFIGURATION	TO PROCESS PLANT	FROM PROCESS PLANT
Base Plant	Steam: 4.72×10^6 W 6.35×10^9 B 915 P 720 F	Boiler Feedwater: 4.72×10^6 W 1.64×10^9 B 3115 P 370 F
	Reformer Effluent: 4.94×10^6 W 400 P 1590 F	Reformer Feed: 3.75×10^6 W Steam 1.19×10^6 W CH_4 570 P 1050 F
Base Plant with Intermediate Loop	Steam: 5.69×10^6 W 7.6×10^9 B 915 P 705 F	Boiler Feedwater: 4.63×10^6 W Primary 1.61×10^9 B Primary 1.06×10^6 W Intermediate 3.69×10^8 B Intermediate 3115 P 370 F
	Reformer Effluent: 6.6×10^6 W 300 P 1400 F	Reformer Feed: 5.41×10^6 W Steam 1.19×10^6 W CH_4 515 P 1050 F
Power Generation 40 MWe (1)	Steam: 0.322×10^6 W 2.94×10^8 B 1.23 P 108.7 F	Steam: 0.322×18^6 W 4.30×10^8 B 915 P 705 F
Power Generation 100 MWe (1)	Steam: 0.805×10^6 W 7.34×10^8 B 1.23 P 108.7 F	Steam: 0.805×10^6 W 1.08×10^9 B 915 P 705 F

NOTE: (1) Steam removed from and returned to process plant for power generation.

Key: B = Btu/hr P = Psia

W = lb/hr F = ^oF