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MASTER

FINAL REPORT

AND

INITIAL UPDATE

OF THE

ENERGY ECONOMIC DATA BASE (EEDB) PROGRAM
PHASE I

PREPARED FOR

THE U.S. DEPARTMENT OF ENERGY

UNDER CONTRACT NUMBER EN—78-C-02-4954

VOLUME II OF III

BY

united engineers
& constructors inc.

DECEMBER 1979

DISCLAIMER

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REA

CONTENTS

FINAL REPORT AND INITIAL UPDATE OF THE ENERGY ECONOMIC DATA BASE (EEDB) PROGRAM PHASE I

CONTENTS (continued)

FINAL REPORT AND INITIAL UPDATE OF THE
ENERGY ECONOMIC DATA BASE (EEDB) PROGRAM PHASE I

VOLUME III of III

APPENDIX A-1

APPENDIX A-1

DESCRIPTION OF STANDARD HYPOTHETICAL MIDDLETOWN SITE FOR NUCLEAR POWER PLANTS

SITE DESCRIPTION

A1.1 GENERAL

This site description provides the site and environmental data, derived from Appendix A of "Guide for Economic Evaluation of Nuclear Reactor Plant Designs", USAEC Report NUS-531, modified to reflect current requirements. These data form the bases of the criteria used for designing the facility and for evaluating the routine and accidental release of radioactive liquids and gases to the environment.

A1.2 TOPOGRAPHY AND GENERAL SITE CHARACTERISTICS

The site is located on the east bank of the North River at a distance of twenty-five miles south of Middletown, the nearest large city. The North River flows from north to south and is one-half mile (2600 ft) wide adjacent to the plant site. A flood plain extends from both river banks an average distance of one-half mile, ending with hilltops generally 150 to 250 ft above the river level. Beyond this area, the topography is gently rolling, with no major critical topographical features. The plant site itself extends from river level to elevations of 50 ft above river level. The containment building, other seismic Category I structures and the switchyard are located on level ground at an elevation of 18 ft above the mean river level. This elevation is ten feet above the 100-year maximum river level, according to U.S. Army Corps of Engineers' studies of the area.

In order to optimize land area requirements for the nuclear power plant site, maximum use of the river location is employed. The containment structure is located approximately 400 ft from the east bank of the river. The site land area is taken as approximately 500 acres.

A1.3 SITE ACCESS

Highway access is provided to the hypothetical site by five miles of secondary road connecting to a state highway; this road is in good condition and needs no additional improvements. Railroad access is provided by the construction of a spur which intersects the B&M Railroad. The length of the required spur from the main line to the plant site is assumed to be five miles in length. The North River is navigable throughout the year with a 40 ft wide by 12 ft deep channel. The distance from the shoreline to the center of the ship channel is 2000 ft. All plant shipments are assumed to be made overland except that heavy equipment (such as reactor vessel and generator stator) may be transported by barge. The Middletown Municipal Airport is located three miles west of the State highway, 15 miles south of Middletown, and ten miles north of the site.

A1.4 POPULATION DENSITY AND LAND USE

The hypothetical site is near a large city (Middletown, 250,000 population) but in an area of low population density. Variation in population with distance from the site boundary is:

Miles	Cumulative Population
0.5	0
1.0	310
2.0	1,370
5.0	5,020
10.0	28,600
20.0	133,000
30.0	1,010,000

There are five industrial manufacturing plants within 15 miles of the hypothetical site. Four are small plants, employing less than 100 people each. The fifth, near the airport, employs 2,500 people. Closely populated areas are found only in the centers of the small towns so that the local land area used for housing is small. The remaining land, including that across the river, is used as forest or cultivated crop land, except for railroads and highways.

A1.5 NEARBY FACILITIES

Utilities are available as follows:

- Natural gas service is available two miles from the site boundary on the same side of the river.
- Communication lines are furnished to the project boundaries at no cost.
- Power and water for construction activities are available at the southwest corner of the site boundary.
- Two independent offsite power sources (one at 500 kV and one at 230 kV) are available at the switchyard.

A1.6 METEOROLOGY AND CLIMATOLOGY

A1.6.1 Ambient Temperatures

The winters in the Middletown area are moderately cold, with average temperatures in the low 30s. The summers are fairly humid with average temperatures in the low 70s, and with high temperatures averaging around 82°F. The historic maximum wet bulb and dry bulb temperatures are 78°F and 99°F respectively.

The year-round temperature duration curves for the dry bulb temperatures and coincident wet bulb temperatures are shown in Figure A1.1.

A1.6.2 Prevailing Wind

According to Weather Bureau records at the Middletown Airport, located ten miles north of the site on a low plateau just east of the North River, surface winds are predominantly southwesterly 4 - 10 knots during the warm months of the year, and westerly 6 - 13 knots during the cool months.

There are no large diurnal variations in wind speed or direction. Observations of wind velocities at altitudes indicate a gradual increase in mean velocity and a gradual veering of the prevailing wind direction from southwest and west near the surface to westerly and northwesterly aloft.

In addition to the above, studies of the area indicate that there is a significant channeling of the winds below the surrounding hills into the north-south orientation of the North River. It is estimated that winds within the river valley blow approximately parallel to the valley orientation in excess of 50 percent of the time.

A1.6.3 Atmospheric Diffusion Properties

The transport and dilution of radioactive materials in the form of aerosols, vapors or gases released into the atmosphere from the Middletown nuclear power station are a function of the state of the atmosphere along the plume path, the topography of the region, and the characteristics of the effluents themselves. For a routine airborne release, the concentration of radioactive materials in the surrounding region depends on the amount of effluent released, the height of the release, the wind speed, atmospheric stability, and airflow patterns of the site, and various effluent removal mechanisms. Geographic features such as hills and valleys influence diffusion and airflow patterns.

Of the diffusion models that have been developed, the straight-line trajectory model is utilized to calculate the atmospheric diffusion from the Middletown site.

The straight-line trajectory model assumes that the airflow transports and diffuses effluents along a straight line through the entire region of interest in the airflow direction at the release point. The version of this model which is used is the Gaussian straight-line trajectory model. In this model, the wind speed and atmospheric stability at the release point are assumed to determine the atmospheric diffusion characteristics in the direction of airflow.

A long-term continuous release is assumed whose effluent is distributed evenly across a 22-1/2 degree sector. The model treats elevated-only, ground-level only, or mixed elevated-ground level releases, as determined by the interaction of plant characteristics and wind speeds.

For elevated releases, the basic equation, modified from Turner (1970), is:

$$\frac{\bar{X}}{Q}(x,k) = \frac{2.032 \cdot RF_k(x)}{x} \sum_{ij} \frac{DEPL_{ijk}(x) \cdot DEC_i(x) \cdot f_{ijk} \exp - \left(\frac{1}{2} \frac{h_e^2}{\sigma^2_{zj}(x)}\right)}{\bar{u}_i \, \sigma_{zj}(x)} \qquad (1)$$

where

$\frac{\bar{X}}{Q}(x,k)$ = average effluent concentration normalized by source strength at distance x and direction k;

$\bar{u}_i$ = mid-point values of the ith wind speed class;

$\sigma_{zj}(x)$ = vertical (z) spread of effluent at distance x for the jth stability class;

f_{ijk} = joint probability of the ith wind speed class, jth stability class, and kth wind direction;

x = downwind distance from release point or building;

h_e = effective plume height;

$DEC_i(x)$ = reduction factor due to radioactive decay at distance x for the ith wind speed class;

$DEPL_{ijk}(x)$ = reduction factor due to plume depletion at distance x for the ith wind speed class, jth stability class, and kth wind direction; and

$RF_k(x)$ = correction factor for air recirculation and stagnation at distance x and kth wind direction.

Ground release concentrations are calculated using the following two equations modified from Turner (1970):

$$\frac{\overline{X}}{Q}(x,k) = \frac{2.032}{x} RF_k(x) \sum_{ij} DEPL_{ijk}(x) \cdot DEC_i(x) \cdot f_{ijk} \left[\bar{u}_i \left(\sigma_{zj}^2(x) + D_z^2/\pi \right)^{1/2} \right]^{-1} \quad (2)$$

$$\frac{\overline{X}}{Q}(x,k) = \frac{2.032}{x} RF_k(x) \sum_{ij} DEPL_{ijk}(x) \cdot DEC_i(x) \cdot f_{ijk} \left(\sqrt{3}\, \bar{u}_i\, \sigma_{zj}(x) \right)^{-1} \quad (3)$$

Where D_z is the building height which is used to describe the dilution due to the building wake, from Yanskey, et al (1966). Equation 3 represents the maximum building wake dilution allowed; the higher value of $\overline{X/Q}$ calculated from Equations 2 and 3 is utilized.

Values of $\frac{\overline{X}}{Q}(x,k)$ are calculated at 22 downwind distances between 0.25 and 50 miles. Each of the 16 directional sectors are divided into 10 downwind segments and an average value is determined for each sector as follows:

$$\overline{(X/Q)}_{seg} = \frac{R_1 \, \overline{(X/Q)}_{R_1} + r_1 \, \overline{(X/Q)}_{r_1} + \cdots + r_n \, \overline{(X/Q)}_{r_n} + R_2 \, \overline{(X/Q)}_{R_2}}{R_1 + r_1 + \cdots + r_n + R_2} \tag{4}$$

where

$\overline{(X/Q)}_{seg}$ = average value of $\overline{X/Q}$ for the segment;

$\overline{(X/Q)}_r$ = $\frac{\overline{X}}{Q}(x = r, k)$ calculated at distance r;

R_1, R_2 = the downwind distance of the segment boundaries; and

$r_1 \ldots r_2$ = selected radii between R_1 and R_2.

The effluent plume is depleted via dry deposition using Figures 2 through 5 of Regulatory Guide 1.111, Rev. 1 (1977). These depletion factors are adjusted for changes in topography.

From Slade (1968) the reduction factor due to radioactive decay is:

$$DEC = EXP(-.693 t_i / T) \tag{5}$$

where

$$t_i = x/(86400 \, \overline{u}_i), \tag{6}$$

such that DEC = reduction factor due to radioactive decay;

T = half life, in days, of the radioactive material;

t_i = travel time, in days;

x = travel distance, in meters; and

$\overline{u}_i$ = midpoint of the windspeed class, in meters/second.

Finally, for the Middletown site, the $\overline{X/Q}$ values are amended so that they are not substantially underestimated due to the effects of the regional recirculation and stagnation of the air. For downvalley airflow, the relative concentrations are multiplied by five for distances less than 20 miles. For upvalley airflow, the concentrations are multiplied by 1.5 for all distances.

The relative deposition per unit area, $\overline{D/Q}$, is calculated by sector for 22 downwind distances and 10 downwind segments between 0.25 and 50 miles. Elevated-only, ground-level only, or mixed elevated-ground level release are utilized depending on the ratio of the effluent exit velocity to the exit level windspeed.

For a 22-1/2 degree sector, the basic equation to calculate the average D/Q for a specified downwind distance is:

$$\frac{\overline{D}}{Q}(x,k) = \frac{RF_k(x) \cdot \sum_{ij} D_{ij} f_{ijk}}{(2\pi/16)x} \tag{7}$$

where

$\frac{\overline{D}}{Q}(x,k)$ = average relative deposition per unit area at a downwind distance x and direction k, in meters^{-2};

D_{ij} = the relative deposition rate from Figures 6 through 9 of Regulatory Guide 1.111 for the ith wind speed class (since plume height is dependent on windspeed) and jth stability class, in meters^{-1};

f_{ijk} = joint probability of the ith windspeed class, jth stability class, and kth wind direction;

x = downwind distance, in meters; and

$RF_k(x)$ = correction factor for air recirculation and stagnation at distance x and kth wind direction.

Equation 4 is used to calculate average values of D/Q for the downwind segments, with D replacing X in the equation.

A1.6.4 Severe Meteorological Phenomena

A maximum instantaneous wind velocity of 100 mph has been recorded at the site. During the past 50 years, three tropical storms, all of them in the final dissipation stages, have passed within 50 miles of the site. Some heavy precipitation and winds in excess of 40 miles per hour were recorded, but no significant damage other than to crops resulted.

The area near the site experiences an average of 35 thunderstorms a year, with maximum frequency in early summer. High winds near 60 mph, heavy precipitation, and hail are recorded about once every four years.

In forty years of record keeping, there have been twenty tornadoes reported within fifty miles of the site. This moderately high frequency of tornado activity indicates a need to design Seismic Category I structures at the site for the possibility of an on-site tornado occurrence. Maximum tornado frequency occurs in May and June.

During the past forty years, there have been ten storms in which freezing rain has caused power transmission line disruptions. Most of these storms have occurred in early December.

A1.6.5 Potential Accident Release Meteorology

In the event of an accidental release of fission products to the atmosphere, transport and diffusion is determined by the meteorological conditions at the site for the duration of the accident, which is assumed to be 30 days.

The methodology required to calculate radiation dosages from accidental releases involves a series of procedures. The dosages are based upon a ground level release only. Each directional sector from the plant requires a separate X/Q value for the EAB (Exclusion Area Boundary) and the LPZ (Low Population Zone) distances. To evaluate the accident dosages, both the short-term ($\leq$ 2 hrs) and the annual X/Q values are calculated. The annual X/Q value methodology is taken from Regulatory Guide 1.111, Section C.1.c with the effective height defined as:

$$h_e = h_s - h_t$$

where

h_s = stack height

h_t = terrain height

The short-term X/Q values are derived from the conditional equations

$$X/Q = 1/(\bar{u}_{10}\ \pi\ \Sigma_y\ \sigma_z) \quad (1)$$

$$X/Q = 1/\left[\bar{u}_{10}(\pi\ \sigma_y\ \sigma_z + A/2)\right] \quad (2)$$

$$X/Q = 1/(\bar{u}_{10}(3\pi\ \sigma_y\ \sigma_z)) \quad (3)$$

with

$\bar{u}_{10}$ = wind speed at ten meters above ground level,

σ_y, σ_z = horizontal and vertical dispersion coefficients,

A = minimum cross-sectional area of building from which effluent is released,

Σ_y = lateral plume spread; a function of atmospheric stability, wind speed and downwind distance.

For distances greater than 800 meters, $\Sigma_y = (M-1)\sigma_{y_{800\,m}} + \sigma_y$;

M is a function of atmospheric stability and wind speed, as presented in Regulatory Guide 1.145 (1979), Figure 1. For distances less than 800 meters, $\Sigma_y = M\sigma_y$.

The choice of the proper equation determining short-term χ/Q values depends upon the procedure below:

1. The higher χ/Q value is chosen between equations (2) and (3).
2. If the wind speed is less than 6m/sec and the stability class is greater than or equal to D (i.e.; D, E, F or G stabilities), then the lower χ/Q value given by equation (1) or by the higher value of equation (2) or (3) is chosen.

In other words, the values computed from equations (2) and (3) are compared and the higher value is selected. Then, if the meteorological conditions given in Item 2 above are true, the selected value computed from equation (2) or (3) is compared with the value from equation (1), and the lower of these two values is chosen.

The χ/Q value selected as the accident dosage is a function of the effective probability level P_e given by

$$P_e = \frac{P(N/n)}{S} \tag{4}$$

where

P = probability level which is mandated as five percent for a conservative estimate and 50 percent for realistic.

N = total number of valid observations.

n = total number of valid observations within a given sector.

S = number of sectors.

The short-term χ/Q values for each meteorological condition during a given time period are tallied in a cumulative distribution table and normalized to 100 percent. The χ/Q distributions for each direction are plotted on cumulative probability paper. The conservative and realistic average short-term X/Q values are selected from the graph using the effective probability values. Logarithmic interpolation is performed between the graph-selected X/Q values and the annual average X/Q values at time intervals of eight hours, 16 hours, three days and 26 days for each sector and distance of interest. For each distance, the X/Q accident values for the 16 directions are compared and the highest value is selected.

A1.7 HYDROLOGY

The North River provides an adequate source of raw make-up water for the station. The average maximum temperature is 75°F, and the average minimum is 39°F. The mean annual temperature is 57°F.

U.S. Army Corps of Engineers' studies indicate that the 100 year maximum flood level rose to eight feet above the mean river level. There are no dams near the site whose failure could cause the river to rise above the eight foot level.

A1.8 GEOLOGY AND SEISMOLOGY

A1.8.1 Soil Profiles and Load Bearing Characteristics

Soil profiles for the site show alluvial soil and rock fill to a depth of eight feet; Brassfield limestone to a depth of 30 ft; blue weathered shale and fossiliferous Richmond limestone to a depth of 50 ft; and bedrock over a depth of 50 ft. Allowable soil bearing is 6,000 psf and rock bearing characteristics are 18,000 psf and 15,000 psf for Brassfield and Richmond strata, respectively. No underground cavities exist in the limestone.

A1.8.2 Seismology

The site is located in a generally seismically inactive region. Historical records show three earthquakes have occurred in the region between 1870 and 1975. A safe shutdown earthquake (SSE) with a horizontal ground acceleration of 0.25 g provides conservative design margin. For design purposes, the horizontal and vertical component Design Response Spectra given in NRC Regulatory Guide 1.60, Rev. 1, December 1973, are linearly scaled to a horizontal ground acceleration of 0.25 g.

A1.9 SEWAGE AND RADIOACTIVE WASTE DISPOSAL

A1.9.1 Sewage

All sewage receive primary and secondary treatment prior to discharge into the North River.

A1.9.2 Gaseous and Liquid Radioactive Wastes

The gaseous and liquid effluent releases from this plant comply with 10 CFR Part 20 and the intent of Appendix I of 10 CFR Part 50.

A1.9.3 Solid Radioactive Wastes

Storage on site for decay is permissible but no ultimate disposal on site is planned.

References

Briggs, G. A., Plume Rise, AEC Critical Review Series, TID-25075, 1969, Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia.

Turner, D. B., Workbook of Atmospheric Dispersion Estimates, 1970, Office of Air Programs Publication No. AP-26, Environmental Protection Agency, Research Triangle Park, North Carolina.

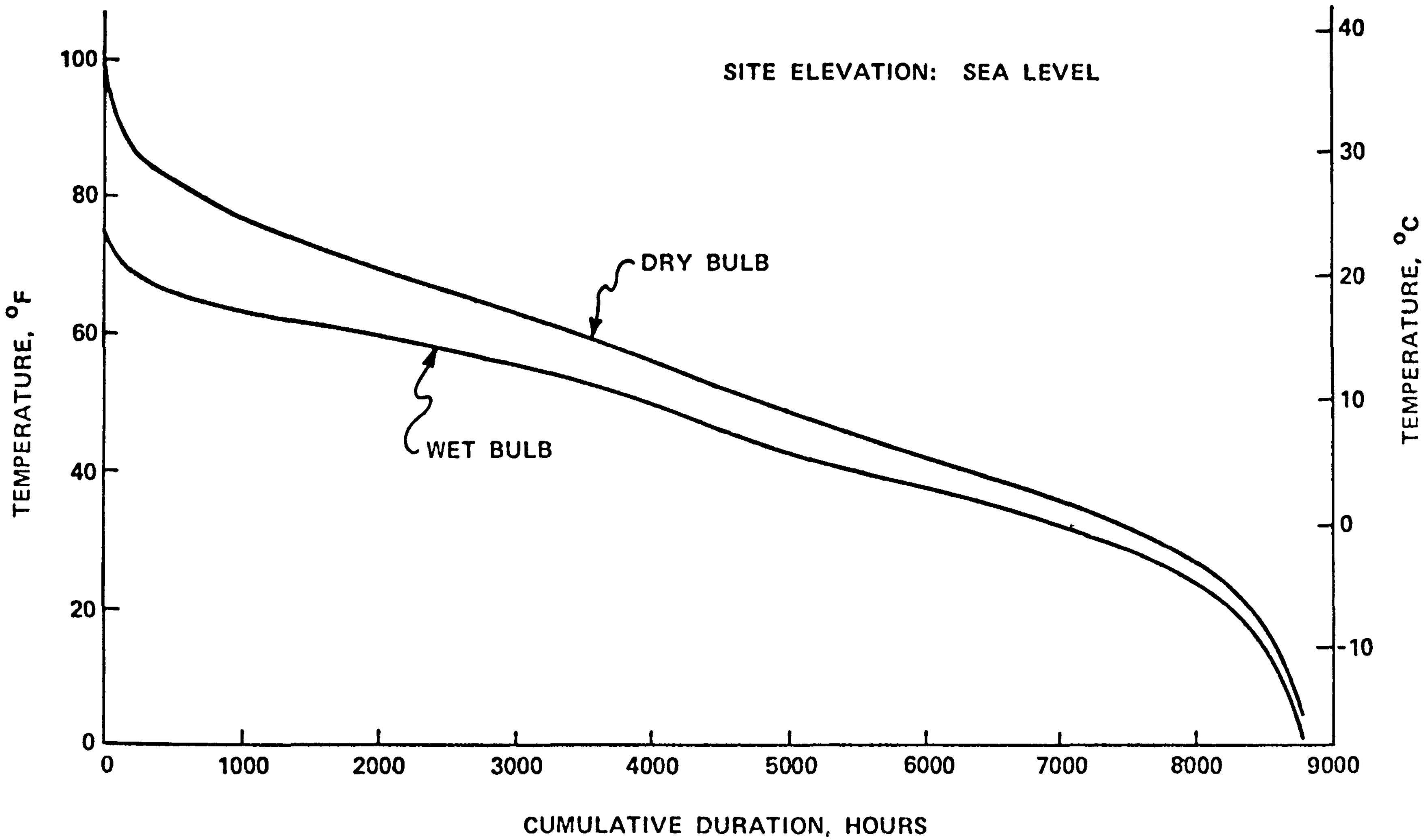
U.S. Nuclear Regulatory Commission, Regulatory Guide 1.111, Revision 1, Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors, 1977, USNRC Office of Standards Development, Washington, D. C.

Yanskey, G. R., Markee, E. H., Jr., and Richter, A. P., Climatography of the National Reactor Testing Station, 1960, Idaho Operations Office, USAEC, IDO-12048, Idaho Falls, Idaho.

U.S. Nuclear Regulatory Commission, Regulatory Guide 1.145, Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants, July 1979, USNRC Office of Standards Development, Washington, D.C.

FIGURE A1.1

TEMPERATURE DURATION CURVES; MIDDLETOWN, U.S.A.



APPENDIX A-2

APPENDIX A-2

DESCRIPTION OF STANDARD HYPOTHETICAL MIDDLETOWN SITE FOR COAL-FIRED PLANTS

SITE DESCRIPTION

A2.1 GENERAL

This site description provides the site and environmental data as derived from Appendix A of "Guide for Economic Evaluation of Nuclear Reactor Plant Designs", USAEC Report NUS-531, and modified to reflect coal plant siting. These data form the bases of the criteria used for designing the facility and for evaluating the release of liquids and gases to the environment.

A2.2 TOPOGRAPHY AND GENERAL SITE CHARACTERISTICS

The site is located on the east bank of the North River at a distance of approximately twenty-five miles south of Middletown, the nearest large city. The North River flows from north to south and is one-half mile (2600 ft) wide adjacent to the plant site. A flood plain extends from both river banks an average distance of one-half mile, ending with hilltops generally 150 to 250 ft above the river level. Beyond this area, the topography is gently rolling, with no major critical topographical features. The plant site itself extends from river level to elevations of 50 ft above river level. The primary structures and the switchyard are located on level ground at an elevation of 18 ft above the mean river level. This elevation is ten feet above the 100 year maximum river level, according to U.S. Army Corps of Engineers' studies of the area.

In order to optimize land area requirements for the coal fueled plant site, maximum use of the river location is employed. The primary structure is located 1200 ft from the east bank of the river. The site land area is approximately 500 acres. An additional 2,000 acres, approximately six miles from the plant site, are available for solid waste disposal.

A2.3 SITE ACCESS

Highway access is provided to the hypothetical site by five miles of secondary road connecting to a State highway. This road is in good condition and needs no additional improvements. Railroad access is provided by constructing a railroad spur which intersects the B&M Railroad. The length of the required spur from the main line to the plant site is assumed to be five miles in length. The North River is navigable throughout the year with a 40 ft wide by 12 ft deep channel. The distance from the shoreline to the center of the ship channel is 2,000 ft. All plant shipments are assumed to be made overland except that heavy equipment may be transported by barge. The Middletown Municipal Airport is located three miles west of the State highway, 15 miles south of Middletown, and ten miles north of the site.

A2.4 POPULATION DENSITY AND LAND USE

The hypothetical site is near a large city (Middletown, of 250,000 population) but in an area of low population density. Variation in population with distance from the site boundary is:

Miles	Cumulative Population
0.5	0
1.0	310
2.0	1,370
5.0	5,020
10.0	28,600
20.0	133,000
30.0	1,010,000

There are five industrial manufacturing plants within 15 miles of the hypothetical site. Four are small plants employing less than 100 people each. The fifth, near the airport, employs 2,500 people. Closely populated areas are found only in the centers of the small towns, so the total land area used for housing is small. The remaining land, including that across the river, is used as forest or cultivated crop land, except for railroads and highways.

A2.5 NEARBY FACILITIES

Utilities are available as follows:

- Natural gas service is available two miles from the site boundary on the same side of the river.
- Communication lines will be furnished to the project boundaries at no cost.
- Power and water for construction activities are available at the southwest corner of the side boundary.
- Two connections to the utility grid (one at 500 kV for the generator connection and one at 230 kV for the reserve auxiliary transformer connection) are available at the switchyard.

A2.6 METEOROLOGY AND CLIMATOLOGY

A2.6.1 Ambient Temperatures

The winters in the Middletown area are moderately cold, with average temperatures in the low 30s. The summers are fairly humid with average temperatures in the low 70s, and with high temperatures averaging around 82°F. The historic maximum wet bulb and dry bulb temperatures are 78°F and 99°F respectively.

The year-round temperature duration curves for the dry bulb temperatures and coincident wet bulb temperatures are shown in Figure A2.1.

A2.6.2 Prevailing Wind

According to Weather Bureau records at the Middletown Airport, located ten miles North of the site on a low plateau just east of the North River, surface winds are predominantly southwesterly 4-10 knots during the warm months of the year, and westerly 6-13 knots during the cool months.

There are no large diurnal variations in wind speed or direction. Observations of wind velocities at altitudes indicate a gradual increase in mean velocity and a gradual veering of the prevailing wind direction from southwest and west near the surface to westerly and northwesterly aloft.

In addition to the above, studies of the area indicate that there is a significant channeling of the winds below the surrounding hills into the north-south orientation of the North River. It is estimated that these winds within the river valley blow approximately parallel to the valley orientation in excess of 50 percent of the time.

A2.6.3 Atmospheric Diffusion Properties

The transport and dilution of materials in the form of aerosols, vapors, or gases released into the atmosphere from the Middletown coal power station are a function of the state of the atmosphere along the plume path, the topography of the region, and the characteristics of the effluents themselves. For a routine airborne release, the concentration of materials in the surrounding region depends on the amount of effluent released, the height of the release, the windspeed, atmospheric stability, and airflow patterns of the site, and various effluent removal mechanisms. Geographic features such as hills and valleys influence diffusion and airflow patterns.

Of the diffusion models that have been developed, the straight line trajectory model is utilized to calculate the atmospheric diffusion from the Middletown site.

The straight-line trajectory model assumes that the airflow transports and diffuses effluents along a straight line through the entire region of interest in the airflow direction at the release point. The version of this model which is used is the Gaussian straight-line trajectory model. In this model, the windspeed and atmospheric stability at the release point are assumed to determine the atmospheric diffusion characteristics in the direction of airflow.

A2.6.4 Severe Meteorological Phenomena

A maximum instantaneous wind velocity of 100 mph has been recorded at the site. During the past 50 years, three tropical storms, all of them in the final dissipation stages, have passed within 50 miles of the site. Some heavy precipitation and winds in excess of 40 miles/h were recorded, but no significant damage other than to crops resulted.

The area near the site experiences an average of 35 thunderstorms a year, with maximum frequency in early summer. High winds near 60 mph, heavy precipitation, and hail are recorded about once every four years.

In forty years of record, there have been twenty tornadoes reported within fifty miles of the site. Maximum tornado frequency occurs during the months of May and June.

During the past forty years, there have been ten storms in which freezing rain has caused power transmission line disruptions. Most of these storms have occurred early in December.

A2.6.5 Ambient Background Concentrations

Background concentrations of SO_2, NO_x and particulates are typical of a rural area approximately 30 miles from a major industrial metropolitan center. They are considered when determining the plant's adherence to the guidelines.

A2.6.6 Air Quality Estimation

Ambient pollutant levels are estimated through the application of atmospheric diffusion models. The estimates are based primarily upon the pollutant emissions, meteorology, topography, and background concentration as previously described. Modeling techniques described in the Turner Atmospheric Dispersion Workbook are used for concentration estimates.*

A2.7 HYDROLOGY

The North River provides an adequate source of raw makeup water for the station. The average maximum temperature is 75°F and the average minimum is 39°F. The mean annual temperature is 57°F.

* Turner, D. B., "Workbook of Atmospheric Dispersion Estimates", Public Health Service Publication No. 999-AP-26, U.S. Department of Health, Education, and Welfare, Public Health Service, Consumer Protection and Environmental Health Service, National Air Pollution Control Administration, Cincinnati, Ohio, Revised 1969.

U.S. Army Corps of Engineers' studies indicate that the 100 year maximum flood level rose to eight feet above the mean river level. There are no dams near the site whose failure could cause the river to rise above the eight foot level.

A2.8 GEOLOGY AND SEISMOLOGY

A2.8.1 Soil Profiles and Load Bearing Characteristics

Soil profiles for the site show alluvial soil and rock fill to a depth of eight feet; Brassfield limestone to a depth of 30 ft; blue weathered shale and fossiliferous Richmond limestone to a depth of 50 ft; and bedrock over a depth of 50 ft. Allowable soil bearing is 6,000 psf and rock bearing characteristics are 18,000 psf and 15,000 psf for Brassfield and Richmond strata, respectively. No underground cavities exist in the limestone.

A2.8.2 Seismology

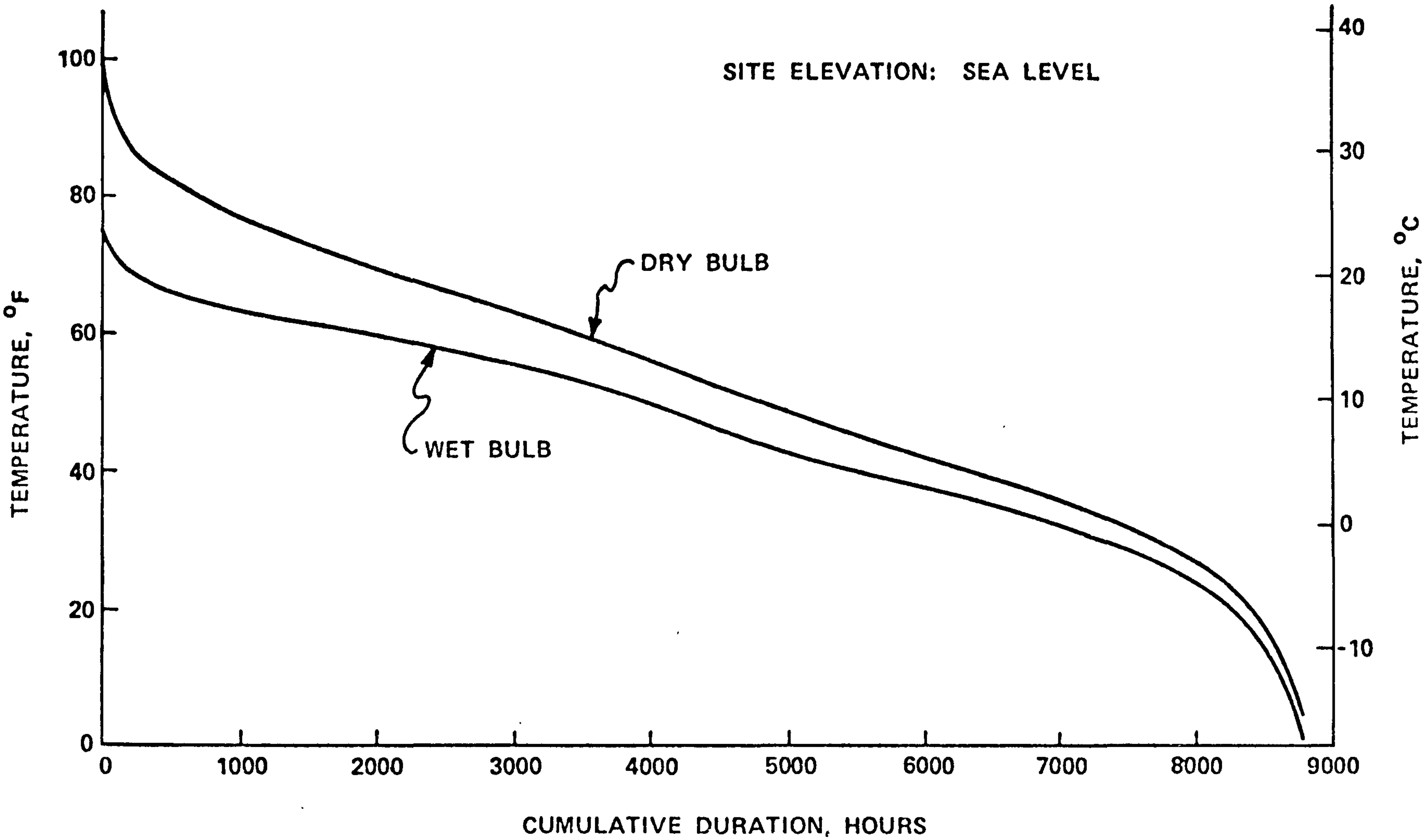
The site is located in a generally seismically inactive region. Historical records show three earthquakes have occurred in the region between 1870 and 1975.

A2.9 SEWAGE AND LIQUID EFFLUENTS

All sewage receives primary and secondary treatment prior to discharge into the North River. Other wastewater is discharged in compliance with EPA effluent standards as promulgated in 40 CFR 423.

FIGURE A2.1

TEMPERATURE DURATION CURVES; MIDDLETOWN, U.S.A.



APPENDIX B

PROPRIETARY NUS-3273

FINAL REPORT
ENERGY ECONOMIC DATA BASE PROGRAM PHASE I

Prepared for

UNITED ENGINEERS & CONSTRUCTORS, INC.

by

NUS CORPORATION
4 Research Place
Rockville, Maryland 20850

October 1978

Approved by: W V Macnabb
W. V. Macnabb
Manager, Nuclear Fuel Cycle
Services Department

PROPRIETARY INFORMATION STATEMENT

TABLE OF CONTENTS

APPENDICES

TABLE OF CONTENTS
(Continued)

LIST OF TABLES

1.0 INTRODUCTION

NUS Corporation has performed consulting services for United Engineers and Constructors (UE&C) under Phase I of the Energy Economic Data Base (EEDB) Program. The services performed have been in support of the nuclear fuel cycle work in Phase I.

The scope of services is contained in UE&C Work Statement 6714-1 of April 4, 1978, which work statement serves as the basis for a subcontract from UE&C to NUS. The prime contract, Contract No. EN-78-C-02-4954 held by UE&C, is with the Department of Energy (DOE).

This document is a final report for Phase I of the EEDB Program. It contains the following information:

1. An overall summary of the conclusions of NUS' work on all NUS tasks.

2. An index of each NUS report submitted to UE&C (and DOE) by task number.

3. A brief summary of each NUS task report, including important conclusions.

4. A Table of Contents of each such report as Appendices to this document.

2.0 SUMMARY OF CONCLUSIONS

The primary objective of NUS' tasks in Phase I of the EEDB Program is to develop baseline technical and cost models for the nuclear fuel cycle, models which display as much detail as possible and which can be periodically updated. Both uranium and thorium fuel cycles have been considered for the following reactor types:

- LWR
- HWR
- HTGR
- GCFR
- LMFBR

The groundrules for Phase I are presented in SCOPE OF SERVICES of UE&C Work Statement 6714-1, April 4, 1978.

Following are the principal conclusions resulting from the nuclear fuel cost analyses in Phase I of the EEDB Program:

1. The baseline 30-year levelized fuel cycle costs for the reactor/fuel cycle systems analyzed in Phase I are given in Table 2-1 for the unit cost inputs shown in Table 2-2.

2. The depletion of uranium is the single largest contributor to fuel costs of the LWR, HWR and HTGR. For the same percentage change in each component of uranium depletion cost, the change in total fuel cost is greatest for the U_3O_8 component of that cost.

TABLE 2-1

SUMMARY OF 30-YEAR LEVELIZED FUEL CYCLE COSTS
(January 1, 1978 Dollars)

Reactor/Fuel Cycle System	$/MBTU for Specified Reactor Startup Date			
PWR/Throwaway	Jan 1, 1987	0.72	Jan 1, 2001	0.76
PWR/U&Pu Recycle	Jan 1, 1991	0.66	Jan 1, 2001	0.67
HTGR/Throwaway	Jan 1, 1995	0.75	Jan 1, 2001	0.76
HTGR/U-233 Recycle	Jan 1, 1995	0.72	Jan 1, 2001	0.73
HWR/(nat. U) Throwaway	Jan 1, 1995	0.72	Jan 1, 2001	0.73
HWR/(LEU) Throwaway	Jan 1, 1995	0.40	Jan 1, 2001	0.40
HWR/(Th) Throwaway	Jan 1, 1995	1.03	Jan 1, 2001	1.04
HWR/(Th) U&Pu Recycle	Jan 1, 1995	0.60	Jan 1, 2001	0.62
LMFBR/Oxide Fuel, U blanket			Jan 1, 2001	0.39
LMFBR/Oxide Fuel, Th blanket			Jan 1, 2001	0.48
GCFR/Oxide Fuel, U blanket			Jan 1, 2001	0.45
GCFR/Oxide Fuel, Th blanket			Jan 1, 2001	0.43

TABLE 2-2

SUMMARY OF FUEL CYCLE UNIT PRICES
(January 1978 Dollars)

Natural Uranium (\$/lb U_3O_8)	45 (in 1985) - 62 (in 2000)
Conversion to UF_6 (\$/kg U)	4.7
Enrichment (\$/SWU)	91
Bred Fuel Value	0

	PWR	HTGR	CANDU[1]	LMFBR	GCFR
Fabrication (\$/KgHM)	177[2]	469[3]	104 (174)	769[4]	842[5]
Spent fuel shipping (\$/KgHM)	20	250	12	94	94
Reprocessing (\$/KgHM)	280[6]	720[7]	- (200)	370[8]	370[8]
HLW Disposal (\$/KgHM)	62	117	- (23)	194	194
Spent Fuel Disposal (\$/KgHM)	134	370	83	-	-

(1) Numbers in parentheses are for thorium fuel cycle.
(2) Fabrication of UO_2 fuel. For PuO_2 - UO_2 fuel, \$486/KgHM.
(3) Fabrication of makeup reload fuel (\$2620/block). For recycle fuel, \$1413/KgHM (\$7894/block), all estimated on the basis of \$/block.
(4) Fabrication of core fuel.
(5) Fabrication of core fuel.
(6) Reprocessing in 1991, decreasing to \$200/KgHM in 2000.
(7) For reload fuel based on estimated reprocessing cost of \$4035/block.
(8) Reprocessing in 2001, decreasing to \$260/KgHM in 2011.

3. The fuel cycle cost for LMFBR and GCFR is very sensitive to the assumed value of bred fuel, resulting in higher costs as bred fuel values increase.

4. The fuel cycle cost of the PWR and HTGR with recycle is not sensitive to the assumed value of bred fuel.

5. The fuel cycle cost difference between the once-through cycle and recycle of bred fuel in PWR and HTGR systems is small. The fuel cost benefit associated with recycle of bred fuel for these systems is markedly affected by changes in fuel cycle unit prices and assumed inflation rate for the future.

6. The PWR 30-year levelized fuel cycle cost is representative of that of the LWR, i.e., PWR or BWR, as evidenced by previous NUS evaluations. Furthermore, regarding annual costs experienced by industry, data reported to FERC from 1973 through 1977 show variations of 0.005 to 0.05 $/MBTU between average annual BWR and PWR fuel costs. (See Table 2 of NUS-3223, <u>A Survey of Fuel Costs for U.S. Nuclear Power Plants 1973-1977</u>.)

7. Increased automation of cost models is justifiable in subsequent phases of the EEDB Program, especially in developing unit costs for U_3O_8, fabrication of rod-type fuel, and waste and fuel disposal (and storage) costs. Such automation will reduce future labor efforts, provide greater capability and assure consistency of methodology from year to year.

8. Mass flows developed under the NASAP Program and evaluated by ORNL should continue to be used in the EEDB Program. If such information should become unavailable for some reason, the next best source is the present NASAP characterization contractor producing such information with data evaluation by NUS.

3.0 REPORT INDEX AND SUMMARY

The following subsections, 3.1 through 3.8, contain an index of task reports submitted to DOE and UE&C during Phase I of the EEDB Program. The second digit of the subsection number (e.g., the digit 2 in subsection number 3.2) corresponds to the NUS task number of UE&C Work Statement 6714-1 of April 4, 1978.

3.1 Task 1 Reports

The reports in satisfaction of Task 1 are identified and summarized below. A Table of Contents of each report is contained in Appendix A.

NUS-3190 Fuel Cycle Cost Estimates for LWR, HTGR, CANDU-TYPE HWR, LMFBR and GCFR

This report presents the detailed cost inputs and unit cost results for the following reactor/fuel cycle systems:

PWR (throwaway fuel cycle)
PWR (U&Pu recycle)
HTGR (throwaway fuel cycle)
HTGR (U-233 recycle)
HWR (natural U throwaway fuel cycle)
HWR (LEU throwaway fuel cycle)
LMFBR (oxide fuel, U blanket)
LMFBR (oxide fuel, Th blanket)
GCFR (oxide fuel, U blanket)
GCFR (oxide fuel, Th blanket)

Both input unit costs and output costs are presented according to a code of accounts developed for Task 4 (see subsection 3.4). Output costs are presented in $/MBTU on both an annual and a 30-year levelized basis.

The report contains identification of cases analyzed, discusses groundrules and assumptions, and presents the fuel cycle cost methodology.

Sensitivity studies are reported for assumed changes in costs for U_3O_8, SWU, fabrication, total back end costs, and bred fuel value. In addition, the variation in 30-year levelized $/MBTU resulting from different on-site storage time (PWR and HTGR only) and capacity factor is reported.

- -

NUS-3244 Additional Fuel Cost Studies - Escalation, 2001 Startup and CANDU Thorium System

This report presents nuclear fuel cycle cost inputs and results for the same systems covered in NUS-3190 but with the effects of escalation and a uniform commercial operation date of January 1, 2001. Escalation rates of 6, 7 and 8 percent per year are evaluated.

In addition, a CANDU-type HWR on a thorium fuel cycle is selected for evaluation both with and without recycle. The resulting $/MBTU results show a large incentive to recycle in this system, however, the uncertainties in this result are probably large.

3.2 Task 2 Reports

The results of Task 2 are incorporated into the Task 1 reports already described in subsection 3.1.

3.3 Task 3 Reports

The reports in satisfaction of Task 3 are identified and summarized below:

NUS-3237 Recommendations Relating to Acquisition of Mass-Flow Data for the EEDB Program

This report presents NUS' finding related to sources of fuel cycle mass flow data. Options evaluated for future phases of the EEDB Program include continued use of NASAP data, use of data developed by NASAP contractors but separate from NASAP funding, use of NUFUEL, or development of a code specific to EEDB Program needs.

Our findings are to continue to rely on NASAP data and data evaluation by the national laboratories. Lacking availability of such data, the preferred backup is to rely on NASAP contractors for data with evaluation of such data by NUS.

A Table of Contents of NUS-3237 is contained in Appendix B.

- -

EnSD-FS-528 EEDB Progress Report for Month of August, 1978

With regard to an economics code this report presents our findings that FUELCOST-V is preferred for future use. Furthermore, with some minor changes to the code, costs for future EEDB updates can be reduced.

3.4 Task 4 Reports

The reports in satisfaction of Task 4 are identified and summarized below:

EnSD-FS-471 EEDB Progress Report for Month of July, 1978

This report presents a preliminary listing of a code of accounts for the nuclear fuel cycle.

NUS-3190 Appendix B	Fuel Cycle Cost Estimates for LWR, HTGR, CANDU-type HWR, LMFBR and GCFR
and	
NUS-3244 Appendices A and B	Additional Fuel Cost Studies - Escalation, 2001 Startup and CANDU Thorium System

These report appendices present the final cost code of accounts for each reactor/fuel cycle system evaluated in Phase I. The accounts are structured in such a way as to accommodate other reactor systems as the need arises and to expand the detail of reporting. The Table of Contents of these two reports is given in Appendix A.

Further detail of the input cost accounts has been developed as part of this task and reported in the Task 5 final reports (see below).

3.5 Task 5 Reports

The reports in satisfaction of Task 5 are identified and summarized below. A Table of Contents of each report is contained in Appendix C.

NUS-3196	Cost of Enrichment Services
NUS-3198	UF_6 Conversion Cost
NUS-3199	Heavy Water Production Costs
NUS-3203	Spent Fuel and Reprocessing Waste Disposition
NUS-3204	Costs for Spent Fuel Shipping
NUS-3207	HTGR Fuel Cycle
NUS-3209	Costs of U_3O_8
NUS-3224	Reprocessing Cost Model for LWR, LMFBR and GCFR
NUS-3242	Fabrication Costs for "Rodded" Nuclear Fuels

Each of the above nine (9) reports is organized in the same way to describe a base technical model of the material or process being analyzed. Costs are then developed for the fuel cycle component. In most cases costs are developed according to a set of subcomponent cost items. These cost breakdowns are then presented in accordance with the cost accounts developed under Task 4. Cost figures developed in this task are used as input to the computations in Tasks 1, 2 and 10.

3.6 Task 6 Reports

The report in satisfaction of Task 6 is identified and summarized below. A Table of Contents of this report is contained in Appendix D.

NUS-3243	Recommendations Relating to Evaluation of Nuclear Fuel Unit-Cost Data for EEDB Program

This report reviews the needs of the EEDB Program for automation of the development of unit cost inputs. The findings of the study result in recommendations for improvements to the uranium price model, and automation of the calculation of fuel fabrication and spent fuel and waste disposal (storage) costs. Manual techniques are recommended for the computation of the other cost components.

3.7 Task 7* Reports

The report in satisfaction of Task 7 is identified and summarized below. A Table of Contents of this report is contained in Appendix E.

NUS-3223 A Survey of Fuel Costs for U.S. Nuclear Power 1973-1977

This report presents statistics reported to the Federal Energy Regulatory Commission (FERC, formerly FPC) on nuclear fuel unit costs (mills/kwhr) and data sources for cost tracking. The tracking procedure is described in EnSD-FS-345. A listing of reactors and their annual fuel expense is tabulated. A simplified statistical analysis is performed on the data for purposes of identifying "high" and "low" cost plants. This data may be useful in subsequent phases of the EEDB Program when choosing specific reactors for further analysis of costs.

3.8 Task 8** Reports

The reports in satisfaction of Task 8 are NUS-3140 and NUS-3244 which

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* Numbered as Task 9 in NUS Proposal 7802097 to DOE of March, 1978.

** Numbered as Task 10 in NUS Proposal 7802097 to DOE of March, 1978.

have already been discussed under Task 1. The specific parts of these documents applicable to Task 8 are (see EnSD-FS-471, pp. 3-4):

1. NUS-3190

   - effect of capacity factor variations from 0.55 to 0.75
   - effect of 10-year spent fuel storage time at reactors with a throwaway fuel cycle (PWR and HTGR only)
   - effect of 10-year and 20-year levelized costs in addition to 30-year levelized costs.

2. NUS-3244

   - effect of escalation at rates of 6, 7 and 8 percent per year
   - effect of a January 1, 2001 commercial operation date for all systems
   - costs of a CANDU-type HWR on a thorium fuel cycle

APPENDIX A

Table of Contents for NUS-3190

and

Table of Contents for NUS-3244

NUS-3190

TABLE OF CONTENTS

TABLE OF CONTENTS
(Contents)

TABLE OF CONTENTS
(Continued)

NUS-3244

TABLE OF CONTENTS

APPENDICES

APPENDIX B

Table of Contents for NUS-3237

NUS-3237

TABLE OF CONTENTS

APPENDIX C

Table of Contents for NUS-3196

Table of Contents for NUS-3198

Table of Contents for NUS-3199

Table of Contents for NUS-3203

Table of Contents for NUS-3204

Table of Contents for NUS-3207

Table of Contents for NUS-3209

Table of Contents for NUS-3224

Table of Contents for NUS-3242

NUS-3196

TABLE OF CONTENTS

NUS-3198

TABLE OF CONTENTS

NUS-3199

TABLE OF CONTENTS

NUS-3203

TABLE OF CONTENTS

NUS-3204

TABLE OF CONTENTS

NUS-3207

TABLE OF CONTENTS

NUS-3209

TABLE OF CONTENTS

NUS-3224

TABLE OF CONTENTS

APPENDIX D

Table of Contents for NUS-3243

NUS-3243

TABLE OF CONTENTS

APPENDIX E

Table of Contents for NUS-3223

NUS-3223

TABLE OF CONTENTS

APPENDIX C-1

APPENDIX C-1

INFLATION-FREE FIXED CHARGE RATES

C1.1 GENERAL

This discussion introduces the concepts involved and addresses methods of calculation of fixed charges applicable to investor-owned utilities, as used in the Energy Economic Data Base.

For every investment made in a capital asset, the owner company commits itself to a program of payments over the life of that asset. These payments, or charges against income which the company expects to realize from its investment, are generally fixed in nature, related only to the actual initial investment, and independent of the actual usage of the asset. Such payments are commonly called fixed charges (also referred to as annual or carrying charges) and represent the absolute minimum revenue requirements which the investment must command.

Because the investment in plant is recovered over its life by periodic depreciation or amortization charges, the net investment declines and consequently the fixed charges, as a percent of initial investment, vary from year to year. Therefore, it is convenient to know a "levelized" fixed charge value, which will incorporate not only the actual year by year values of fixed charges, but also the time variance in payments. This levelized annual value (or uniform annual equivalent) permits the engineer to make economic comparisons of alternative investment plans which may have quite different time schedules of fixed charge payments.

The levelized annual value is calculated as a weighted average of the actual year by year values. The weighting factors represent the time value of money and are called present-worth factors. The single payment present-worth factor is calculated from the expression $\frac{1}{(1 + R)^n}$ where "R" is the cost of money or rate of return per time interval expressed as a decimal, and "n" is the number of time periods. To illustrate the concept, it is necessary to consider the total assets of the company as a bank or pool of money, where money borrowed is charged interest or money deposited in advance earns interest. Under this arrangement, consider the present worth of $100 spent "n" years from now, where the cost of money is 5.42 percent per year:

n	Present Worth Factor	$ Spent	Present Worth of $ Spent
0	$\frac{1}{(1 + .0542)^0}$	100	$100.00
1	$\frac{1}{(1 + .0542)^1}$	100	$ 94.86
5	$\frac{1}{(1 + .0542)^5}$	100	$ 76.81

The table gives substance to the intuitive belief that a plan involving an expenditure in the future is less costly than one which requires the same amount of money to be spent earlier. In the example, $76.81 now in hand and earning 5.42 percent interest will support a $100 expenditure to be made five years from now, whereas the same $100 spent one year from now has the higher present value of $94.86.

The fixed charges on investment plus the fuel cycle and operating and maintenance costs represent the total revenue requirements needed to support the project. Therefore, these revenue requirements can be used for economic comparisons of alternative investment plans. The plan having the smallest revenue requirement yields the lowest costs to the consumer or, where income is fixed, the greatest net return for the company.

Fixed charges include the following basic items:

1. Return on Investment and/or the cost of borrowed money
2. Depreciation, amortization or repayment of principal
3. Taxes on Income
4. State and Local Taxes
5. Insurance
6. Interim replacements

Since the components of fixed charges are all related to the initial investment, it is usually more convenient to work with fixed charge rates rather than actual dollars. The levelized annual rate, consisting of the summation of levelized annual rates of each of the above components and levelized by present-worth methods, can then be applied to the alternative investments to yield the uniform annual equivalent total fixed charges in dollars.

The concept of capital recovery encompasses the first two components of fixed charges tabulated above, namely return on investment (rate of return) and depreciation (retirement of principal). The capital recovery rate is a levelized annual charge and is a function of the overall rate of return and the life of the asset (book life for accounting purposes). The capital recovery factor is calculated from the expression $\frac{R\ (1 + R)^n}{(1 + R)^n - 1}$ where "R" is the rate of return expressed as a decimal and "n" is the life of the asset in years. Capital recovery factors are tabulated in many interest tables. This factor gives the annual charge which would pay all cost of money and fully recover the invested capital over the life of the asset in equal payments. Again using the money pool concept, any schedule of payments which accomplishes the same results over the same period will have the same present-worth as the uniform annual payment schedule. For instance, the capital recovery factor for 5.42 percent and 30 years is 0.0682. This means that a payment of $6.82 per $100 of investment, made each year for 30 years, would fully support return plus depreciation.

Now for the same case, consider paying interest on the full investment each year, and putting an amount into the interest-bearing money pool such that at the end of 30 years we could withdraw $100 to retire the principal. That annual deposit can be calculated from the expression $\frac{R}{(1 + R)^n - 1}$ which is called a sinking fund factor. For our example, it comes out to be 0.014 or $1.40 per $100 of investment. Therefore, the total $6.82 annual capital recovery can be considered to consist of:

Formation of Annual Capital Recovery

$ 5.42	Return at 5.42%
+1.40	Sinking Fund Depreciation
$ 6.82	Annual Capital Recovery

On the other hand, we may choose to retire the $100 principal in 30 equal annual installments of $3.33, which represents a straight line depreciation rate of 3.33 percent ($\frac{1}{n} = \frac{1}{30} = 0.033$). It is now necessary to pay interest or return on only the net investment (outstanding balance). The interest payments therefore decrease annually as shown below:

Decrease in Interest Payments

Year	Net Investment	Interest at 5.42%
1	$100.00	$ 5.42
10	70.00	3.79
20	36.67	1.99
30	3.33	0.18

If we compute the present-worth of all interest payments over the full 30 years, and then the uniform annual interest, the levelized payment is $3.49. Therefore, the $6.82 annual capital recovery can be considered to consist of:

Formation of Annual Capital Recovery	
$ 3.49	Levelized Return at 3.49%
+3.33	Straight Line Depreciation
$ 6.82	Annual Capital Recovery

However, the more common presentation is in the former format (i.e., return plus sinking fund depreciation).

In summary, it can be demonstrated that any pay-back schedule results in the same levelized annual total for return plus depreciation which is readily found by using the capital recovery factor.

The various components of fixed charges as they apply to private (investor-owned) utilities, are discussed in Section C1.2.

C1.2 INVESTOR-OWNED UTILITIES

C1.2.1 Return on Investment

The overall rate of return is the average cost of money to the utility and is a composite of interest on debt and earnings for equity. Debt money comes from bondholders, while equity money is supplied by the stockholder. For a particular project, the economic analysis must be based on the average capital structure of the company, since in actual operation the investment under study will become just a part of total investment in the business.

For investor-owned utilities a 50/50 debt-equity ratio is not uncommon, and the range of 40/60 to 60/40 includes most companies. Most indentures of trust limit the debt to not more than 2/3 of added property. In some states, the percentage of total capital raised by debt is limited by law. State and Federal Regulatory Commissions also have some control.

Having established the debt-equity ratio, the interest or earnings on each component must be determined. Here the bond interest rate, to be used in studies, must be that which would have to be paid for new bonds, not an average of all outstanding debt which might be considerably lower. The interest rate must also be commensurate with risk. A company with traditionally high debt financing will require the bondholders to incur higher risk, and they in turn will command higher rates. Equity earnings must also reflect the risk involved, and must be in proper perspective to debt interest. The overall return, illustrated in the example below, must also be evaluated for its reasonableness. In practice, return of the regulated electric utility industry is controlled within rather close limits, generally falling within the range of approximately five percent on an inflation-free basis.

EXAMPLE OF OVERALL RATE OF RETURN IN AN INFLATION-FREE SCENARIO

Financial Structure		Interest or Earnings Rate		Weighted Rate of Return	
51.4% Bonds	@	3.93%	=	0.0202	Debt
48.6% Common Stock	@	7.00%	=	0.0340	Equity
		Total:		0.0542 or 5.42%	

The financial structure and bond and equity rates of return used in this discussion are based upon information reported in DOE/EIA-0044 (April 1978), "Statistics of Privately Owned Electric Utilities in the United States in 1976 (Class A and B Companies)", as cited in the NUS Corporation Report NUS-3190, "Fuel Cycle Cost Estimates for LWR, HTGR, CANDU - Type HWR, LMFBR and GCFR." The inflated rates from these documents, 6.93 percent and 10 percent for bonds and equity respectively, were deflated by three percent to obtain the inflation-free rates used in this example.

Several economic indicators were used to measure the past effects of inflation and develop the average deflator of three percent per year. These indicators and their sources are cited in NUS-3190 as follows:

1. Consumer-Price Index (CPI) - As reported in "Consumer Price Index for All Urban Consumers (Revised CPI-U), U.S. City Average, U.S. Department of Labor, Bureau of Labor Statistics."

2. Gross National Product (GNP) Deflator - Based upon private communication with the Bureau of Economic Analysis, U.S. Department of Commerce.

3. Wholesale Price Index for Industrial Commodities (WPI) - Based upon private communication with Bureau of Labor Statistics, U.S. Department of Labor.

C1.2.2 Depreciation

Depreciation or amortization represents retirement of principal. For book purposes (plant valuation) property is depreciated linearly over its book life. This straight line method can be represented by an annual charge at the rate of $\frac{1}{n}$ as discussed earlier, or in levelized form by the appropriate sinking fund factor. The life selected should be the best estimate of life expectancy considering both physical deterioration and economic obsolescence factors. Commonly used lives of nuclear and fossil power generating stations are approximately 30 years. In comparison, hydroelectric installations are often assigned lives of 40 to 50 years or more.

Some components of the total investment cost of a generating station are for non-depreciable property, the prime example of which is land. In some very detailed economic studies, the cost of land and other non-depreciable components of capital investment, such as materials and supplies and working capital, are segregated. When this is done, a different fixed charge rate is applied to the non-depreciable assets, which does not include depreciation and hence does not decline with time. However, in many economic studies this distinction is not made, and the resulting error is not significant unless the non-depreciable components are responsible for an unusually high percentage of the total capital cost.

C1.2.3 Taxes on Income

Of the revenue required to cover fixed charges, all components except equity earnings are expense items which are deductible from gross income for income tax purposes. However, to any requirement of revenue for equity earnings must also be added the necessary revenue to pay the income tax. For example, at the present corporate federal income tax rate of 48 percent it would take \$100 in gross revenue to net \$52 of equity return. Each year federal income tax liability declines with net investment. The levelized annual income tax rate can be calculated from the fraction of levelized return that is equity earnings, as shown below in an example using previously cited sample data.

Example of Calculation of Levelized Annual Income Tax ($\bar{t}$)

$$\bar{t} = \left(\frac{T}{(1 - T)}\right) \left(CRF - \frac{1}{n}\right) \left(\frac{R - bi}{R}\right)$$

where: T = federal income tax rate of 48%

$\left(CRF - \frac{1}{n}\right)$ = levelized return, computed previously as the difference between capital recovery factor and straight line depreciation rate (6.82% - 3.33% = 3.49% for 5.42% return and 30 year life).

$\left(\frac{R - bi}{R}\right)$ = the fraction of levelized return which is equity earnings.
R is overall return of 5.42%
b is bond ratio of 51.4%
i is bond interest of 3.93%

$$\text{Levelized income tax } \left(\bar{t}\right) = \left(\frac{0.48}{0.52}\right) (0.0349) \left(\frac{0.0542 - 0.0202}{0.0542}\right) = 2.02\%$$

State income taxes can generally be handled in a similar fashion, as can other taxes on income. Calculations often can be simplified by working with a composite tax rate which is the sum of federal plus state plus other income tax rates. In this study, however, "Taxes on Income" are restricted to federal taxes only.

While the utility industry almost universally uses the straight-line method for book depreciation, liberalized or accelerated depreciation methods are commonly used for tax purposes. These methods do not reduce the total tax dollars paid over the life of the asset, but they do lead to reduction of the levelized annual tax charge by deferring some of the taxes in the early years to later payments. There are two commonly used methods of calculating accelerated tax depreciation. They are the Sum-of-Years-Digits (SYD) method and the Double-Rate-Declining-Balance (DRDB or DDB) method.

With SYD, the annual tax depreciation rate is a fraction whose denominator is the summation of all the numbers from one to end of plant life in years. The numerators decrease from end of plant life in years to one. For 30 years, $\sum_{n=1}^{30} n = 465$. Therefore, the first year depreciation rate is $\frac{30}{465}$, second year $\frac{29}{465}$ ... decreasing to $\frac{1}{465}$ in the last year. It is obvious that:

$$\frac{30}{465} + \frac{29}{465} + \frac{28}{465} \; . \; . \; . \; \frac{3}{465} + \frac{2}{465} + \frac{1}{465} = 100\%$$

Double declining balance tax depreciation is calculated each year as twice the straight line rate times net investment. For example, for 30 year life, the normal straight line rate is $\frac{1}{30} = 3.33$ percent and the DDB rate is 6.67 percent. The computation procedure is as follows:

Annual DDB Tax Depreciation

Year	Net Investment (%)	DDB Depreciation (%)
1	100.00	6.67
2	93.33	6.23
3	87.10	5.81
4	81.29	5.42

If this computation were continued for 30 years, the summation of annual depreciation entries in the DDB column will not yield 1.00 or 100 percent. It is therefore necessary to switch to the straight line method about half-way through plant life.

There are rather complex formulae for computing the levelized annual value of accelerated depreciation. These are presented in the sample calculations at the end of this discussion in Section C1.3. Also given is a formula, which is used to levelize income tax using previously calculated levelized accelerated depreciation. The tax formula reflects the fact that the tax savings attributable to accelerated depreciation is $\frac{T}{1 - T}$ times the difference between straight line and the levelized annual tax depreciation used.

The federal investment tax credit (10 percent of qualified investment deductible from income tax in the first year only) also produces a small reduction in the levelized income tax charge. This reduction is calculated as the annual capital recovery of the present worth of the 10 percent credit in year one, and is calculated to be 0.0048 or 0.48 percent as shown in Section C1.3.4.

Calculation of fixed charges on a flow-through basis (benefits passed on to consumers), incorporating liberalized tax depreciation and the 10 percent credit as used by most companies, yields minimum revenue requirements since the income tax component is reduced.

C1.2.4 State and Local Taxes

There are a variety of other types of taxation which are encountered in the investor-owned utilities industry. The more important ones are property, franchise and gross revenue taxes. Property taxes are levied by the local community, and the rate is applied to the original (undepreciated) value of the asset.

In several of the states where the franchise tax is paid, the levy is on net income. Therefore, it is treated as a state income tax, which has been discussed previously.

The gross revenue or gross receipts tax, on the other hand, is levied on all revenue which the utility collects without deductions or exemptions. The tax then is a revenue requirement in itself, and when used must be added to the subtotal of all other fixed charges. It must be noted that unlike other types of taxation, the gross receipts tax revenue requirement must also be added to operation and maintenance and fuel expenses in economic studies. However, since in comparison of alternatives, the effect of a gross revenue tax is to increase the differential costs between alternatives by the tax rate percentage, it is sometimes handled in that way, instead of carrying it through individual alternative fixed charge rate and operating expense calculations.

The fixed charge rate of 2.55 percent for state and local taxes, shown in Section C1.2.8, is based upon information reported in DOE/EIA-0044, as cited in NUREG-0480, "Coal and Nuclear: A Comparison of the Cost of Generating Baseload Electricity by Region." It is an average for the years 1972 through 1976 (the last five years of published data), and does not reflect the effects of general inflation over the life of the plant.

C1.2.5 Insurance

Insurance coverage for power plants include both property damage and public liability. Liability coverage is not directly related to plant investment and is therefore included in O&M costs. The fixed charge rate of 0.06 percent for property damage, shown in Section C1.2.8, is based upon data reported in DOE/EIA-0044, as cited in NUREG-0480. It is an average of the ratios of the property insurance paid by privately-owned utilities to their total investment in plant and equipment, for the years 1972 through 1976.

Annual charges for insurance usually amount to less than one percent of the capital investment, and in some cases are even considered negligible in developing the total fixed charge rate.

C1.2.6 Interim Replacements

Some utilities include a rate for interim replacements in their fixed charges. The charges represent large expenditures for replacing major equipment components of the asset during its life, where failure of such components would impair the integrity of the asset. Interim replacement charges, as used here, do not include normal maintenance costs or cost of additions made after the original construction. When used, the most commonly applied rate is 0.35 percent annually, which is based upon fossil-fueled power station experience. Long term experience upon which to base the value of this allowance for nuclear plants is lacking. However, it is believed that the 0.35 percent value is conservative for them, since safety-related nuclear components are subject to more stringent design specifications and quality control inspections. The fixed charge rate of 0.35 percent for interim replacements, shown in Section C1.2.8, does not reflect the effects of general inflation over the life of the plant.

C1.2.7 Discount Rate

The fixed charge rate developed in the preceding sections reflects the levelized value of revenue requirements for capital investment over the life of the plant. The cost levelization involves the process of present worthing or discounting and was performed using a discount rate expression, which relates the fractions of debt and equity capital and their interest rates as follows:

$$x_1 = bi\ (1-b)\ j$$

Where: x_1 = discount Rate

b = debt capital

$(1-b)$ = equity capital

i = interest rate on debt capital

j = interest rate on equity capital

For this case, the discount rate is equal to the rate of return of 5.42 percent. This is the classical way that many utilities use to develop fixed charge rates.

However, and with increasing frequency, a significant number of utilities are using an effective discount rate for the levelization process. This effective discount rate takes into consideration the deductibility of interest expense on bonds, so that a dollar of bond interest requires less revenue than a dollar of equity return. It is calculated from the expression

$$x_1 = (1-T)(bi) + (1-b)\ j$$

Where: T is the income tax rate

It appears to be a matter of utility preference as to which approach is used.

C1.2.8 Typical Inflation-Free Fixed Charges for Investor-Owned Utility Nuclear and Fossil Power Generating Stations

The fixed charge rate developed for the Energy Economic Data Base Cost Summary has the value of 10.56 percent for privately owned utilities operating in the service area containing the "Middletown Site". This value is subject to variations depending upon utility type, station type and station location.

The levelized 10.56 percent inflation-free rate is composed of the following components:

EEDB Fixed Charge Rate

51.4% Bonds	@ 3.93%	=	2.02%
48.6% Common Stock	@ 7%	=	3.40%
Return on Investment			5.42%
Depreciation (30 year sinking fund)			1.40%
Federal Income Tax (including 10% credit and based on SYD depreciation)			0.78%
State and Local Taxes			2.55%
Insurance			0.06%
Interim Replacements			0.35%
Fixed Charge Rate			10.56%

C1.3 FORMULAE AND SAMPLE CALCULATIONS FOR LEVELIZED VALUES OF ACCELERATED TAX DEPRECIATION AND FEDERAL INCOME TAX

All sample calculations are based on the following parameters:

5.42% Return on Investment	(R = 0.0542)	
51.4/48.6 Debt/Equity Ratio	(b = 0.514)	(Debt/Capital Structure Ratio)
3.93% Bond Interest	(i = 0.0393)	
30-Year Life	(n = 30)	

C1.3.1 Double Declining Balance (DDB) Depreciation Method

$$\bar{D} = SFF \left[\frac{\frac{2}{n}(CAF) + R \left(1 - \frac{2}{n}\right)^n}{R + 2/n} \right]$$

Where:
$\bar{D}$ = Levelized Annual Depreciation
SFF = Sinking Fund Factor (SFF = 0.014)
n = Life (n = 30)
CAF = Single Payment Compound Amount Factor (CAF = 4.87)
R = Rate of Return (R = 0.0542)

Sample calculation:

$$\bar{D} = 0.014 \left[\frac{\frac{2}{30}(4.87) + 0.0542 \left(1 - \frac{2}{30}\right)^{30}}{0.0542 + 2/30} \right] = 3.84\%$$

C1.3.2 Sum of Years Digits (SYD) Depreciation Method

$$\overline{D} = \frac{2\left(CRF - \frac{1}{n}\right)}{R\ (n + 1)}$$

Where: $\overline{D}$ = Levelized Annual Depreciation
CRF = Capital Recovery Factor (CRF = 0.682)
n = Life (n = 30)
R = Rate of Return (R = .0542)

Sample calculation:

$$\overline{D} = \frac{2\left(0.682 - \frac{1}{30}\right)}{0.0542\ (30 + 1)} = 4.15\%$$

C1.3.3 Federal Income Tax

$$\overline{t} = \frac{T}{1 - T}\left[R - d - \frac{bi}{R}(R - d_o)\right]$$

Where: $\overline{t}$ = Levelized Annual Federal Income Tax
T = Federal Income Tax Rate (T = 0.48)
R = Rate of Return (R = 0.0542)
d = $\overline{D}$ - SFF or Difference between levelized depreciation for a particular method and sinking fund depreciation
b = Bond Ratio (b = .514)
i = Bond Interest Rate (i = .0393)
d_o = $\frac{1}{n}$ - SFF or Difference between straight line and sinking fund depreciation

Sample calculations:

1. With straight line tax depreciation (not accelerated)

$$d = d_o = \frac{1}{n} - SFF = \frac{1}{30} - 0.014 = 0.0193$$

$$\bar{t} = \frac{0.48}{1 - 0.48}\left[0.0542 - 0.0193 - \frac{(0.514)(0.0393)}{0.0542}(0.0542 - 0.0193)\right] = 2.02\%$$

2. With double declining balance tax depreciation

$$d = \bar{D} - SFF = 0.0384 - 0.014 = 0.0244$$

$$d_o = \frac{1}{n} - SFF = 0.0193 \text{ as above}$$

$$\bar{t} = \frac{0.48}{1 - 0.48}\left[0.0542 - 0.0244 - \frac{(0.514)(0.0393)}{0.0542}(0.0542 - 0.0193)\right] = 1.55\%$$

3. With SYD tax depreciation

$$d = \bar{D} - SFF = 0.0415 - 0.014 = 0.0275$$

$$d_o = \frac{1}{n} - SFF = 0.0193 \text{ as above}$$

$$\bar{t} = \frac{0.48}{1 - 0.48}\left[0.0542 - 0.0275 - \frac{(0.514)(0.0393)}{0.0542}(0.0542 - 0.0193)\right] = 1.26\%$$

C1.3.4 Levelized Effect of Ten Percent Investment Tax Credit in First Year

$$\bar{t}_c = 0.10\ (PWF_1)\ (CRF)\ (0.75)$$

Where: $\bar{t}_c$ = Levelized effect of 10% tax credit in year one
PWF_1 = Single Payment Present-Worth Factor for year one
CRF = Capital Recovery Factor
0.75 = Portion of investment qualified for investment tax credit

$$\bar{t}_c = 0.10\ \frac{1}{1.0542}\ (0.0682)(0.75) = 0.48\%$$

C1.3.5 Summary of Sample Calculations

Tax Depreciation Method	Levelized Annual Depreciation in Percent	Levelized Annual Federal Income Tax in Percent: Tax	Levelized Annual Federal Income Tax in Percent: 10% Credit in Year 1-Levelized	Levelized Annual Federal Income Tax in Percent: Net Tax
	$\bar{D}$	$\bar{t}$	$\bar{t}_c$	$\bar{t} - \bar{t}_c$
Straight Line	3.33	2.02	0.48	1.54
Double Declining Balance	3.84	1.55	0.48	1.07
Sum of Years Digits	4.15	1.26	0.48	0.78

APPENDIX C-2

APPENDIX C-2

ENERGY ECONOMIC DATA BASE (EEDB)

CAPITAL COST UPDATE PROCEDURE

C2.1 INTRODUCTION

The Advanced Engineering Department of United Engineers & Constructors Inc. plans to continue to update the EEDB on a yearly basis through FY1980 as a minimum, and on a semi-basis when necessary, under their contract with DOE. Generally, capital cost drivers do not advance or retreat at rates that cause bottom line cost changes to accumulate to significant levels in periods less than one year. When such cost changes do occur, they are evaluated for their significance, and updates issued at intervals less than one year, if required.

Each plant model update consists of review and revision of its capital, fuel cycle and operating and maintenance costs in accordance with the EEDB update procedures. This appendix describes the capital cost update procedures only, since the fuel and O&M costs are included in the EEDB as developed. Updates of fuel and O&M costs, and the development of procedures for accomplishing them, are planned during FY79.

Capital cost updates are performed at two levels:

a. incorporation of cost changes caused by the passage of time (inflation) to the new EEDB effective date, and by changes in labor productivity

b. incorporation of cost changes caused by design changes initiated by advances in the state-of-the-art, modifications of industry practice, promulgation of regulations and proliferation of codes and standards

All plant models are revised at level "a" during each capital cost update, and models for which design changes are identified are concurrently revised at level "b". During any EEDB update, models may be deleted and new models added, depending on the evaluation requirements of DOE.

C2.2 EEDB CAPITAL COST UPDATE PROCEDURE

Capital cost updates are done in two parts. First the plant technical models are updated for necessary design changes. Then, the updated technical models are used to update the capital cost models for incorporation of cost changes.

C2.2.1 Preparation for Technical Model Update

The first step in the technical model update is the review of pertinent information sources, to identify the following for each plant model in the EEDB:

a. advances in the state-of-the-art

b. modifications of industry practices

c. new and revised regulations

d. new and revised codes and standards

Each of the four reviews is performed under the supervision of the EEDB Program Project Manager. Reviews of advances in the state-of-the-art and modifications of industry practices are performed with the assistance of the Lead Technical Engineer for each of the various plant models in the EEDB. Resource data for these reviews are drawn from currently active UE&C power plant projects. Reviews of regulations and codes and standards are performed with the assistance of the Manager of Licensing and the Senior Consultant on Codes and Standards. Resource data for these reviews are drawn from the UE&C document "A Compilation of Federal Regulations for the Design and Licensing of Power Plants Including Engineering Guidelines for Their Implementation," the American Nuclear Society (ANS) Nuclear Power Plant Standards Committee (NUPPSCO), the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PVC) and the Institute of Electrical and Electronics Engineers (IEEE) Nuclear Power Engineering Committee (NPEC).

The reviewers determine which technical models require design changes, and what the changes must consist of, to upgrade them to reflect current technology. Once this is done, technical models are revised where required by the Lead Technical Engineers with the assistance of the Structural, Nuclear, Mechanical, Chemical, Electrical, Instrumentation and Control, Heating, Ventilating and Air Conditioning, and Piping Design Engineers.

C2.2.2 <u>Technical Model Updates</u>

Following the above preparatory steps, the Technical Model updates are performed in the following sequential steps:

a. Lead Technical Engineers, under the supervision of the EEDB Program Project Manager, identify design changes necessary in the Base Technical Models to reflect current design practices and/or to comply with current regulatory requirements, based upon the reviews described above.

b. Design Engineers, under the supervision of the Lead Technical Engineers, then modify the existing conceptual design, the heat balance diagram, plant layout drawings, equipment arrangement drawings, block flow diagrams, electrical diagrams and mini-specifications of the Base Technical Models.

c. Design Engineers, under the supervision of the Lead Technical Engineers and coordinated by the EEDB Program Project Manager, prepare necessary revisions to the existing PEGASUS mini-specifications, equipment and commodity quantities and necessary additions or deletions of complete accounts of the Base Technical Models.

C2.2.3 <u>Ground-Rules for Capital Cost Model Update</u>

Whether or not technical model revisions are required, the major update effort is to develop new commodity and equipment costs and labor manhours for each of the multitude of accounts in all models. The objective is to have the capability to provide an accurate, substantive, detailed cost estimate in a very short time frame.

Tables C2-1 and C2-2 tabulate installed costs for major groups of plant commodities and equipment and the relation of these costs to total direct plant costs for the PWR (1139 MWe Pressurized Water Reactor NPGS) and the HS8 (794 MWe High Sulfur Coal-Fired FPGS) Base Data Studies listed in Table 1-3. Component costs are grouped in accordance with the method by which costs are developed by PEGASUS. Computer Costed Items, such as cubic yards of concrete and tons of steel, are obtained from published national and/or company indices that are available for direct input into computer data files. Quotation Costed Items are obtained from estimating quotations submitted by vendors and are stored in data files in the computer. Handbook Costed Items are developed from manufacturers' catalogs, apparatus price handbooks or informal sales office estimates and stored in data files in the computer. Generally, costs are not taken from actual purchase order data to preclude the random variations of the marketplace from impacting estimates used in comparing alternatives over long periods of time.

Tables C2-1 and C2-2 reveal that only six of the total items listed for the PWR and HS8 Base Data models comprise 76.4 and 70.0 percent of their total direct plant costs respectively. Of these six, two are automatically costed by the computer from data files of national or company indices. These six items are as follows:

a. Structural Commodities

b. Piping and Ductwork

c. Nuclear Steam Supply

d. Turbine-Generator

e. Electric Plant

f. Instrumentation and Control

Therefore, in order to accomplish the stated objective, the following ground-rules are established for making cost changes:

a. New components, or those subject to technical change, other than Computer Costed Items, are recosted as Quotation Costed Items or as Handbook Costed Items, as described above.

b. Components not subject to technical change, other than Computer Costed Items, Nuclear Steam Supply or Boiler, Turbine-Generator, Electric Plant and Instrumentation and Control, are escalated per the update ground-rules.

c. New manufacturers estimating quotations are obtained for the Nuclear Steam Supply or Boiler and Turbine-Generator whether or not these items are subject to technical change.

d. The Electric Plant and Instrumentation and Control are recosted from manufacturers' handbooks, catalogs or informal estimates, as required, whether or not these items are subject to technical change.

e. The material and labor rates in the computer data files are updated from national and/or company indices.

During the update, items which are escalated only are spot-checked to determine if the escalated cost deviates unacceptably from an estimating quotation cost. Where such deviations are detected, new estimated costs are substituted for the escalated costs.

C2.2.4 Capital Cost Model Update (Direct Costs)

Following the above ground-rules, the Capital Cost model updates of direct costs are made as follows, based on either the existing, updated or new technical model:

a. Design Engineers and Cost Estimating Engineers, under the supervision of the Lead Technical Engineers and the coordination of the EEDB Program Project Manager, update:

- the PEGASUS unit cost data files for Computer Costed Items from published national and company indices;
- escalation data, as required;

- o unit cost data for Quotation Costed Items, as required;
- o unit cost data for Handbook Costed Items, as required.

b. Cost Estimating Engineers, under the supervision of the Lead Technical Engineers and the coordination of the EEDB Program Project Manager, update the unit field labor manhours, and the unit field material cost based on published national indices and UE&C project experience.

c. Cost Estimating Engineers, under the supervision of the EEDB Program Project Manager, update:

- o the PEGASUS data files for craft labor hours and account crew mixes to establish the new composite labor rates;
- o the auxiliary sort code for each account for applying unit pricing and escalation and for obtaining commodity sort printouts.

d. Computer Technicians make a preliminary run of the PEGASUS/CONCICE program to provide data for compiling the indirect costs.

C2.2.5 Capital Cost Model Update (Indirect Costs)

Capital Cost model updates of indirect costs are made in one step based on the preliminary PEGASUS/CONCICE output.

a. Cost Estimating Engineers and the Engineering Economist, under the supervision of the EEDB Program Project Manager, prepare the inputs for the indirect cost accounts from proprietary relationships established from UE&C nuclear and fossil plant engineering and construction project experience.

C2.2.6 Updated Technical and Capital Cost Model Data

Following the sequences described above, the computer technicians run the full PEGASUS/CONCICE program for each model in the data base and receive:

a. PEGASUS Equipment List printout which establishes the details of the new or updated Technical Model;

b. CONCICE Capital Cost (Direct plus Indirect) printout which establishes the new or updated Total Base Costs for the Capital Cost Model;

c. CONCICE Commodity List printout which establishes the new or updated lists of commodities and equipment for the new or updated Technical Model.

Effective Date - 7/1/76
Sheet 1 of 2

TABLE C2-1

ENERGY ECONOMIC DATA BASE

RELATION OF INSTALLED COMPONENT COST TO TOTAL DIRECT PLANT COST

	PWR	
	Cost $\$(10^6)$	% of Total Plant Cost
1. COMPUTER COSTED ITEMS		
a. Structural Commodities	88.5	21.0
b. Piping and Ductwork	61.0	14.5
c. Lighting and Service Power	2.8	0.7
d. Land Cost	2.0	0.5
Subtotal	154.3	36.7
2. QUOTATION COSTED ITEMS		
a. Nuclear Steam Supply	65.0	15.5
b. Turbine-Generator	56.0	13.3
c. Cooling Towers	12.6	3.0
d. Containment Liner	10.5	2.5
e. Condensers	7.4	1.8
f. Diesel-Generator Units	4.0	1.0
g. Circulating Water Pumps	2.7	0.6
h. Feedwater Heaters	2.7	0.6
i. Radwaste Evaporators	2.6	0.6
j. Large Cranes	2.3	0.5
k. Condensate Polishing System	2.1	0.5
l. Boiler Feed Pumps and Turbines	1.6	0.4
m. Makeup Water Pretreatment System	1.5	0.4
n. Volume Reduction System	1.2	0.3
o. Water Treatment System	0.9	0.2
p. Hydrogen Recombiners (Containment)	0.8	0.2
q. Plant Closed Cooling Water Heat Exchangers	0.6	0.1
r. Hydrogen Recombiners (Radwaste)	0.5	0.1
s. Solid Radwaste System	0.5	0.1
Subtotal	175.5	41.7

TABLE C2-1

ENERGY ECONOMIC DATA BASE

RELATION OF INSTALLED COMPONENT COST TO TOTAL DIRECT PLANT COST

		PWR	
		Cost (10^6)	% of Total Plant Cost
3.	HANDBOOK COSTED ITEMS		
a.	Wire and Cable	13.5	3.2
b.	Electrical (except Wire and Cable Raceways)	13.8	3.3
c.	Instrumentation and Control	11.3	2.7
d.	Valves	10.6	2.5
e.	Raceways	8.1	1.9
f.	HVAC	5.4	1.3
g.	Pumps	4.3	1.0
h.	Insulation (Thermal)	4.1	1.0
i.	Miscellaneous Reactor Items	4.0	1.0
j.	Tanks	3.8	0.9
k.	Nuclear Fuel Storage Tools	2.3	0.5
l.	Pipe Whip Restraints	1.7	0.4
m.	Communication Equipment	1.4	0.3
n.	Suspense Items	1.2	0.3
o.	Heat Exchangers	1.1	0.3
p.	Water Treatment Equipment	1.0	0.2
q.	Miscellaneous Structures	0.9	0.2
r.	Air Compressors	0.8	0.2
s.	Auxiliary Boilers	0.6	0.1
t.	Fire Protection System	0.3	0.1
u.	Miscellaneous	0.9	0.2
	Subtotal	91.1	21.6
	TOTAL	420.9	100.0

TABLE C2-2

ENERGY ECONOMIC DATA BASE

RELATION OF INSTALLED COMPONENT COST TO TOTAL DIRECT PLANT COST

	HS8	
	Cost $\$(10^6)$	% of Total Plant Cost
1. COMPUTER COSTED ITEMS		
a. Structural Commodities	48.1	17.5
b. Piping and Ductwork	31.7	11.5
c. Land Cost	2.0	0.7
d. Lighting and Service Power	1.4	0.5
Subtotal	83.2	30.2
2. QUOTATION COSTED ITEMS		
a. Boiler	49.4	18.0
b. Turbine-Generator	29.5	10.7
c. SO_2 Scrubbers	9.5	3.5
d. Coal Handling Equipment	8.5	3.1
e. Precipitators	8.3	3.0
f. Cooling Towers	6.2	2.3
g. Condensers	5.9	2.1
h. Ash Handling	4.9	1.8
i. Boiler Feed Pumps and Turbines	3.1	1.1
j. Feedwater Heaters	2.7	1.0
k. Circulating Water Pumps	1.5	0.6
l. SO_2 Booster Fan	1.4	0.5
m. Condensate Polishing System	1.2	0.4
n. Makeup Water Pretreatment System	1.1	0.4
o. Lime Handling System	0.8	0.3
p. Water Treatment System	0.7	0.3
q. Diesel Locomotives	0.4	0.1
r. Large Cranes	0.4	0.1
s. Diesel-Generator Units	0.1	*
Subtotal	135.6	49.3

*Negligible

TABLE C2-2

ENERGY ECONOMIC DATA BASE

RELATION OF INSTALLED COMPONENT COST TO TOTAL DIRECT PLANT COST

	HS8	
	Cost (10^6)	% of Total Plant Cost
3. HANDBOOK COSTED ITEMS		
a. Electrical (except Wire and Cable Raceways)	14.9	5.4
b. Wire and Cable	6.7	2.4
c. Raceways	7.3	2.7
d. Instrumentation and Control	5.0	1.8
e. Insulation (Thermal)	4.1	1.5
f. Tanks	2.7	1.0
g. Valves	2.6	1.0
h. Pumps	2.0	0.7
i. Miscellaneous Equipment	2.0	0.7
j. HVAC	1.7	0.6
k. Miscellaneous Structures	1.3	0.5
l. Air Compressors	1.0	0.4
m. Suspense Items	0.9	0.3
n. Auxiliary Boilers	0.8	0.3
o. Miscellaneous Drains	0.7	0.3
p. Heat Exchangers	0.6	0.2
q. Communication Equipment	0.6	0.2
r. Fire Protection System	0.2	0.1
s. Miscellaneous Fans	0.2	0.1
t. Miscellaneous	0.9	0.3
Subtotal	56.2	20.5
TOTAL	275.0	100.0

APPENDIX D-1

CE-FBR-78-532 October 23, 1978

NSSS CAPITAL COSTS FOR A MATURE LMFBR INDUSTRY

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Acknowledgements

This report was prepared under the valuable guidance of Dr. C. L. Storrs and Mr. R. C. Noyes. Major contributions to this study were made by Messrs. R. J. Bergeron, E. R. D'Ammadio, D. D. DeFur, C. F. G. Dupen, J. S. Greacen, M. A. Marroni, C. H. Meijer, P. O'Brien and K. E. Shotwell.

CONTENTS

CONTENTS (Cont'd)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

SECTION 1

SUMMARY

1.1 INTRODUCTION

The conceptual design of a commercial LMFBR (Target Plant) and its NSSS capital cost have been developed in support of the United Engineers and Constructors Contract EN-78-C-02-4954 with the Department of Energy. The objective of this work is to provide the Department of Energy/Office of Program Planning and Analysis - Nuclear Energy Programs with periodic updates of technical, capital cost, fuel cycle cost, and operating and maintenance cost information. This effort supports Task 3B of the UE&C's Phase I Energy Economic Data Base (EEDB) Program.

Past estimates of LMFBR capital costs have generally predicted that these costs would be higher than those of a comparably sized LWR, primarily due to the more demanding technology associated with higher temperatures and the large number of engineered systems. The LMFBR, because of its low fuel cycle costs, can tolerate a capital cost premium relative to thermal reactors. The key issues, therefore, are: the allowable LMFBR cost premium, and the steps necessary to reduce the capital cost below the projected allowable cost premium for a safe and reliable plant.

Within the scope of the economic feasibility of a safe and reliable plant, the primary objectives of this study are as follows:

- Develop the capital cost estimate of the Target Plant NSSS.
- Identify areas where major cost savings could be implemented without compromising the safety and reliability of the plant.
- Establish a cost basis for further optimization of the plant.

Considerable C-E effort has been devoted to the design and development of a loop-type commercial LMFBR (Target Plant). The four loop, 3800 MWT (1390 MWe) Target Plant has been designed with reasonable extrapolation of CRBRP components and permits direct cost and performance comparison with the C-E System 80. The four-loop aspect of the plant also permits a scale down to three loops (1040 MWe) with identical component sizes and piping layout. A summary of the principal NSSS parameters for the Target Plant is given in Table 1.1.

The reactor vessel for the Target Plant is 27.0 ft. inside diameter and 49.0 ft. high, and is slightly bigger than the CRBRP vessel. Three rotating plugs in the reactor vessel head facilitate annual through-the-head refueling. Each of the four heat transport loops consists of a primary loop circulating radioactive sodium from the Reactor Vessel to an intermediate heat exchanger (IHX), and an intermediate sodium loop circulating non-radioactive sodium from IHX to the steam generators.

Each of the Primary Heat Transport System (PHTS) loops is rated at 950 Mwt and consists of a centrifugal variable-speed pump in the hot leg, an IHX, isolation valves and interconnecting piping. Each of the PHTS loops is located in an inerted cell within a 184.0 ft. inside diameter, Reactor Containment Building.

Each of the Intermediate Heat Transport System (IHTS) loops consists of a cold leg centrifugal pump, an expansion tank, two once-through steam generators rated at 475 Mwt each, isolation valves, and interconnecting piping. The water/steam flowing on the tube side of the steam generators is heated by the IHTS sodium flowing on the shell side of the steam generators.

There are two independent and redundant Auxiliary Heat Transport System (AHTS) loops rated at 57 Mwt each which provide for emergency decay heat removal from the reactor. Each of the AHTS loops transfers heat from the reactor vessel to a non-radioactive NaK loop via an Auxiliary Heat Exchanger. The heated NaK is circulated through air-blast heat exchangers for heat dissipation to the air. The primary legs of the AHTS, classified as Safety Class I, are

TABLE 1.1

SUMMARY OF PRINCIPAL NSSS PARAMETERS

Plant Rating	3800 MWt
Electrical Rating (net)	1390 MWe
Steam Temperature	850°F
Steam Pressure	2200 psig
Reactor Outlet Temperature	950°F
Reactor Inlet Temperature	650°F
Primary Sodium Flow/Loop	35.8×10^6 lbs/hr
IHTS Sodium IHX Outlet Temperature	910°F
IHTS Sodium IHX Inlet Temperature	590°F
IHTS Sodium Flow/Loop	33.4×10^6 lbs/hr

located within the Reactor Containment Building. The secondary legs, classified as Safety Class II, are located within Seismic Category I structures adjacent to the RCB.

The other systems included in the NSSS and described in Section 2 are:

Fuel Handling and Storage System
Na/H_2O Reaction Protection System
Inert Gas System
Liquid Metal Storage and Purification System
Equipment Heating and Temperature Control System
Instrumentation and Control System

The unique features in the plant which are believed to be cost-effective are as follows:

- In-vessel check valves to minimize loss of coolant and to ensure core cooling on loss of one loop. Need for guard vessels for components is diminished.

- Siphon - breaker lines to minimize loss of coolant. In conjunction with the in-vessel check valves, these lines ensure that the sodium level in the vessel remains above the minimum safe level for decay heat removal. No guard vessels for pumps and IHX's are required.

- An advanced design, redundant secondary Shutdown System ensures automatic reactor shutdown upon loss of flow. It's independence from occurences outside the reactor boundary eliminates common mode failure possibilities. As a result the reactor system, the heat transport systems and the Reactor Containment Building are not dependent upon CDA considerations.

- Once-through steam generators (Benson Cycle) eliminate miscellaneous components needed for other cycles. The steam generator design is simplified and its duty cycle is moderated.

- Provision of two independent and redundant AHTS, directly off the reactor vessel, eliminates the need for emergency decay heat removal through the IHTS. Hence, the IHTS and steam generator system (SGS) train outside the RCB may be designed to commercial standards without compromizing the plant and public safety. The IHTS and SGS are therefore classified as non-nuclear safety systems; and the steam generator buildings are non-seismic Category I structures and are designed to the uniform building code.

- The steam generator buildings are positioned symmetrically around the Reactor Containment Building in a satellite arrangement. This arrangement results in identical (or mirror image) layouts of the piping and components, with substantial reduction in the piping runs and the number of expansion loops. Piping analysis conducted for one loop is applicable to all loops and fabrication, erection and support systems are identical for all loops.

- The Cavity Filler System, consisting of replaceable filler blocks, is designed for ease of installation and inservice inspection of the reactor vessel. The material cost savings for such a system as compared to a guard vessel may be marginal, but access for the installation of the reactor vessel and the connected piping is improved substantially. This leads to improvements in field erection costs and schedule.

A summary of the Target Plant parameters in comparison with PLBR is given in Table 1.2.

1.2 GROUND RULES

The major ground rules used in this study are as follows:

- The reactor plant design is based on the Target Plant described in Section 2.0, key plant parameters are shown in Table 1.1.

TABLE 1.2

COMPARISON OF TECHNICAL PLANT PARAMETERS - TARGET PLANT VS. PLBR'S

Parameter	GE Phase II	W Phase II	AI (Loop) Phase II	AI (Pool) Phase I	C-E Target Plant
A. General					
1. Thermal power, MWt	2890	2550	2600	2600	3800
2. Electric power, MWe (gross)	998	990	1000		1460
3. Electric power, MWe (net)/Eff.%	914/31.6	925/36.3	944/36.3	900/34.6	1390/36.6
4. Primary heat transport system configuration	Piped	Piped	Piped	Pool	Piped
5. Steam conditions, turbine inlet, full power					
a. Pressure, psig	1015	2285	2200	2475	2200
b. Temperature, °F	546	855	850	905	850
6. Feedwater temperature, °F	420	380	470	470	470
7. Feedwater Flow, 10^6 lb/hr	13.1708	9.0345	9.7026	---	14.24
8. Turbine Steam Flow, 10^6 lb/hr	11.9183	8.0604	9.7026	---	14.24
B. Reactor					
1. Core lattice configuration					
a. Geometry	Hexagonal	Hexagonal	Hexagonal	Hexagonal	Hexagonal
b. Total number of lattice positions	799 (includes 270 for shielding)	769 (includes 258 for shielding)	703 (includes 120 for reflectors)	547 (includes 78 for reflectors)	973 (includes 198 for reflectors)

N/A indicates Parameter Not Applicable.
--- indicates Missing Data

TABLE 1.2 (Continued)

Parameter	GE Phase II	W Phase II	AI (Loop) Phase II	AI (Pool) Phase I	C-E Target Plant
C. Reactor Vessel (piped) or Primary Tank (pool)					
1. Dimensions					
a. Inside diameter, in.	528	500.5	592	696 OD	324
b. Height, in.	714	647.5	687	642	589
c. Wall thickness, in.	---	1.75 to 5	3 (max)	2-7/8(max.)	2.5 to 3.5(max)
2. Material	304 SS	304 SS	316 SS	316 SS and 304 SS	304 SS
D. Heat Transport System					
1. No. of coolant loops (primary/intermediate)	4/4	3/3	3/3	3/3	4/4
2. Coolant flow, 10^6 lb/hr					
a. Primary (total/per loop)	115/28.8	95.3/31.8	104/34.7	110.7/36.9	143.2/35.8
b. Intermediate (total/per loop)	122/30.5	94.18/31.4	97.4/32.5	108.9/36.3	133.6/33.4
3. Coolant temperature, °F					
a. Primary (hot leg/cold leg)	875/595	947.5/647.5	930/650	980/715	950/650
b. Intermediate (hot leg/cold leg)	815/550	900/595	900/600	940/670	910/590
4. Pumps					
a. No. of pumps per loop (primary/intermediate)	1/1	1/1	1/1	1/1	1/1
b. Pump capacity, 10000 gpm (primary/intermediate)	68.4/71.6	82.0/82.1	83.2/74.0	93.3/80.0	86.2/76.7
c. Pump location	Hot Leg/ Hot Leg	Hot Leg/ Cold Leg	Hot Leg/ Cold Leg	Cold Leg/ Cold Leg	Hot Leg/ Cold Leg

TABLE 1.2 (Continued)

Parameter	GE Phase II	W Phase II	AI (Loop) Phase II	AI (Pool) Phase I	C-E Target Plant
D. 5. Intermediate heat exchangers					
a. Configuration	straight tube counterflow	straight tube counterflow	straight tube counterflow	straight tube counterflow	straight tube counterflow
b. Primary coolant location	shell side	shell side	shell side	shell side	shell side
c. No. of modules per primary loop/ total sq. ft.	$1/2.05 \times 10^5$	$1/{\sim}1.80\times10^5$	$1/2.17 \times 10^5$	$2/2.129\times10^5$	$1/2.264 \times 10^5$
6. Steam generators					
a. Configuration	straight double-wall tubes with recirculation (6 to 1)	straight double-wall tubes with continuous blowdown (4-3/4%)	Once through hockey stick single-wall tubes	Once through hockey	Once through straight tube
b. Intermediate coolant location	shell side	shell side	shell side	shell side	shell side
c. Tube material					
(1) Evaporator	2-1/4 Cr 1 Mo	---	combined 2-1/4 Cr 1 Mo	combined 2-1/4 Cr 1Mo	combined 2-1/4 Cr 1 Mo
(2) Superheater	N/A	---			
(3) Reheater	N/A	N/A	N/A	N/A	N/A
d. No. of modules per intermediate loop					
(1) Evaporator/total sq. ft.	$1/2.49 \times 10^5$	1/2.04	$3/2.49 \times 10^5$	$3/1.85 \times 10^5$	$2/4.01 \times 10^5$
(2) Drum	1	1	0	0	0
(3) Superheater/total sq. ft.	N/A	1/---	In Item (1)	In Item (1)	In Item (1)
(4) Reheater/total sq. ft.	N/A	N/A	N/A	N/A	N/A
7. Coolant system piping and valving					
a. Means of accommodating deflections	Expansion loops	Bellows & expansion loops	Bellows & expansion loops	Bellows & expansion loops	Expansion loops

TABLE 1.2 (Continued)

Parameter	GE Phase II	W Phase II	AI (Loop) Phase II	AI (Pool) Phase I	C-E Target Plant
D. 7. b. Pipe outside diameter, inc.					
(1) Primary (hot leg/cold leg)	36/36	36/36	36/2-28	26/---	44/36 & 36
(2) Intermediate (hot leg/cold leg)	36/36	36/36	36/36	36/36	36/36
c. Materials					
(1) Primary (hot legs/cold leg)	304 SS/304 SS	316 SS/304 SS	316 SS/304 SS	316 SS/304SS	316 SS/304 SS
(2) Intermediate (hot leg/cold leg)	304 SS/304 SS	316 SS/2-1/4 Cr 1 mo (Ex. Cont.) 304 SS (In. Cont.)	304 SS/304 SS	304 SS	304 SS
d. Primary coolant valves (hot leg stop/cold leg stop/check)	No/No/Yes	No/No/Yes	No/No/Yes	No/Yes/No	Yes/Yes/Yes
e. Intermediate coolant valves (steam generator module isolation)	No	No	Yes	---	Yes
E. Turbine-Generator					
1. Type	Tandem Compound, 4 Flow, Reheat	Tandem Compound, 6 Flow, Reheat	Tandem Compound, 4 Flow,	Tandem Compound 6 Flow, Reheat	
2. Speed, r/min	1800	3600	1800	3600	
F. Auxiliary Systems					
1. Coolant purification method	Cold Trap	Cold Trap	Cold Trap	Cold Trap	Cold Trap
2. Inert gas systems					
a. Gas & Pressure					
(1) Primary	Ar - 10" WG	Ar - 0 psig (Rx Vessel)	He - 10" WG	He - 10" WG	Ar
(2) Intermediate	Ar - 130 psia	Ar - 140 psig	Ar - ---	He - ---	Ar
(3) Equipment cells	N_2- ---	N_2- ---	N_2- ---	N_2- ---	N_2
b. Inert cell atmosphere coolant	N_2- ---	N_2- ---	N_2- ---	N_2- ---	N_2

TABLE 1.2 (Continued)

Parameter	GE Phase II	W Phase II	AI (Loop) Phase II	AI (Pool) Phase I	C-E Target Plant
G. <u>Shielding, Containment, Safety Features</u>					
1. Shielding material					
a. In-vessel	304 SS	316 SS	Steel	Steel	Steel/graphite
b. Ex-vessel	Concrete	Concrete	Concrete	Concrete	Concrete
2. Containment					
a. Design basis					
(1) Tornado wind loading, mph	360	360	360	360	360
(2) Seismic acceleration (horizontal/vertical) SSE	0.30/---	---/---	0.3/R.G.1.60 0.4 for NSSS	0.3/R.G.1.60 0.4 for NSSS	
(3) HCDA energy release, MW-sec					
b. Configuration	Rectangular	Domed Cylinder	Domed Cylinder	Domed Cylinder	Domed Cylinder
c. Dimensions, ft.	222/210/184	228/166	220/185 ID	183/118 ID	184 ID
d. Material	Reinforced Concrete	Reinforced Concrete	Reinforced Concrete and Steel	Reinforced Concrete	Reinforced Concrete
e. Gross volume, 10^6 cu ft	8.58	4.86	5.52	1.855	
f. Design pressure, psig	3.0	10	3	3	
g. Allowable leak rate (vol. %/day)	0.17 to confinement	0.2% (Primary cont.)	0.001% (Cont./Conf.)	---	
3. Principal engineered safety features	-Removal of decay heat by 4 independent cooling loops	-Removal of decay heat by 3 independent redundant cooling loops or auxiliary feedwater systems	-Removal of decay heat by 2 diverse cooling systems	-Removal of decay heat by two diverse cooling systems	-Removal of decay heat by 2 redundant, independent aux. heat transfer systems

TABLE 1.2 (Continued)

	Parameter	GE Phase II	W Phase II	AI (Loop) Phase II	AI (Pool) Phase I	C-E Target Plant
G.	3. Principal engineered safety features (Continued)	-Containment isolation on increased radiation -Elevated piping guard vessel concept to limit effect of pipe rupture -2 redundant 100% capacity gas-engine generators for decay heat removal	-Containment isolation -3 100% capacity diesel generators	-Containment isolation on increased radiation or reactor trip -Elevated piping guard vessel concept to limit effect of pipe rupture - 3 diesel generators	-Containment isolation on increased radiation -Primary sodium restricted to reactor vessel -2 redundant full capacity diesel generators	-Containment isolation; check valves in RV, and Siphon breaker lines to limit effects of pipe rupture -2 redundant 100 % capacity diesel generators
H.	Protection and Control					
	1. Principal reactor protection criterion	2 diverse independent reactor shutdown systems	2 diverse independent reactor shutdown systems	3 diverse independent reactor shutdown systems	3 diverse independent reactor shutdown systems	2 diverse independent shutdown systems
	2. Reactor protection method	---	---	---	---	---
	3. Reactor power control basis	Nominally constant steam pressure, variable steam flow, constant steam temperature	Nominally constant steam pressure, variable steam temperature and reactor outlet temperature	Nominally constant steam pressure, variable steam flow, constant steam temperatures	Nominally constant steam pressure, variable steam flow, constant steam temperatures	Constant steam pressure and temperature, variable steam flow

TABLE 1.2 (Continued)

		Parameter	GE Phase II	W Phase II	AI (Loop) Phase II	AI (Pool) Phase I	C-E Target Plant
H.	4.	Reactor flow control basis	Nominally constant power to flow ratio	Nominally constant coolant ΔT.	Nominally constant outlet temperature	Nominally constant outlet temperature	Nominally constant outlet temperature
I.	Refueling						
	1.	Operations within reactor vessel or primary tank	Underhead transfer of fuel to transfer bucket	Underhead transfer of fuel to transfer bucket	Underhead transfer of fuel to transfer bucket	Underhead transfer of fuel to transfer bucket	Underhead transfer of fuel to transfer pot
	2.	Removed from reactor vessel or primary tank	via fixed transfer tube to fuel storage tank in containment	via fixed transfer tube to excontainment fuel storage tank	via fixed transfer tube to excontainment fuel storage tank	via fixed transfer tube to excontainment fuel storage tank	via fixed transfer tube to in-containment fuel storage tank
	3.	Spent fuel decay storage positions	727 in fuel storage tank (1.37 x core)	704 (1.38 x core)	980 (1.39 x core) includes reflectors	707 (1.29 x core) includes reflectors	298 core assemblies

- Cost data is based on prices as of January 1978.

- The cost estimate is for a single unit fifth-of-a-kind plant.

- The cost estimate is developed in accordance with a modified version of the AEC Code of Accounts (USAEC Report NUS-531).

- Safety classification, seismic categories, and design codes for the components are given in the Equipment List (Section 6).

- Escalation and interest during construction are not included in the cost estimate.

- The plant has on-site reactor core storage capacity for 1/3 core.

- The plant is designed for 40-years life.

- The plant is base loaded with availability of better than 90% (including refueling downtime).

1.3 COST SUMMARY

The estimated total cost of the Target Plant NSSS is $267,574,000 (Table 1.3) subject to the exclusions noted in Table 1.4. The costs associated with engineering (design changes, modifications and development), erection and startup services are also shown in Table 1.3 under the item "engineering" which may be reallocated to indirect costs.

The estimated costs are based on F.O.B. vendor shop sell prices of the components listed in the equipment list (section 6). These costs include the component engineering, materials, fabrication and the company margin in January 1978 dollars. The costs do not include escalation, interest during construction, erection and field equipment, and labor.

TABLE 1.3

COST ESTIMATE SUMMARY

		COSTS (Thousands of Dollars)
220A.211	Reactor Vessels	31,881
220A.212	Reactor Vessel Internals	13,619
220A.213	Control Rod System	2,730
220A.221	Primary Heat Transport System	59,442
220A.222	Intermediate Heat Transport System	23,323
220A.23	Steam Generation System	48,499
220A.23	Safeguards System	9,431
220A.25	Fuel Handling and Storage System	29,902
220A.26	Other Equipment	29,378
220A.27	Instrumentation + Controls	19,369
	220A.2 NSSS Costs (Partial - Exclusions Noted in Table 1.4)	267,574
	Engineering	15,330

TABLE 1.4

EXCLUSIONS FOR COST ESTIMATES

220A.21122	Heating and Cooling Equipment (Reactor Vessel Head)
220A.21251	Core Assemblies
220A.21252	Blanket Assemblies
220A.21253	Reflector and Shield
220A.21254	Fuel Transfer Assemblies
220A.2216	Insulation (Primary Heat Transport System)
220A.2226	Insulation (Intermediate Heat Transport System)
220A.2236	Insulation (Steam Generation System)
220A.267	Auxiliaries Cooling Equipment
220A.268	Maintenance Equipment

The cost estimates for the major components of the Target Plant (Reactor vessel, IHX, steam generators) were developed by C-E using a cost basis similar to that used for C-E System 80 components. The cost estimates for the piping systems were derived from 1974 CRBRP cost estimates, adjusted to 1978 dollars.

The cost estimates for the reactor vessel internals and the reactor enclosure system have been developed using a cost basis similar to the C-E System 80 components.

The cost estimates for the primary and secondary pumps are based on prices developed by the Byron Jackson Co. for large sodium pumps.

The cost estimate for the fuel handling and storage system is generally based on similar components for C-E System 80 except for the EVST and the fuel handling machines which are based on CRBRP with some adjustments for a fifth-of-a-kind plant.

The cost estimates for the conventional components such as tanks, piping, valves, etc. of the auxiliary systems are based on similar components for C-E System 80. The cost estimates for the sodium components were developed through quotations from vendors.

In summary, the cost basis of C-E System 80 has been generally utilized for the Target Plant components except for the sodium components, for which approximate prices were obtained from various vendors.

1.4 COMPARISON

A comparison of the estimated costs of the major components of the Target Plant with those of the CRBRP and the PLBR is shown in Table 1.5. When the cost numbers are adjusted for the power differences, there seems to be good agreement between the PLBR and the Target Plant prices for the majority of the components, such as the reactor vessel, the vessel internals, the

TABLE 1.5

COMPARISON OF DIRECT CAPITAL COSTS

(in Millions of Dollars)

	CRBRP 975 MWt 1978	AI/B&R PLBR 2600 MWt 1977	GE/BECHTEL PLBR 2890 MWt 1977	CE/UE&C 3800 MWt 1978
NSSS COSTS				
REACTOR SYSTEM				
Reactor Vessel	34.88	18.62	29.30	25.92
Reactor Internals	15.24	11.94	(Incl.)	13.62
Total	50.12	30.56	29.30	39.54
HEAT TRANSPORT SYSTEM				
Primary Pumps	76.23	7.49	29.70	18.16
Intermediate Pumps		6.23	14.00	14.80
Primary Piping	6.37	13.11	12.29	13.05
Intermediate Piping	15.68	4.74	14.57	2.82
IHX's	39.00	17.11	26.40	21.45
Total HTS System	137.28	46.68	96.96	70.28
STEAM GENERATOR SYSTEM				
Evaporators	96.35	44.20	40.20	41.99
Superheaters		(Incl.)	20.50	(Incl.)
Recirculation Systems	1.50	-----	6.60	0
Total SG System	97.85	44.20	67.30	41.99
NSSS				
TOTAL COST (OF THE ABOVE)	285.25	123.44	193.56	151.81

primary pumps, the primary piping, and the IHX. Higher prices for the CRBRP components reflect on the first-of-a-kind nature of the plant, and may include substantial costs associated with research and development and shop retooling.

The secondary piping and associated components of the Target Plant are designed and fabricated to commercial standards and therefore cost less than those for PLBR. The steam generators, also designed to commercial standards, are straight tube once-through units (Benson cycle). Their lower costs are due to both simplicity of design and fabrication, and the smaller number of units as compared to the PLBR designs.

As compared to a PWR, the major cost increases are related to the physical requirements of the LMFBR design; including the requirement for intermediate loops in the coolant system, the addition of a sodium-water protection system for the steam generators, unique piping requirements for the high temperature sodium systems, and a large number of engineered systems.

The conceptual design of the Target Plant was developed using extrapolations of the available information from CRBRP and other LMFBR studies. For large components such as the reactor vessel, vessel internals, closure head, IHX, and the steam generators, the design evolved by extrapolation with limited effort devoted to their optimization. Due to the significant portion of the capital cost associated with these components, further optimization will result in some reduction in the capital cost of the Target Plant.

The cost estimates for the refueling system and the auxiliary systems have been conservatively developed based on extrapolation of the design of CRBRP and limited cost information available for sodium components. Further effort in simplifying this design and improvements in the cost estimates should lead to some reduction in NSSS costs. Similarly a cost reduction seems possible in the I&C costs with better definition of design and costs.

Several design changes have been proposed to reduce the capital cost of the LMFBR. Of those which could be implemented in the near term, the most promising are the following:

(1) Use of super-chrome ferritic steel for sodium components and piping instead of austenitic steel;

(2) Bellows joints instead of expansion loops to accommodate thermal expansion in the sodium piping;

(3) Three heat transfer loops instead of four.

Each of these concepts has an impact on the design, operation and licensability of the plant. By paying careful attention to these things it may be possible to reduce the capital cost significantly without compromising the safety and reliability of the plant.

SECTION 2

PLANT DESCRIPTION
(NUCLEAR STEAM SUPPLY SYSTEM)

2.1 INTRODUCTION

This section describes the C-E Target Plant design. The material presented in this section is organized to correspond to Account 22 of the uniform system of accounts (USAEC Report NUS-531) used for the detailed cost estimate. This format correlates the plant design description with the detailed cost estimate (Section 3) and the detailed equipment list (Section 6).

A summary description is provided in Section 2 for each major account. This is followed by detailed descriptions of major components for each system.

2.2 PLANT DESIGN CRITERIA

The major criteria for the Target Plant Cost Study have been addressed in Section 1.2. The plant is designed for a 40-year life. The thermal power of the plant is 3800 Mwt in accordance with the NRC upper limit and equal to the power of the C-E System 80. The plant is a loop design which permits extrapolation of the CRBRP arrangement for sodium systems. The reactor cover gas is argon. Safety classifications, seismic categories and design codes for the major components, as interpreted from NRC regulatory guides, are given in the Equipment List (Section 6).

2.3 PLANT DESIGN DESCRIPTION

The Target Plant reference design is a 3800 Mwt loop-type, sodium-cooled, fast-breeder reactor plant. The reactor vessel is large enough to accommodate heterogeneous or homogeneous core designs, oxide or carbide fuel, and thorium or uranium fertile assemblies. Connected to the reactor vessel are four primary heat transport loops, two auxiliary heat transport loops, the overflow and makeup sodium loop, and the argon cover gas loop. The principle parameters of the Target Plant are summarized in Table 2.1.

Each of the primary heat transport loops, rated at 950 MWt, transfers heat from the reactor to the Intermediate Heat Exchanger (IHX) where the heat is transferred to the intermediate heat transport system (IHTS). The IHTS consists of an IHTS pump, expansion tank, and associated piping and valves, and transfers the heat to the water and steam side (tube side) of the steam generators.

The reactor system, the Primary Heat Transport System (PHTS), a portion of the fuel handling system, and most of the radioactive auxiliary systems are located in the Reactor Containment Building. The Intermediate Heat Transport System (IHTS) and the Steam Generator System (SGS) are located in the Steam Generator building. The remaining fuel handling facilities and equipment and the Auxiliary Systems are located in the Reactor Service Building and the Auxiliary Buildings. The plant arrangement is shown in Figure 2.1. The system layout drawings are given in Section 5.

2.3.1 Reactor System

2.3.1.1 Reactor Vessel and Reactor Vessel Closure Head

The reactor vessel is placed centrally within the LMFBR NSSS. This vessel, with the closure head installed, provides the primary coolant boundary for the core and the core coolant fluid (molten sodium). The molten sodium, while serving as a coolant for the core, picks up heat and thus becomes the working heat transfer medium for the LMFBR System.

A major portion of the sodium flow enters the reactor vessel from each of the four primary loops through the high pressure inlet nozzles while the remaining portion enters through the low pressure inlet nozzles. The inflowing fluid is combined in the respective high and low pressure inlet

TABLE 2.1

SUMMARY OF PRINCIPAL PLANT PARAMETERS

Plant Thermal Rating	3800 MWt
Electrical Rating (net)	1390 MWe
Type	Loop, 4 Loops
Steam Temperature	850°F
Steam Pressure	2200 Psig
Feedwater Temperature	470°F
Primary Sodium Temperatures, Hot/Cold	950/650°F
Secondary Sodium Temperatures, Hot/Cold	910/590°F
Primary Sodium Flow Rate/Loop	35.8×10^6 lbm/hr
Secondary Sodium Flow Rate/Loop	33.4×10^6 lbm/hr
Primary Pump	Single-Stage Centrifugal, 86,200 gpm at 375 ft.
Secondary Pump	Single-Stage Centrifugal, 76,700 gpm at 300 ft.
Steam Generators	Once-through, straight-tube Two per loop 475 MWt each

plena and is passed upward through the core region of the reactor vessel where it is heated prior to exiting into the large outlet plenum above the core. (A description of the reactor internals is given in 2.3.1.2). The hot leg primary pumps supply the IHX's with heated sodium drawn from the outlet plenum through nozzles provided in the upper shell region of the vessel.

The reactor vessel closure head provides the required thermal and biological shielding, serves as a cover gas seal, and provides access for manipulating core elements, control rod, and other hardware which must be periodically removed and replaced, inserted and withdrawn, etc., as required to operate the reactor system.

As shown in Figure 2.2, the reactor vessel is a vertically oriented, top supported, cylindrical component with a lower eliptical head. Except for the uppermost shell course and the shell/flange transition, the vessel has a constant thickness of 2.50 inches. The uppermost shell course and shell/flange transition are 3.00 inches thick. The vessel wall is penetrated by 28 nozzles, the sizes and functions of which are as tabulated below:

Quantity	Outside Diameter	Function
4	36.00 inch	High Pressure Sodium Inlet
4	14.00 inch	Low Pressure Sodium Inlet
2	12.75 inch	Auxiliary Sodium Inlet
4	44.00 inch	Sodium Outlet
2	12.75 inch	Auxiliary Sodium Outlet
1	8.63 inch	Sodium Make-up
1	10.75 inch	Sodium Overflow
4	8.63 inch	Siphon Breaker
4	10.75 inch	Pump Overflow
1	4.50 inch	Cover Gas Inlet
1	4.50 inch	Cover Gas Outlet

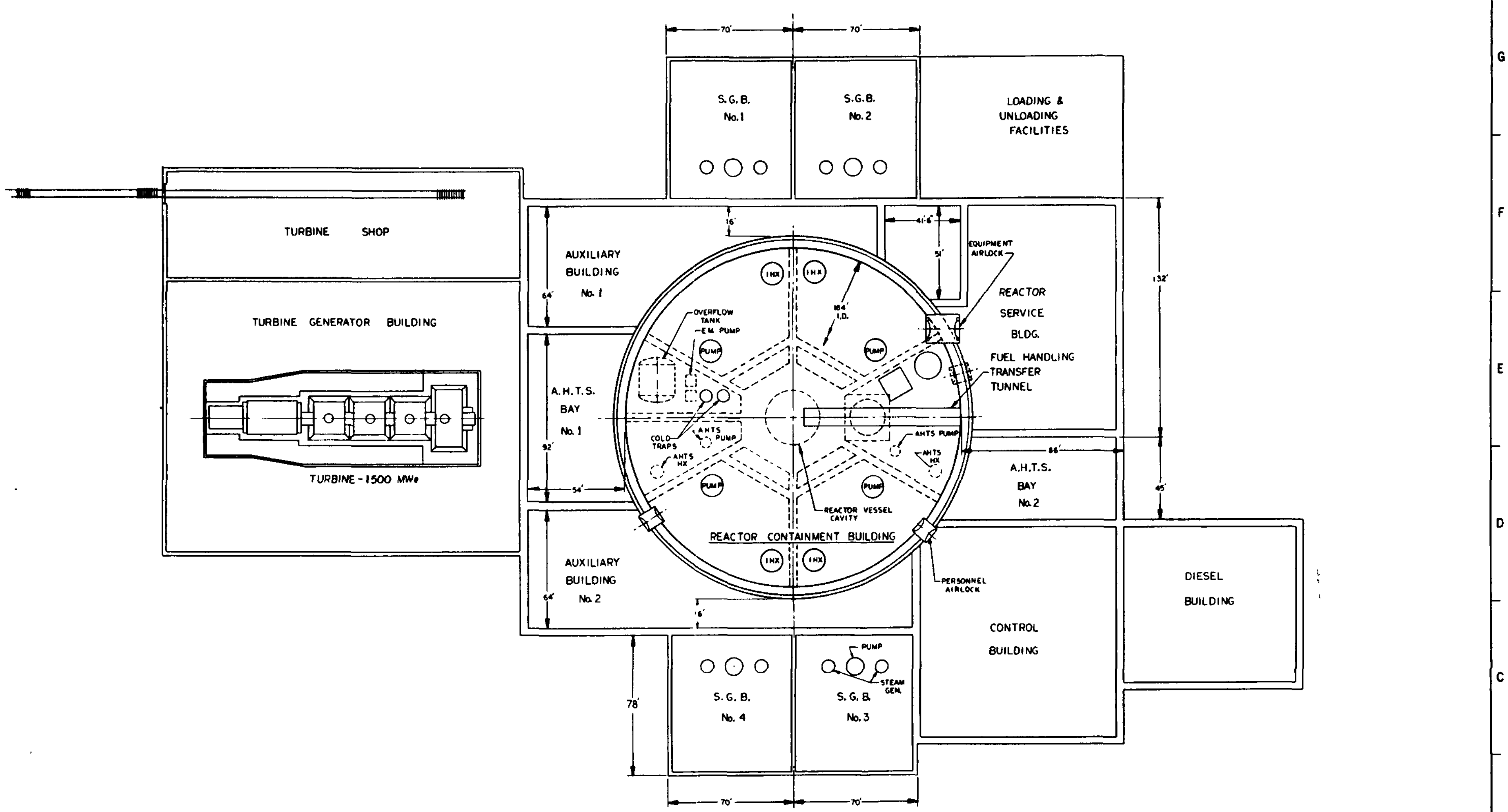


FIGURE 2.1
TARGET PLANT LAYOUT

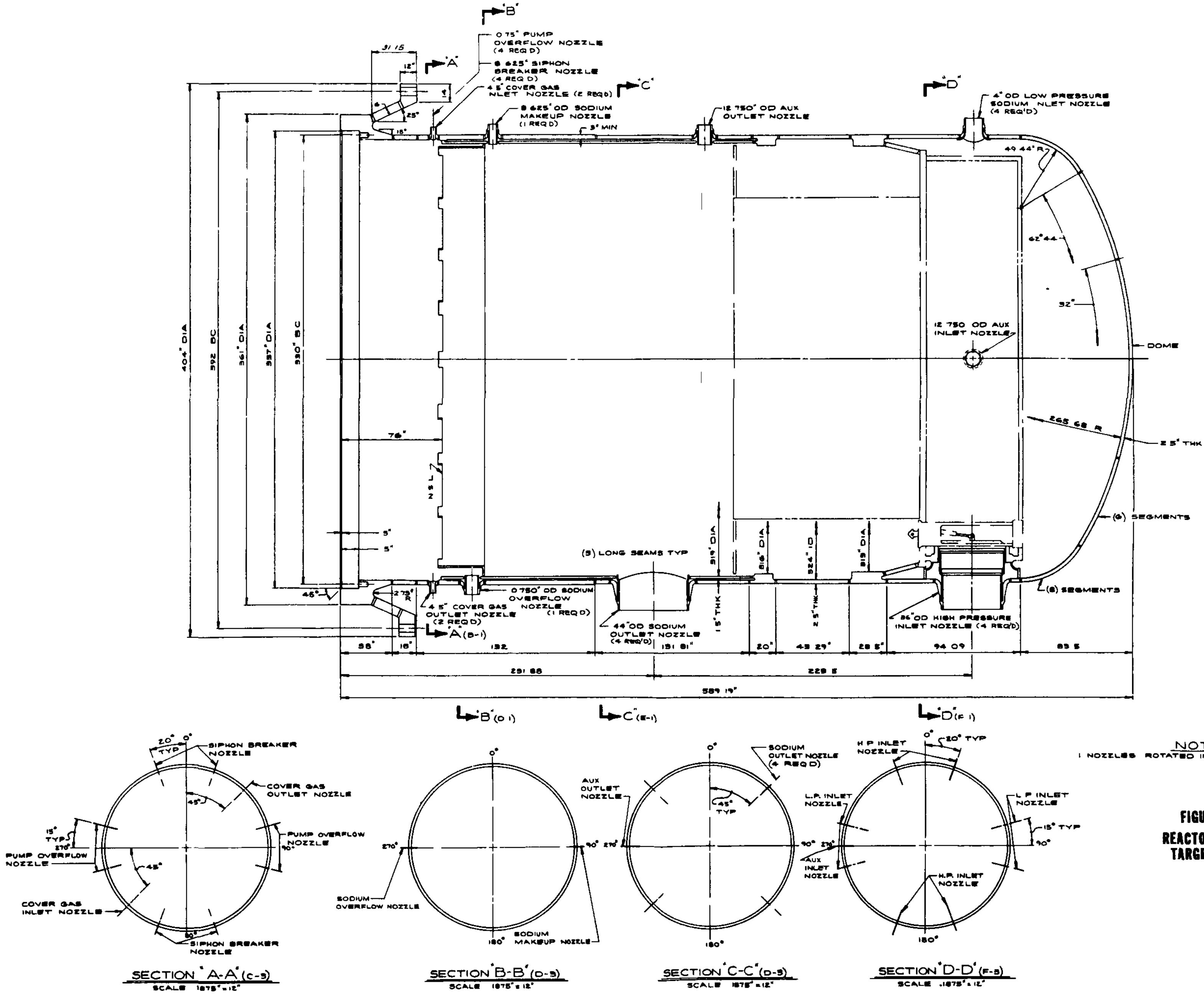


FIGURE 2.2
REACTOR VESSEL
TARGET PLANT

A thermal liner is provided on the upper region of the shell. This liner, which is 1.5 inches thick, extends upward from a point just below the top of the core barrel to an elevation just above the normal operating sodium/cover gas interface. This liner is concentric with the inside diameter of the vessel and provides a stagnant sodium-filled annulus to soften thermal transients and to reduce the radial gradient through the wall. The liner is extended into the nozzles by slip joint designs which allow for relative motions caused by temperature differentials.

The upper flange of the vessel is machined internally to accept and interface with the closure head and also serves as an integral part of the inverted conical skirt vessel support system. A short transition shell course, 18 inches in height, is provided to accommodate the differential thermal expansion between the uppermost shell course of the vessel and the cooler support flange.

There are two other rings found within the reactor vessel weldment. These are located at the lower extremity of the thermal liner and at the core support elevation. (The reactor vessel/reactor internals interface is defined as being at the weld joint at the lower end of the core support cone. The core support, structure, core barrel, and other internals shown in phantom or omitted from the above referenced drawing are described in Section 2.3.1.2 of this report).

Maximum overall dimensions for the reactor vessel are found to be the outside diameter of the support skirt flange which is 33'-8"; the outside diameter of the upper and lower shell regions which are 27'-6" and 27'-5", respectively. The inside diameter of the vessel is 27'-0", and the overall length is 49'-1.19". The total dry weight of the vessel is approximately 463 tons.

All of the constituent parts of the reactor vessel are made from SA-240, Type 304, stainless steel except for the shell/flange transition course, which is SB-168, the flange, which is SA-508, Class 3, the support skirt and support skirt flange, which are SA-516, Grade 70, and the nozzle forgings, which are SA-182, F-304.

The vessel is designed and constructed to the requirements of Section III, Class 1 of the ASME Boiler and Pressure Vessel Code for Nuclear application, including Code Case 1592 for high temperature service. Design pressure and temperatures for the inlet and outlet plena are 165 psia/675°F and 40 psia/975°F, respectively.

As shown in Figure 2.3, the reactor vessel closure head is composed of four parts: a fixed outer ring (FOR) which is mechanically attached to the reactor vessel flange; a large rotating plug (LRP); an intermediate rotating plug (IRP); and, a small rotating plug (SRP). The four parts are similiar in cross section in that each has a 24.00 inch structural plate (uppermost material thickness), 28.50 inches of graphite blocks, a 4.00 inch lower structural plate, seven (7) 0.125 inch pieces of reflective insulation, and a 0.50 inch suppressor plate (suspended 23.25 inches below the reflective insulation). The graphite blocks are contained within canisters which are attached to the 24.00 inch structural plate.

There are 64 penetrations through the three rotating plugs of the closure head assembly. The following tabulation identifies the penetration types and quantities provided in each of the rotating plugs:

Penetration Type	Number in SRP	Number in IRP	Number in LRP	Number in FOR
Control rod drive and instrument tree housing	7	23	0	0
Instrument tree housing	6	25	0	0
In-vessel fuel handling machine	1	0	0	0
Ex-vessel fuel transfer port	0	0	0	1
Inlet check valve removal port	0	0	1	0

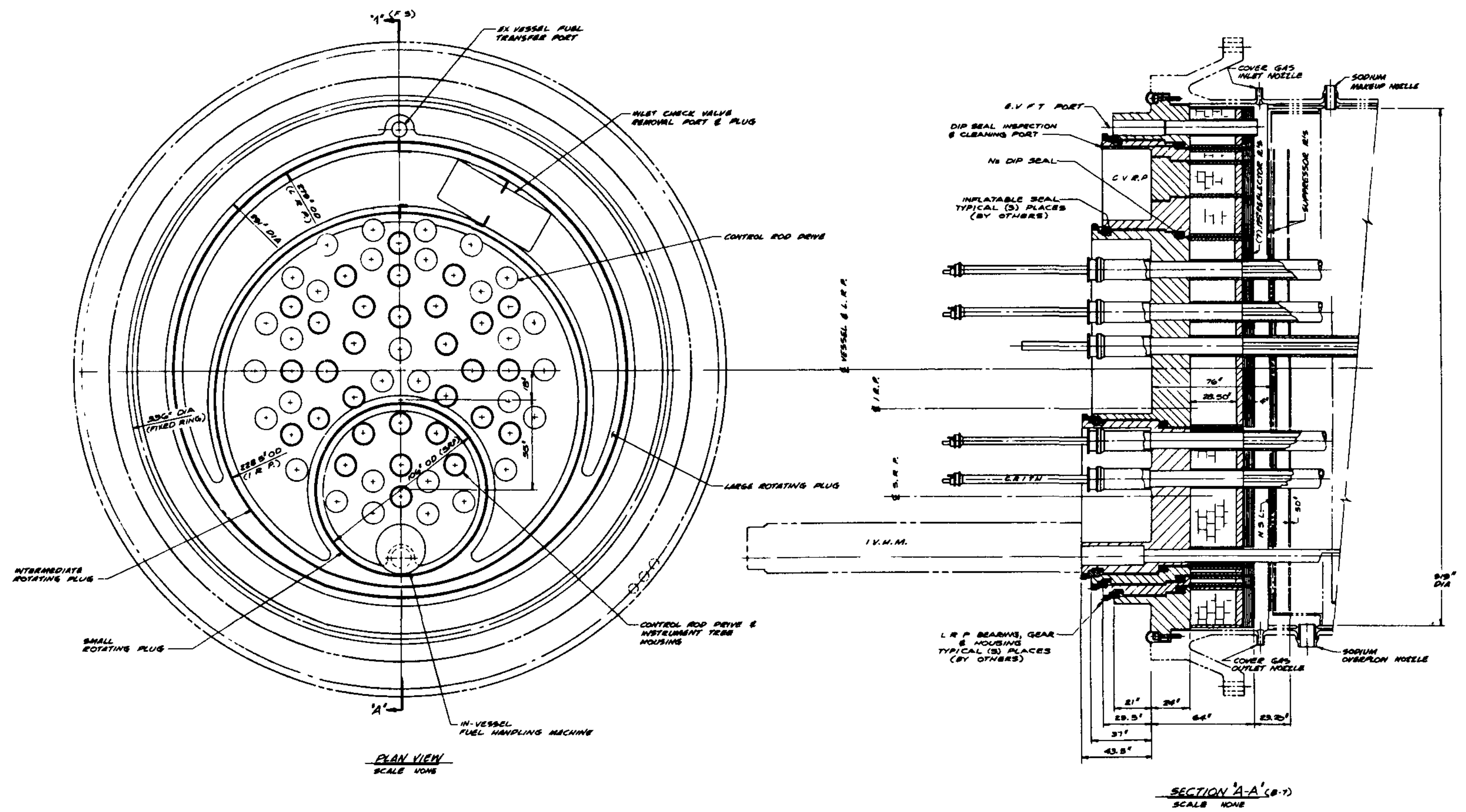


FIGURE 2.3
REACTOR VESSEL CLOSURE HEAD
TARGET PLANT

The fixed outer ring rests on and is mechanically attached to the reactor vessel upper flange. A welded flexible seal is installed across the vessel flange/outer ring interface to provide a cover gas seal. The large rotating plug is supported on bearings such that it can be rotated within the fixed outer ring. The intermediate rotating plug is supported on bearings within a hole in the large rotating plug. The centerline of the intermediate rotating plug is located 18 inches eccentric from the centerline of the large rotating plug. The small rotating plug is supported on bearings within the intermediate rotating plug. This plug is located 55 inches eccentric from the centerline of the intermediate rotating plug. Thus, the ability to rotate this set of three plugs with their eccentricity to each other and to the vessel affords access to all core assembly locations.

The aggregate weight of the four constituent parts of closure head assembly is approximately 690 tons. The assembly is 28 feet in diameter and measures approximately 11 feet from the bottom of the suppressor plate to the top of the rotational drive extensions.

Materials used in fabricating the closure head are as follows:

Upper Structural Plate (24" thickness)	SA-508, Class 3
Biological Shielding Blocks	Graphite
Lower Structural Plate (4" thickness)	SA240, Type 304
Shielding Canisters	SA-240, Type 304
Reflective Insulation	SA-240, Type 304

The closure head is designed and constructed to the requirements of Section III, Class 1 of the ASME Boiler and Pressure Vessel Code for Nuclear Application, including Code Case 1592 for high temperature service. Design pressures and temperatures are 40 psia and 200°F for the structural elements and 40 psia and 975°F for the insulation.

2.3.1.2 Reactor Vessel Internals

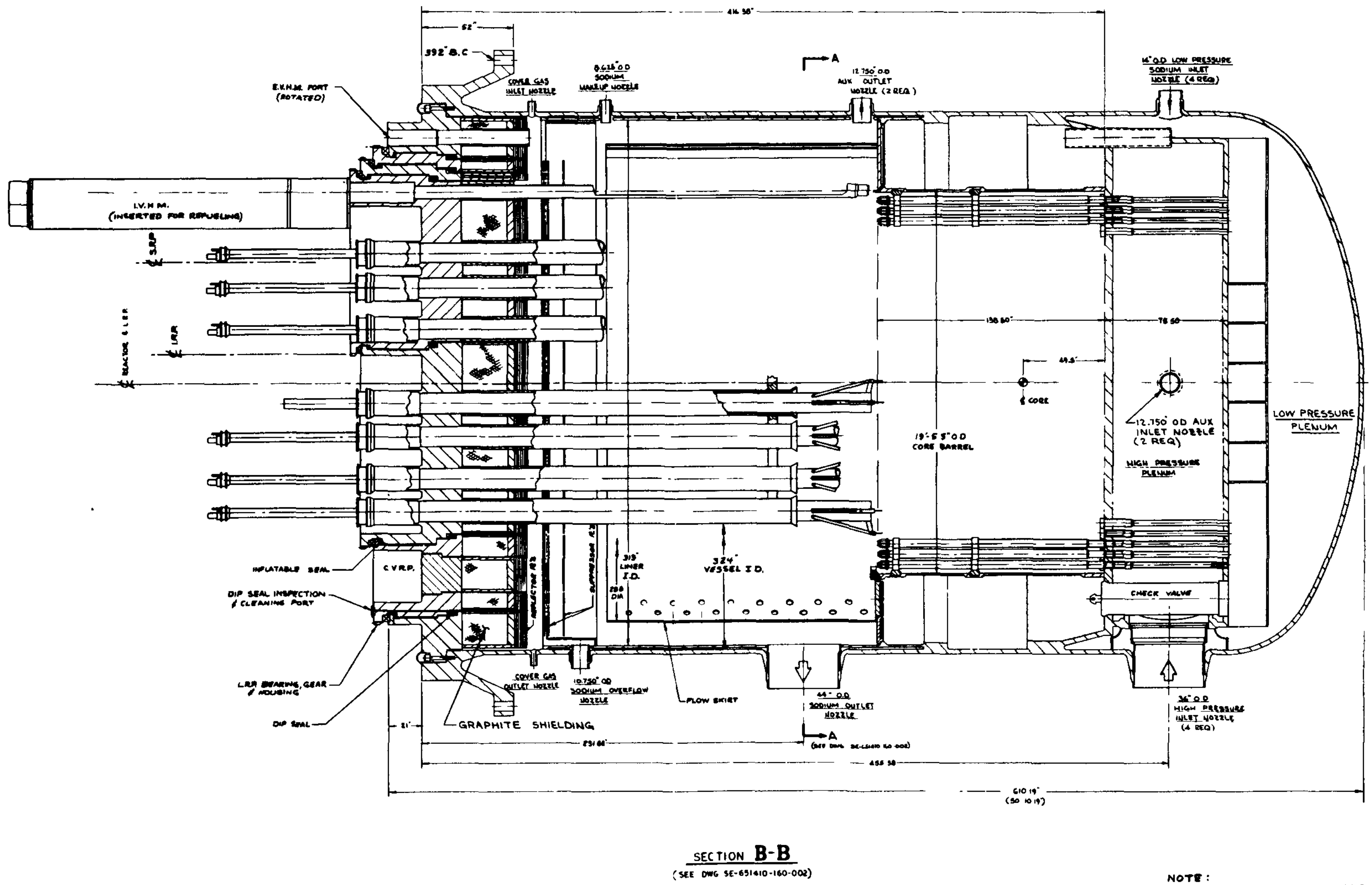
The reactor vessel internals as shown in Figures 2.4 and 2.5 provide support for the core, flow distribution through the core, and support for instruments and control rod drives.

The core is supported concentrically in the reactor vessel by the core support structure, welded to the vessel wall through a conical skirt. The region directly beneath the core is the high pressure inlet plenum which is connected to each of the high pressure inlet nozzles by a sliding pipe joint. The surrounding space, bounded by the vessel shell and the lower closure head, forms the low pressure plenum. Coolant enters the high pressure plenum through check valves, which are located at each inlet nozzle and can be removed for maintenance. There is also a check valve at each of the inlet nozzles of the Auxiliary Heat Transfer System.

Lateral restraint of the core is provided by the two subassembly support rings. These rings are fabricated in segments to fit the contour of the core at the core component support pads and are held in position by the core barrel, which is in turn attached to the core support structure. The core barrel supports the circular horizontal baffle plates which are welded to the vessel liner at their outer ends.

Suppressor plates, supported by the closure head, are provided directly above the free surface of the sodium to break up the sodium jets emitting from the assembly nozzles. These plates minimize gas entrainment at the sodium surface. An overflow weir at about normal sodium level directs the excess sodium to an overflow nozzle for circulation through a sodium cleanup (cold trapping) system.

A flow shroud, supported on the baffle plates, provides for mixing of the hot sodium before it is directed to the outlet nozzles. Multiple small holes in the shroud provide a high resistance path to the outlet nozzles thus forcing most of the flow over the shroud.

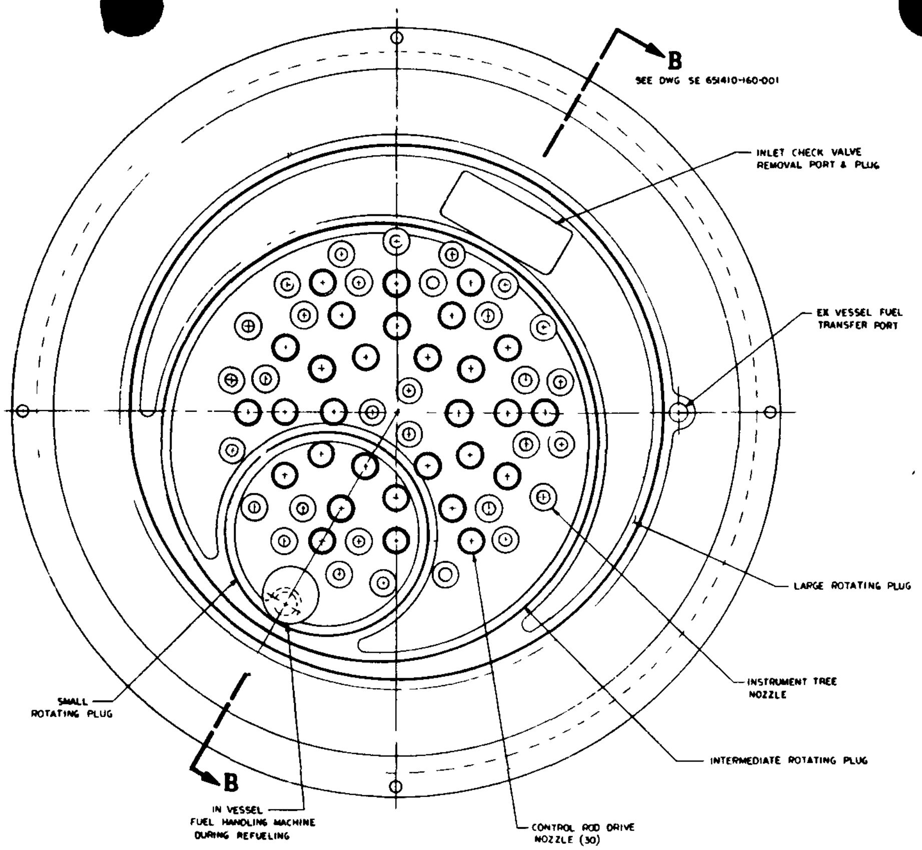


NOTE: ALL NOZZLES SHOWN ARE ROTATED INTO VIEW.

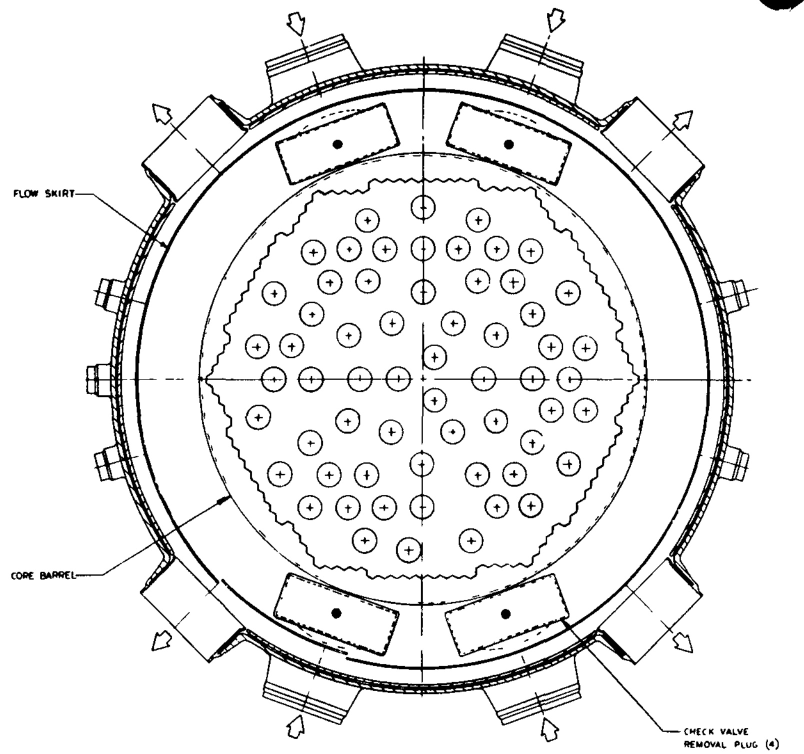
FIGURE 2.4

REACTOR VESSEL INTERNALS ASSEMBLY ELEVATION

(DWG. NO. SE-651410-160-001)



PLAN VIEW



SECTION **A-A**

FIGURE 25

REACTOR VESSEL INTERNALS

PLAN VIEW

(DWG. NO. SE-651410-160-002)

The head is penetrated by 61 control rod guide tubes and instrument nozzles. There are 30 nozzles which guide the safety and shim rod drivers in addition to the core outlet instrumentation. The 31 remaining nozzles are utilized for core outlet instrumentation only. The basic instrumentation consists of an eddy-current flowmeter and redundant thermocouples.

The upper internals of the reactor vessel incorporate 61 control rod and instrument assemblies (CRITA's) a concept developed by C-E. Each CRITA unit, incorporating 19 instrument probes, is a laterally retractable assembly which is removable through the nozzles in the rotating plug. The CRITA performs the functions of monitoring sodium temperature and flow and of mechanical holddown of the core assemblies. A total of 61 CRITA assemblies provide 100% core coverage.

2.3.1.3 Reactor Core

A summary of the principle reactor parameters is included in Table 2.2. The conceptual design utilizes hexagonal subassemblies with a 6.48 inch lattice pitch. Fuel management is carried out by annual replacement of 1/3 the total core subassemblies to limit the fuel burnup and consequential swelling.

2.3.1.4 Cavity Filler System

The Target Plant cavity filler system provides for reactor vessel enclosure. In the unlikely event of a leak, it contains radioactive sodium and limits the volume available for sodium spills in order to maintain a safe sodium level inside the vessel for continuity of heat removal from the reactor core.

The cavity filler system consists of a carbon steel lined cavity which houses the reactor vessel. The outer periphery of the cavity liner has cooling coils containing heat transfer fluid. These cooling coils limit the concrete temperature during reactor operations. The annular space

TABLE 2.2

SUMMARY OF PRELIMINARY PRINCIPAL REACTOR PARAMETERS

			Initial Core	
1.	Number of driver region subassemblies			
	a.	Fuel	438	
	b.	Control	30	
	c.	Total		468
2.	Number of internal blanket subassemblies			156
3.	Number of radial blanket subassemblies			151
4.	Number of radial reflector subassemblies			198
5.	Total number of reactor subassemblies			973

between the liner and the reactor vessel is filled with steel-clad graphite filler blocks. Each vertical row of filler blocks is installed on a support column which also acts as a screw lift for removal of the blocks when access for maintenance or inspection is desired. The filler blocks provide shielding and reduce the radioactivity in the adjacent heat transport cells to acceptable levels. A 9-inch insulation and trace heating is integrated in the filler blocks to provide the necessary insulation and heat-up capability, as well as removability for accessibility to the reactor vessel for inspection and maintenance.

The cavity filler system is compatible with in-service inspection of the reactor vessel, maintenance and/or repair of the reactor vessel and instrumentation, and installation of seismic restraints at critical locations which are accessible for inspection and adjustments. The inside diameter of the reactor cavity is large enough (by $\sim$6') to permit the installation of the reactor vessel with nozzles attached.

2.3.2 Heat Transport Systems

2.3.2.1 Primary Heat Transport System

The Primary Heat Transport System (PHTS) of the Target Plant consists of four main heat transport loops of equal capacity, each rated at 950 Mwt. Each loop consists of a volute-type centrifugal pump, an intermediate heat exchanger, an isolation valve, an electro-magnetic flowmeter and associated piping. All four PHTS loops are symmetrically arranged around the reactor vessel in separate steel-lined shielded vaults within the containment building. A schematic diagram for the heat transport system is illustrated in Figure 2.6.

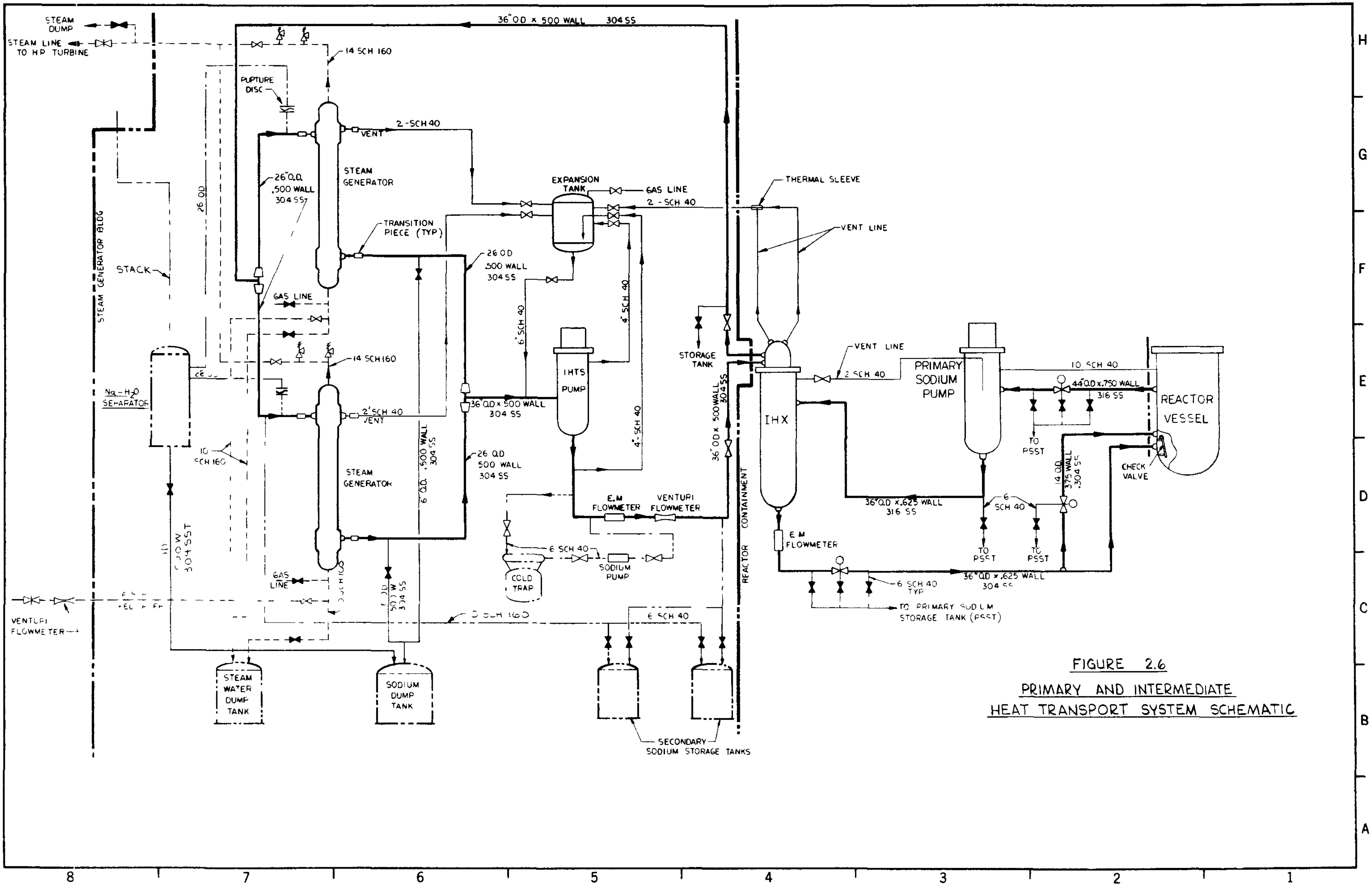


FIGURE 2.6

PRIMARY AND INTERMEDIATE HEAT TRANSPORT SYSTEM SCHEMATIC

Primary sodium from the reactor vessel upper plenum is directed to the four outlet nozzles leading to the main heat transport loops. Normal sodium level in the reactor is maintained by the overflow and make-up systems. The sodium flow in each loop is directed through a hot-leg isolation valve to a double-suction centrifugal pump via a 44" O.D. Type 316 SS pipe. The pump circulates sodium through a vertically mounted Intermediate Heat Exchanger (IHX) before returning it to the reactor vessel through a 36" O.D. pipe.

Before entering the reactor, the sodium flow branches into 36" O.D. and 14" O.D. lines to the high pressure plenum inlet and the low pressure plenum inlet respectively. The low pressure flow passes through a throttling valve, where flow rate is controlled to the reactor inlet nozzles and then directed to the blanket, reflector and control assemblies. Sodium flowing into the high pressure plenum passes through a check valve located within each reactor vesssel inlet nozzle. The main function of the valve is to limit flow reversal in the loop affected by a primary pump failure.

2.3.2.1.1 Primary Pumps

A hot leg pump is provided in each of the primary heat transport loops to circulate heated sodium from the reactor vessel to the shell side of the IHX. The primary sodium, cooled by secondary sodium flowing in the tube side of the IHX, is returned to the reactor vessel inlet plenums for recirculation through the reactor core. The primary pumps are located within the Reactor Containment Building.

The primary pump is a double-suction, single-stage, centrifugal pump (Figure 2.7) similar to the one developed by Byron Jackson under DOE/ERDA contract. The pump consists of a stainless steel double-suction impeller with radial suction and discharge, a 12" diameter SS hollow shaft, a 112" diameter SS volute casing and associated bearings and seals. The overall length of the pump is 395" including the shielding, the pump support flange and the driver mount; its weight is approximately 302,000 lbs. The 9000 HP Pump will deliver 87,000 GPM at 375 ft. TDH.

The impeller casing, also made of 304 SS, is voluted for radial suction and discharge. The piped suction with level control allows system operation with low available NPSH (30 ft.) The cover gas is pressurized and automatically controls the sodium level through an overflow line.

The pump is designed and constructed to the requirements of the ASME Code Section III Class I and code case 1592 for high temperature service.

The pump is driven by a 9000 HP AC induction motor which is vertically mounted on the pump with a mechanical coupling to the pump shaft. The axial thrust due to the impeller is taken up by the rotor bearings of the motor. The motor is supplied with a variable freqency supply from a generator driven by a 13.2 KV AC induction motor through a hydraulic coupling. The variable frequency supply to the main motor permits operation of the primary pump at speeds from 40% to 100% of the full speed.

A pony motor is also provided and connected to the main motor shaft through a gear box. This allows pump operation with pony motors at 10% of full flow.

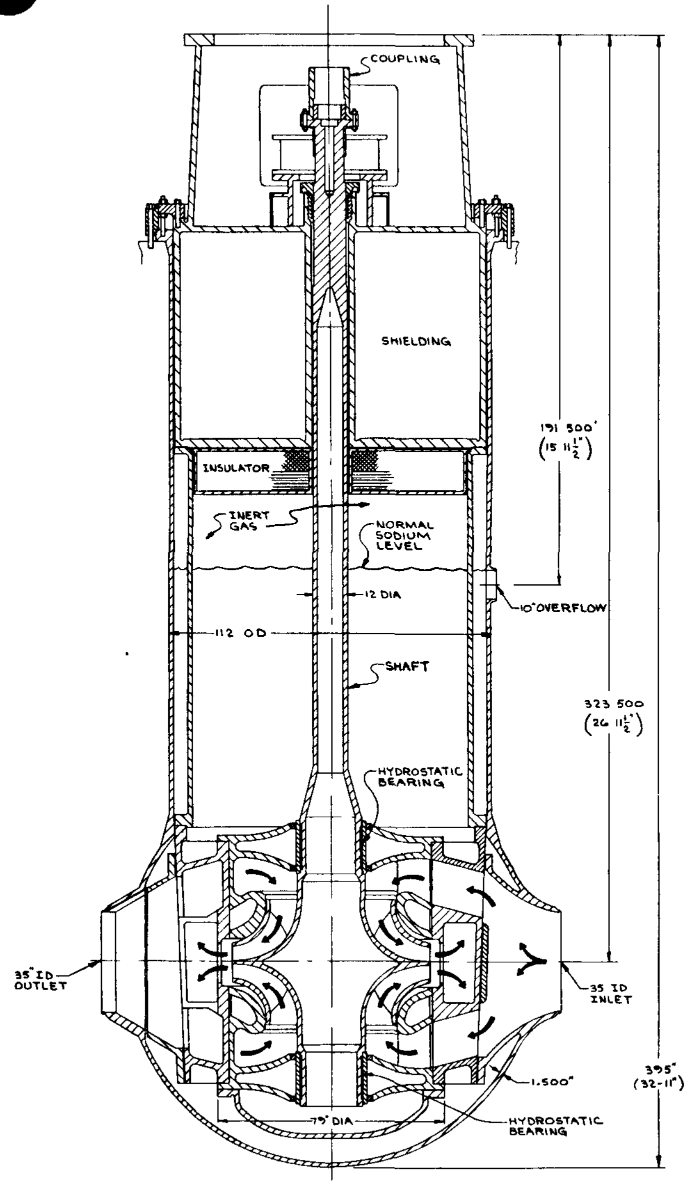
2.3.2.1.2 Primary Piping System

The primary piping system maintains sodium flow between the main components of the primary heat transport system (reactor vessel, IHX's, pumps), in addition to performing siphon, overflow, drain and vent functions. As part of the primary heat transport system, its functional requirements are:

a) to transfer heat generated in the reactor to the secondary heat transport system through the intermediate heat exchanger,

b) to transfer heat generated in the reactor at the temperature and heat rate called for by plant demand,

c) to maintain coolant flow in the reactor core, and



NOTES:
1. 4 PRIMARY PUMPS AND 4 SECONDARY PUMPS
2. SECONDARY PUMPS DO NOT REQUIRE SHIELDING OTHERWISE SIMILAR TO THAT SHOWN

FIGURE 2.7
PRIMARY PUMP

d) to safely contain activated liquid sodium coolant.

The primary piping system consists of four parallel main coolant circuits. The piping in each circuit consists of a 44" O.D. line from the reactor outlet nozzle through a hot-leg isolation valve to the primary coolant pump, a 36" O.D. line from the pump to the shell side of the IHX, and a 36" O.D. line from the IHX through a cold-leg isolation valve to the reactor high pressure inlet plenum. A 14" O.D. line, branching off from this last segment of piping, passes through a throttling valve on its way to the reactor low pressure inlet plenum. 2" vent lines and 6" drain lines are provided at high and low points, respectively, in the circuit. Type 304/316 stainless steel is used throughout the system.

The design of the primary piping system is in accordance with ASME Code Section III Class I. The design temperature and pressure are 950°F/50 psig for the reactor vessel to pump run, 950°F/150 psig for the pump to IHX run, and 700°F/150 psig for the IHX to reactor vessel run. A thermal stress analysis was performed, using the MEC-21 computer program, to ensure that the thermal expansion stresses were within the allowable for each of the primary coolant piping runs.

All piping runs for the Primary Heat Transport System are supported at specific locations and restrained against seismic disturbances by mechanical shock and vibration arrestors, also known as seismic snubbers. These snubbers are of the mechanical friction type (non-hydraulic). They allow free movement of the pipe during expansion and contraction of the piping system, but lock up if the pipe moves faster than the design displacement rate along the axis of the snubber.

2.3.2.1.3 Intermediate Heat Exchanger

The Intermediate Heat Exchanger (IHX) serves as an interfacial device between the radioactive primary loop and the non-radioactive intermediate loop. Thus, the IHX's are placed within the containment building with the reactor vessel to isolate the radioactive sodium. There is one IHX per loop i.e., four IHX's per plant.

The IHX receives primary sodium from the hot outlet plenum of the reactor vessel through the hot leg primary pump. This fluid enters the shell side of the IHX through an inlet plenum located around the upper region of the tube bundle. After having passed through a perforated distribution cylinder, the sodium enters the shell side of the tube bundle and flows downward giving up heat to the cooler intermediate sodium which is flowing through the tubes. The primary sodium exits the tube bundle at the lower end of the unit by flowing outward and through the concentric annulus formed by the shell and lower tubesheet periphery. After having passed between the lower floating head and the outer head of the IHX, the sodium exits through the IHX outlet nozzle and is returned to the high pressure plenum of the reactor vessel.

Intermediate sodium is supplied to the IHX from the steam generators by the cold leg intermediate pump. This flow of relatively cool sodium enters the IHX through an insulated downcomer. This downcomer extends downward through the central region of the tube bundle to a lower floating head which serves as an inlet plenum to the tube side of the component. As the intermediate sodium flows upward through the tubes it receives heat from the counter-flowing primary sodium. After emptying into the upper head region of the IHX, the heated secondary fluid exits the IHX and is piped to the steam generators.

As shown in Figure 2.8, the IHX design is a vertically oriented, top supported, centerflow heat exchanger featuring the higher temperature primary sodium on the shell side and the lower temperature intermediate sodium on the tube side. The design provides for differential thermal expansion between the shell and tube bundle by having the lower tubesheet and head keyed to the shell such that it is restrained only in the horizontal direction. A bellows is provided to accommodate relative axial motion between the tubebundle and downcomer.

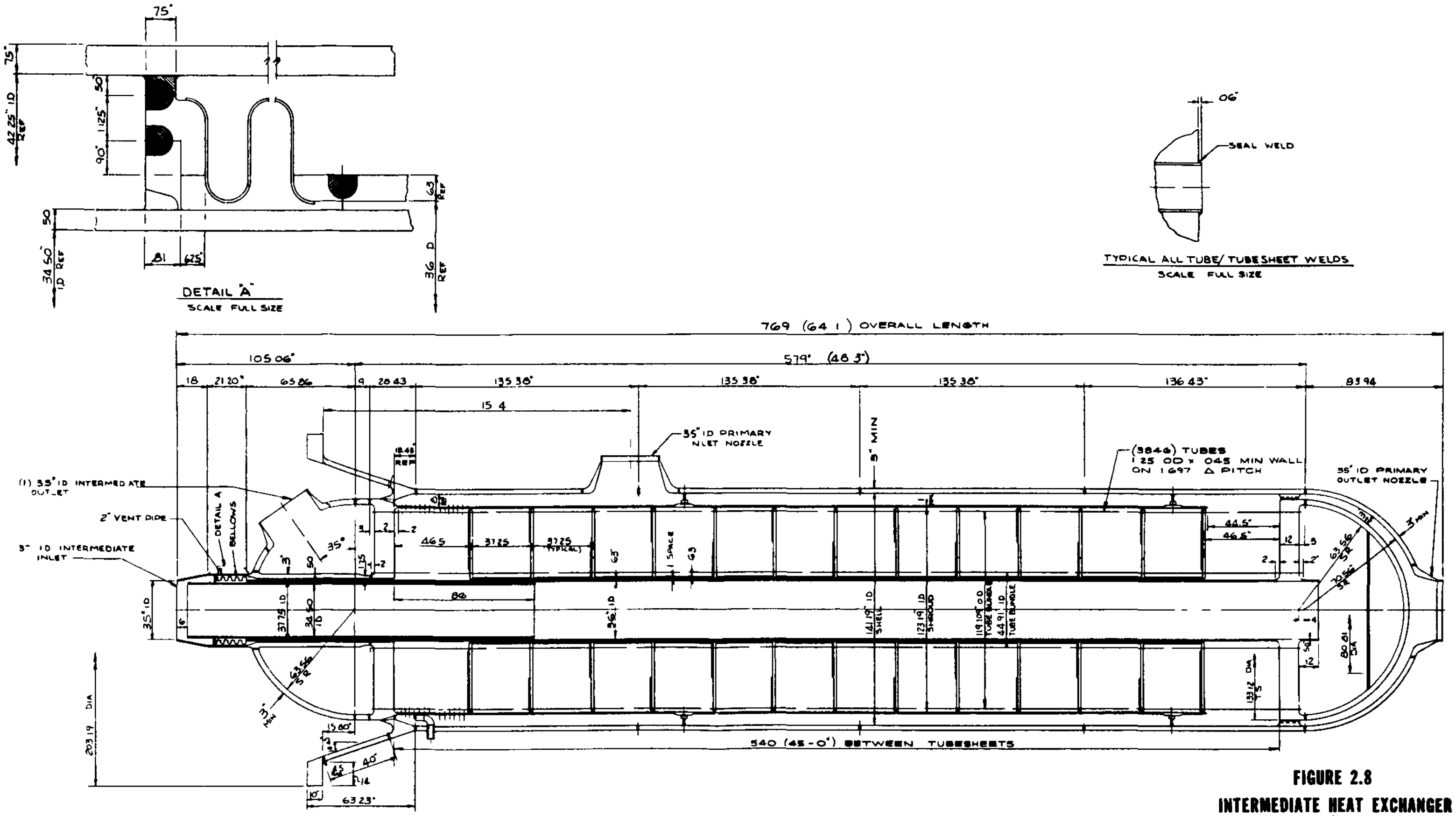


FIGURE 2.8

INTERMEDIATE HEAT EXCHANGER TARGET PLANT

All shell plate thicknesses, including the hemispherical heads, are 3.00 inches. The shell has four major nozzles: one intermediate sodium inlet, one intermediate sodium outlet, one primary sodium inlet, and one primary sodium outlet. These nozzles are of a common 35.00 inch inside diameter size. Other pertinent material thicknesses are the inner and outer flow shrouds which are 0.63 inches and 1.00 inches, respectively; the central downcomer and thermal liner (located in the upper region of the downcomer) which are 0.63 inches and 0.50 inches, respectively; the two tubesheets which are 12.00 inches; and, the support skirt and support flange which are 3.00 inches and 10.00 inches, respectively.

The tube bundle is comprised of 3,846-1.25 inch outside diameter tubes positioned in a triangular array on 1.697 inch centers. Tube wall thickness is 0.045 inches and the heated length is 45 feet. Thus the total heat transfer area is 56,600 ft^2 per IHX. There are thirteen eggcrate type tube supports located on 37.25 inch centers. Plates are added to the eggcrate tube supports to yield a disc and doughnut flow effect. Tube-to-tubesheet welds are of a rolled and seal welded design.

The vessel is designed and constructed to the requirements of Section III, Class 1, of the ASME Boiler and Pressure Vessel Code, including Code Case 1592 for high temperature service. Design pressure and temperature for the IHX are 165 psia and 975°F, respectively. The primary sodium enters the unit at 950°F and exits at 650°F. Primary and intermediate side flow rates are 35.8×10^6 and 33.4×10^6 lbm/hr, respectively. The IHXs are designed as 950 Mwt units.

Materials for the IHX are as tabulated below:

Plate Material	SA-240, Type 304
Tubing	SA-213, Type 304
Tubesheets and Nozzles	SA-182, Type F304

The dry weight of an IHX is approximately 320 tons. Maximum diameters are the support skirt flange which is 203.19 inches and the component shell which is 147.19 inches. The overall length of the IHX is 64'1".

2.3.2.2 Intermediate Heat Transport System

The Intermediate Heat Transport System (IHTS) consists of four identical sodium loops (Figure 2.6) required to transport reactor heat from the Intermediate Heat Exchanger to the Steam Generating System. Each loop has a rated capacity of 950 Mwt. The secondary loops contain non-radioactive sodium which is circulated by a secondary sodium pump from the tube side of the IHX through the shell side of the steam generators and back to the IHX.

The secondary sodium flow is completely isolated from the radioactive primary sodium by the IHX tube walls which provide a mechanical barrier. In addition, the secondary sodium pressure within the IHX is maintained above the shell side (primary) sodium pressure, so that in the event of a tube leak, radioactive sodium will not enter into the secondary system; this provides a backup barrier. Each loop is comprised of one single stage centrifugal pump, an expansion tank, sodium piping leading to and from the IHX and the steam generators.

The secondary sodium from the IHX is routed through a 36" O.D. pipe from the reactor containment building into the steam generator building. The flow is split and directed to the combined unit steam generators through 26" O.D. pipes. After exiting the steam generators, cooled sodium flows through two parallel 26" O.D. lines before recombining into a single 36" O.D. line leading to the sodium pump inlet. The pump is a vertical, single-stage centrifugal pump designed to deliver 76,700 gpm of sodium with a rated head of 300 feet. From the pump discharge sodium flows into 36" O.D. piping to complete the circuit through the IHX.

Electro-magnetic flowmeters in the cold leg downstream from the pump provide flow rates for control and plant protection. Venturi meters (in two loops only) provide the flow measurements required in the instrumentation of the steam generators.

An expansion tank in each loop accommodates sodium volume change due to thermal expansion over the operating range. The expansion tank is located in the steam generator building near the corresponding sodium pump. The expansion tank is interconnected to the pump tank as well as to the high point of the steam generators and the IHX.

As shown in Figure 2.9, the Secondary Sodium Expansion Tank is a vertically-oriented top-supported cylindrical vessel closed at both ends by an elliptical head. All plate stock used within the weldment, including material for the two heads is of a constant 2.53 inch thickness. The vessel wall is penetrated by one 16.00 inch manway and seven small diameter nozzles. Except for short elbowed pipe extensions on three of the nozzles, the vessel has no internals.

Physically, the vessel has an overall length of 191.63 inches and shell and flange outside diameters of 123.25 inches and 150.00 inches, respectively. The total dry weight of the vessel is approximately 24 tons.

The vessel is fabricated using 304 SS material for all plate stock and the flange forging. The expansion tank is designed to the requirements of Section VIII, Division 2, of the ASME Boiler and Pressure Vessel Code. Design pressure and temperature are 300 psia and 600°F, respectively.

For coolant purification, air-cooled cold traps in the cold leg of each loop remove inpurities. Each loop has similar components and maintains equal flow. Piping configurations within the steam generator cell is identical for all the loops.

2.3.2.3 Steam Generator System

The steam generator system (SGS) reliably and safely provides superheated steam (850°F at 2200 psig), suitable for the turbine-generator system by transferring heat from intermediate sodium to water/steam in the steam generators. The SGS also provides redundant decay heat removal paths subsequent to a reactor shutdown. The SGS consists of the following subsystems:

(1) Steam generator subsystem

(2) Sodium/water reaction relief subsystem

(3) Leak detection subsystem

(4) Sodium dump subsystem

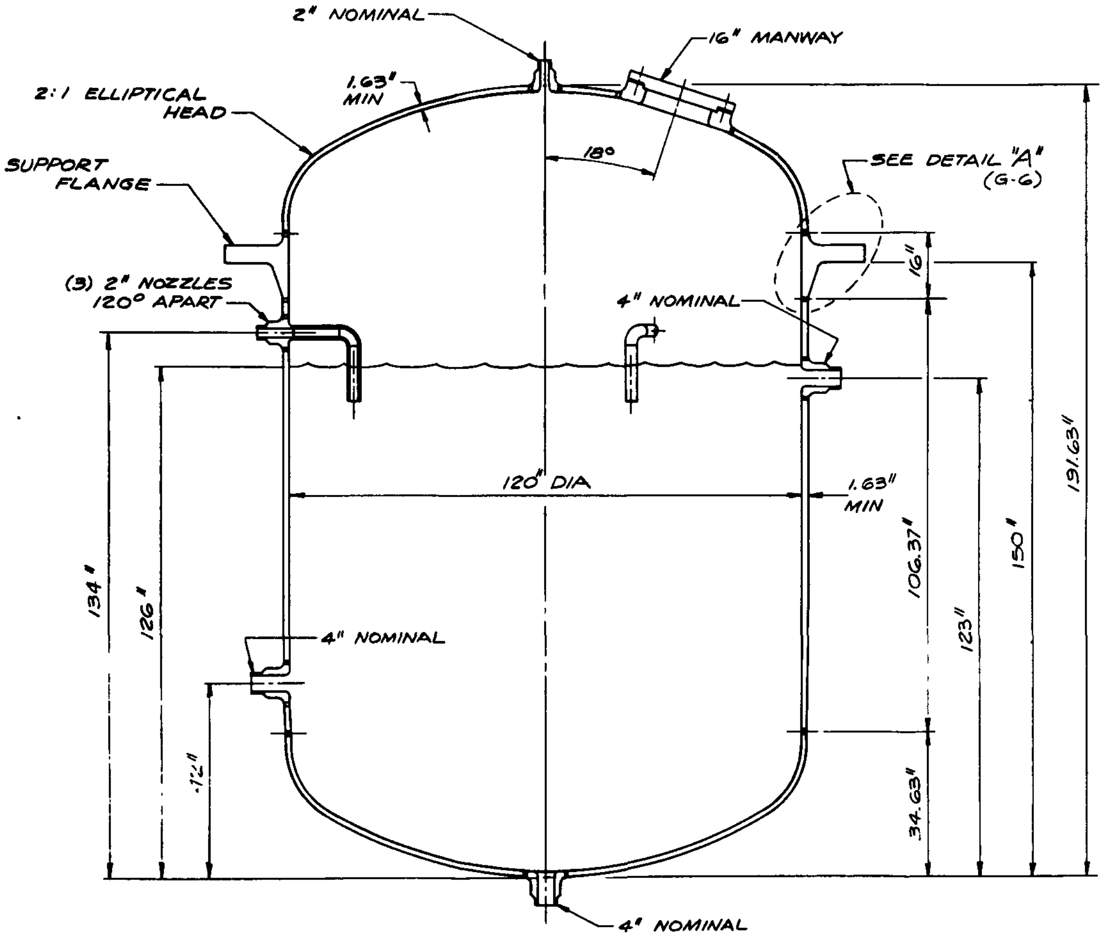
(5) Water dump subsystem

2.3.2.3.1 Steam Generator Subsystem

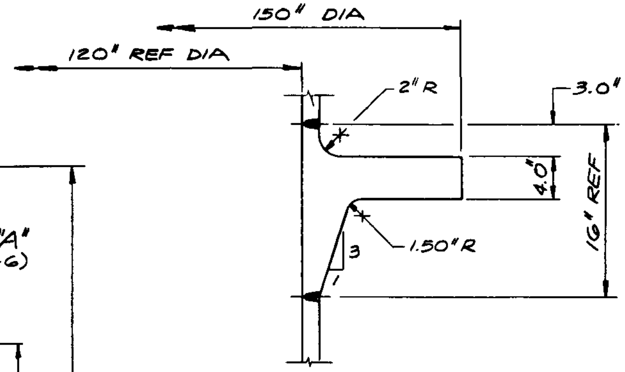
The steam generator subsystem transfers reactor-generated heat from the intermediate sodium to the water/steam in the steam generators and delivers steam to the turbine at a rate dictated by load demand and reactor operating conditions.

There are four steam generator subsystems corresponding to four IHTS loops. The steam generator subsystem for each loop consists of two steam generators, associated piping and valves. The heated sodium from the IHX is divided into two streams; one to each steam generator. Feedwater from the condenser, after being heated in the feedwater heaters, enters the steam generators, boils and is heated to superheated steam conditions. The steam from the steam generators is routed to the high pressure inlet of the turbine.

The steam generators are counterflow, shell and tube, single-wall heat exchangers. They are installed at an elevation higher than the IHX to promote natural circulation in case pumping power is lost. This arrangement provides for decay heat removal subsequent to a reactor shutdown and loss of power.



SECTIONAL ELEVATION
SCALE NONE



DETAIL "A" (D-6)
SCALE: 1.5" = 12"

FIGURE 2.9
EXPANSION TANK-I.H.T.
TARGET PLANT

The steam generator represents a critical link in the LMFBR System. This component not only transforms the heat extracted from the reactor core into steam for rotating the turbines, it also serves as the interfacial device between the sodium and water loops. Even though the sodium which passes through the steam generator is non-radioactive, a failure in the pressure boundary could result in a violent exothermic chemical reaction which occurs when sodium and water are mixed. For this reason, the steam generator must exhibit a high degree of design and structural integrity.

Being in the non-radioactive portion of the loop, the steam generators may be located outside the reactor containment building. There are two steam generators per loop or eight per plant.

Hot sodium from the intermediate heat exchanger enters the shell side of the steam generator through an upper distribution plenum. After flowing upward through an orifice plate, the sodium enters the tube bundle and flows downward giving up heat to the water/steam which is flowing within the tubes. The spent sodium then exits the tube bundle through the outlet plenum to be returned to the IHX.

Feedwater enters the steam generator through a hemispherical head at the lower end of the component. As the sub-cooled liquid begins its upward flow through the tube bundle, it begins receiving heat from the counter-flowing sodium and is thus heated to the boiling state. As it continues the upward passage through the tube bundle, it receives additional heat and is eventually dried out and superheated prior to exiting the steam generator. The superheated steam leaves the component through a floating outlet plenum.

As shown in Figure 2.10, the steam generator design is a vertically-oriented, top supported, counterflow heat exchanger featuring the higher temperature intermediate sodium on the shell side and the lower temperature water/steam on the tube side. The unit is a once-through combined unit in that it receives feedwater at 470°F through the waterside inlet nozzle and provides superheated steam at 854°F through the steam outlet nozzle. The steam outlet pressure and flow rate is 2200 psig and 1.78×10^6 lbm/hr. The design provides for differential thermal expansion between the shell and tube bundle by having the upper tubesheet and steam outlet plenum keyed to the shell such that it is restrained only in the horizontal direction. A bellows is provided at the upper extremity of the shell to provide a flexible containment for the sodium. As shown in the Figure, the bellows joint features a mechanically attached protective housing which also serves as a back-up seal.

The vessel shell thickness is 1.50 inches throughout the cylindrical portion of the vessel except for the uppermost shell course which is 2.50 inches. The upper hemispherical head, which completes the sodium containment, is also 1.50 inches thick. There are four nozzles opening through the sodium shell: two 25.00 inch ID nozzles for sodium inlet and outlet; and, two 24.00 inch ID nozzles which are utilized as access ports during the steam generator tubing operation. Thermal liners are provided on the sodium side at the tubesheets and on the shell in the inlet and outlet regions. A 1.00 inch flow baffle is fitted as tightly as possible around the outside diameter of the tube bundle. The upper and lower tubesheet thicknesses are 26.00 inches and 23.00 inches, respectively, and the waterside inlet and outlet hemispherical heads are 5.00 inches and 5.50 inches, respectively. The feedwater inlet nozzle is sized for compatibility with 10 inch Schedule 160 pipe and the steam outlet nozzle for 14 inch Schedule 160 pipe. In both cases, mechanically attached flanges are provided to permit access to the waterside of the tubesheets.

The tube bundle consists of 3547 0.75 inch outside diameter by 0.125 inch wall tubes located on 1.250 inch centers in a triangular array. The tube bundle heated length is 72'-0", thus each of the eight steam generators has a total heat transfer area of 50,145 ft^2. There are 20 drilled plate type tube supports located along the length of the tube bundle. Flow holes are sized in such a way as to simulate disc and doughnut type flow. Tube-to-tubesheet welds are of a front side, back side configuration as shown in detail on the above referenced figure. This type of design provides a highly reliable crevice-free joint which enhances the overall reliability of the unit.

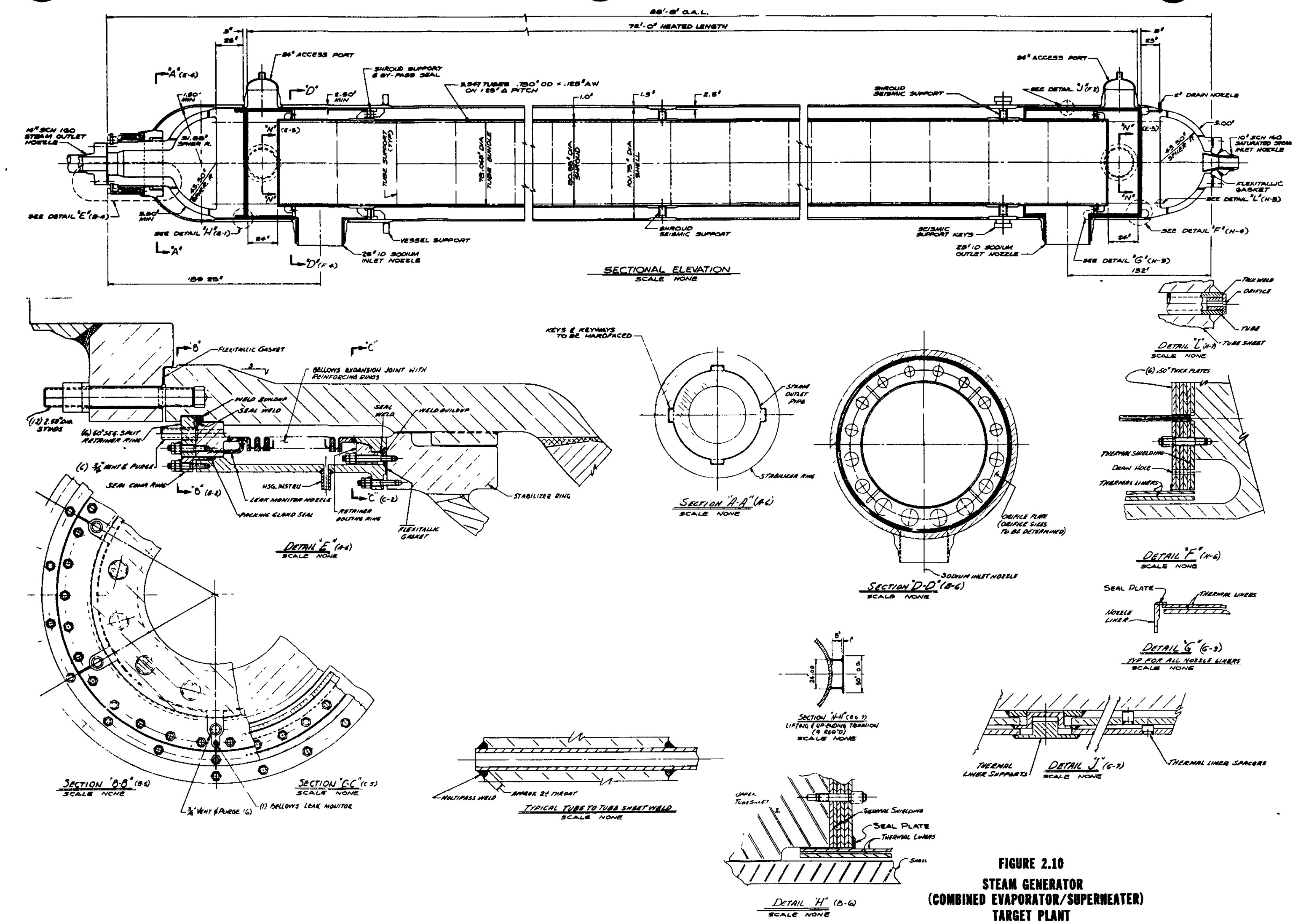


FIGURE 2.10

STEAM GENERATOR (COMBINED EVAPORATOR/SUPERHEATER) TARGET PLANT

The vessel is designed and fabricated in accordance with Section VIII, Division 2 of the ASME Boiler and Pressure Vessel Code. The design pressure and temperature for the shell side of the component is 300 psia and 935°F, respectively. The 16.7 x 10^6 lbm/hr of sodium enters the steam generator at 910°F and exits at 590°F. The waterside flow rate, temperatures, and pressure are as stated above. Each steam generator is designed as a 475 Mwt unit; thus, two steam generators are fed from one 950 Mwt IHX.

Materials for construction for the steam generators are as follows:

Shell Plate	SA-387, Gr. 22, Cl. 1
Tubesheets	SA-336, F22
Tubes	SA-213, Gr. T22

The maximum diameter of the steam generator shell is 106.75 inches, and the overall length is 88'-8". The total dry weight of a single component is approximately 325 tons.

2.3.2.3.2 Sodium/Water Reaction Relief Subsystem

The steam generator sodium/water reaction relief subsystem is provided to prevent overpressurization of the Intermediate Heat Transport System and the IHX which would lead to failure of the primary coolant boundary. The overpressure protection is provided by means of rupture discs designed to rupture at a preset pressure. The rupture discs are installed in lines leading to a separator tank. Subsequent to a large sodium/water reaction, the pressure pulse due to the reaction bursts the rupture discs and the sodium/water reaction products along with some sodium are routed to a separator tank. In the separator tank the hydrogen is centrifugally separated from liquid sodium and reaction products and flared through a stack. The liquid sodium from the separator tank is drained to a drain tank for disposal and/or cleanup.

2.3.2.3.3 Leak Detection Subsystem

The steam generator leak detection subsystem consists of hydrogen detection units installed on the bypass lines from the steam generator units to the expansion tank. The bypass stream flow rate is set to facilitate quick detection of a sodium/water reaction, identification of the leaking unit and appropriate protective actions, e.g., isolation and quick dump from the water and/or sodium side of the steam generators.

2.3.2.3.4 Sodium Dump Subsystem

The sodium dump subsystem functions to limit the consequences of a sodium/water reaction in the steam generators by a quick dump of the sodium into sodium storage tanks. The system consists of piping and valves suitably located to ensure sodium drain from the loop affected by a large sodium/water reaction. The sodium storage tanks, which are part of the auxiliary liquid metal system, have adequate capacity to ensure complete evacuation of the affected loop.

2.3.2.3.5 Water Dump Subsystem

The water dump tanks provide for the water/steam dump subsequent to a leak in the steam generators. Quick-close isolation valves provide evacuation of any unit without affecting the operational status of other loops.

2.3.3 Auxiliary Heat Transfer System

Two Auxiliary Heat Transfer Systems (AHTS) with maximum capability of removing 57 Mwt each (1.5% of full power), are provided to satisfy the plant requirements for independent and redundant means of decay heat removal from the reactor. They each consist of a primary and secondary loop (Figure 2.11) for ultimate heat rejection to air.

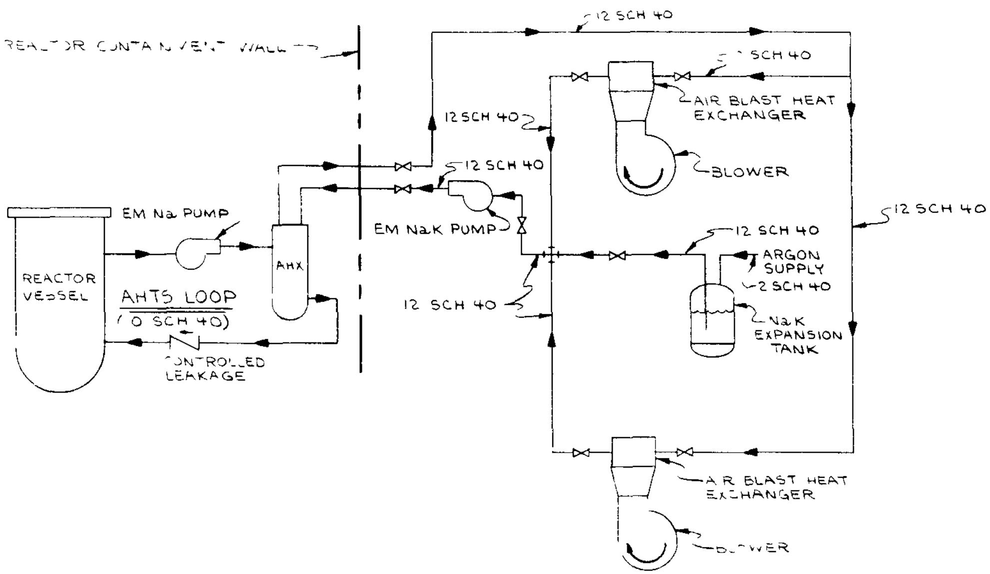


FIGURE 2 11

AUXILIARY HEAT TRANSPORT SYSTEM SCHEMATIC

Radioactive primary sodium is circulated by means of a hot-leg flat linear induction electromagnetic pump to an Auxiliary Heat Exchanger (AHX), where heat is transferred to the secondary coolant (NaK) circulating in the tube side of the AHX. The primary sodium is then returned to the high pressure plenum of the reactor vessel. The secondary loop using a cold-leg flat linear induction electromagnetic pump circulates NaK from the AHX to two FFTF-type Forced Air Heat Exchangers (FAHX), where heat is rejected to the atmosphere.

The primary loop, wholly contained within the reactor containment building, is enclosed within a system of guard pipes and guard vessels to limit the quantity of sodium leakage. In the event of a leak, a minimum sodium level is maintained in the reactor vessel for continuity of heat transfer. The secondary loop is located within a seismic Category I, tornado and missile protected building and is maintained at a higher pressure than that of the primary sodium to preclude any outleakge of the radioactive primary sodium.

A check valve, with an orifice in the valve disk, is provided in the line between the AHX and Reactor Vessel to limit the reverse flow through the system to about 100 gpm to maintain the primary loop of the AHTS at about the reactor inlet temperature. This is to limit the thermal transients imposed on the system when AHTS operation is initiated.

By provision of independent and redundant decay heat removal systems, i.e., two AHTS cooling systems, the secondary HTS and Steam Generator Systems (SGS) are not required to perform decay heat removal functions. Therefore, the non-radioactive secondary HTS and SGS, associated components and structures may be designed and constructed to commercial standards.

2.3.4 Fuel Handling and Storage System

An area of major impact on the total plant availability and, hence, importance to the purchasing utility, is the system for refueling the reactor. Since approximately 280 fuel, blanket and absorber assemblies must be replaced annually for the Target Plant, a strong incentive exists to hold refueling time down to 1.0 hour per subassembly, giving 10-20 days for refueling. C-E has developed a modified EBR-II type arrangement which can achieve this target (Figure 2.12).

A conceptual design of a refueling system utilizing this concept is described below. The concept features:

1 - A straight pull in-vessel handling machine.

2 - A triple rotating plug system.

3 - A transfer arm and in-vessel elevator to minimize the vessel size.

4 - A method of exchanging core components that allows the in-vessel and ex-vessel portions of the refueling system to operate simultaneously.

5 - A transfer tunnel for movement of fuel between the reactor vessel and the ex-vessel storage tank that does not breach the containment boundary during handling of core components.

6 - A limited function ex-vessel handling machine for efficiency.

7 - A system of air locks (valves) that minimizes danger of accidental discharge of radioactive material in the event of an accident.

With this system, an In-Vessel Handling Machine (IVHM) mounted atop the inner of three eccentric rotating plugs transfers individual subassemblies to a position above the outermost radial reflector assembly. When a new fuel assembly is lowered by elevator to the same elevation at the periphery of the reactor vessel, a double-ended transfer arm is rotated 90° to engage and lock onto the handling socket of both new and spent assemblies on

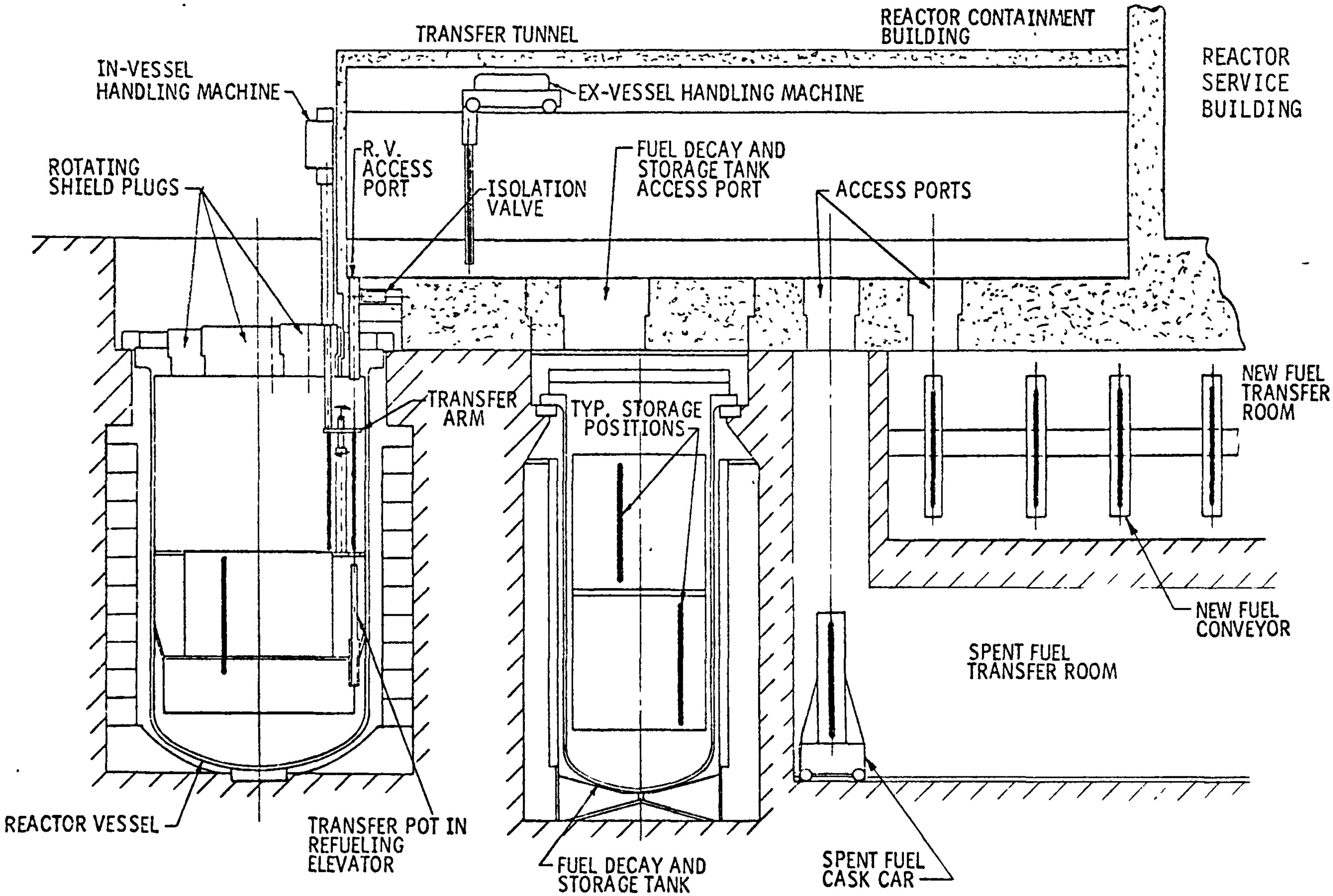


FIGURE 2.12

REFUELING SCHEME

opposite ends. At this time, the IVHM disengages from the spent assembly and the ex-vessel transfer pot is lowered by a ball/screw elevator mechanism below the new assembly. The transfer arm is thus clear to rotate 180" and permit exchange of the assemblies.

The transfer pot, positioned under the spent assembly, is raised by the elevator to contain the spent assembly; the IVHM locks onto the handling socket of the new assembly. The transfer arm is then disengaged and rotated 90° to permit insertion of the fresh assembly and removal of the spent assembly via the transfer pot from the vessel.

The Ex-Vessel Handling Machine (EVHM) is mounted on tracks in a shielded tunnel above the operating floor. During refueling, it shuttles between the vessel head transfer port and the decay storage transfer port exchanging spent and new assemblies. Before refueling, it receives new assemblies after appropriate examination and preheating for insertion in the decay tank. After a sufficient decay period, the EVHM removes the spent assemblies for drying and loading into shipping casks for transport to a processing facility.

Key features of this fuel handling method are its simplicity, and the simultaneous handling of new and spent assemblies by IVHM and EVHM equipment.

The reactor Refueling System provides the means for storing, transporting and handling core components within the Reactor Plant. The following components are defined as core components:

1. Core fuel assemblies

2. Radial blanket assemblies

3. Control assemblies

4. Removable radial shield assemblies

Of the new core assemblies arriving at the Target Plant, only the new fuel core assemblies require shielding and criticality control. In the interest of simplicity of procedure because fuel assemblies make up the majority of the components replaced, one uniform system and procedure is utilized for all core component handling. Irradiated core components require shielding and decay heat removal. Irradiated core components containing fuel also require criticality control and containment of fission gas, in the event of leaks in fuel rods.

The refueling system is made of the following major subcategories: fuel handling equipment; special tools and service equipment; cranes, hoists and shipping casks; storage and transfer facilities. The following list defines the major subcategories of the refueling system:

2.3.4.1 Fuel Handling Equipment

This category includes:

1. In-vessel handling machine (IVHM)
2. Transfer arm (TA)
3. Refueling elevator
4. Ex-vessel handling machine (EVHM)
5. Transfer pots (TP)
6. New fuel conveyor

2.3.4.2 Special Tools and Service Equipment

This category includes special purpose lifting and handling fixtures, adapter equipment, shielded valves and seal plugs for use at access ports, removal containers for use in replacing or removing the IVHM on the rotating shield plugs, and special equipment that may be required to determine the status of equipment in inaccessible locations.

2.3.4.3 Cranes, Hoists, Carts and Shipping Casks

This category includes general purpose cranes and hoists within the reactor building and in the fuel handling building. Included in this category are the shipping casks and cask carts.

2.3.4.4 Storage Facilities

Covered under this category are the ex-vessel storage tank, new fuel storage vault and the ancillary equipment required for proper operation.

Ex-Vessel Storage Tank

The Ex-Vessel Storage Tank (EVST) used for this study is esentially the same as that designed for use in the Clinch River Reactor Plant. Minor dimensional and tolerance changes were assumed for the purpose of this study and the guard tank was omitted.

The Ex-Vessel Storage Tank (EVST), as shown in Figure 2.13 is actually comprised of three components: a Storage Vessel, a Closure Head, and a Turntable Assembly. These three components are described as separate entities with concluding paragraphs which describes how the parts are assembled.

The Storage Vessel is a vertically oriented, top supported, cylindrical vessel with a lower elliptical head. Except for the uppermost shell course, the pressure boundary has a constant thickness of 1.50 inches. The uppermost shell course is 3.00 inches thick. The vessel wall is penetrated by a number of small diameter nozzles to provide for the control of cover gas and the removal of heat generated by the fuel elements stored within the vessel. There is a flow distribution plenum in the lower head of the vessel. The vessel flange is machined internally to accept the turntable bearings and on the upper surface to support and seal with the closure head.

Maximum overall dimensions for the vessel are the outside diameter of the flange which is 279.00 inches; the cylindrical shell outside diameter which is 236.00 inches; and the overall length of the vessel which is 59'-2". The dry weight of the vessel is approximately 210 tons.

Construction materials for the vessel are SA-240, Type 304, for the shell and lower head and SA-508, Class 2, for the support flange.

The vessel is designed and fabricated to the requirements of Section III, Class 2, of the ASME Boiler and Pressure Vessel Code for Nuclear Application.

Referring again to Figure 2.13, the Closure Head is similar in cross-section to the Reactor Vessel Closure Head. It has a 12.00 inch upper structural member from which insulation canisters are suspended. Thermal insulation is afforded by twenty-five 0.063 inch shielding plates stacked on spacers such that gas spaces separate the plates.

The head is made up of two major parts: a fixed outer ring, and a fixed central cover. Plated "C" rings are utilized for sealing at both the vessel/outer ring interface and at the outer ring/central cover interface. There are nine access ports through the head which permit withdrawal and insertion of the elements into the storage positions of the turntable. These ports are arranged to align with the concentric array of storage positions within the turntable.

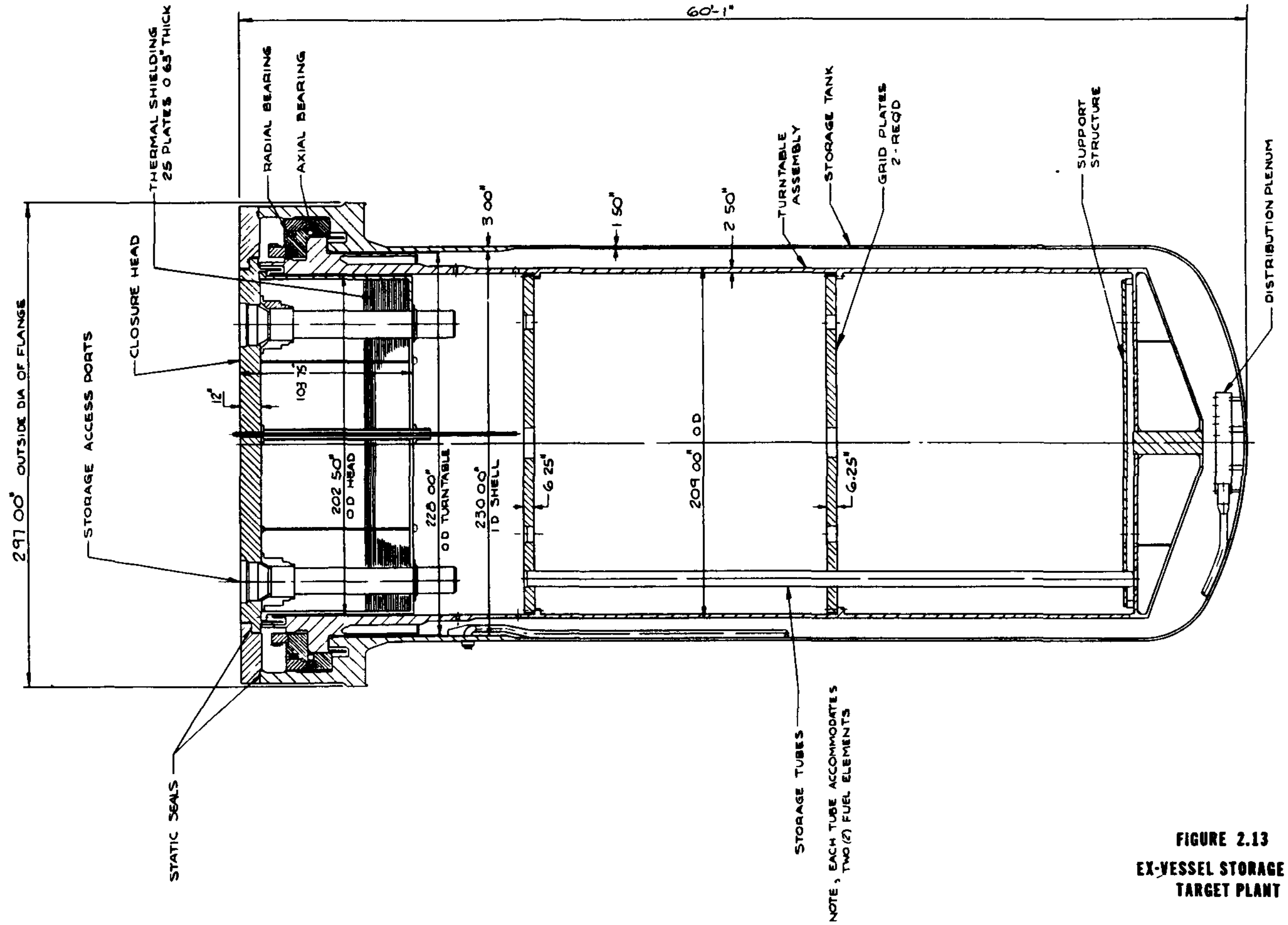


FIGURE 2.13
EX-VESSEL STORAGE TANK
TARGET PLANT

The physical size of the head is defined by the 294.00 inch outside diameter, the 103.75 inch height (including the insulation canister); and, the total assembled weight of approximately 150 tons.

Materials of construction for the closure head are SA-240, Type 304, for the insulation material and canisters and SA-633, Grade B, Class 1, for the 12.00 inch structural plate.

The closure head is designed and fabricated in accordance with the requirements of Section III, Class 2, of the ASME Boiler and Pressure Vessel Code.

The turntable assembly is perhaps the most complicated component of the EVST. It can be described as a vertically-oriented cylindrical structure which provides support for and defines the location of the fuel storage tubes. The upper flange of the turntable assembly is machined to rest on bearings within the upper vessel flange.

The outer wall, or structural member, of the turntable is 2.50 inches thick throughout most of the component length. A cylindrical skirt is attached in the flange region and extends downward. This skirt is closely machined to fit the inside diameter of the storage vessel to facilitate sodium frost removal. The lower end of the component is closed by a flat support structure weldment which has flow holes to permit the passage of sodium up through the fuel storage tubes. There are two 6.25 inch grid plates located as shown in the figure at intermediate elevations within the turntable assembly. The two grid plates and the support structure provide accurately located holes for supporting the storage tubes.

The turntable assembly has a total weight of approximately 246 tons, is 56 feet long and the flange and outer wall diameters are approximately 226 and 209 inches, respectively. It is manufactured entirely from SA-240, Type 304, steel and is designed and fabricated in accordance with the requirements of Section III of the ASME Boiler and Pressure Vessel Code.

Referring again to the above referenced figure, the turntable is suspended within the vessel on bearings. Thus, after the closure head has been installed, the turntable can be rotated within the stationary vessel/closure head assembly. A drive mechanism is provided such that the turntable can be indexed to a known position. Thus, after the correct access port plug has been removed, access is provided to all the storage positions within the turntable.

2.3.5 Inert Gas System

The inert gas receiving and processing system consists of the following subsystems:

- Argon Distribution Subsystem (ADS)
- Nitrogen Distribution Subsystem (NDS)
- Radioactive Argon Processing Subsystem (RAPS)
- Cell Atmosphere Processing Subsystem (CAPS)

2.3.5.1 Argon Distribution Subsystem

The Argon Distribution subsystem provides cover gas to all liquid metal free surface areas, including inflatable and buffered head seals. The system provides the required inert atmosphere to the liquid metal containers for draining, purging or filling these containers. The argon gas itself is also cleansed of any oxide impurities. Separate systems are provided for the primary and intermediate sodium systems.

The radioactive ADS is supplied by gas bottles stored in the Reactor Service Building and supplies argon via a header arrangement to the EVS sodium system, the reactor vessel head seals, primary cold traps, the primary sodium storage tank, and the fuel handling systems. Recycled argon from the RAPS is introduced into the primary ADS from which it is distributed to the reactor vessel and to the sodium pumps and overflow vessel.

The intermediate system ADS is supplied by gas bottles stored in the steam generator buildings. A header arrangement distributes fresh argon to the intermediate system at the intermediate expansion tank and the intermediate sodium dump tanks. Since this gas is not radioactive, venting to the atmosphere is done via an oil bubbler.

Primary and intermediate systems have the same general component makeup with the exception that the primary argon discharge goes to a radioactive cover gas header for processing by the RAPS. The major components include argon gas bottles, vaporizers, argon filters, sampling packages, relief vents, vapor traps, freeze vents, feed-bleed valves, and the associated piping.

2.3.5.2 Nitrogen Distribution Subsystem

The Nitrogen Distribution Subsystem (NDS) functions primarily to provide an inert atmosphere and thus reduce the sodium-air reaction problems in case the liquid sodium coolant escapes its designed pressure boundaries. The system also provides cooling for the various cells containing radioactive sodium or sodium vapors. Additionally, the NDS provides a cover gas to the radioactive liquids produced by the RAPS.

Cold traps and other regenerative heat exchangers such as those in the RAPS use nitrogen as the cooling gas. In some instances, the nitrogen may be processed in the RAPS if it becomes radioactive.

Nitrogen stored in the containment building is used to inert primary and auxiliary loop heat transport cells, inert the EVST cell, furnish nitrogen to the CRITAS, and provide cooling in liquid form for the RAPS.

Nitrogen stored in the steam generator building is used as a cover gas to Dowtherm tanks for servicing the sodium components cleaning facility, and to provide the capability for inerting steam generator cells in the event of a sodium water reaction.

2.3.5.3 Radioactive Argon Processing Subsystem (RAPS)

The RAPS system removes radioactivity, due mostly to fission gases, from argon and returns clean argon to a storage tank for recycling through the plant systems. The contaminated argon from the reactor vessel, overflow tank, primary pumps, cold traps, isolation valves, fuel storage tank, and fuel handling equipment flows through vapor traps, filters, delay tanks, charcoal adsorbers and a distillation column for removal of radioactive impurities (Figure 2.14). Clean argon is returned to a storage tank for redistribution to the plant systems. The vapor traps located near the sodium components remove the sodium vapor and the particulates are removed in the on-line absolute filters. Delay tanks provide for decay of short lived isotopes and the gaseous fission products are removed in charcoal beds by adsorption and in the distillation column by liquidification. The clean argon, containing less than 10^{-5} μC_i/cc radioactivity, is returned to the storage tank for recycle. The system is sized to provide for argon recycle which may be necessary in case of reactor operation with 1% fuel failure. The nominal argon flow rate is 8 SCFM whereas the maximum flow rate is 25 SCFM to provide for normal and abnormal requirements for cover gas purification.

A part of the argon stream coming from the distillation column is mixed with contaminated argon flowing to charcoal columns to provide for desired flow and density distribution between argon and radioactive contaminants. The pressure of clean argon in regenerative heat exchangers is maintained above the pressure of the contaminated argon to prevent any contamination of clean argon. Except for some piping connections, most of the radioactive argon processing system is contained within the Reactor Service Building.

2.3.5.4 Cell Atmosphere Processing Subsystem

The Cell Atmosphere Purification Subsystem (CAPS) is essentially a second gas purification system ensuring that effluent gases released from the plant will have radioactivity levels as low as practicable. The usual

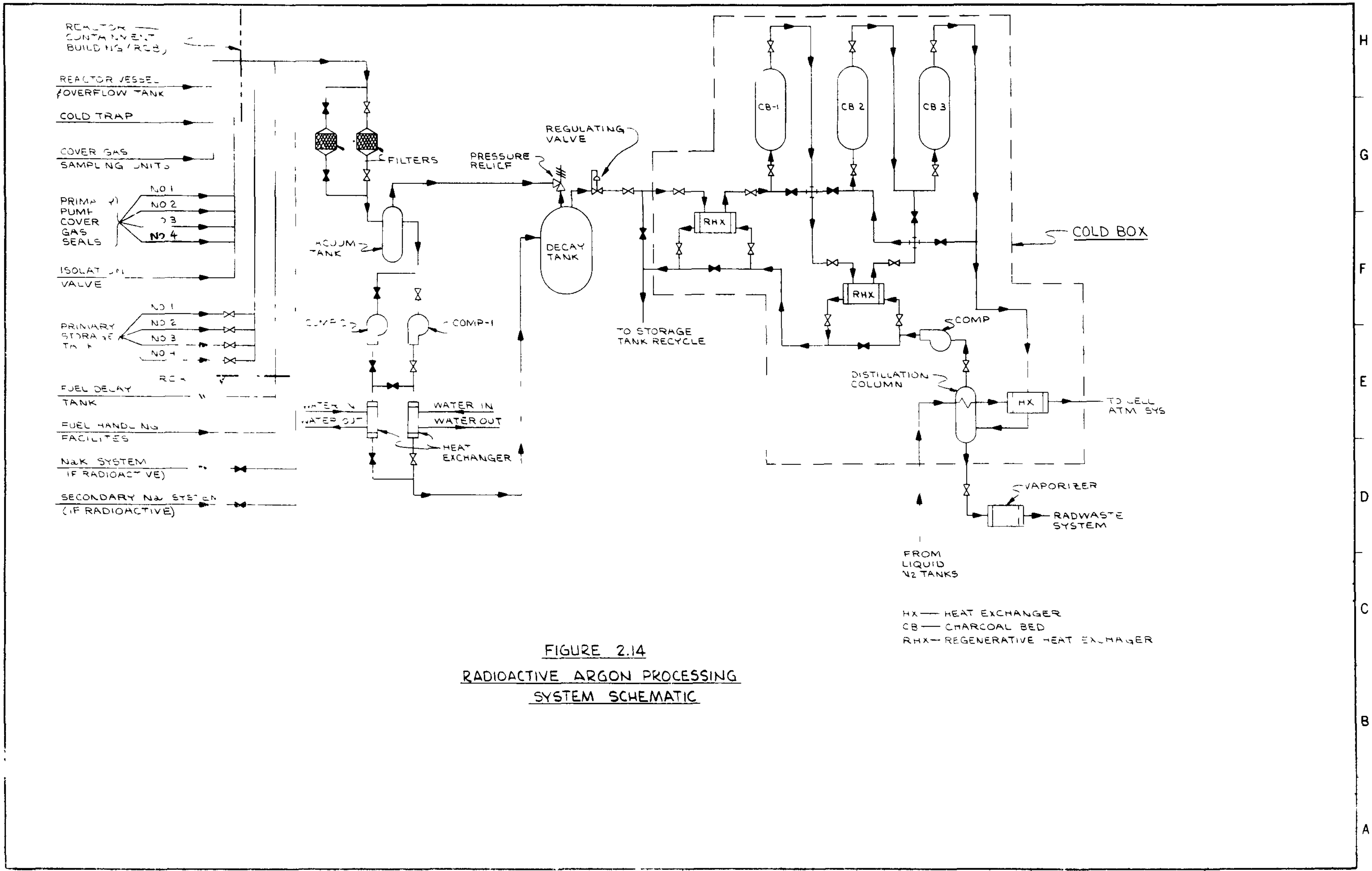


FIGURE 2.14

RADIOACTIVE ARGON PROCESSING SYSTEM SCHEMATIC inputs to CAPS are nitrogen used to inert the various cells, low level radioactive argon cover gas from the intermediate systems, and effluents from atmospheric vents located throughout the plant. The normal function of this system is to remove tritium from the air and nitrogen prior to release to the plant exhaust.

Vapor Traps

Vapor traps in the argon piping are located near the sodium components to minimize the length of trace heaters between the trap and the component. The vapor trap is a vertically mounted shell and tube heat exchanger with air or N_2 blowers. Hot cover gas enters at the bottom of the shell and is cooled by cell air or N_2 which is blown counter-current through the tubes. Sodium vapor is condensed on the tube surfaces. Resistance heating elements are provided to melt sodium for draining as required.

Particulate Filters

Particulate filters are provided to remove any particulate material which may pass through the vapor traps. These filters are cylindrical vessels containing stainless steel filter elements which can be replaced by remote methods.

Vacuum Tank

This carbon steel vessel has 4000 gallons capacity and is rated at 150 psig at 120°F. The vessel is approximately 7'-0" diameter by 14'-0" and is installed with its longitudinal axis in a horizontal plane. This vessel is connected to two compressors rated average at 8 SCFM and maximum of 25 SCFM. The vessel provides sufficient volume to allow for one compressor to reduce the vessel pressure from -2 psig to -7 psig in 20 minutes of operation.

Cold Box

The cold box consists of a series of charcoal columns, regenerative heat exchangers and a distillation column. Radioactive argon is cooled in the regenerative heat exchanger, and is passed through charcoal beds. Heavy isotopes, i.e., Krypton and Xenon, are retained in the charcoal by absorption, whereas the relatively clean argon flows to a distillation column. Liquid N_2 cools the gases in the distillation column, liquefying radioactive impurities in argon which are delivered to the radwaste system. Clean argon from the distillation column is heated in regenerative heat exchangers and pumped to a storage tank for recycling through the system.

Compressors

The compressors are 25 SCFM units designed for radioactive gas service. These compressors are used to pump argon to the RAPS surge and delay tank. The compressors are located in the Reactor Service Building in cells which have sufficient shielding to allow maintenance of one compressor while the other is operating. The minimum compressor inlet pressure is -7 psig and maximum discharge pressure is +135 psig.

Surge and Delay Tank

This carbon steel vessel has 7200 gallon capacity and is rated at 150 psig pressure at 120°F. The vessel is approximately 7'0" diameter by 25' long and is installed with its longitudinal axis in a horizontal plane. The vessel provides a hold-up time of a minimum of 4 hours.

Charcoal Absorber Beds

The Argon Processing System utilizes 3 charcoal beds. These charcoal beds are located in the cold box in the Reactor Service Building. Each bed is approximately 3 feet in diameter and 8' long. The beds will be operated at temperatures down to -290°F and have a design pressure of 150 psig. The charcoal columns have the axial line in vertical position to ensure uniformity of flow and charcoal compactness. The radioactive argon gas enters the column at the bottom and leaves the bed via the nozzle at the top of the column.

Cryogenic Distillation Column

A cryogenic distillation column is used in the Radioactive Argon Processing System to remove 99.9% of the Krypton and 99.99% of Xenon. These removal factors are necessary to reduce the effluent activity to less than 10^{-5} μC_i/cc. Also the above removal factors are approximately the maximum.

Cold argon near its saturation temperature enters near the bottom of the packed distillation column and rises up through the packing. The vapor is constantly scrubbed by reflux liquid argon flowing down through the column which extracts the Krypton and Xenon from the vapor phase. The resulting clean argon passes through the top of the column while the Krypton and Xenon collect as a liquid in the bottom of the column. Liquid nitrogen provides the refrigeration for the column but does not come into direct contact with argon, thus maintaining argon purity.

Xenon/Krypton Vaporizer

This vaporizer in the argon processing system is an air-to-liquid heat exchanger used to vaporize the argon/Xenon/Krypton mixture when it is periodically removed from the bottom of the distillation column.

2.3.6 Auxiliary Liquid Metal System

The Auxiliary Liquid Metal System provides the facilities for receipt, storage, and purification of all liquid metals used in the plant. The system consists of the following subsystems:

- Sodium Loading and Unloading System

- Primary Sodium Overflow and Makeup System
- Primary Sodium Purification and Storage System
- Ex-vessel Storage Tank Sodium Processing System
- Intermediate Sodium Purification and Storage System
- NaK Storage and Purification System

2.3.6.1 Primary Sodium Overflow and Makeup System

The reactor overflow and makeup circuit operates continuously during reactor operation to maintain a constant sodium level in the reactor by accommodating volumetric changes in the primary sodium due to temperature variations. During operation, sodium overflows from the reactor vessel by gravity to the primary sodium overflow tank. The primary sodium makeup pumps continuously pump sodium from the overflow tank to the reactor vessel at a constant makeup rate of 350 gpm. The overflow rate varies during system transients but is equal to the makeup rate during steady state operation of the plant systems. The makeup requirement corresponding to a load variation which results in ±3.5°F/minute change in sodium temperature is 312 gpm. Thus, the makeup rate of 350 gpm ensures that maximum makeup requirements are met to maintain a constant sodium level in the reactor vessel. Two electromagnetic pumps each having 100% capability are provided to ensure redundancy and reliability.

The overlfow tank size (20' x 25') is based on the expansion of primary sodium from 400°F (refueling temperature) to design temperature (950°F). A 700 gallons margin is included for possible secondary Na leakage into primary sodium. A 20% margin is reserved for gas volume in the overflow tank.

2.3.6.2 Primary Sodium Purification System

The primary sodium purification system, as illustrated in Figure 2.15, consists of three 100% capability NaK-cooled sodium cold traps installed in parallel to each other and to the primary sodium makeup line. The makeup pumps take suction from the overflow tank and deliver sodium to the reactor vessel. Part of this flow is directed to the cold traps for sodium cleaning and impurity control. Normally, only one cold trap in operation is required during plant operation to maintain the primary sodium purity level to required specifications, but during refueling when the inleakage may be larger than normal, all three cold traps could be pressed into service to maintain sodium purity.

2.3.6.3 Primary Sodium Storage System

Eight storage tanks, two per loop, are provided for the Target Plant primary sodium storage. Each storage tank is sized to accommodate complete drainage of a PHTS loop. A 10% margin is provided for cover gas volume.

Drain connections with isolation valves are provided at low points of the PHTS to provide for complete drainage of primary sodium by gravity to the overflow tank.

2.3.6.4 Ex-Vessel Storage Tank Sodium Processing System

The Ex-vessel Storage Tank (EVST), which provides for storage of spent fuel subassemblies and other reactor components, is located below the floor in the Reactor Containment Building. The EVST sodium processing system controls the temperature and purity of the sodium contained in the EVST.

The EVST sodium cooling system has two independent cooling circuits, each consisting of a sodium electromagnetic pump, a sodium-to-NaK heat exchanger, a NaK electromagnetic pump, a Nak-to-air forced-air heat exchanger and associated piping and valves. Each circuit is sized to remove about 3.5 Mwt heat, estimated to be the maximum decay heat load due to radioactive

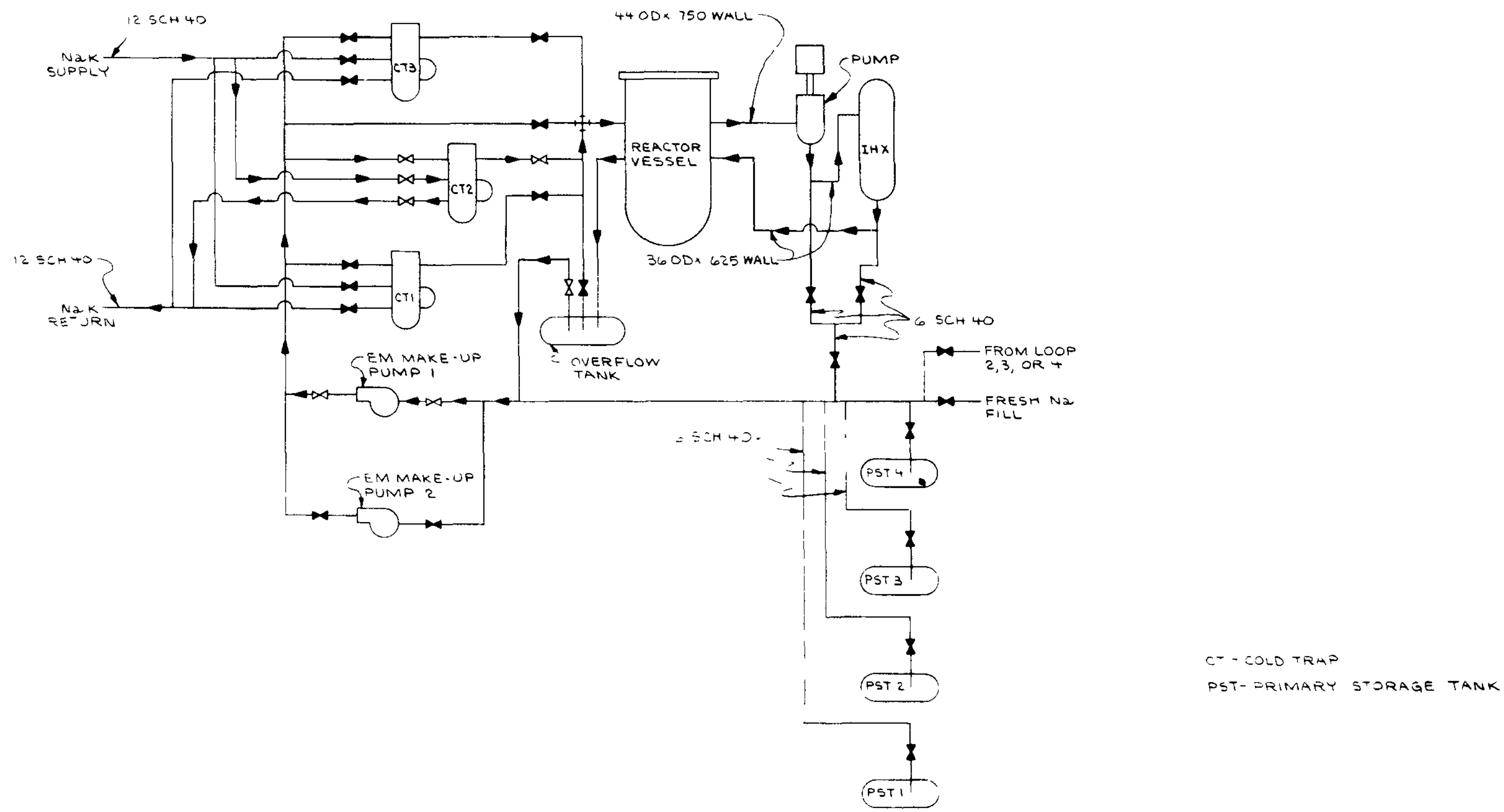


FIGURE 2.15

PRIMARY SODIUM PURIFICATION SYSTEM SCHEMATIC components in the storage tank. The two cooling circuits are supplied by the essential bus, and redundancy, independence and reliability of the cooling circuits are assured. The sodium pumps are rated at 980 gpm for 100 ft. of total developed head. One of the primary storage tanks provides for drainage of the EVST as well as for any sodium makeup requirements.

The EVST purification system consists of two 100% capacity purification circuits. Each circuit consists of one regenerative heat exchanger, a NaK-cooled sodium cold trap (rated at 100 gpm) connected in parallel to each of the EVST cooling circuits. Only one cold trap circuit is required for maintaining normal purity of sodium with an EVST inventory turnover of about 10 hours. During fuel handling, however, both the cold traps are pressed into service to provide for cleanup.

2.3.7 Equipment Heating and Temperature Control System

All pipes, tanks, heat exchangers, and other equipment containing sodium must have heating systems for preheating and melting the sodium which is solid below 208°F. This heat is required to preheat sodium systems prior to fill, to prevent sodium freezing and to maintain preestablished temperature differences in the systems. To perform the heat-up function, the heating system must be capable of preheating the sodium systems from ambient temperature (70°F) to any temperature between ambient and a maximum of 400°F at a rate of 3°F/hr, before the system is filled with sodium. This heating is done over a long period of time and at a very slow heat-up rate (four to six days) in order to minimize temperature differences within the sodium process system.

The heating systems use forced circulation of heated nitrogen and electric resistance heaters. The forced nitrogen circulation is used in conjunction with trace heating to preheat vessels, component internals and cavities before the systems are filled with sodium. The second method (trace heating) is utilized to provide the applicable heatup rate for the particular system or components when filled with sodium, and to hold system temperatures when filled with sodium during prolonged shutdowns.

These heaters are arranged, grouped and controlled in zones of uniform heat output. Temperature sensing devices (thermocouples) monitor each zone and provide the necessary feedback for power level adjustment in the heaters. The heater physical mounting arrangement and associated hardware must be designed to prevent damage to the component being heated and not to impair the ability of the components to perform their safety function. The heaters are of a resistance type consisting of a single spiral wound nickel-chromium alloy resistance wire insulated from its Inconel or stainless steel tubular sheath by tightly packed magnesia powder. Several inches on each end of each heater are unheated having a heavy lead-out conductor to the electrical termination.

The heaters stand off from the sodium containing metal boundary for the safety-related piping and components. For the nonsafety-related components, the heaters may be applied directly in contact with the sodium containing metal boundary. Shorting of heater elements to the heater sheath is prevented by insertion of ground current detection and interrupting devices in the heater circuits. Heater redundancy is provided where failure could cause undesirable thermal stresses, or where access for heater replacement is restricted. Reliability is improved by operating the heaters at half their rated power. They may be operated above half power should additional heat output be required.

Depending on the application the power to the heaters may be controlled by manual switches, solenoid-operated contractors, transformers or triacs. The use of the above circuits is dictated by heat requirements such as infrequent heat, routine load, constant load or fast changing heat output. Chromel-alumel thermocouples Type "K" are used throughout the sytems for monitoring the temperature of the metal boundary of the sodium containing components. Signals are relayed to the data handling and display system, where the input is fed to the controllers and recorded in the data handling and display system.

Electric heaters are provided for all piping and equipment containing sodium or sodium vapors. Some applications, such as storage tanks, may require electric heat continuously during all phases of plant operation. Other applications, such as main heat transport systems, require heat only at startup and during shutdowns.

The major systems requiring heaters, temperature sensors and instrumentation are listed below:

Reactor System
Reactor Refueling System
Primary Heat Transport System
Intermediate Heat Transport System
Steam Generator System
Auxiliary Heat Transfer System
Auxiliary Liquid Metal Systems
Inert Gas Receiving and Processing System
Sodium Impurity Monitoring System

2.3.8 Instrumentation and Control System

The Instrumentation and Control System for the Target Plant consists of the following subsystems:

- Data Processing System
- Safety Systems
- Control Systems
- NSSS Process Monitoring Systems

2.3.8.1 Data Processing System

The Data Processing System is a digital-computer-based data system which is used to monitor, analyze and record the plant data used for evaluation of plant performance. Essentially all other control systems provide input signals to the Data Processing System. The System performs no control or safety function and is used to fulfill the following primary functions:

(1) Reactor core thermal/hydraulic map

(2) Fuel burnup calculations, Fuel Management

(3) Reactivity worth and control rod calibration

(4) Heat balance calculations

(5) Performance calculations of key components, e.g. pumps, IHX, Steam Generators

The plant operator communicates with the system via pushbuttons which permit him to call up data for display or printout. Permanent data records are stored on magnetic tape for subsequent recall and analysis.

2.3.8.2 Safety Systems

The safety systems consist of the following:

(1) Plant Protection System

(2) Containment Isolation System

Plant Protection System

The plant protection system consists of two reactor shutdown systems which are as follows:

(1) Primary Shutdown System

(2) Secondary Shutdown System

The primary and secondary shutdown systems, developed by C-E, employ electromagnetic and pneumatic release mechanisms respectively and provide an independent and diverse means of reactor scram. The latch, holding the control assembly, is released upon receipt of a scram signal. The control assembly release and drop times (less than 2 seconds) are comparable to those of CRBRP.

An alternate secondary shutdown system, incorporating a self actuated feature, has been developed by C-E under contract to EPRI. The self actuated shutdown system relies on sodium flow to both hold out (at normal flow rates) and release (at low flow rates) the control assembly. In addition the control assembly is automatically released upon occurrence of a fast decrease in flow rates which exceeds the normal rate of change of flow rates. This is due to activation of a rate-of-change-of-pressure device which acts on the principle of release of stored potential energy upon a sharp drop in flow rate to release the control assembly for reactor shutdown. The device is an integral part of the control assembly and is wholly contained within the reactor assembly so that it is not influenced by occurrences outside the reactor boundary. The self activated shutdown system, therefore, protects the reactor against events such as pump trip without scram and serves as a backup to the primary shutdown system. This alternate design is also actuated by the Plant Protection System.

Each system has detectors capable of responding to all anticipated faults, and a reactivity control system capable of reactor shutdown with one stuck control rod. Each system is redundant within itself and capable of meeting the single failure criterion in conformance with NRC guidelines.

Containment Isolation System

The Containment Isolation System consists of redundant instrumentation which senses the need for closure of certain valves in lines directly connected to the containment atmosphere. The system is designed so that the isolation valves are automatically closed within a specified time to secure the containment and limit release of radioactivity.

2.3.8.3 Control Systems

The instrumentation and control equipment used for control of the reactor and heat transfer system and the auxiliary and process systems which make up the NSSS are divided into the following systems:

1) Neutron Flux Monitoring

2) Process Instruments

3) Plant Control

4) Process Control

Neutron Flux Monitoring

This system measures the reactor neutron flux, which is proportional to the thermal power generated in the core. During power operation, the system provides a neutron flux control signal to the Plant Control System which sets reactor power to the setpoint power by moving control rods. If emergency or unsafe conditions arise, the system will generate signals which will be used by the Plant Protection System to shut down the reactor and stop the main heat transfer system sodium pumps.

The Neutron Flux Monitoring System is composed of two separate and independent systems:

1) The In-Vessel Flux Monitoring System, which is used for refueling subcriticality determination.

2) The Ex-Vessel Flux Monitoring System, which is used during reactor operation.

The In-Vessel Flux Monitoring System, used for determination of the shutdown reactivity during refueling operations, consists of neutron detectors, preamplifiers, power supplies, and a subcriticality monitoring unit. The output of the system, in the event that loading errors lead to an approach to criticality, is an interlock signal to the IVTM to prevent the further addition of fuel.

The Ex-Vessel Flux Monitoring System measures the reactor neutron flux over the full range from the initial source level to 200% power, and provides signals to the Plant Control System, the Plant Protection System, and the Plant Data System. The system consists of three types of instrument channels - wide range, linear protective, and linear power channels - each consisting of three redundant channels.

Process Instruments

This category includes all process instruments (sensors and signal conditioning equipment) that supply input signals to the Reactor Power Control System and the control Systems for the various auxiliary and process systems, with the exception of the Neutron Flux Monitoring System described earlier. The more significant of these are as follows.

Temperature measurements throughout the NSSS are made with stainless steel-sheathed, magnesium-oxide-insulated, Chromel-Alumel thermocouples. The temperature of fluids or gases in piping or heat transfer components is measured with thermocouples welded to the outside of the piping or vessel or, if a short time constant is important, located in a thermal well.

The basic instrument for the measurement of sodium flow in all sodium systems is the permanent magnet electromagnetic (EM) flowmeter. This type of flowmeter can be used on all pipe sizes from 1 in. up to that required for the main heat transfer loops. A multi-electrode configuration is used to obtain improved linearity of the flow vs. output voltage characteristic, and to provide for signal isolation when used in the protection system.

NaK-filled volumetric pressure transducers will be used for pressure measurements in sodium systems. These transducers consist of a diaphragm or bellows which is in contact with the sodium and acts as a seal, an interconnecting capillary line between the seal and a pressure measurement elastic member, and a transducer which converts displacement to an electrical or pneumatic signal. The capillary is filled with NaK, a sodium-potassium alloy. The pressure-sensing portion of the device is of all-welded construction and is welded into the pipe or vessel where the pressure measurement is to be made. The seal member senses the sodium pressure changes through the diaphragm (or bellows) seal and transmits them via the incompressible fluid NaK through the capillary to a transducer located remotely in a less severe environment.

Two basic types of sodium level measurement devices are used. The first type provides a simple on-off type signal when a given level is reached. The second provides a continuous measurement of level over a specified range. Both types employ inductive coils which are installed in closed-end, stainless-steel thimbles extending into the sodium. They operate on the principle that a coil energized by an alternating current will induce a current in any closed conducting path surrounding the coil that depends on the impedance (sodium or air) of the surrounding material.

Sensors provide control rod position information for the control rod drives. In the reference design, the shim-safety rod drives have two methods of rod position indication. Linear variable differential transformers (LVDT) are used as an absolute measure of rod drive position. A more precise differential position measurement is obtained by counting the number of pulses to the roller nut drive motors.

Conventional process instruments are used for pressure and flow measurement of argon and nitrogen gas, water and steam, etc.

Plant Control

The control system for the once through steam generator system consists of reactor and heat transport feedback control systems, and a master control (MC). The master control provides the setpoints for the feedback control systems and can be used for "fed forward" or anticipatory control for reactor operation at 40% to 100% range of power level. Below 40% power level, the plant systems are in the manual control mode of operation.

When a load increase is demanded, simultaneous increases are demanded in feedwater flow, intermediate loop sodium flows, and primary loop sodium flows. The total primary loop flow increases, resulting in a demand for inceased neutron flux, and is met by pulling reactor control rods. Hence, with an increase in load, there is a rapid increase in system flows and in reactor flux. Thereafter, a number of trim signals are applied to the controllers to maintain steam pressure and sodium temperatures at the values determined by the part-load schedule. These trim control actions include adjustment of feedwater pressure, reactor outlet temperature, and the cold and hot leg temperature of the intermediate sodium loops.

The power demand plus the main steam header pressure control error signal are inputs to the master control unit and form the plant load demand. The master control unit converts the load demand to properly scaled setpoints for the individual control systems according to the part load schedule for that particular controlled variable.

It is possible for the plant operator to set the load demand manually. If steam pressure is then placed under control of the initial pressure regulator on the turbine, the plant operates in a "load-forcing" mode where the turbine accepts the power produced by the reactor.

The final control elements are the shim-safety control rods which are positioned by a controller in response to feedback from flux sensors. This subassembly is called the flux controller.

The main index for the flux controller is the product of measured total sodium flow through the reactor and calculated reactor differential temperature set by the master control unit and the measured reactor inlet temperature. During normal operation, differential temperature is nearly constant, but it represents a scaling factor on measured flow.

The flux controller maintains, within the allowable deadband, reactor power at the demand value. The demand flux is primarily the steady-state power established by total primary sodium flow. A trim on outlet temperature is added to the demand for changing conditions.

The reactor temperature control system provides the trim signal to the flux controller. This signal maintains the reactor outlet temperature within its prescribed limits. The fuel assembly outlet temperature is fed back to the temperature controller. The setpoint for the controller is a floating proportional signal computed from the measured reactor outlet temperature and the corresponding setpoint signal provided by the master control unit.

The intermediate flow control is achieved with a cascade control system. The measured flow signal is compared by a flow controller to the setpoint value set by the master control unit. The output of the flow controller provides the setpoint for the cascade pump speed controller.

The primary flow control system is also a cascade control system similar to the intermediate system. However, an intermediate hot leg temperature trim control is combined with the flow setpoint signal set by the master control unit. The temperature trim signal acts to maintain the intermediate hot leg temperature and thus, steam temperature is at prescribed value and automatically compensates for heat transfer performance difference.

The feedwater flow controller modulates the throttle valves in the feedwater line to maintain the flow at the value set by the master control unit. The intermediate cold leg temperature is maintained within prescribed limits by a trim signal derived from the measured value and master control unit setpoint, which is combined with the feedwater flow setpoint.

The feedwater pressure control system maintains feedwater pressure required to achieve a satisfactory differential pressure across the valves used for final control of feedwater flow.

Process Control Systems

Each of the following process and auxiliary systems has a separate instrumentation and control system as an integral part of this system:

1) Sodium Supply and Purification System

2) Stored Fuel Cooling System

3) Steam Generator Rupture Relief System

4) Argon Supply System

5) Nitrogen Supply System

6) Steam Generator Startup and Dump System

7) Radioactive Vent and Argon Purification System

8) Liquid and Solid Waste System

2.3.8.4 NSSS Process Monitoring Instrumentation Systems

The instrumentation systems used to monitor the performance of the systems and components in the NSSS portion of the plant are grouped into the following systems:

1) In-Core Fuel and Core Structure Monitoring

2) Equipment Operating Surveillance

3) Coolant Composition Monitoring

4) Failed Element Detection and Location (FEDAL)

5) Radiation Monitoring System

In-Core Fuel and Core Structure Monitoring System

The In-Core Fuel and Core Structure Monitoring System provides the sensors and signal conditioners required to monitor the thermal, hydraulic, and structural performance of the reactor core complex. This system provides inputs to the Reactor Power Control System, the Plant Protection System and the Plant Data System.

Equipment Operating Surveillance System

The Equipment Operating Surveillance System provides the sensors, signal conditioning and, in some cases, the display and recording equipment used for: detection of anomalous performance, incipient failure detection, malfunction diagnosis, and verification of design parameters. These instruments are not required for normal plant operation. The majority of information developed by these instruments is recorded and displayed for use by the operator via the Plant Data System.

Coolant Composition Monitoring System

The Coolant Composition Monitoring System provides the instruments and equipment used to measure the level of impurities in the sodium of the various heat transfer and process systems. Readout of these instruments is by locally mounted indicators and recorders and via the Plant Data System.

Failed Element Detection and Location

The FEDAL System is intended to provide monitoring instrumentation necessary to detect and locate failed or leaking fuel assemblies.

Radiation Monitoring System

The Radiation Monitoring System provides the instrumentation, control and indication circuits and devices required to detect, indicate and record the radiation levels in the various plant areas, process systems, and gaseous and liquid effluents. The Radiation Monitoring System will provide instrumentation to initiate containment isolation, to control safe refueling, and to monitor personnel. In addition, the system will provide indication and alarms to advise personnel of radiation levels throughout the plant, and portable radiation detection equipment for monitoring special activities such as refueling, maintenance activities and radiation surveys of the plant areas.

SECTION 3

COST ESTIMATE

3.1 INTRODUCTION

This section contains the details of the total direct capital costs for the Nuclear Steam Supply System of the LMFBR plant described in Section 2. The criteria used to develop the cost estimates are specified in Section 1 and 2. The cost estimates reflect the reference plant design at the "Middletown" hypothetical site.

The total direct capital cost for the NSSS is $267,574,000 or $192/KWe based on January 1978 prices. This cost is the factory shop-door sell price and does not include owner's contingency, interest, escalation and installation costs.

The costs are organized in accordance with the expanded AEC Code of Accounts (USAEC Report NUS-531). Therefore, it corresponds in structure to the plant design description (Section 2) and the equipment list (Section 6).

3.2 COST BASIS

The cost bases for the major components and systems are presented here.

Reactor Vessel and Reactor Vessel Closure Head

The reactor vessel and reactor vessel closure head designs were analyzed from a cost point of view assuming the following conditions:

- The estimates include only hardware shown on the referenced figures (Section 2).
- The components are the fifth of a kind to be fabricated in C-E's shops; thus, the necessary specialized fixtures, shop handling equipment, and shop procedures are already in existence.

- All basic engineering has been previously performed and only certain specalized customer-requested changes must be addressed.

- The estimates are based on shop-door costs of the completed components and do not include shipping fixtures or other costs associated with component transportation to the site, nor do the estimates include fees for installation or overseeing the installation of the components.

Primary Pumps

Rough estimates for pump costs and drives were obtained from the Byron Jackson Pump Division of the Borg Warner Company. These estimates are based on 1978 dollars and are subjects to escalation. These estimates are based on the following assumptions:

(1) Pumps are fifth-of-a-kind.

(2) Order of four plants per year is assumed.

(3) The estimates are for factory shop-door costs including design engineering and fabrication.

(4) Shipping and installation costs are not included.

(5) Pump supports, insulation and trace heating are not included.

Intermediate Heat Exhangers

The intermediate heat exchanger design was analyzed from a cost point of view assuming the following conditions:

- The estimate includes only that hardware shown in the referenced figure (Section 2).

- The components are the fifth of a kind to be fabricated in C-E's shops; thus, the necessary specalized fixtures, shop handling equipment, and shop procedures are already in existence.

- All basic engineering has been previously performed and only certain specalized customer-requested changes must be addressed.

- The estimates are based on shop-door costs of the completed components and do not include shipping fixtures or other costs associated with component transportation to the site, nor do the estimates include fees for installation or overseeing the installation of the components.

Piping

Piping lengths for large diameter piping were estimated by measurement of centerline distances between fittings from the layout drawings (Section 5). The piping lengths for small diameter piping were estimated by applying a length factor to the centerline distance between components. The length factors used for the sodium and gas piping are 2.0 and 1.5 respectively to allow for expansion loops and routing. The costs for the piping was derived from the CRBRP piping costs by adjustments for escalation and classification.

Steam Generators

The steam generator design was analyzed from a cost point of view assuming the following conditions:

- The estimate includes only that hardware shown in the reference figure (Section 2).

- The components are the fifth of a kind to be fabricated in C-E's shops; thus, the necessary specialized fixtures, shop handling equipment, and shop procedure are already in existence.

- All basic engineering has been previously performed and only certain specialized customer-requested changes must be addressed.

- The estimates are based on shop-door costs of the completed components and do not include shipping fixtures or other costs associated with component transportation to the site, nor do the estimates include fees for installation or overseeing the installation of the components.

Expansion Tank

The Secondary Sodium Expansion Tank design was analyzed from a cost point of view assuming the following conditions:

- The estimate includes only that hardware shown in the above referenced figure (Section 2).

- The components are the fifth of a kind to be fabricated in C-E's shops; thus, the necessary specialized fixtures, shop handling equipment, and shop procedures are already in existence.

- All basic engineering has been previously performed and only certain specialized customer-requested changes must be addressed.

- The estimates are based on shop-door costs of the completed components and do not include shipping fixtures or other costs associated with component transportation to the site, nor do the estimates include fees for installation or overseeing the installation of the components.

Fuel Handling Components

In-Vessel Handling and Auxiliary Handling Machines

These machines are similar in function and design to those for the CRBRP. The cost extimates for these machines were, therefore, based on the CRBRP cost estimates with adjustments for a fifth of a kind plant.

Ex-Vessel Handling Machine

This machine is similar in function to the EBR II unloading machine and the C-E System 80 refueling machine. The cost estimate for this machine was, therefore, developed using the cost data base of the C-E System 80 refueling machine. Some adjustments to the price were made for complexity and additional hardware required for cooling and shielding of the Target Plant machine.

Ex-Vessel Storage Tank

The EVST was assumed to be similar in design and layout as that for CRBRP. The Ex-Vessel Storage Tank design was analyzed from a cost point of view assuming the following conditions:

- The estimate includes only that hardware shown on the referenced figure (Section 2).

- The components are the fifth-of-a-kind to be fabricated in C-E's shops; thus, the necessary specialized fixtures, shop handling equipment, and shop procedures are already in existence.

- All basic engineering has been previously performed and only certain specialized customer requested changes must be addressed.

- The estimates are based on shop door costs of the completed components and do not include shipping fixtures or other costs associated with component transportation to the site nor do the estimates include fees for installation or overseeing the installation of the components.

Other components for the Fuel Handling System such as floor valves, cranes, conveyors, etc., are fairly common industrial components. The prices for these components were obtained from the C-E System 80 data base.

Every proposed LMFBR reactor design includes a unique refueling scheme and refueling machines. Because of non-typicality a large uncertainty remains in the cost estimates of these machines inspite of exercise of experienced engineering judgement. It is estimated that this uncertainty could result in cost to estimate ratio between 0.5 and 2.0.

Auxiliary System

All component costs were estimated on a basis similar to current LWR practice, especially those items similar in kind to current LWR components. Cost estimates were provided for a fifth-of-a-kind plant. Standard sodium components such as electromagnetic pumps and filters were priced by contacting vendors using Target Plant design requirements. Vaporizers, distillation units, etc., were treated as heat exchangers and priced according to similar LWR units. All tanks were priced as 304SS and were treated according to function as similar LWR tanks. Other sodium related equipment was priced according to design description and function using LWR cost estimators.

Sodium valve requirements were extrapolated from existing LMFBR designs and scaled to the Target Plant specifications with one generic valve type assumed to represent all valves. Classification of valves as remote and manual actuation was also estimated. Sodium piping lengths for the auxiliary systems were produced by considering the straight line lengths from one component to another and using a factor of 2 to account for thermal expansion and pipe routing additions. Inert gas valve requirements were based on Target Plant specifications for systems currently designed such as the RAPS, and were approximated for other systems currently under design such as the CAPS. A single valve type was assumed to allow for the estimation of inert gas valve costs. Piping lengths were based on a straight line distance between distribution manifolds and the various components. A factor of 1.5 was applied to account for routing and thermal expansion effects.

Instrumentation and Control

The prices for standard I&C were obtained from the comparable C-E System 80 cost data base. The costs of the specialty components were estimated based on information obtained from various vendors.

3.3 COST ESTIMATE

A summary of the cost estimates for the Nuclear Steam Supply System is given in Table 3.1.

TABLE 3.1

COST ESTIMATE SUMMARY

1390 MWe LIQUID METAL FAST BREEDER REACTOR PLANT

		QUANTITY	COST (DOLLARS) (THOUSANDS)
220A.21	Reactor Equipment		
220A.211	Reactor Vessels		
220A.2111	Reactor Vessel Shell	1	14,820
220A.2112	Vessel Head + Accessories		
220A.21121	Vessel Closure Head	1	11,102
220A.21122	Heating + Cooling Equipment	Not Included	
220A.21123	Gears + Misc. Equipment	1 set	22
220A.21124	Plug Drive + Control	1 set	600
220A.21125	Rotary Seals + Maintenance Tools	1 set	30
220A.21126	Bearings	1 set	156
220A.21127	Shielding	187,000 lbs.	449
220A.21128	Insulation	Included in 220A.21121	
220A.2113	Cavity Filler System		
220A.21131	Filler Blocks	860,000 lbs.	3,612
220A.21132	Filler Block Handling + Support Mechanisms	1 set	1,090
	220A.211 Reactor Vessels Total		31,881

TABLE 3.1 (Continued)

		QUANTITY	COST (DOLLARS) (THOUSANDS)
220A.212	Reactor Vessel Internals		
220A.2121	Lower Internals		
	Core Support Structure	1	6,023
220A.2122	Upper Internals		
	Suppressor Plate Assembly	1	818
	Upper Shroud	1 set	876
	CRITA Support/Guide Tubes	61	1,560
220A.2123	Core Restraint/Core Barrel	1 set	1,326
220A.2124	Baffles/Seals	1 set	541
220A.2125	Assemblies		
220A.21251	Core Assemblies	Not Included	
220A.21252	Blanket Assemblies	Not Included	
220A.21252	Reflector + Shield	Not Included	
220A.21254	Fuel Transfer Assemblies	Not Included	
220A.21255	Instrumentation Assemblies	61	1,638
220A.25256	Piping Assembly (Check Valves)	4	837
	220A.212 Reactor Vessel Internals Total		13,619
220A.213	Control Rod System		
220A.2131	Control Rods	Not Included	
220A.2132	Control Rod Drives	30	2,730
	220A.213 Control Rod System Total		2,730

TABLE 3.1 (Continued)

		QUANTITY	COST (DOLLARS) (THOUSANDS)
220A.22	Heat Transport Systems		
220A.221	Primary Heat Transport System		
220A.2211	Pumps	4	13,360
	Motors	4	2,000
	Control (Variable Speed Drives)	4	2,800
	Pony Motors	4	200
220A.2212	Primary Piping System		
220A.22121	Piping		
	Large Diameter Piping	2100'	13,046
	Intermediate Diameter Piping	628'	520
	Small Diameter Piping	736'	202
	Supports (Materials only)		2,840
220A.22122	Valves		
	Large Valves	8	1,584
	Small Valves	36	1,440
220A.2213	Intermediate Heat Exchanger	4	21,450
220A.2214	Guard Vessels	Not Applicable	
220A.2215	Heating System	Included in 220A.262	
220A.2216	Insulation	Not Included	
	220A.221 Primary Heat Transport System Total		59,442

TABLE 3.1 (Continued)

		QUANTITY	COST (DOLLARS) (THOUSANDS)
220A.222	Intermediate Heat Transport System		
220A.2221	Pump + Motor + Control		
	Pumps	4	10,200
	Motors	4	1,800
	Control (Variable Speed Drive)	4	2,800
	Pony Motors		200
220A.22221	Int. Piping System		
	Large Diameter Piping	3120'	2,821
	Small Diameter Piping	2088'	90
	Supports (Material)		1,512
220A.22222	Valves		
	Large Valves	8	1,440
	Small Valves	56	1,680
220A.2224	Tanks		
	Expansion Tanks	4	780
220A.2225	Heating System	Included in 220A.262	
220A.2226	Insulation	Not Included	
	220A.222 Intermediate Heat Transport System Total		23,323

TABLE 3.1 (Continued)

		QUANTITY	COST (DOLLARS) (THOUSANDS)
220A.223	Steam Generation System		
220A.2232	Steam Generators		
220A.22321	Evaporators	8	41,990
220A.22322	Superheaters	Included above	
220A.22323	Steam Drums	Not Applicable	
220A.2233	Na/H_2O Reaction Protection System		
220A.22331	Centrifuges, Tanks	12	5,544
220A.22332	Piping + Valves		
	Piping	764'	361
	Valves	50	604
220A.2236	Insulation	Not Included	
	220A.223 Steam Generation System Total		48,499
	220A.22 Heat Transport Systems		133,947

TABLE 3.1 (Continued)

		QUANTITY	COST (DOLLARS) (THOUSANDS)
220A.23	Safeguards Systems		
220A.231	Backup Heat Removal System		
220A.2311	Pumps, Fans + Motors	8	1,968
220A.2311	Heat Exchange Equipment	6	4,160
220A.2313	Tanks	2	158
220A.2314	Piping + Valves		
	Piping	1014'	985
	Valves	18	2,160
	220A.231 Backup Heat Removal System		
	220A.23 Safeguards Systems Total		9,431

TABLE 3.1 (Continued)

		QUANTITY	COST (DOLLARS) (THOUSANDS)
220A.25	Fuel Handling and Storage		
220A.251	Rec., Storage and Shipping		
	New Fuel Handling Crane	1 set	66
	New Fuel Storage Racks	1 set	374
220A.252	Ex-Vessel Storage Tank	1	17,485
220A.253	Ex-Vessel Handling Mechanisms		
	EVHM Trolley + Rails	1 set	19
	EVHM	1	2,672
	Spent Fuel Cask Cart	1	180
220A.254	Transfer Mechanisms		
	Transfer Arm + Motor	1 set	42
	Refueling Elevator and Motor	1 set	42
	Transfer Pots	300	2,422
220A.255	Invessel Handling Mechanisms	1	1,100
220A.256	Fuel Handling Cells		
	New Fuel Conveyor + Tubes	1 set	60
	Cell Equipment	1 set	48
220A.257	Piping + Valves		
	Piping	2440'	886
	Valves	14	241
	Supports (Materials Only)		751

TABLE 3.1 (Continued)

		QUANTITY	COST (DOLLARS) (THOUSANDS)
220A.258	Misc. Equipment		
	Auxiliary Handling Machine	1	1,600
	Tanks	2	11
	Pumps	6	607
	HX		528
	Cold Traps		768
	220A.25 Fuel Handling and Storage Total		29,902

TABLE 3.1 (Continued)

		QUANTITY	COST (DOLLARS) (THOUSANDS)
220A.26	Other Equipment		
220A.261	Inert Gas Receiv. + Process		
220A.2611	Pumps, Compressors + Drives	5	420
220A.2612	Gas Supply/Storage Tanks	27	2,083
220A.2613	Gas Purification Units	70	2,292
220A.2615	Piping, Valves + Fittings		3,480
	220A.261 Inert Gas Receiv.+ Process Total		8,275
220A.262	Special Heating Systems		
220A.2621	Trace Heater System		6,390
	220A.262 Special Heating Systems Total		6,390
220A.264	Sodium Storage, Relief, Makeup		10,412
220A.265	Sodium Purification System		4,301
220A.266	NA Leak Detection System	Included in 220A.27	
220A.267	Auxiliaries Cooling Equipment	Not Included	
220A.268	Maintenance Equipment	Not Included	
	220A.26 Other Equipment Total		29,378
220A.27	Instrumentation + Controls		19,369
	220A.2 Distributed NSSS Cost		267,574

SECTION 4

COMPARISON AND DISCUSSION

In order to identify the major cost differentials between an LMFBR and an LWR, the C-E System 80 was selected for comparison with the Target Plant. The two plants have an identical thermal rating (3800 Mwt) and utilized a similar cost data base for the development of capital costs. A comparison of cost related parameters (commodities) of the major systems and components, therefore, should bring out the reasons for cost differentials between the two plants. This comparison is presented in this section.

Overall Plant

A comparative layout of the two plants is shown in Figure 4.1. The Target Plant layout indicates a larger containment building due to a larger reactor vessel, the expansion loops of the PHTS and a need for housing a large number of components associated with fuel handling and auxiliary systems as compared to that of the C-E System 80. Furthermore, additional steam generator buildings are required for the Target Plant to house the steam generator system; no such buildings are required for the C-E System 80.

Reactor Vessel and Reactor Vessel Closure Head

In comparing the LMFBR Vessel and Closure Head with the C-E System 80 Reactor Vessel and Closure Head, few similarities are found. The commodities lists given in Tables 4.1 and 4.2, provide a detailed comparison of pertinent features and constituent parts of the two assembies. Certain of the more cost-influential of these comparisons are discussed in the following paragraphs.

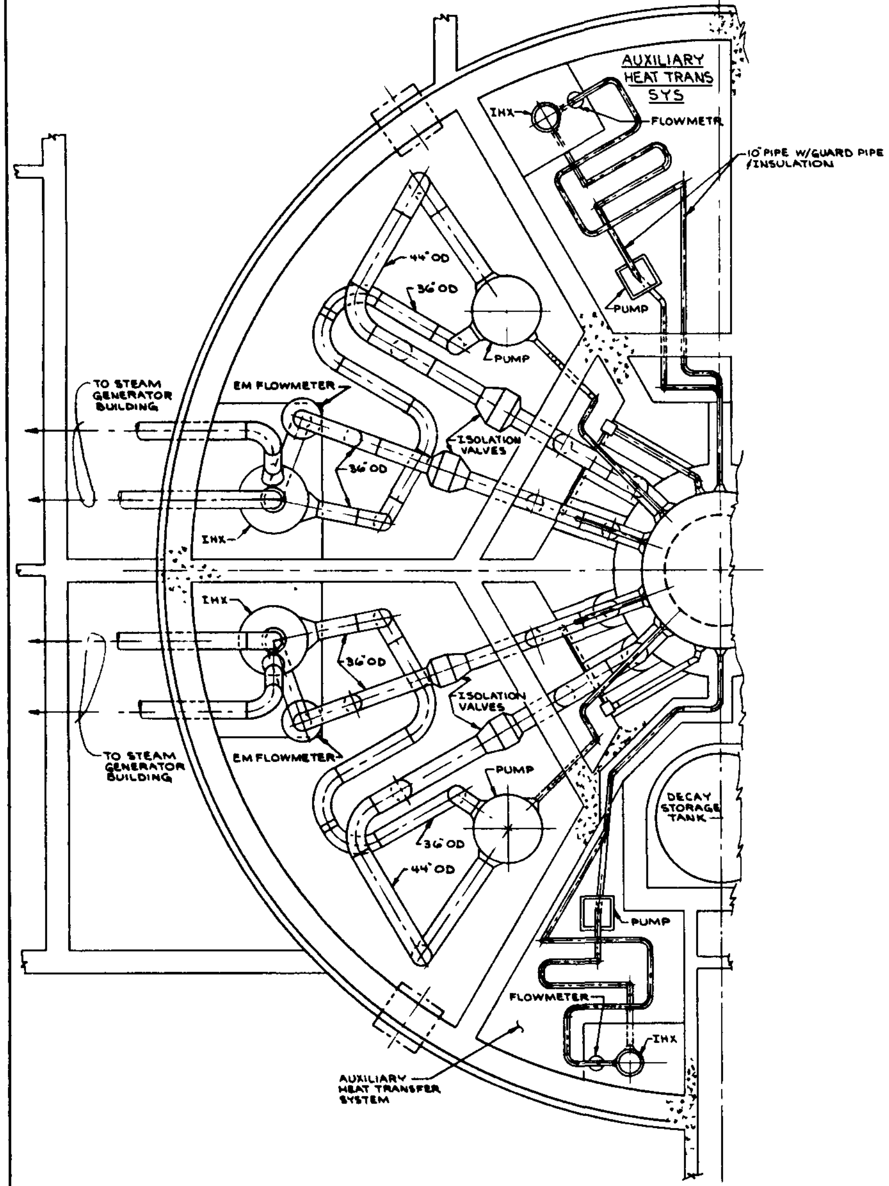
The LMFBR and PWR Reactor Vessels, as illustrated in Figure 4.2, are both designed and fabricated to the requirements of Section III Class 1 of the ASME Boiler and Pressure Vessel Code; however, the LMFBR Vessel design must also include the more costly considerations of Code Case 1592 for high temperature applications.

The LMFBR Vessel is physically larger than the PWR Vessel (to facilitate the breeder core); however, the design and operational pressure are much lower, thus the vessel wall is much thinner for the LMFBR than for the PWR. (Wall thicknesses for the LMFBR are in the 2.5 to 3.5 inch range as opposed to the 9.0 to 12.0 inch range for the PWR.) It is interesting to note that the larger size/thinner wall configuration of the LMFBR Reactor Vessel results in a component weight which is essentially the same as that of the smaller size/thicker wall PWR. In addition, the LMFBR Vessel has approximately 3.5 times as many linear feet of weld as does the PWR Vessel, but the total poundage of weld metal is approximately the same. This, again, is due to the thinner wall of the LMFBR Vessel. The entire inner surface of the PWR Vessel is clad with stainless steel while the entire LMFBR Vessel is fabricated with stainless steel. Thus, from the materials and construction points of view, it can be concluded that the LMFBR Vessel is fabricated from an equal weight of more expensive material utilizing an equal amount of weld metal with more linear feet of weld.

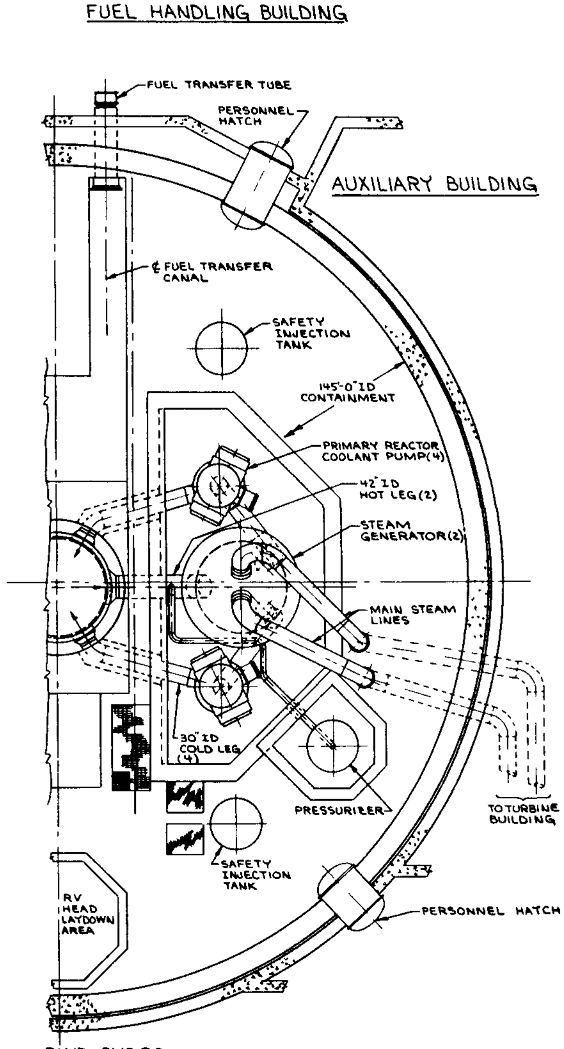
The LMFBR Vessel includes a thermal liner which complicates design and fabrication particularly in the areas where nozzle liners must penetrate the thermal liner. Since the PWR Vessel has no such liner, this feature must be considered as a major cost influencing item.

The large number of nozzles (28 total) found within the LMFBR Vessel somewhat balance out the smaller number of nozzles found within the PWR Vessel (6 total) when the PWR's 61 control rod penetrations are considered.

There is really no meaningful way to compare the LMFBR Closure Head to the PWR Closure Head. One is complicated in nature containing precision moving parts, biological and thermal shielding, etc. while the other is simply a flanged hemispherical weldment. The weight of the composite LMFBR Head is approximately six times that of the PWR Closure Head. While the simple



LMFBR-TPRD (3800MWT)
PLAN VIEW BELOW OPERATING FLOOR



PWR-SYS 80 (3817 MWT)
PLAN VIEW @ OPERATING FLOOR

FIGURE 4.1
LAYOUT COMPARISON
TARGET PLANT vs CE SYSTEM 80

TABLE 4.1

COMPARISON OF REACTOR VESSELS

DESCRIPTION	PWR C-E SYSTEM 80	LMFBR TARGET PLANT
Number of Components per Plant	1	1
Design and Operating Conditions		
Design Pressure/Temp. (Inlet Plenum)	2500 Psia/650°F	165 Psia/675°F
Design Pressure/Temp. (Outlet Plenum)	2500 Psia/650°F	40 Psia/975°F
Flow Rate	164×10^6 lbm/hr	143.2×10^6 lbm/hr
Fluid	H_2O	Na
Inlet Temperature/Outlet Temperature	565.0°F/621.2°F	650°F/950°F
Heat Load	3800 Mwt	3800 Mwt
Safety Class	Section III Class I	Section III, Cl. I
Physical Size and Weight		
Maximum Diameter (Shell)	17'-1.65"	27'-5.00"
Overall Length	39'-2.66"	49'-1.19"
Dry Weight	996,730 lbs.	924,900 lbs.
Materials		
Shell	SA-533, Gr. B, Cl. I	SA-240, Type 304
Flange	SA-508, Class 3	SA-508, Cl. 3
Shell to Flange Transition	None	SB-168
Thermal Liner	None	SA-240, Type 304
COMPARISON OF COMPONENT SHELLS		
Shell Plate Thicknesses		
Upper Cylindrical Region	11.19"	3.50"
Lower Cylindrical Region	9.06"	2.50"
Lower Head	6.50"	2.50"
Internal Cladding		
Location	Entire Inner Surface	None
Material/Thickness	Stainless Steel	None
Nozzles		
Inlet - Qty./I.D.	4/30.00"	4/35.00"
Outlet - Qty./I.D.	2/42.00"	4/43.00"
Other - Qty.	None	20

TABLE 4.1 (Continued)

COMPARISON OF COMPONENT SHELLS (Cont)	PWR C-E SYSTEM 80	LMFBR TARGET PLANT
Penetrations in Lower Head - Qty.	61	None
Lineal Feet of Welds	320 Ft.	1085 Ft.
Upper Flange		
Inside Diameter	175.00"	324.00"
Outside Diameter	215.63"	361.00"
Height	28.82"	38.00"
THERMAL LINER COMPARISON		
Outside Diameter	None	26'-10.0"
Thickness	None	1.50"
Length	None	10'-7.00"
SUPPORT SYSTEM COMPARISON		
Flange		
Outside Diameter	None*	404.00"
Height	None*	12.00"
Skirt		
Thickness	None*	6.00"
Height	None*	19.15"
COMPARISON OF CONSTITUENT WEIGHTS		
Weight of Shell		
Shell Plate	663,300 Lbs.	525,600 Lbs.
Nozzles	118,500 Lbs.*	17,300 Lbs.
Weld Metal	17,900 Lbs.	18,700 Lbs.
Upper Flange	76,600 Lbs.	153,900 Lbs.
Total Weight of Shell	876,300 Lbs.	715,500 Lbs.

*Weight of Support System (Pads on Nozzles) included with Inlet Nozzles.

TABLE 4.1 (Continued)

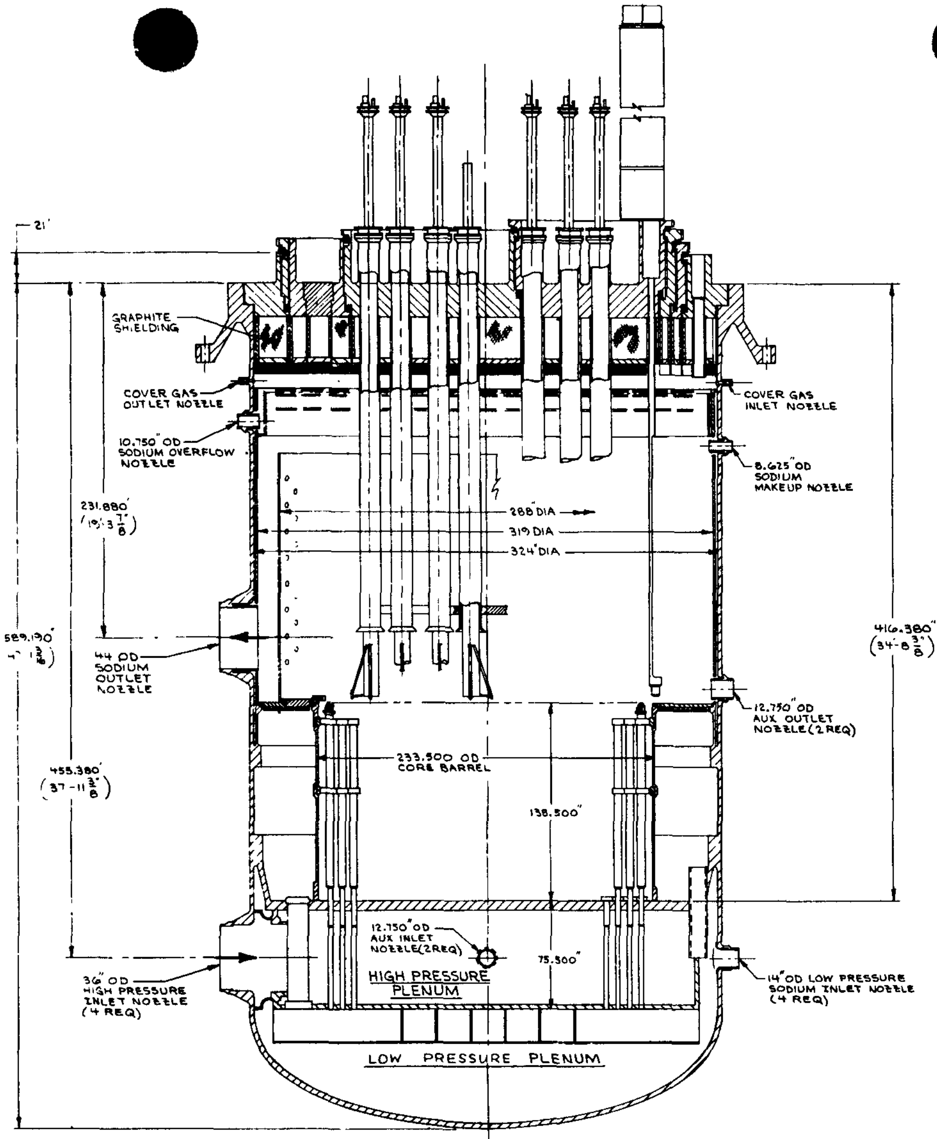
COMPARISON OF CONSTITUENT WEIGHTS (Cont)	PWR C-E SYSTEM 80	LMFBR TARGET PLANT
Weight of Support Skirt and Flange		
Flange Weight	*	68,300 Lbs.
Skirt Weight	*	41,500 Lbs.
Total Support Skirt and Flange Weight	*	109,800 Lbs.
Weight of Thermal Liner		
Total Weight of Thermal Liner	None	69,300 Lbs.
Weight of Miscellaneous Items		
Total Weight of Miscellaneous Items	120,430 Lbs.	30,300 Lbs.

*Weight of Support System (Pads on Nozzles) Included with Inlet Nozzles.

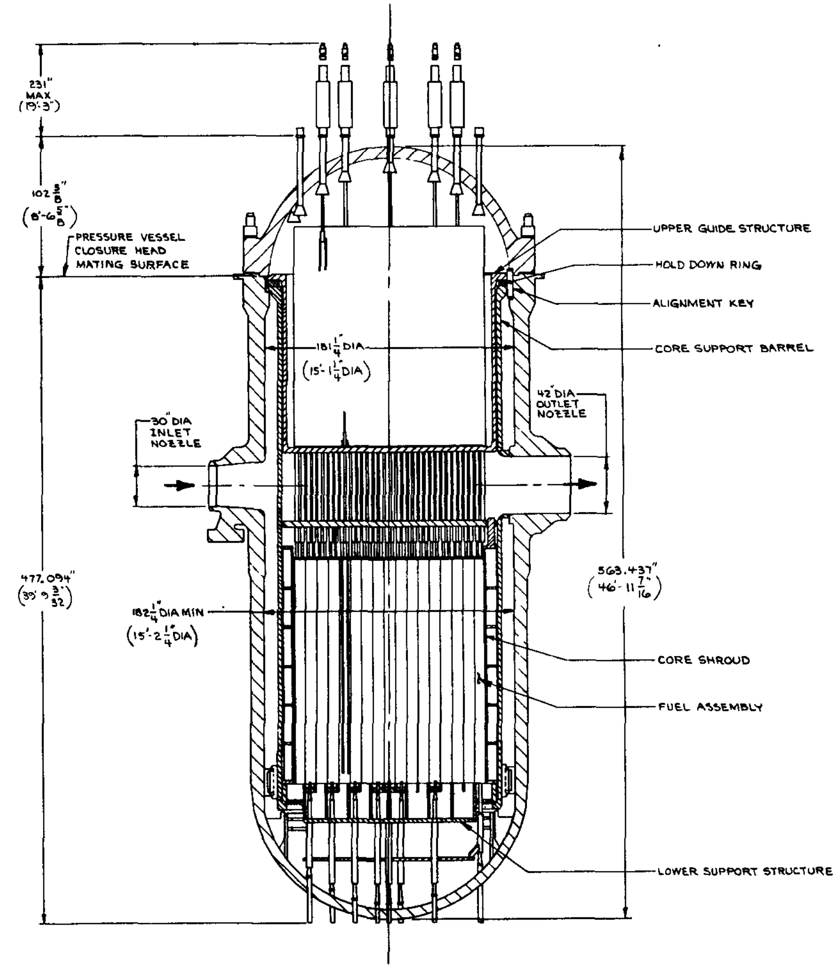
TABLE 4.2

COMPARISON OF CLOSURE HEADS

DESCRIPTION	PWR C-E SYSTEM 80	LMFBR TARGET PLANT
Number of Components per Loop	1	1
Component Type or Configuration	Flanged Hemispherical	Flat w/3 Rotating Plugs
Design and Operation Conditions		
Design Pressure/Temp. (Structure)	2,500 Psia/650°F	40 Psia/200°F
Design Pressure/Temp. (Insulation)	None/None	40 Psia/975°F
Safety Class	Section III, Class I	Section III, Class I
Physical Sizes and Weights		
Flange Outside Diameter	17'-11.63"	28'-0.00"
Flange Inside Diameter	13'-7.68"	22'-6.00"
Flange Height	28.22"	24.00"
Head Radius (Inner)	88.19"	Flat
Head Thickness	8.00"	24.00"
Large Rotating Plug Diameter	None	279.00"
Intermediate Rotating Plug Diameter	None	228.50"
Shell Rotating Plug Diameter	None	106.00"
Thickness of Biological Shielding	None	30.00"
Thickness of Thermal Shielding	None	12.00"
Overall Height	96.91"	120.00"
Total Weight	224,900 Lbs.	1,380,000 Lbs.
Material		
Flange	SA-508, Class 3	SA-508, Class 3
Head	SA-533, Gr. B	SA-508, Class 3
Biological Shielding	None	Graphite
Thermal Shielding	None	SA-240, Type 304
Seals		
Quality	1 Set of 2	3 Sets
Type	Metal O-Ring	Inflatable and Na Dip
Material	Inconel 718	Silicon Rubber and Na
Number of Control Rod Penetrations	97	61
Number of Bearings, Drives, and Controls	None	3



TARGET PLANT REACTOR VESSEL ASSY



SYSTEM 80 REACTOR VESSEL ASSY

FIGURE 4.2

COMPARISON OF REACTOR VESSELS

TARGET PLANT vs. GE SYSTEM 80

design of the PWR Closure Head offsets a portion of the cost of the LMFBR Head, the LMFBR Head can almost be viewed as a component unique to the LMFBR System.

Reactor Vessel Internals

Comparative parameters of the reactor vessel internals for the plant are shown in Table 4.3.

The reactor vessel internals of the Target Plant incorporate a large number of baffles, shrouds and flow dividers due to the requirement for flow distribution in a high temperature system. Furthermore the incorporation of removable check valves and instrument trees impose complex design and fabrication requirements for the reactor vessel internals. The vessel internals for the C-E System 80, in comparison, are simple in design and fabrication because of the lower temperature of that system. The core support structure for the Target Plant is approximately two times larger and four times heavier because of the larger core and has an additional requirement of hydraulic holdown for the fuel assemblies as compared to that of the C-E System 80. Under-the-plug refueling for the Target Plant also imposes complex engineering requirements for the reactor vessel internals as compared to the open head refueling for the C-E System 80. Overall, the reactor vessel internals weigh approximately 50% more and are more numerous and complex than those for the C-E System 80.

Cavity Filler System

The reactor vessel for the Target Plant must be enclosed with a volume limiting system to limit the loss of sodium from the primary sodium system. In the Target Plant, this is achieved by means of a system of filler blocks rather than with a guard vessel. This system ensures continuity of core submergence in sodium and heat removal subsequent to a loss of coolant accident. It is a major cost item which has no parallel in the C-E System 80.

TABLE 4.3

COMPARISON OF REACTOR VESSEL INTERNALS

DESCRIPTION	PWR C-E SYSTEM 80	LMFBR TARGET PLANT
Number of Components (sets)	1	1
Design Temperature (°F)	650	975/675
Fluid	H_2O	Na
Flow Rate (LBM/HR)	164×10^6	143.2×10^6
Material	304 SS	304 SS
Lower Internals		
Core Barrel		
Size	150" x 175" x 7/8"	233" x 138" x 1"t
Weight (lbs)	39,222	78,444
Core Support Structure		
Size	156" x 30" x 1.75"	300" x 75" x 3"
Weight (lbs)	81,000	323,970
Upper Internals		
CRITA Tubes/Supports		
Quantity	None	61
Size		15"ϕ x 17' x 1/2't
Weight (lbs)		92,300
Shroud		
Size	148" x 30" x 1.25"	300" x 165" x 1"
Weight (lbs)	5,039	38,260
Suppressor Plates		
Quantity	1	3
Size	124"ϕ x 1-3/4"	306"ϕ x 1/2"t
Weight (lbs)	3,677	33,890
Check Valves		
Quantity	None	4
Type		Swing Disc
Size		36"
Weight (lbs)		41,840
Total Weight of Internals (lbs)	453,088	644,930
Total Feet of Weld		67,435

TABLE 4.3 (Continued)

DESCRIPTION	PWR C-E SYSTEM 80	LMFBR TARGET PLANT
CRITA		
Quantity	61	61
Type	Fixed Tubes	Telescoping
Size	3"ϕ	15"ϕ x 20'
Control Rod Drives		
Quantity	99	30
Type	Magnetic Jack	Servo Drive
Size	4" ϕ x 28'	12"ϕ x 30'
Control	Electro Magnet	Pneumatic
Stroke	148"	48"

Heat Transport System Pumps

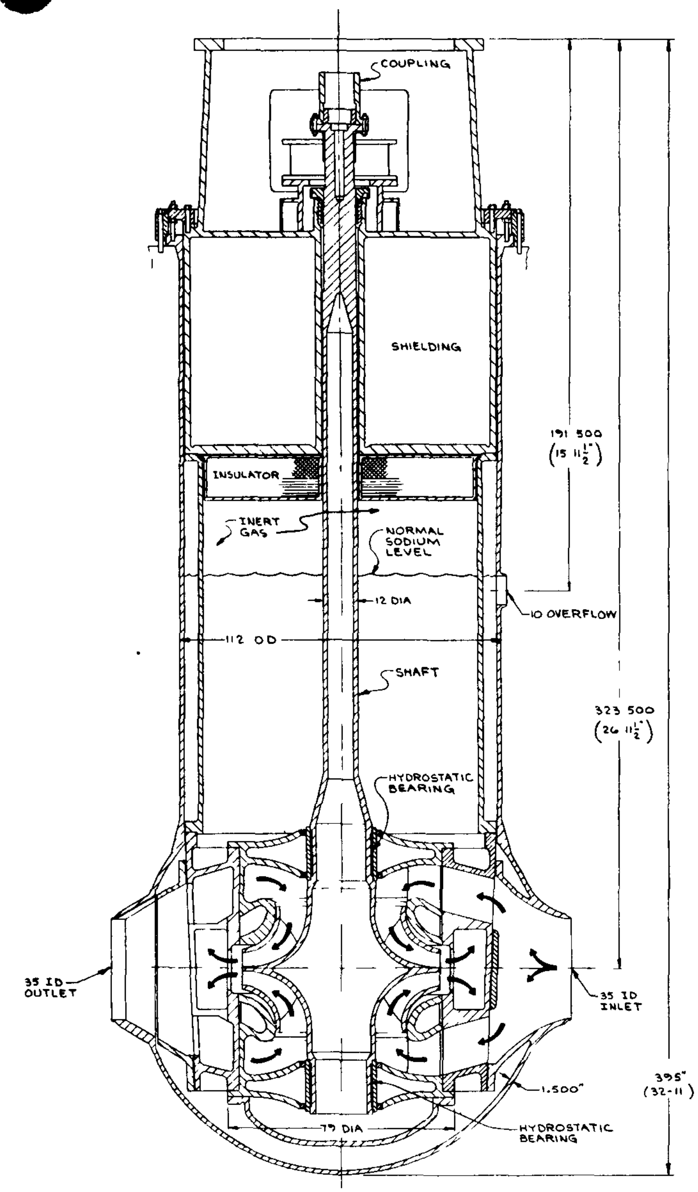
Eight large pumps, four primary and four secondary are required for the heat transport systems of the Target Plant, compared to four for the C-E System 80. Comparative sketches of the pumps are shown in Figure 4.3 and parameters are compared in Table 4.4.

The Target Plant uses variable speed pumps to meet the requirement of 40% to 100% variable flow which corresponds to the 40% to 100% power level range of reactor operation. This requirement for speed variation necessitates the provisions of a speed control mechanism such as a motor-generator set in addition to the main drive motor for each pump.

To avoid a shaft seal against sodium, the pumps have a large surge tank with a free surface of sodium. The shaft seal to retain the cover gas over this free surface must prevent the in-leakage of even minute quantities of air. In the case of the primary pumps, the cover gas may be contaminated with radioactive fission gases, so out-leakage must also be avoided. For this reason (among others) pressurization of the cover gas in the primary pumps (and the reactor vessel) is avoided. The primary pumps particularly must also be designed to operate with low available NPSH.

The sodium pumps have long shafts supported at the lower end by hydrostatic bearings under sodium, and must have provisions for sodium level control in their surge tanks. The primary pumps also require shielding against sodium-24 activity.

In comparison, the C-E System 80 uses conventional centrifugal pumps, which are more compact and simpler in design. While the seals must withstand the high system pressure, a small amount of leakage is tolerable and expected. The comparatively heavy case is offset by the compact size. Thermal transients are not a problem, and the pumps operate at constant speed.

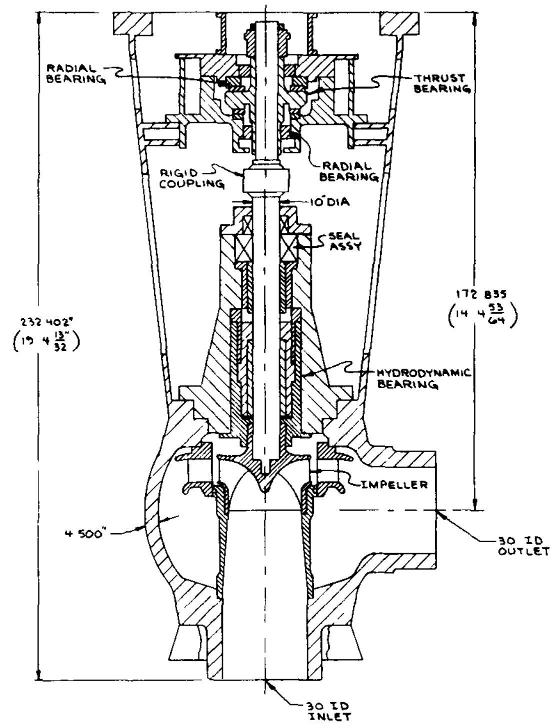


TARGET PLANT SODIUM PUMP

(8 REQUIRED)

NOTES:

1. 4 PRIMARY PUMPS AND 4 SECONDARY PUMPS
2. SECONDARY PUMPS DO NOT REQUIRE SHIELDING OTHERWISE SIMILAR TO THAT SHOWN



SYS-80 KSB PUMP

(4 REQUIRED)

FIGURE 4.3

COMPARISON OF HEAT TRANSPORT SYSTEM PUMPS

TARGET PLANT vs GE SYSTEM 80

TABLE 4.4

COMPARISON OF HEAT TRANSPORT SYSTEM PUMPS

DESCRIPTION	PWR C-E SYSTEM 80	LMFBR TARGET PLANT Primary	LMFBR TARGET PLANT Secondary
Design Temperature, °F	650	950	625
Design Pressure, psia	2500	165	300
Flow (GPM)	111,400	86,200	76,700
TDH (Ft.)	365	363	291
Pump Weight (Lbs)	121,000	283,000	200,000
Motor Rating (HP)	12,000	9,000	6,000
Speed Regulator Rating (HP)	None (Constant Speed)	9,000	6,000
Pony Motor/Drive Rating (HP)	None	100	100

Steam Generators

A complete and detailed listing of comparative information is provided in Table 4.5; however, certain of the more salient of these comparative data are discussed below. Comparative sketches of the steam generators are shown in Figure 4.4.

The Systems 80 PWR Plant is of a two-loop/one steam generator per loop configuration. The total weight of steam generating apparatus is approximately 1,430 tons with a total heat transfer area of 249,600 ft^2. These totals are significantly less than those required for the four-loop/two steam generators per loop configuration of the LMFBR. Total steam geneator weight and heat transfer area for the LMFBR System are approximately 2,600 tons and 401,200 ft^2, respectively. At first light, these gross differences seem unjustifiable since the LMFBR shell thicknesses are thin (1.50 to 2.50 inch) compared with those of the much higher pressure PWR Shells (5.63 to 6.88 inch). However, a review of the constituent weights discloses the total plant tubing weight for the LMFBR components to be one of the most significant contributors. Since the LMFBR Steam Generators are combined evaporator/superheater units, the tube wall must be sized to accommodate the high temperature and pressure at the superheater outlet end. Tube wall thickness for the LMFBR Components is 0.125 as compared with 0.042 inch for the PWR Components. This wall thickness is excessive in the evaporator region and thus reduces the heat transfer efficiency throughout a major portion of the heated length of the tube bundle. In addition, the tube pitch is large to facilitate the back side tube-to-tubesheet weld and this influences tubesheet diameter and thickness. It can be concluded that the LMFBR steam generating equipment might be more nearly optimized if the evaporators were separated from the superheaters such that thinner tubes could be used in the evaporator units. (Perhaps a more logical selection might be to utilize two or three parallel evaporators with one or two superheater units per loop, in lieu of the two combined units per loop).

TABLE 4.5

COMPARISON OF STEAM GENERATORS

DESCRIPTION	PWR C-E SYSTEM 80	LMFBR TARGET PLANT
Number of Components per plant	2	8
Component Type or Configuration	U-Tube	St. Tube
Flow Characteristics	Mixed Flow	Counterflow
Orientation	Vertical	Vertical
Shell Side Design and Operating Conditions		
Design Pressure/Design Temperature	1270 psia/575°F*	300 psia/935°F
Flow Rate	4.92×10^6 lbm/hr	16.65×10^6 lbm/hr
Fluid	H_2O	Na
Inlet Temperature/Outlet Temperature	450°F/553°F	910°F/590°F
Tubeside Design and Operating Conditions		
Design Pressure/Design Temperature	2500 psia/650°F	2275 psia/875°F
Flow Rate	82.0×10^6 lbm/hr	1.74×10^6 lbm/hr
Fluid	H_2O	H_2O
Inlet Temperature/Outlet Temperature	621°F/565°F	470°F/854°F
Heat Load per Component	1900 Mwt	475 Mwt
Safety Class	Section III, Cl. 1&2**	Section VIII, Div. 2
Physical Size and Weight		
Maximum Diameter (Shell)	243.75"	106".75"
Overall Length	68'-6.25"	88'-8.0"
Dry Weight - Per Component/Per Plant	1,552,800/3,105,600 lbs	648,000/5,184,000 Lbs
Materials		
Shell Plate	SA-533, Gr. A & Gr. B	SA-387, Gr. 22, Cl. 1
Tubesheet(s)	SA-508, Cl. 3	SA-336 F22
Tubes	SB-163	SA-213, Gr. T22

* Except for lower head and tubesheet which have the same design pressure and temperature as the tubeside.

**Primary side is Class 1 and secondary side is Class 2.

TABLE 4.5 (Cont'd)

COMPARISON OF COMPONENT SHELLS	PWR C-E SYSTEM 80	LMFBR TARGET PLANT
Shell Plate Thicknesses		
Upper Cylindrical Shell Region	5.88"	2.50"
Conical Transition Shell Course	6.88"	None
Lower Cylindrical Shell Region	5.63"	1.50"
Steam Outlet Hemispherical Head	4.25"	5.50"
Upper Sodium Hemispherical Head	None	1.50"
Lower Hemispherical Head	8.19"	5.00"
Internal Cladding		
Location	Lower Head	None
Material/Thickness	S.S./0.19"	None
Nozzles		
Shell Side Inlet - Qty./I.D.	2/14.00"	1/25.00"
Shell Side Outlet - Qty./I.D.	2/28.00"	1/25.00"
Tube Side Inlet - Qty./I.D.	1/42.00"	1/18.00"
Tube Side Outlet- Qty./I.D.	2/30.00"	1/18.00"
Access Ports or Manways - Qty./I.D.	4/16.00"	2/24.00"
Handholes - Qty./I.D.	2/6.00"	None
Linear Feet of Welds	560 ft.	310 Ft.
COMPARISON OF COMPONENT TUBE BUNDLES		
Number of Tubes - per Comp./ per Plant	11,012/22,024	3,547/28,376
Mean Heated Length	57'-8.64"	72'-0"
Tube Size-OD/Wall Thickness/Pitch	0.75"/0.042"/1.000"	0.75"/0.125"/1.250"
Heat Transfer Area-Per Comp./ per Plant	124,800 Ft^2/249,600 FT^2	50,145 ft^2/401,160 Ft^2
Tube Support Concept	Eggcrate	Drilled Plates
Type of Tube-to-Tubesheet Weld	Rolled & Face Side	Face & Back Side
Tube Bundle Shroud		
Inside Diameter	168.50"	80.88"
Thickness	1.25"	1.00"
Length	37'-11.25"	67'-6.00"

TABLE 4.5 (Continued)

COMPARISON OF COMPONENT TUBE SHEETS	PWR C-E SYSTEM 80	LMFBR TARGET PLANT
Number per Component	1	2
Finished Diameter - Upper/Lower	185.76"/None	101.00"/101.00"
Finished Thickness - Upper/Lower	23.50"/None	26.00"/23.00"
Clad Material/Clad Thickness	S.S./0.25"	None/None
COMPARISON OF CONSTITUENT WEIGHTS		
Weight of Shell (Pressure Boundary)		
Plate Material	520,300 Lbs	161,000 Lbs
Nozzles, Access Ports, Manways, Etc.	46,800 Lbs	18,300 Lbs
Weight of Weld Metal	16,200 Lbs	2,400 Lbs
Total Weight of Shell	583,300 Lbs	181,700 Lbs
Weight of Tube Bundle		
Tubing	233,750 Lbs	226,700 Lbs
Tube Supports	31,500 Lbs	30,300 Lbs
Shrouds	82,900 Lbs	66,100 Lbs
Total Weight of Tube Bundle	348,150 Lbs	323,100 Lbs
Weight of Tubesheets		
Upper	None	49,100 Lbs
Lower	124,100 Lbs	36,600 Lbs
Total Weight of Tubesheets	124,100 Lbs	82,700 Lbs
Weight of Steam Separation Equipment		
Weight of Separators	26,000 Lbs	None
Weight of Dryers	11,300 Lbs	None
Weight of Supports	37,700 Lbs	None
Total Weight of Steam Separator Equip.	75,000 Lbs	None
Miscellaneous Parts		
Total Weight of Miscellaneous Parts	422,250 Lbs	60,500 Lbs

It should be borne in mind that the LMFBR Steam Generator by necessity requires a high degree of integrity to prevent sodium water reactions. The tube-to-tubesheet joint selected for use in these units provides this high integrity and will perhaps always be the limiting factor in determining tube wall thicknesses.

In regard to configuration comparisons, the LMFBR Steam Generators are straight-tube straight-shell counterflow units which should be more efficient than the U-tube configuration of the PWR. The tube-to-tubesheet welds, thermal liners, etc., along with the larger number of components make the LMFBR components more complicated from a fabrication point of view.

Expansion Tanks/Pressurizer

There is no component within the PWR for direct comparison with the Secondary Sodium Expansion Tank; however, for the purpose of this study, it was decided that a comparison with the PWR pressurizer might be in order. There is one pressurizer in a PWR System while there are four Secondary Sodium Expansion Tanks. Comparative parameters of the two components are shown in Table 4.6.

Physically the expansion tanks are approximately one-third the height of the pressurizers and have much thinner walls due to the difference in design pressure (300 psia for the expansion tank and 2500 psia for the pressurizer). Thus, the four expansion tanks weigh approximately the same as one pressurizer, have much less poundage of weld metal, and a much larger total linear footage of weld seams.

As stated in the design description in Section 2, the expansion tank is a Section VIII, Division 2, Vessel while the pressurizer is a Section III, Class 1, vessel. The expansion tank is fabricated from stainless steel and the pressurizer is primarily made from SA-533, Grade A, Class 1, material with stainless steel clad over the entire inner surface of the vessel.

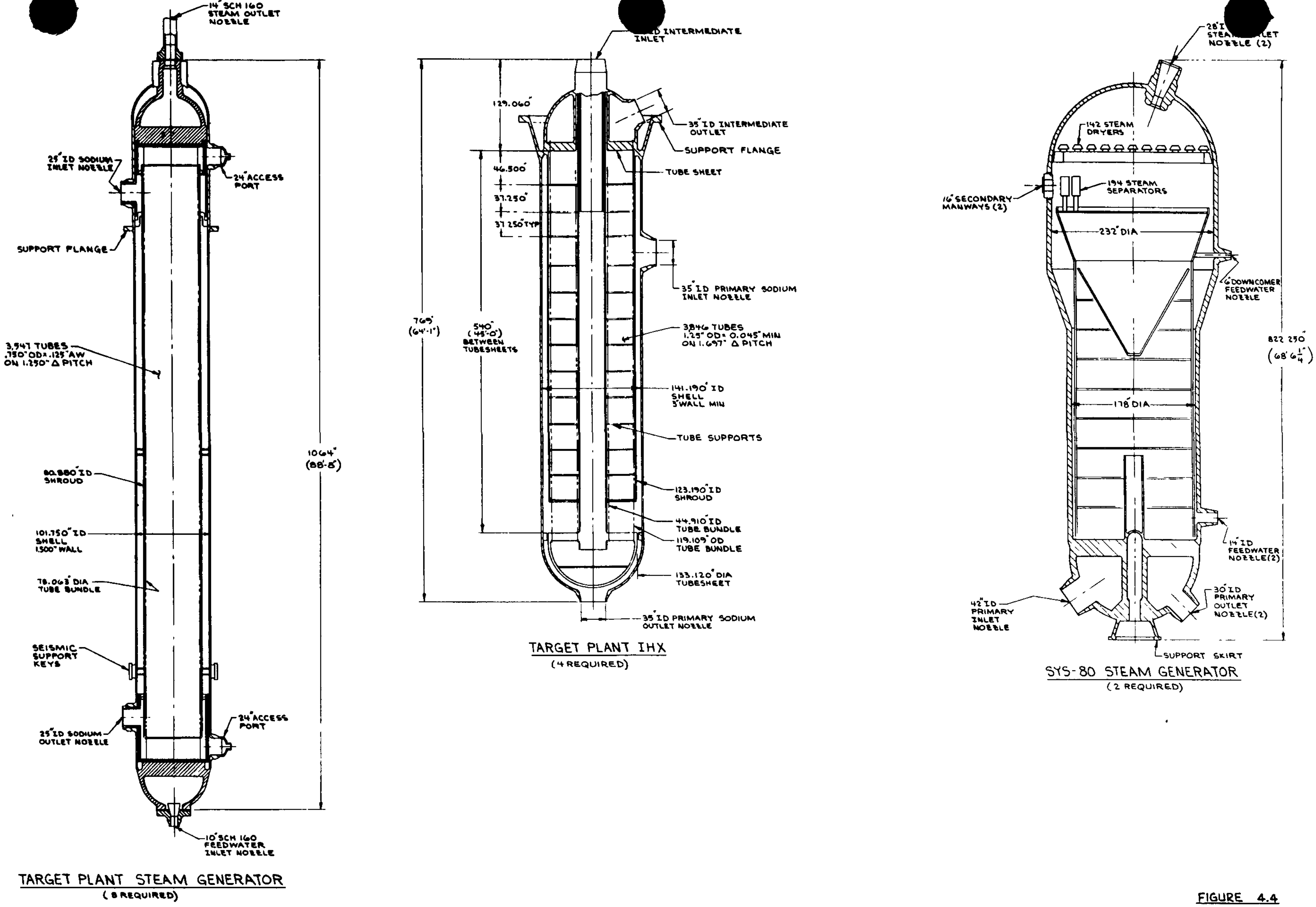


FIGURE 4.4

COMPARISON OF STEAM GENERATORS
TARGET PLANT vs. CE SYSTEM 80

TABLE 4.6

COMPARISON OF SECONDARY SODIUM

EXPANSION TANK AND PWR PRESSURIZER

	PWR C-E SYSTEM 80	LMFBR TARGET PLANT
Number of Components per Plant	1	4
Design and Operating Conditions		
Design Pressure/Temperature	2500 Psia/700°F	300 Psia/600°F
Fluid	H_2O	Na
Heat Input Capacity	1800 KW	None
Safety Class	Section III, Cl. 1	Section VIII, Div. 2
Physical Size and Weight		
Maximum Diameter (Shell)	106.25"	123.26"
Overall Length	42'-5.63"	15'-11.63"
Dry Weight	221,800 Lbs	47,900 Lbs
Material		
Shell Plate	SA-533, Gr. A, Cl. 1	304 SS
Supoort Skirt	SA-516	None
Support Flange	SA-516	304 SS
COMPARISON OF COMPONENT SHELLS		
Shell Plate Thicknesses		
Cylindrical Shell Region	5.00"	1.63"
Upper and Lower Heads	4.00"	1.63"
Internal Cladding		
Location	Entire Inner Surface	None
Material/Thickness	S.S./0.19"	None
Nozzles and Manways		
Total Number	8	6
Range of Inside Diameters	3.63" thru 9.63"	2.00" thru 4.00"
Manway - Qty./Size	1/16.00"	1/16.00"
Heater Penetrations - Qty.	36	None
Instrument Nozzles - Qty.	6	None
Lineal Feet of Welds		135 Ft.

TABLE 4.6 (Continued)

COMPARISON OF CONSTITUENT WEIGHTS	PWR C-E SYSTEM 80	LMFBR TARGET PLANT
Weight of Shell		
Shell Plate	201,000 Lbs	35,300 Lbs
Nozzles and Manways	2,400 Lbs	850 Lbs
Weld Metal	5,500 Lbs	650 Lbs
Support Skirt	7,400 Lbs	None
Support Flange	2,300 Lbs	11,000 Lbs
Total Weight of Shell	218,600 Lbs	47,800 Lbs
Weight of Miscellaneous Parts		
Total Weight of Miscellaneous Parts	3,200 Lbs	100 Lbs

Piping and Valves

A large portion of the capital cost of the Target Plant is associated with heat transport piping. This large amount of piping between the heat transport components is required for piping flexibility, while the components are rigidly fixed. The C-E System 80 pumps and heat exchangers have sliding supports and do not require any significant amount of piping. The piping, valves and fitting estimates for the two plants are summarized in Table 4.7.

Safeguards Cooling Systems

The safeguards cooling systems provide emergency cooling capability in the event the main heat transport systems are unable to function. The safeguards systems for the two plants are different in function and design due to generic differences between the LMFBR and the LWR. Also there are significant differences in the events against which protection is provided by these safeguards systems.

For the LWR, a guillotine rupture at the reactor inlet produces a loss of coolant accident and results in rapid depressurization of the reactor vessel. The LWR safeguards cooling systems are, therefore, designed to flood the reactor vessel with additional coolant to prevent loss of a coolable core geometry and to maintain fuel temperatures at a safe level.

There are two safeguards cooling systems for the LWR, i.e., a High Pressure Coolant Injection System (HPCIS) and a Low Pressure Coolant Injection System (LPCIS). The HPCIS injects borated water into the reactor vessel at high pressures and protects the reactor for small leaks. The LPCIS provides cooling water to the reactor vessel from the refueling water tank or from the reactor vessel for events which are beyond the capability of the HPCIS. Both systems utilize multiple pumps and flow paths for redundancy and reliability. This results in relatively high capital cost of the LWR safeguards systems due to their large number of components and complexity of design.

TABLE 4.7

COMPARISON OF HEAT TRANSPORT SYSTEM PIPING AND VALVES

DESCRIPTION	PWR C-E SYSTEM 80	LMFBR TARGET PLANT
Material	C.S.	S.S.
Max. Design Temperature, °F	650	970
Max. Design Pressure, Psia	2500	300
Piping Runs	52"ϕ-27' 36"ϕ-183' 12"ϕ-63'	44"ϕ-350' 36"ϕ-1450' 26"ϕ-850' 14"ϕ-250'
Total Large Piping	273'	2900'
Elbows (Number)	52"ϕ-2 36"ϕ-16	44"ϕ-28 36"ϕ-104 26"ϕ-64 14"ϕ-16
Total Large Fittings	18	212
Valves (Number)	None	44"ϕ-4 36"ϕ-12 14"ϕ-4
Total Large Valves	None	20

The low pressure design of the LMFBR minimizes possibility of a pipe rupture and makes the cooling system design less complex than that of the LWR. A normal scram occurs upon loss of flow from the main heat transport systems due to control interlocks. The safeguards cooling system for the LMFBR, called the Auxiliary Heat Transfer System (AHTS), therefore, is used to remove decay heat from the reactor. The AHTS consists of two independent and diverse loops; each utilizes EM pumps, straight tube Na to NaK heat exchangers and air blast heat exchangers for decay heat removal.

The LWR safeguards cooling systems are somewhat more complex and expensive than the LMFBR AHTS, mainly due to the multiple high pressure systems. The LMFBR AHTS are simple and less expensive due to low pressure systems and superior heat transfer characteristics of sodium. Further cost reductions are also possible through improvement in technology and mass production of the sodium components.

Fuel Handling and Storage System

Comparison of the refueling schemes of the C-E System 80 and the Target Plant can be carried out by considering the refueling procedure for the two plants. Refueling schemes for the LMFBR designs are not as firmly fixed as those of LWR reactors. It is, however, felt that the Target Plant refueling system is representative of a typical LMFBR refueling plan both in concept and in cost. High LMFBR refueling costs reflect the penalties due to the reactive sodium coolant. A sealed environment complete with a forced convection cooling system is required for transport of spent subassemblies, and fuel handling operations must be performed remotely. Refueling at high temperatures places restrictions on machine fabrication due to differential thermal expansion. A separate sodium tank is required to dissipate decay heat.

Auxiliary Systems

A comparison between the auxiliary systems used for the Target Plant and the C-E System 80 to maintain the purity and volume of the coolant is of interest. For the Target Plant this is called the Liquid Metal Purification

System (LMPS). It processes 60 gpm of primary sodium through a regenerative heat exchanger and cold trap before returning the flow to the primary coolant stream. A similar system processes 70 gpm for each loop of the secondary system. The main concern on the primary heat transport system is oxygen in-leakage since this system is at low pressure, whereas on the secondary side, a major concern is hydrogen diffusion through the steam generators. Process sodium in the cold trap is cleaned by precipitating out oxidized sodium and other impurities onto stainless steel filters. The cold traps themselves are cooled with NaK, and various impurities are removed from the NaK via diffusion cold traps.

For the C-E System 80, the comparable system is called the Chemical Volume Control System (CVCS). It processes 84 gpm in normal operation through a regenerative heat exchanger, particulate filters and ion exchangers and returns this flow to the main line after obtaining the necessary boron concentration for reactivity control. In this system, chemicals such as hydrazine and hydrogen gas are added to prevent halide-induced corrosion and oxide formation. In addition, provision is made for the removal of fission gas from the coolant. Degassing the coolant and maintaining proper boron chemistry impose significant costs on this system. Other parts of the system such as the refueling water tank are included under this classification because these parts must allow boric acid recycle.

Purification levels for each system reflect the different requirements of their designs. While both systems can suffer from corrosion problems, the LWR system prevents stainless steel stress corrosion whereas the LMFBR system must protect against mass transport from regions of high temperature to regions of low temperature. The differing emphasis is system dependent, arising from the high-pressure, low-temperature LWR environment and the low-pressure, high-temperature LMFBR environment.

The flow path for both purification systems are similar. Both draw a process stream from the cold leg of each of their respective coolant loops. This stream is then cooled, filtered and returned to the main coolant flow. For the LWR, some additional equipment is needed to maintain proper boron control, to minimize coolant radioactivity, and to remove any free hydrogen or oxygen. The gas stripping equipment accounts for a considerable fraction of the CVCS cost.

Pumps used in the CVCS provide circulation, makeup, chemical control, and drain services. Pumps used to send processed coolant back to the main steam are designed for high pressure service and are the most expensive pumps per unit horsepower in the LWR system. Three pumps are required for maintenance and redundancy. Makeup pumps are used to return water from the makeup tank to the main coolant stream. The extra water in this tank allows total recycle, i.e. dilution of borated water to compensate for the loss in reactivity as the fuel is burned. These pumps are low pressure, low temperature and low horsepower and are farily inexpensive. Additional pumps are used to maintain proper water chemistry in the coolant system, bringing the total number of pumps used in the CVCS to 11.

The LMFBR purification system uses pumps for volume control and purification of the primary heat transport system, purification of the intermediate heat transport system, and for cooling the sodium cold trap filters. The overflow pump draws sodium from the overflows tank and sends it through a cold trap before the stream returns to the main loop. There is no need for drain or high pressure pumps in this system because of the low pressure, nor is there any requirement to degas the coolant in a separate component. The secondary loop also has cold trap pumps for each loop in the event that the loop sodium inventory becomes contaminated. Finally, the cooling of all cold trip with NaK requires a set of NaK pumps. In all, 10 LMFBR purification pumps are required. Although the pumping power required for the liquid metal pumps is lower (by a factor of 2.5) than for the LWR pumps, the cost of these pumps is higher by a factor of 2. The reason for this difference is in large part the non-commercial manufacture of electromagnetic pumps. Economies associated with larger pumps could not be specified as only a discrete set of EM pumps have been made; the pumps selected for the Target Plant did not always meet the specifications of current EM pumps, thus producing a cost penalty. The large differential between LMFBR EM pumps and LWR mechanical pumps used in purification will almost certainly be narrowed in the commercial phase of the LMFBR.

Heat exchangers used in the CVCS cool the incoming fluid to a temperature suitable for the long term operation of the purification system. These are both regenerative and letdown heat exchangers acting in series prior to purification. The regenerative heat exchanger is a high-pressure, high-temperature unit because it interfaces with the main heat transport system. The letdown heat exchanger is less expensive because its design requirements are less stringent. Both heat exchangers are of stainless steel shell-and-tube design. The design calls for two regenerative heat exchangers and one letdown heat exchanger.

A greater number of purification heat exchangers is required for the LMFBR as all heat transfer loops are designed to be independent. Thus, each primary and secondary loop has its own heat exchanger to cool the process stream prior to purification. These units are also of shell-and-tube design with a somewhat higher design temperature than the LWR regenerative heat exchangers. All units are 304 SS. The LMFBR heat exchangers are more expensive than their LWR counterparts for the purification system, but it is anticipated that these cost penalties would become smaller in the commercial stage of the LMFBR. The total cost of LMFBR heat exchangers in the purification system exceeds that of the LWR by a factor of 3. Part of this differential is due to the greater number of heat exchangers specified for the LMFBR, and the cost per unit surface area for LMFBR heat exchangers is also higher than the LWR units.

Filters for the LWR system include purification strainers, ion exchangers, and gas strippers. The filters are stainless steel, particulate mesh, types designed for trapping particles 2 microns and larger. Lithium and ionic radionuclides are removed from the process stream in mixed bed ion exchangers. A gas stripper is also utilized to remove hydrogen produced by nuclear heating. Some of the purification apparatus is clearly due to the use of water as reactor coolant.

Trapping of the particulates in the LMFBR coolant stream employs close-packed mesh filters and additional coolant of the process stream to precipitate out components of sodium with oxygen, hydrogen, carbon and other impurities. Design temperature for this equipment is somewhat higher than for the LWR filters. Costs quoted for the Target Plant cold traps are for off-the-shelf units and significant cost reductions are expected for commercial LMFBR plants. For purification units the cost of the LMFBR system exceeds that of the LWR system by a two-to-one ratio.

Storage requirements for the LWR purification system exceed those of the LMFBR design due to the boron deletion requirements. Holdup and makeup tanks are large, field-fabricated vessels holding about 400,000 gallons of borated water. Estimates of capital costs of these vessels were unavailable, but their cost is expected to exceed the cost of LMFBR purification tankage, which consists essentially of the primary overflow tank.

Purification costs for the Target Plant exceed those of the C-E System 80 by about 2 to 1, not including the large field fabricated tanks. Although these quotations were received from vendors, there is reason to believe the cost differential may be reduced. These reductions should come about by commercialization and possibly by a reduction in design requirements.

Heat Transfer Area

A comparative summary of heat transfer areas required for the two plants is given in Table 4.8. As expected, the heat transfer area required for the Target Plant is approximately twice that of the C-E System 80. This is mostly due to the intermediate sodium loop required between the radioactive primary sodium loop and the feedwater/steam system.

Storage Tanks

A comparative summary for volume of storage tanks is given in Table 4.9. The storage tanks is given in Table 4.9. The aggregate tank volumes for the two plants are similar. However the tanks for the Target Plant are for high temperature sodium systems and must be engineered and fabricated to relatively high standards.

TABLE 4.8

COMPARISON OF HEAT TRANSFER AREA

COMPONENT	PWR C-E SYSTEM 80		LMFBR TARGET PLANT	
	Units	HT Area (Ft^2)	Units	Total HT Area (Ft^2)
Intermediate Heat Exchangers	-	--	4	226,400
Steam Generators	2	249,600	8	401,100
Safeguard Heat Exchangers	2	13,400	2	5,000
Safeguards Air Blast Heat Exchangers	6	92,700	2	16,000
Refueling Heat Exchangers	2	4,400	2	600
Refueling Air Blast Heat Exchangers	-	--	2	1,900
Purification Heat Exchangers	3	1,100	11	1,700
		361,200		652,700

TABLE 4.9

COMPARISON OF STORAGE TANK VOLUMES

SYSTEM	PWR C-E SYSTEM 80		LMFBR TARGET PLANT	
	Total Units	Tankage Gallons	Total Units	Tankage Gallons
Heat Transport System	1	6,700	5	222,600
Safeguards System	4	72,000	2	4,800
Fuel Handling	1	590,000	2	300
Purification	9	458,100	4	300
Coolant Storage	1	450,000	19	950,800
Inert Gas	-	--	27	151,100
		1,576,800		1,329,900

Summary

Major differences between the two plants emanate from the choice of different coolants, i.e., water vs liquid metal, necessitated by the core specific power, neutron energy spectrum and operating temperatures and pressures.

High temperatures and low pressures attendant with liquid metals in the LMFBR lead to selection of thin-walled stainless steel components, whereas thick-walled carbon steel components are suitable for low temperature, high pressure water systems for the C-E System 80 Plants.

Utilization of liquid metals in the LMFBR necessitates remote control of fuel handling and component maintenance, inert atomsphere, appropriate shielding and trace heating of the systems. An intermediate heat transfer loop is also required for physical separation between the radioactive primary sodium and the water side of the steam generator system, accounting for additional heat transfer area, piping and components.

As discussed in the preceding paragraphs the high cost difference areas for the Target Plant are:

- Reactor Vessel and closure head
- Heat Transport System
- Refueling System
- Auxiliary System

The reactor vessel as designed reflects limited optimization, and some cost reductions are possible with further optimization. But there does not appear to be a ready solution to the higher cost of LMFBR reactor vessels because most of the design requirements are mandated by the use of liquid metals at high temperatures. Utilization of alternate materials of construction is a possibility. One such material is super-chrome ferritic steel which has high strength and low creep and fatigue damage characteristics and may be suitable after it has been code approved.

The heat transfer system which contribute significantly to the higher cost of the LMFBR are also mandated by the coolant characteristics. To change this cost picture, the amount and complexity of the piping and components required must be modified. The following are the possibilities for such modifications.

- Use pool-type LMFBR instead of loop-type
- Use bellows joints instead of expansion loops for sodium piping
- Use Super-chrome ferritic steel instead of stainless steel for sodium components such as steam generators, IHX, piping etc.

The refueling system costs are to a great degree dependent on the coolant characteristics and the level of radioactivity in the spent fuel assemblies. One way of simplifying would be the inclusion of a transfer station between the EVST and the reactor vessel for off-loading the assemblies from the transfer pots prior to installation into the EVST. This would have the following effects; (1) It would reduce the number of transfer pots from the present level of one for every assembly in the reload to one or two, (2) It would permit a smaller EVST. This change would be offset somewhat by the cost of a transfer station and the need for another grapple and hoist.

Some reductions in the capital cost of the auxiliary systems are possible with improvements in the system design and with the availability of improved commercial cost data of the sodium components. These would come about through additional design effort to delineate system design and collection of cost data through industry contacts.

Overall, the present estimate of the capital costs of the Target Plant NSSS contains potential for cost reductions in all major systems. These cost reductions in the capital cost are possible through optimization of system and component design, utilization of innovative concepts and improved collection of commercial cost data for LMFBR components.

SECTION 5

DRAWINGS

This section contains the drawings for the 1390 Mwe LMFBR Target Plant described in Section 2. These drawings are the General Arrangement Drawings for the Target Plant.

Figure	Title	Drawing
5.1	Reactor Containment and PHTS Plan View	SE-651410-160-010
5.2	Reactor Containment and PHTS Elevation	SE-651410-160-004
5.3	Steam Generator Building and IHTS Plan View	SE-651410-160-007
5.4	Steam Generator Building and IHTS Elevation	SE-651410-160-006
5.5	Reactor Service Building Layout	SE-651410-160-011
5.6	Reactor Service Building Sectional Elevation	SE-651410-160-012
5.7	Auxiliary Building Plan View	SE-651410-160-013
5.8	Auxiliary Building Elevation	SE-651410-160-014

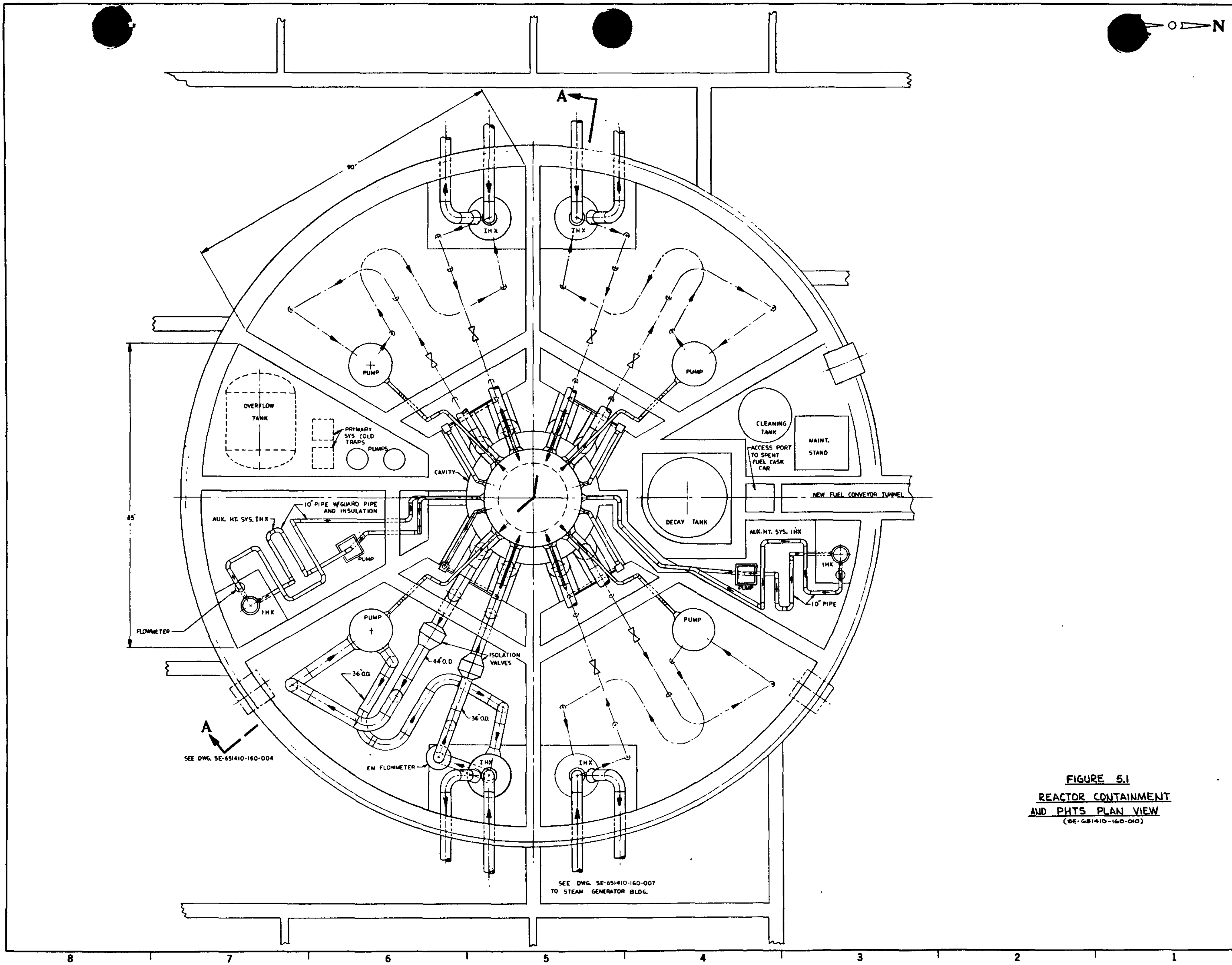


FIGURE 5.1

REACTOR CONTAINMENT AND PHTS PLAN VIEW

(SE-651410-160-010)

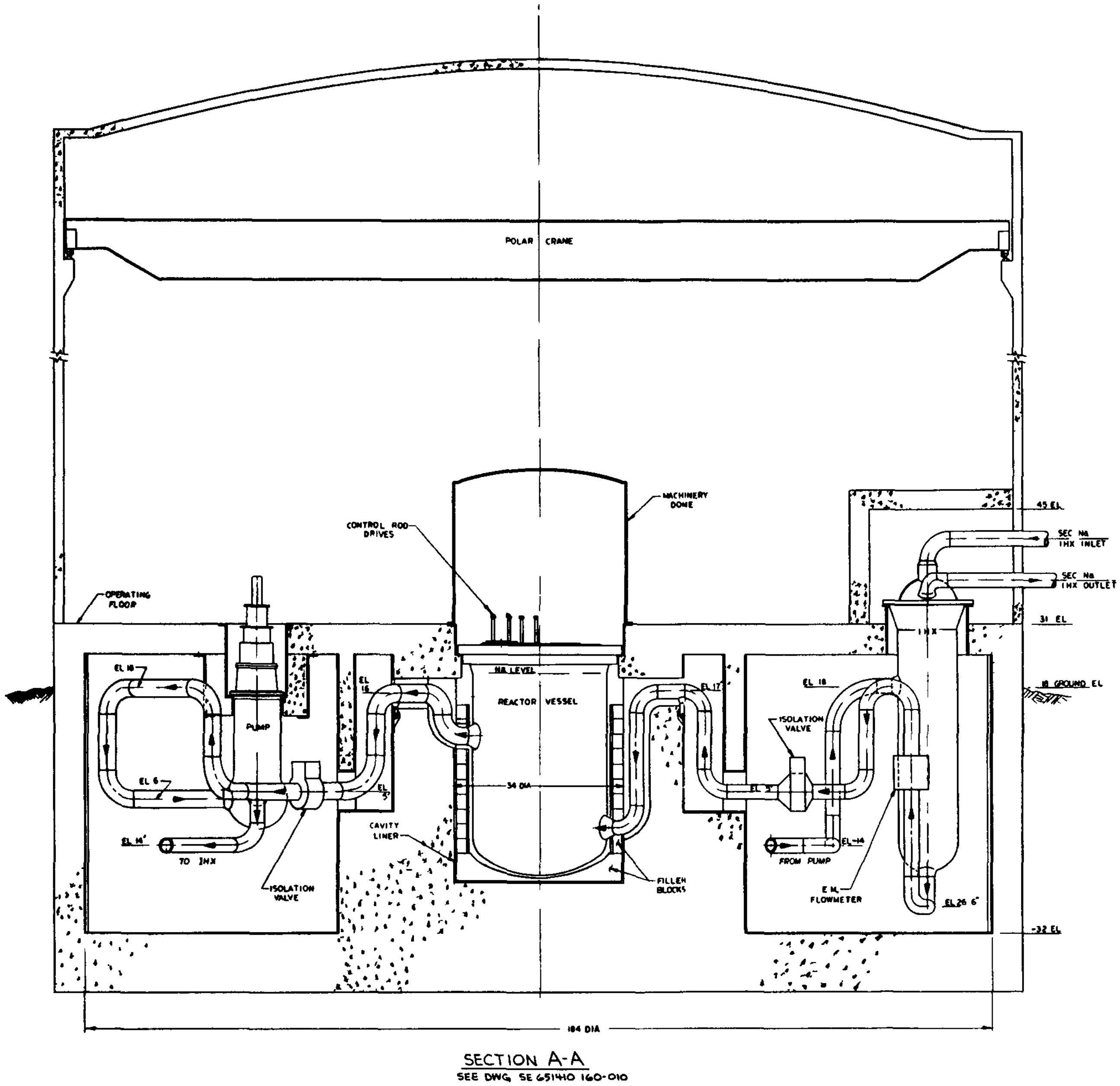


FIGURE 52
REACTOR CONTAINMENT AND PHTS ELEVATION
(SE 681410 160 004)

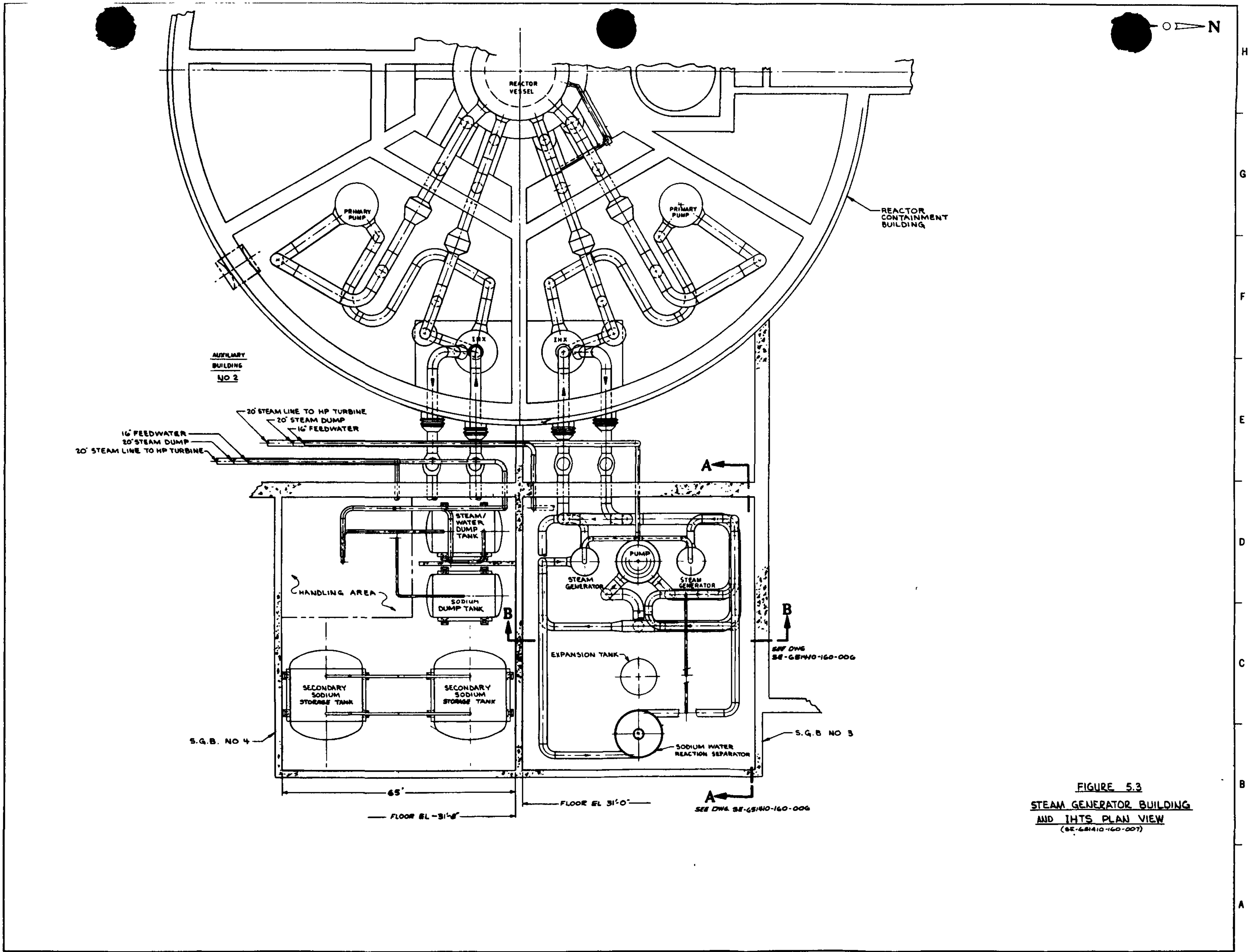
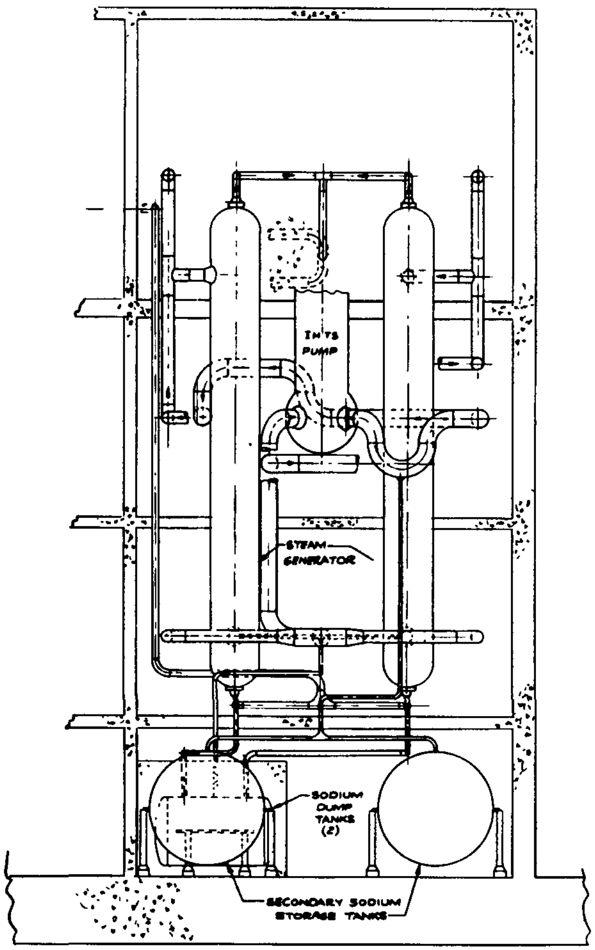
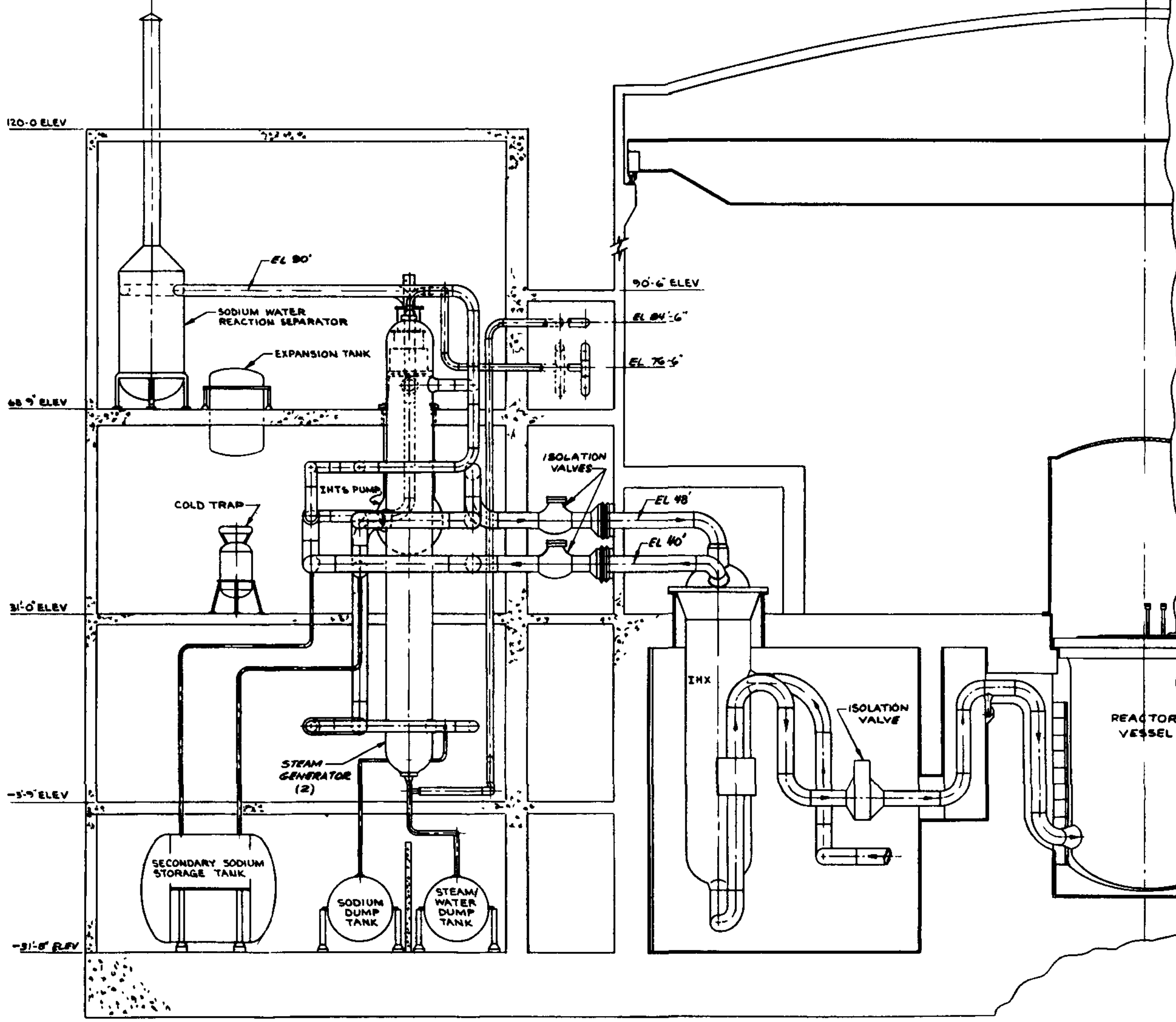


FIGURE 5.3
STEAM GENERATOR BUILDING AND IHTS PLAN VIEW
(SE-651410-160-007)



SECTION **B-B**
(SE-651410-160-007)



SECTION **A-A**
(SE-651410-160-007)

FIGURE 5.4
STEAM GENERATOR BUILDING AND IHTS ELEVATION
(SE-651410-160 006)

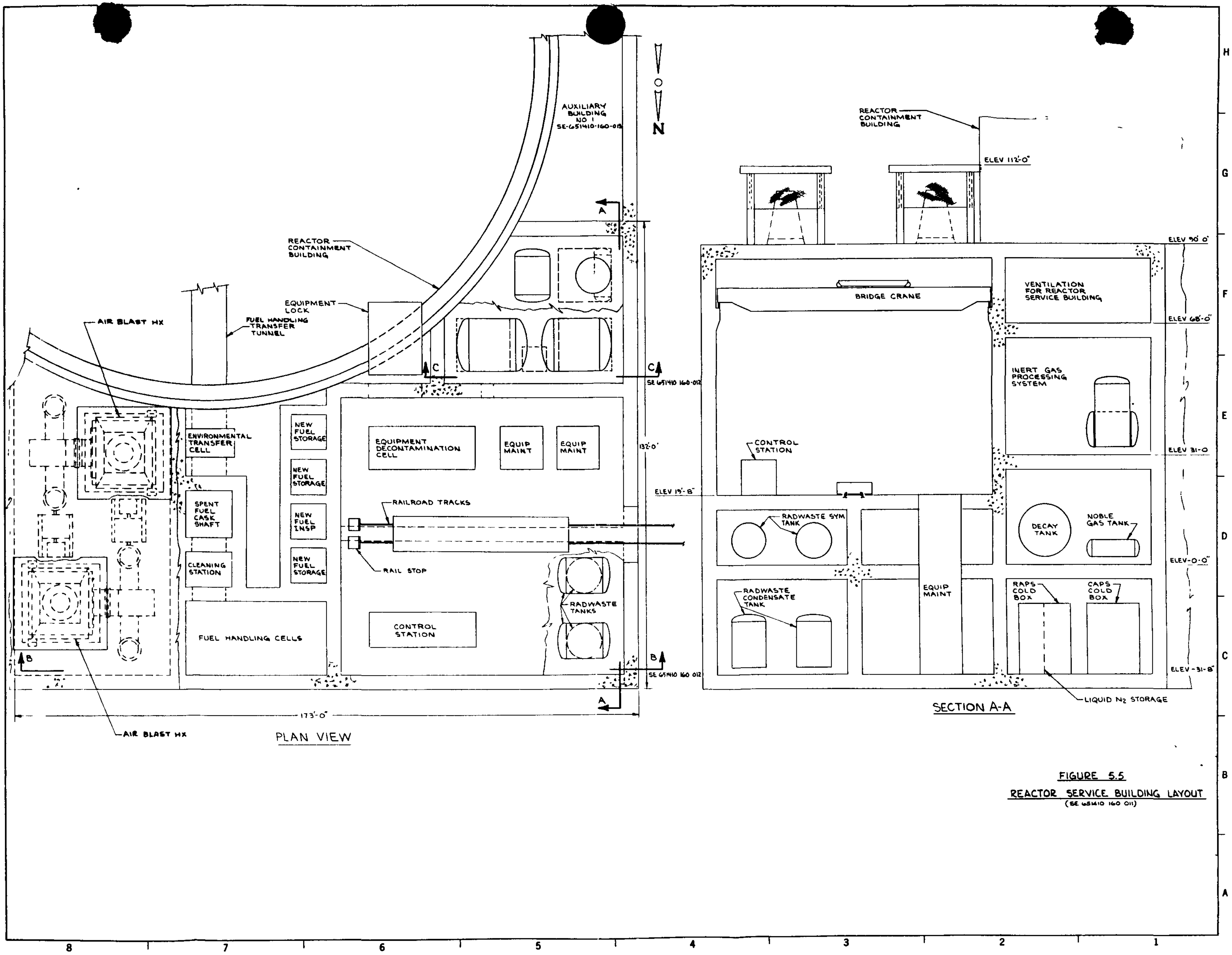


FIGURE 5.5

REACTOR SERVICE BUILDING LAYOUT

(SE 651410 160 011)

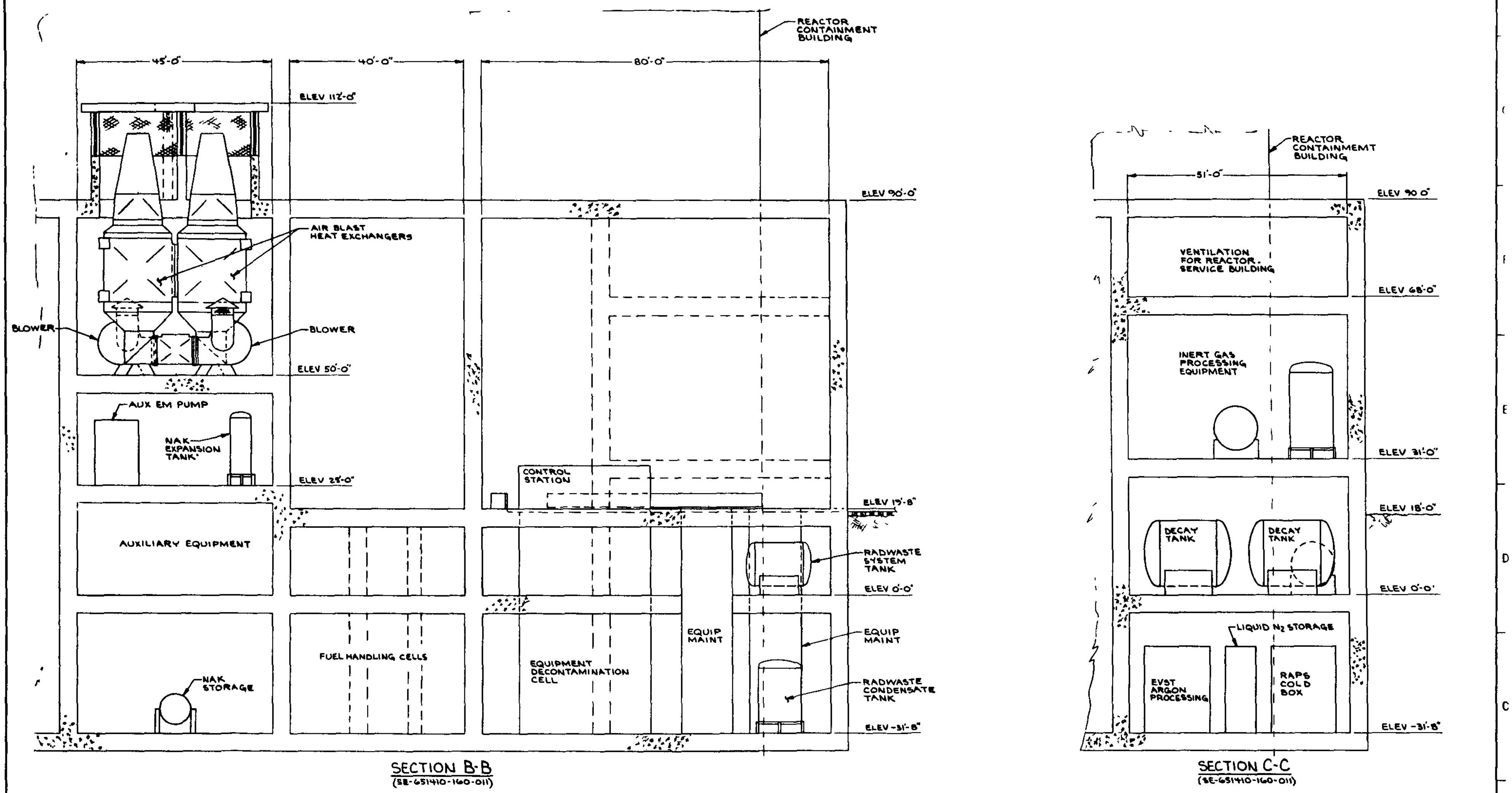


FIGURE 5.6

REACTOR SERVICE BUILDING SECTIONAL ELEVATION

(SE-651410-160-012)

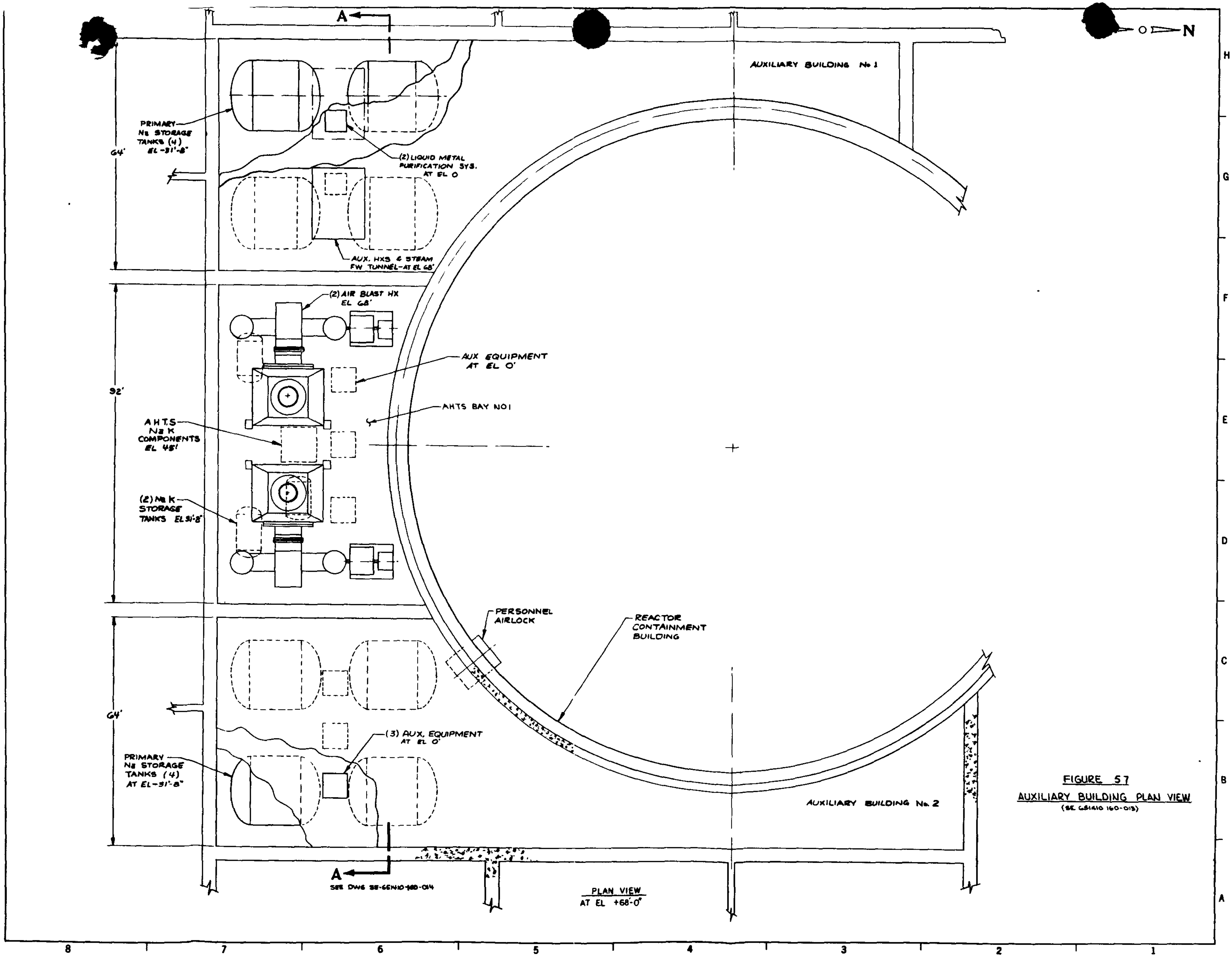


FIGURE 57

AUXILIARY BUILDING PLAN VIEW

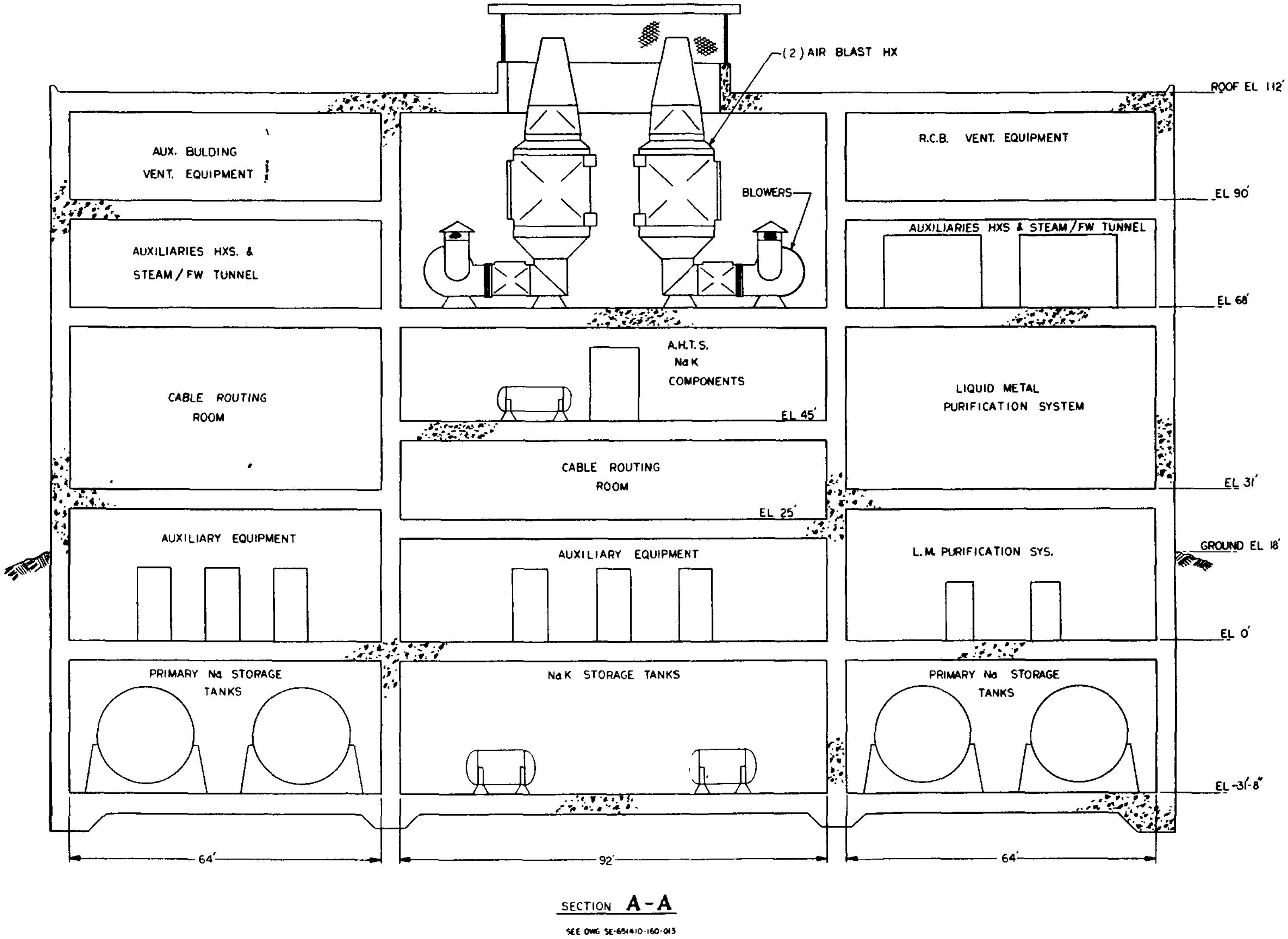


FIGURE 5.8

AUXILIARY BUILDING ELEVATION

(SE-651410-160-014)

SECTION 6

EQUIPMENT LIST

This section describes, in detail, the major components of the LMFBR Target Plant design developed by C-E for this study. Each of component is described in terms of quantity, type, orientation, capacity, design pressure, design temperature, etc., in sufficient detail to permit preparation of the cost estimates given in Section 3 of this report. The components are listed in accordance with an expanded AEC code-of-accounts (USAEC Report NUS-531), in the following Table 6.1 which permits correlation and cross referencing with the detailed cost estimates.

TABLE 6.1

EQUIPMENT LIST

220A.2111 REACTOR VESSEL

DESCRIPTION	LMFBR TARGET PLANT
Number of Components per Plant	1
Design and Operating Conditions	
Design Pressure/Temperature (Inlet Plenum)	165 Psia/675^{0}F
Design Pressure/Temperature (Outlet Plenum)	40 Psia/975^{0}F
Flow Rate	143.2 x 10^6 lbm/hr
Fluid	Na
Inlet Temperature/Outlet Temperature	650^{0}F/950^{0}F
Heat Load	3800 MWt
Safety Class	Section III Class I
Physical Size and Weight	
Maximum Diameter (Shell)	27'-5.00"
Overall Length	49'-1.19"
Dry Weight	924,900 lbs.
Materials	
Shell	SA-240, Type 304
Flange	SA-508, Cl. 3
Shell to Flange Transition	SB-168
Thermal Liner	SA-240, Type 304
COMPONENT SHELLS	
Shell Plate Thicknesses	
Upper Cylindrical Region	3.50"
Lower Cylindrical Region	2.50"
Lower Head	2.50"
Internal Cladding	
Location	None
Material/Thickness	None
Nozzles	
Inlet - Quantity/I.D.	4/35.00"
Outlet - Quantity/I.D.	4/43.00"
Other - Quantity	20

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
Penetrations in Lower Head - Quantity	None
Linear Feet of Welds	1085 ft.
Upper Flange	
Inside Diameter	324.00"
Outside Diameter	361.00"
Height	38.00"
<u>THERMAL LINER</u>	
Outside Diameter	26'-10.0"
Thickness	1.50"
Length	10'-7.00"
<u>SUPPORT SYSTEM</u>	
Flange	
Outside Diameter	404.00"
Height	12.00"
Skirt	
Thickness	6.00"
Height	19.15"
<u>CONSTITUENT WEIGHTS</u>	
Weight of Shell	
Shell Plate	525,600 lbs.
Nozzles	17,300 lbs.
Weld Metal	18,700 lbs.
Upper Flange	153,900 lbs.
Total Weight of Shell	715,500 lbs.
Weight of Support Skirt and Flange	
Flange Weight	68,300 lbs.
Skirt Weight	41,500 lbs.
Total Support Skirt and Flange Weight	109,800 lbs.
Weight of Thermal Liner	
Total Weight of Thermal Liner	69,300 lbs.
Weight of Miscellaneous Items	
Total Weight of Miscellaneous Items	30,300 lbs.

TABLE 6.1 (Continued)

220A.2112 CLOSURE HEAD

DESCRIPTION	LMFBR TARGET PLANT
Number of Components per Loop	1
Component Type or Configuration	Flat W/3 Rotating Plugs
Design and Operating Conditions	
Design Pressure/Temperature (Structure)	40 Psia/200^{o}F
Design Pressure/Temperature (Insulation)	40 Psia/975^{o}F
Safety Class	Section III Class 1
Physical Sizes and Weights	
Flange Outside Diameter	28'-0.00"
Flange Inside Diameter	22'-6.00"
Flange Height	24.00"
Head Radius (Inner)	Flat
Head Thickness	24.00"
Large Rotating Plug Diameter	279.00"
Intermediate Rotating Plug Diameter	228.50"
Small Rotating Plug Diameter	106.00"
Thickness of Biological Shielding	30.00"
Overall Height	120.00"
Total Weight	1,380,000 lbs.
Material	
Flange	SA-508, Class 3
Head	SA-508, Class 3
Biological Shielding	Graphite
Thermal Shielding	SA-240, Type 304
Seals	
Quantity	3 Sets
Type	Inflatable and Dip Seals
Material	Silicon Rubber and Liquid Met.
Number of Control Rod Penetrations	61
Number of Bearings, Drives, and Controls	3

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
Bearings	
Quantity	3
Type	Roller
Diameters	279", 228", 106"
Drive and Motor and Control	
Quantity	6
Type	Reduction Gears
Control	Servo Control

TABLE 6.1 (Continued)

220A.2113 CAVITY FILLER SYSTEM

DESCRIPTION	LMFBR TARGET PLANT
Graphite Blocks	
Quantity	236
Material	Graphite Clad with Steel Plate
Size	3' x 3' x 3' (Approximately)
Weight	860,000 lbs (Total)
Support System	
Quantity	30
Type	Screw Shafts Supported on Thrust Bearings
Lift System	
Quantity	1
Type	Motor/Gear Straight Pull Rails for Transport

TABLE 6.1 (Continued)

220A.212 REACTOR VESSEL INTERNALS

DESCRIPTION	LMFBR TARGET PLANT
Number of Components	1
Design Pressure	40/165 Psia
Design Temperature	975/675^{o}F
Fluid	Sodium
Flow Rate	143.2 x 10^6 lbm/hr
Material	304 SS
Lower Internals	
Core Barrel, Size	233"ϕ x 138" x 1"t
Weight	78,444 lbs.
Core Support Structure, Size	288" x 75" x 3"t
Weight	323,970 lbs.
Baffles, Size	318" O.D. x 233" I.D. x 4"t
Weight	32,000 lbs.
Upper Internals	
CRITA Supports/Tubes, Size	17' x 15"ϕ x 1/2"t
Quantity	61
Weight	92,300 lbs.
Shroud, Size	301"ϕ x 165" x 1"
Weight	38,260 lbs.
Suppressor Plates, Size	306" x 1/2"t
Quantity	3
Weight	33,890 lbs.
Check Valve, Size	36"ϕ
Quantity	4
Type	Swing Disc
Weight	41,840 lbs.
Total Weight (Internals)	644,930 lbs.
Feet of Weld	67,435 ft.

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
CRITA	
Quantity	61
Type	Telescoping
Size	20' x 15"ϕ
<u>CONTROL ROD DRIVES</u>	
Quantity	30
Type	Telescoping Servo Drive
Size	30' x 12"ϕ
Control	Pneumatic
Stroke	48"

TABLE 6.1 (Continued)

220A.2211 PRIMARY PUMP AND MOTOR AND CONTROL

DESCRIPTION	LMFBR TARGET PLANT
Quantity	4
Design Pressure/Temperature	165 Psia/950^{o}F
Type	Centrifugal/Single Stage
Orientation	Vertical
Flow Rate	35.8 x 10^{6} lbs/hr
Speed	690 rpm
TDH	363 ft.
BHP	9000 HP
NPSH	30 ft.
Efficiency	80%
Material	SS
Safety Class	I
Pump Casing	304SS
Diameter	12'
Length	27'
Weight	149,000 lbs.
Pump Shaft	304SS
Diameter	12"
Length	20'-8"
Weight	12,000 lbs.
Impeller	304SS
Diameter	68"
Weight	8000 lbs.
Bearings	
Number	2
Type	Hydrostatic

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
Shielding	Shots
Weight	
Pump Supports	
Type	Flange Mounted (Fixed)
Weight	
Motors	
Type	Induction AC
Rating	9000 HP
Speed Control	
Type	Motor/Generator
Rating	9000 HP
Total Weight (Pump Only)	302,000 lbs.

TABLE 6.1 (Continued)

220A.22121 PRIMARY PIPING

DESCRIPTION	LMFBR TARGET PLANT
Design Temperature (Hot Leg)	$975^{\circ}F$
Design Temperature (Cold Leg)	$675^{\circ}F$
Design Pressure (HP)	165 Psia
Design Pressure (LP)	40 Psia
Safety Class	I
Material	316SS/304SS
Large Piping	
Size	44" O.D. x 5/8"t
Length	754'
Elbows	36
Flow	35.8×10^{6} lbs/hr
Size	36" O.D. x 1/2"t
Length	1348'
Elbows	64
Medium Piping	LP, Siphon, Overflow
Diameter	8"-14" Schedule 40
Length	628'
Small Piping	Drain and Vent
Diameter	6" and Smaller Schedule 40
Length	736'

TABLE 6.1 (Continued)

220A.22122 PRIMARY VALVES

DESCRIPTION	LMFBR TARGET PLANT
Hot Leg Isolation Valves	
Design Pressure	50 Psia
Design Temperature	975^{o}F
Quantity	4
Type	Disc/Wedge
Size	44"ϕ
Material	304SS
Cold Leg Isolation Valves	
Design Pressure	165 Psia
Design Temperature	675^{o}F
Quantity	4
Type	Wedge
Size	36"ϕ
Material	304SS
Throttle/Check Valves	
Quantity	4
Type	Needle
Size	14"
Material	304SS
Drain Valves	
Quantity	22
Type	Wedge/Disc
Size	6"
Siphon Breaker Diodes	
Quantity	4
Type	Nozzles
Size	8"
IHX Vent Line Orifices	
Quantity	4
Type	Orifice Plates
Size	1"

TABLE 6.1 (Continued)

220A.2213 INTERMEDIATE HEAT EXCHANGER

DESCRIPTION	LMFBR TARGET PLANT
Number of Components per Plant	4
Component Type or Configuration	St. Tube/St. Shell
Flow Characteristics	Counterflow
Orientation	Vertical
Shell Size Design and Operating Conditions	
Design Pressure/Design Temperature	165 Psia/975°F
Flow Rate	35.8 x 10^6 lbm/hr
Fluid	Na
Inlet Temperature/Outlet Temperature	950°F/650°F
Tube Side Design and Operating Conditions	
Design Pressure/Design Temperature	165 Psia/975°F
Flow Rate	33.4 x 10^6 lbm/hr
Fluid	Na
Inlet Temperature/Outlet Temperature	590°F/910°F
Net Load Per Component	950 MWt
Safety Class	Section III Class I
Physical Size and Weight	
Maximum Diameter (Shell)	12'-3.19"
Overall Length	64'-1.00"
Dry Weight - Per Component/Per Plant	639,400/2,557,600 lbs
Materials	
Shell Plate	SA-240, Type 304
Tubesheets	SA-182, Type 304
Tubes	SA-213, Type 304
COMPONENT SHELL	
Shell Plate Thicknesses	
Cylindrical Shell Region	3.00"
Upper Hemispherical Head	3.00"
Lower Hemispherical Head (Inner)	3.00"
Lower Hemispherical Head (Outer)	3.00"

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
Nozzles	
Shell Side Inlet - Quantity/I.D.	1/35.00"
Shell Side Outlet - Quantity/I.D.	1/35.00"
Tube Side Inlet - Quantity/I.D.	1/35.00"
Tube Side Outlet - Quantity/I.D.	1/35.00"
Lineal Feet of Welds	510 ft.
<u>COMPONENT TUBE BUNDLE</u>	
Number of Tubes - Per Component/Per Plant	3,846/15,384
Mean Heated Length	45'-0.00"
Tube Side - O.D./Wall Thickness/Pitch	1.25"/0.045"/1.697"
Heat Transfer Area - Per Component/Per Plant	56,600 ft.^{2}/226,400 ft.^{2}
Tube Support Concept	Eggcrates w/baffles
Type of Tube to Tubesheet Weld	Rolled and Seal Welded
Tube Bundle Shroud (Outer)	
Inside Diameter	123.19"
Thickness	1.00"
Length	41'-3.5"
Tube Bundle Shroud (Inner)	
Inside Diameter	39.25"
Thickness	0.63"
Length	37'-7.0"
Downcomer	
Inside Diameter	36.00"
Thickness	0.63"
Length	57'-0.0'
Upper Thermal Liner	
Inside Diameter	34.50"
Thickness	0.50"
Length	9'-2.0"
<u>COMPONENT TUBESHEETS</u>	
Number Per Component	2
Finished Diameter - Upper/Lower	133.12"/133.12"
Finished Thickness - Upper/Lower	12.00"/12.00"

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
CONSTITUENT WEIGHTS	
Weight of Shell (Pressure Boundary)	
Plate Material	297,300 lbs.
Nozzles	10,100 lbs.
Weld Metal	7,800 lbs.
Total Weight of Shell	315,200 lbs.
Weight of Tube Bundle	
Tubing	107,200 lbs.
Tube Supports and Baffles	15,400 lbs.
Shrouds	67,100 lbs.
Downcomer	12,900 lbs.
Total Weight of Tube Bundle	202,600 lbs.
Weight of Tubesheets	
Upper Tubesheet	27,900 lbs.
Lower Tubesheet	29,800 lbs.
Total Weight of Tubesheets	57,700 lbs.
Weight of Miscellaneous Items	
Total Weight of Miscellaneous Items	63,900 lbs.

TABLE 6.1 (Continued)

220A.2221 SECONDARY PUMP AND MOTOR AND CONTROL

DESCRIPTION	LMFBR TARGET PLANT
Pump	
Quantity	4
Design Pressure/Temperature	300 Psia/625^{o}F
Type	Centrifugal
Orientation	Vertical
Flow Rate	33.4 x 10^{6} lbs/hr
Speed	700 rpm
TDH	291 ft.
BHP	6700 HP
NPSH	148 ft.
Efficiency	85%
Material	304SS
Safety Class	NNS
Pump Casing	304SS
Diameter	12 ft.
Length	21 ft.
Weight	116,000 lbs.
Pump Shaft	304SS
Diameter	12"
Length	15 ft.
Weight	8,700 lbs.
Impeller	304SS
Diameter	68"
Weight	8,000 lbs.
Bearings	304SS
Number	2
Type	Hydrostatic
Shielding	Not Required
Weight	
Pump Supports	
Type	Flange, Fixed
Weight	

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
Motors	
Type	AC-Induction
Rating	7000 HP
Speed Control	
Type	Motor/Generator
Rate	7000 HP
Total Weight (Pump Only)	284,000 lbs.

TABLE 6.1 (Continued)

220A.22221 SECONDARY PIPING

DESCRIPTION	LMFBR TARGET PLANT
Safety Class	NNS
Design Pressure	300 Psia
Design Temperature (Hot/Cold)	950/625^{o}F
Material	304SS
Large Piping	
Diameter	36" O.D. x 1/2"t
Length	1600'
Elbows	72
Diameter	26" O.D. x 1/2"t
Length	1520'
Elbows	68
Small Piping	
Diameter	6" and Smaller, Schedule 40
Length	2088'

TABLE 6.1 (Continued)

220A.22222 SECONDARY VALVES

DESCRIPTION	LMFBR TARGET PLANT
Design Pressure	300 Psia
Design Temperature	950/625°F
Material	304SS
Safety Class	NNS
Large Valves	
Quantity	8
Size	36"
Type	Isolation
Small Valves	
Quantity	56
Size	6" and Smaller
Type	Isolation

TABLE 6.1 (Continued)

220A.2224 SECONDARY EXPANSION TANK

DESCRIPTION	LMFBR TARGET PLANT
Number of Components per Plant	4
Design and Operation Conditions	
Design Pressure/Temperature	300 Psia/600^{o}F
Fluid	Na
Heat Input Capacity	None
Safety Class	NNS
Physical Size and Height	
Maximum Diameter (Shell)	123.26"
Overall Length	15'-11.63"
Dry Weight	47,900 lbs.
Material	
Shell Plate	304SS
Support Skirt	None
Support Flange	304SS
COMPONENT SHELLS	
Shell Plate Thicknesses	
Cylindrical Shell Region	1.63"
Upper and Lower Heads	1.63"
Internal Cladding	
Location	None
Material/Thickness	None
Nozzles and Manways	
Total Number	6
Range of Inside Diameters	2.00" thru 4.00"
Manway - Quantity/Size	1/16.00"
Heater Penetrations - Quantity	None
Instrument Nozzles - Quantity	None
Lineal Feet of Welds	135 ft.

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
<u>CONSTITUENT WEIGHTS</u>	
Weight of Shell	
Shell Plate	35,300 lbs.
Nozzles and Manways	850 lbs.
Weld Metal	650 lbs.
Support Skirt	None
Support Flange	11,000 lbs.
Total Weight of Shell	47,800 lbs.
Weight of Miscellaneous Parts	
Total Weight of Miscellaneous Parts	100 lbs.

TABLE 6.1 (Continued)

220A.2232 STEAM GENERATOR

DESCRIPTION	LMFBR TARGET PLANT
Number of Components Per Plant	8
Component Type or Configuration	St. Tube/St. Tube
Flow Characteristics	Counterflow
Orientation	Vertical
Shell Side Design and Operating Conditions	
Design Pressure/Design Temperature	300 Psia/935^{o}F
Flow Rate	16.70 x 10^{6} lbm/hr
Fluid	Na
Inlet Temperature/Outer Temperature	910^{o}F/590^{o}F
Tubeside Design and Operating Conditions	
Design Pressure/Design Temperature	2275 Psia/875^{o}F
Flow Rate	1.78 x 10^{6} lbm/hr
Fluid	H_2O
Inlet Temperature/Outlet Temperature	470^{o}F/854^{o}F
Heat Load Per Component	475 MWT
Safety Class	NNS-ASME Section VIII
Physical Size and Weight	
Maximum Diameter (Shell)	106.75"
Overall Length	88'-8.0"
Dry Weight - Per Component/Per Plant	648,000/5,184,000 lbs.
Materials	2-1/2 Cr-1Mo
Shell Plate	SA-387, GR. 22, CL. 1
Tubesheet(s)	SA-336 F22
Tubes	SA-213, GR. T22
COMPONENT SHELLS	
Shell Plate Thicknesses	
Upper Cylindrical Shell Region	2.50"
Conical Transition Shell Course	None
Lower Cylindrical Shell Region	1.50"
Steam Outlet Hemispherical Head	5.50"
Upper Sodium Hemispherical Head	1.50"
Lower Hemispherical Head	5.00"

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
Internal Cladding	
Location	None
Material/Thickness	None
Nozzles	
Shell Side Inlet - Quantity/I.D.	1/25.00"
Shell Side Outlet - Quantity/I.D.	1/25.00"
Tube Side Inlet - Quantity/I.D.	1/18.00"
Tube Side Outlet - Quantity/I.D.	1/18.00"
Access Ports or Manways - Quantity/I.D.	2/24.00"
Lineal Feet of Welds	310 ft.
TUBE BUNDLES	
Number of Tubes - Per Component/Per Plant	3,547/28,376
Mean Heated Length	72'-0"
Tube Size - O.D./Wall Thickness/Pitch	0.75"/0.125"/1.250"
Heat Transfer Area - Per Component/Per Plant	50,145 Ft^2/401,160 Ft^2
Tube Support Concept	Drilled Plates
Type of Tube-to-Tubesheet Weld	Face and Back Side
Tube Bundle Shroud	
Inside Diameter	80.88"
Thickness	1.00"
Length	67'-6.00"
TUBE SHEETS	
Number Per Component	2
Finished Diameter - Upper/Lower	101.00"/101.00"
Finished Thickness - Upper/Lower	26.00"/23.00"
Clad Material/Clad Thickness	None/None
CONSTITUENT WEIGHTS	
Weight of Shell (Pressure Boundary)	
Plate Material	161,000 lbs.
Nozzles, Access Ports, Manways, Etc.	18,300 lbs.

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
Weight of Weld Metal	2,400 lbs.
Total Weight of Shell	181,700 lbs.
Weight of Tube Bundle	
Tubing	226,700 lbs.
Tube Supports	30,300 lbs.
Shrouds	66,100 lbs.
Total Weight of Tube Bundle	323,100 lbs.
Weight of Tubesheets	
Upper	49,100 lbs.
Lower	36,600 lbs.
Total Weight of Tubesheets	82,700 lbs.
Weight of Steam Separation Equipment	
Weight of Separators	None
Weight of Dryers	None
Weight of Supports	None
Total Weight of Steam Separator Equipment	None
Miscellaneous Parts	
Total Weight of Miscellaneous Parts	60,500 lbs.

TABLE 6.1 (Continued)

220A.2233 Na/H_2O REACTION PROTECTION

DESCRIPTION	LMFBR TARGET PLANT
Rupture Disks	
Quantity	16
Type	
Material	304SS
Weight	
Reaction Products Sep. Tanks	
Quantity	4
Diameter	12'
Length	24'
Volume	70,000 gallons
Material	304SS
Weight	87,000 lbs
Steam Water Dump Tanks (4)	
Sodium Dump Tanks (4)	
Quantity	8
Diameter	14'
Length	15'
Volume	12,760 gallons
Material	304SS
Weight	18,000 lbs.
Large Piping	
Diameter	26"
Length	764'
Material	Carbon Steel
Small Piping	
Diameter	6" and Smaller
Length	1292'
Material	Carbon Steel
Valves	
Quantity	36
Type	Gate
Size	6" and Smaller - 20 10" - 8 26" - 8

TABLE 6.1 (Continued)

220A.231 SAFEGUARDS SYSTEM

DESCRIPTION	LMFBR TARGET PLANT
Decay Heat Removal Pumps	
Quantity	2
Type	EM
Fluid	Na
Flow	5200 GPM
Head	140 ft.
Design Pressure/Design Temperature	100 Psia/970^{o}F
Safety Class	2
Materials	304SS
Rating	540 HP
Quantity	2
Type	EM
Fluid	NaK
Flow	7086 GPM
Head	67 ft.
Design Pressure/Design Temperature	200 Psia/650^{o}F
Safety Class	2
Material	304SS
Rating	352 HP
AHTS Fans	
Quantity	4
Type	Centrifugal
Flow	2.5 x 10^{5} CFM
Rating	1250 HP
AHTS Heat Exchangers	
Quantity	2
Type	Shell/Tube
Fluid	Na/NaK
Safety Class	1
Flow	5200/7086 GPM
Design Pressure	200 Psia
Design Temperature	1050^{o}F
Thermal Rating	194 x 10^{6} BTU/HR
Material	304SS
Ht. Area, Ft.^{2}	2,500 each

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
AHTS ABHX	
Quantity	4
Type	Forced Convection
Fluid	NaK/Air
Flow	3543 GPM/2.5 x 10^5 CFM
Design Pressure/Design Temperature	200 Psia/1050^{o}F
Safety Class	2
Thermal Rating	97 x 10^6 Btu/hr
Material	304SS
Ht. Area, Ft.^{2}	3,981 each
Piping	
2" and smaller	50' Schedule 40
10"	620'-10" Schedule 40 (Na)
12"	344'-12" Schedule 40 (NaK)
Valves	
Quantity	18
Type	Isolation
Size	10" to 12"
Tanks	
Quantity	2
Type	NaK Expansion
Fluid	NaK
Design Pressure	200 Psia
Design Temperature	700^{o}F
Size	15' x 5'ϕ
Volume	2,400 gallons
Material	304SS
Weight	8000 lbs.

TABLE 6.1 (Continued)

220A.25 REFUELING SYSTEMS - RECEIVING, STORAGE AND SHIPPING

DESCRIPTION	LMFBR TARGET PLANT
New Fuel Handling Crane	
Travel (ft.)	50 (Bridge), 30 (Trolley)
Hoist Capacity (ton)	0.50
Lift (ft.)	20 Approximately
Classification	
No. of Drives	3
Weight (lb.)	4,000
New Fuel Storage Racks	
Dimensions	6.25" FTF, 14' High
Capacity	298 Fuel Assemblies
Classification	
Weight (lb.)	700 lbs. per cell

TABLE 6.1 (Continued)

220A.25 REFUELING SYSTEMS - EX-VESSEL STORAGE TANK

DESCRIPTION	LMFBR TARGET PLANT
Number of Components per Plant	1
Design Pressure/Temperature	Vertical
Fluid Contained	Na
Safety Class	2
Physical Size and Weight (Assembled)	
Maximum Shell Diameter	19'-9.38"
Overall Length	50'-0"
Total Weight	1,213,000 lbs.*
Materials for Tank	
Shell	SA-240, Type 304
Flange	SA-508, Class 2
Materials for Closure Head	
Structural Cover	SA-533, GR. B, CL. 1
Materials for Turntables	
Barrel	SA-240, Type 304
Grid Plates	SA-240, Type 304
Lower Support Structure	SA-240 and 479, Type 304
COMPONENT SHELL	
Shell Plate Thicknesses	
Upper Cylindrical Region	3.00"
Lower Cylindrical Region	1.50"
Lower Head	1.50"
Nozzles	
Total Number	11
Range of Inside Diameters	1.96" thru 4.02"

* Does not include weight of drive mechanisms or storage tubes.

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
CLOSURE HEAD	
Structure Cover Thickness	12.00"
Thermal Shielding	
Number of Plates	25
Thickness of Plates	.063"
Number of Penetrations	36
Type of Seals	Plated Double "C"
TURNTABLE	
Barrel Thickness	2.53"
Grid Plate Thickness/Number	6.25/2
Number of Storage Positions	334
DRIVE MECHANISMS	
Number of Bearings	2
Drive Motor Power	**
Drive Motor Control	**
CONSTITUENT WEIGHTS	
Total Weight of Tank	420,000 lbs.
Total Weight of Closure Head	300,000 lbs.
Total Weight of Turntable	493,000 lbs.
Total Weight of Drive Mechanism	***

** Unknown

*** Does not include the weight of storage tubes.

TABLE 6.1 (Continued)

220A.25 REFUELING SYSTEMS - EX-VESSEL HANDLING MECHANISMS

DESCRIPTION	LMFBR TARGET PLANT
EVHM Trolley Line	
Track Length/Gauge	75'/5' Centers
Load (tons)	16 on Rails
Classification	
Weight (lbs)	2,000
Spent Fuel Rails	
Track Length (ft.)	50
Grapple Guide (ft.)	28
Load (tons)	37 on Rails
Classification	
Weight (lbs.)	2,500
EVHM	
Dimensions	6'-9" x 12'-0" x 28'-0" High
Stroke (ft.)	50 (Maximum)
Motors (number)	4
Drives (number)	6
Classification	
Weight (tons)	16
Spent Fuel Cask Cart	
Dimensions	12'-0" x 12'-0" x 22'-0" High
Motors (number)	4
Drives (number)	1 Cart, 1 Welder Head, 1 Welding Power Supply
Classification	
Weight (lbs.)	24,000 (less cask)

TABLE 6.1 (Continued)

220A.25 REFUELING SYSTEMS - TRANSFER MECHANISMS

DESCRIPTION	LMFBR TARGET PLANT
Transfer Arm and Motor	
Dimensions	Arm and Structure 18' Long 12" x 18" Drive Package with 6' Drive Shaft
Swing	31.75" with 800 lb. load
Classification	
Weight (lbs.)	3,250
Refueling Elevator and Motor	
Dimensions	15" x 36" x 30' long
Load (lbs.)	1,250
Lift (ft.)	12 (Approximately)
Classification	
Weight (lbs.)	3,000 (no load)
Transfer Pots	
Number	300
Dimensions	10" O.D. x 13.5' long
Classification	
Weight (lb.)	850

TABLE 6.1 (Continued)

220A.25 REFUELING SYSTEMS - IN-VESSEL HANDLING MECHANISMS

DESCRIPTION	LMFBR TARGET PLANT
IVHM	
Dimensions	12" Diameter x 32' long (lower) 6'-6" Square x 26' long (upper)
Lift (ft.)	27 for Removal
Stroke (in.)	170
Drives (number)	4
Classification	
Weight (lb.)	17,500

TABLE 6.1 (Continued)

220A.25 REFUELING SYSTEM - FUEL HANDLING CELLS

DESCRIPTION	LMFBR TARGET PLANT
New Fuel Conveyor and Tubes	
Track Length (ft.)	85 (Approximately)
Load	8 Assemblies @ 400 lb. each 11" long
Classification	
Weight (lb.)	7,000
Environmental Change	
Cell Equipment	
Hoist	1/2 Ton, 20' Lift
Shuttle	1/2 Ton Capacity; 10' Travel Manual Drive
Fuel Guide	Fixed Lead in for Floor Valve
Classification	
Weight (lbs.)	1,500

TABLE 6.1 (Continued)

220A.25 REFUELING SYSTEMS - PIPING AND VALVES

DESCRIPTION	LMFBR TARGET PLANT
Floor Valves	
Number	4
Dimensions	3.5'Diameter x 12" High + Actuator
Classification	
Weight (lbs.)	5,200

TABLE 6.1 (Continued)

220A.25 REFUELING SYSTEMS - MISCELLANEOUS EQUIPMENT

DESCRIPTION	LMFBR TARGET PLANT
Auxiliary Handling Machine	
Dimensions	6' x 6' x 75' high
Stroke (ft.)	35
Number of Drives	4
Classification	
Weight (tons)	50
Tanks	
Quantity	2
Type	EVST NaK Exp. Tanks
Fluid	NaK
Design Pressure	65 Psia
Design Temperature	$200^{o}F$
Size	5' x 2.5'ϕ
Volume	150 gallons
Material	Carbon Steel
Weight	
Pumps	
Quantity	2
Type	EM
Fluid	Radioactive Na
Flow	981 GPM
Head	100 ft.
Design Pressure	100 Psia
Design Temperature	$550^{o}F$
Material	304SS
Weight	
Rating	46 HP
Quantity	2
Type	EM
Fluid	NaK
Flow	1141 GPM
Head	100 ft.

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
Design Pressure	100 Psia
Design Temperature	470^{o}F
Material	304SS
Weight	
Rating	75 HP
Quantity	2
Type	ABHX Compressor
Fluid	Air
Flow	3.22 x 10^{4} CFM
Coolant	
Rating	

TABLE 6.1 (Continued)

220A.25 FUEL HANDLING AND STORAGE

DESCRIPTION	LMFBR TARGET PLANT
Heat Exchangers	
Quantity	2
Type	EVST Heat Exchanger Shell/Tube
Fluid	NaK/Na
Flow	1141/701 GPM
Design Pressure	200/200 Psia
Design Temperature	485/535°F
Thermal Rating	11.9×10^6 BTU/HR
Material	304 SS
Weight	
Heat Transfer Area	305 $Ft.^2$
Quantity	2
Type	EVST Air Blast Heat Exchanger Shell/Tube
Fluid	Air/NaK
Flow	4.12×10^4 CFM/981 GPM
Design Pressure	15/200 Psia
Design Temperature	450/550°F
Thermal Rating	11.9×10^6 BTU/HR
Material	304 SS
Weight	
Heat Transfer Area	946 $Ft.^2$
Quantity	2
Type	EVST Cold Trap, Regenerative Shell/Tube
Fluid	Radioactive Na
Flow	100/100 GPM
Design Pressure	200/200 Psia
Design Temperature	535/485°F
Thermal Rating	1.87×10^6 BTU/HR
Material	304 SS
Weight	
Heat Transfer Area	32 $Ft.^2$
Purification	
Quantity	2
Type	EVST Cold Traps
Fluid	Radioactive Coolant
Flow	100 GPM
Design Pressure	100 Psia
Design Temperature	400°F
Mesh	
Material	304 SS
Weight	

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
Quantity	2
Type	NaK Diffusion Traps
Fluid	NaK
Flow	
Design Pressure	25 Psia
Design Temperature	250^{o}F
Mesh	
Material	Carbon Steel
Weight	

TABLE 6.1 (Continued)

220A.2611 INERT GAS RECEIVING AND PROCESSING

DESCRIPTION	LMFBR TARGET PLANT
Compressors	
Quantity	3
Type	RAPS Compressors
Design Pressure	9 Inlet/135 Discharge Psia
Design Temperature	120°F
Flow	25 CFM
Material	304SS
Rating	
Quantity	2
Type	CAPS Compressors
Design Pressure	9 Inlet/135 Discharge Psia
Design Temperature	120°F
Flow	50 CFM
Material	304SS
Rating	

TABLE 6.1 (Continued)

220A.2612 GAS SUPPLY STORAGE SYSTEMS (TANKS)

DESCRIPTION	LMFBR TARGET PLANT LIQUID	LMFBR TARGET PLANT GASEOUS
Nitrogen Storage Tanks		
Quantity	3	3
Design Pressure/Temperature, Psia/^{O}F	125/-290	250/-290
Height/Diameter	20'/7'	15'/10'
Volume	6000 Gal.	6000 Gal.
Material	304SS	
Weight	24,000 lbs.	12,000 lbs.
Argon Storage Tank		
Quantity	9	
Design Pressure/Temperature	250/120 Psia/^{O}F	
Height/Diameter	7' x 6'	
Volume	1500 Gal.	
Material	304SS	
Weight	4000 lbs.	
Inert Gas Vacuum Tank		
Quantity	2	
Design Pressure/Temperature	150/120 Psia/^{O}F	
Height/Diameter	14' by 7'ϕ	
Volume	538 ft.^{3}	
Material	304SS	
Weight	10,000 lbs.	
Inert Gas Delay Tank		
Quantity	2	
Design Pressure/Temperature	150/120 Psia/^{O}F	
Height/Diameter	25'/7'ϕ	
Volume	960 Ft.^{3}	
Material	304SS	
Weight	20,000 lbs.	
Noble Gas Storage Tank		
Quantity	1	
Design Pressure/Temperature	150/120 Psia/^{O}F	
Height/Diameter	15'/5'	
Volume	300 Ft.^{3}	
Material	304SS	
Weight	2,200 lbs.	

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
Recycle Argon Tank	
Quantity	1
Design Pressure/Temperature	150/120 Psia/^{o}F
Height/Diameter	10' x 10'
Volume	750 $Ft.^3$
Material	304SS
Weight	8000 lbs.

TABLE 6.1 (Continued)

220A.2613 INERT GAS PURIFICATION SYSTEMS (UNITS)

DESCRIPTION	LMFBR TARGET PLANT
Nitrogen Vaporizer	
Quantity	10
Size	
Flow	5,000 SCFM
Material	304SS
Argon Vaporizer	
Quantity	9
Size	
Flow	5,000 SCFM
Material	304SS
Nitrogen Filter	
Quantity	2
Mesh	HEPA
Flow	500 SCFM
Material	304SS
Weight	500 lbs.
Argon Filter	
Quantity	2
Mesh	HEPA
Flow	250 SCFM
Material	304SS
Weight	500 lbs.
Vapor Traps	
Quantity	25
Capacity	5 SCFM
Material	304SS
Purification Unit	
Quantity	1

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
Nitrogen/Argon Charcoal Beds	
Quantity	5
Design Pressure/Temperature	150/-340 Psia/^{o}F
Diameter	14'
Height	28'
Volume	508 Ft.^{3}
Material	PCB Charcoal
Weight	10,000 lbs.
Distillation Unit	
Quantity	1
Design Pressure/Temperature	150/-320 Psia/^{o}F
Diameter	----
Height	----
Flow	25 SCFM
Material	304SS
Weight	----
Heat Exchangers	
RAPS Regenerative Heat Exchanger	
Quantity	2
Design	Tube/Shell
Design Pressure	150 Psia
Design Temperature	120^{o}F
Flow	25 SCFM
Thermal Rating	40,000 BTU/HR
Weight	
Heat Transfer Area	
Material	304SS
RAPS Argon Coolers	
Quantity	2
Design Pressure	150 Psia
Design Temperature	120°F
Flow	25 SCFM
Thermal Rating	40,000 BTU/HR
Weight	
Heat Transfer Area	
Material	304SS
CAPS Nitrogen Cooler	
Quantity	8
Design Pressure	150 Psia
Design Temperature	120^{o}F
Flow	150 SCFM

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
Thermal Rating	10,000 BTU/HR
Weight	
Heat Transfer Area	
Material	304SS

TABLE 6.1 (Continued)

220A.2615 PIPING, VALVES, AND FITTINGS

DESCRIPTION	LMFBR TARGET PLANT
Valves	
Type	Plug
Size	2" and Smaller
Quantity	146
Material	304SS
Piping	
Diameter	2" and Smaller
Length	1700' CAPS
Material	Carbon Steel
	2100' - PHTS Argon
	304SS
	1500' - IHTS Argon
	Carbon Steel
Freeze Vent	
Quantity	37
Size	3"ϕ x 30"
Material	304SS
Weight	450 lbs.
Type	Oil Trap
Quantity	8
Size	27 Ft.^{3}
Material	304SS
Weight	1000 lbs.

TABLE 6.1 (Continued)

220A.264 LIQUID METAL RECEIVING, STORAGE AND MAKEUP

DESCRIPTION	LMFBR TARGET PLANT
Tanks	
Quantity	8
Primary Na Storage	
Fluid	Primary Coolant
Design Pressure	15 Psia
Design Temperature	400^{o}F
Size	25' x 20' x 3/4"
Volume	58,752 Gallon
Material	304SS
Weight	80,000 lbs.
Intermediate Na Storage Tanks	
Quantity	8
Fluid	Secondary Sodium
Design Pressure	175 Psia
Design Temperature	400^{o}F
Size	25' x 20' x 3/4"
Volume	58,752 Gallon
Material	304SS
Weight	80,000 lbs.
NaK Storage Tanks	3
Fluid	NaK
Design Pressure	65 Psia
Design Temperature	400^{o}F
Size	7'ϕ x 14'
Volume	3600 Gallons
Material	304SS
Weight	

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
Filters	
Quantity	2
Type	Sodium Particulate
Fluid	Sodium
Flow	180 GPM
Design Pressure	25 Psia
Design Temperature	350°F
Mesh	20 Micron
Material	304SS
Weight	
Quantity	1
Type	NaK Particulate
Fluid	NaK
Flow	180 GPM
Design Pressure	25 Psia
Design Temperature	70°F
Mesh	20 Micron
Material	304SS
Weight	
Valves	
Quantity/Type	9/2" Plug, NNS 48/2" Plug, SC3 16/3" Plug, NNS
Tanks (Oil Bubbler)	
Quantity	6
Design Pressure	20 Psia
Design Temperature	100°F
Size	3' x 3'ϕ
Volume	202 Gallons
Material	Carbon Steel
Weight	1000 lbs.
Piping	
Quantity/Size	1400'/3" SC3 1700'/3" NNS 150'/3" SC3

TABLE 6.1 (Continued)

220A.265 SODIUM PURIFICATION SYSTEM

DESCRIPTION	LMFBR TARGET PLANT
Pumps	
Overflow Pump	
Quantity	2
Type	EM
Fluid	Primary Sodium
Flow	350 GPM
Head	105 Ft.
Design Pressure	100 Psia
Design Temperature	970^{o}F
Material	304SS
Weight	
Rating	30 HP
Primary Cold Trap Cooling Pumps	
Quantity	2
Fluid	NaK
Flow	160 GPM
Head	235 Ft.
Design Pressure	100 Psia
Design Temperature	600^{o}F
Material	304SS
Weight	
Rating	30 HP
IHTS Cold Trap Pump	
Quantity	4
Fluid	Intermediate Sodium
Flow	70 GPM
Head	200 Ft.
Design Pressure	200 Psia
Design Temperature	640^{o}F
Material	304SS
Weight	
Rating	10 HP

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
IHTS Cold Trap Cooling Pumps	
Quantity	2
Fluid	NaK
Flow	100 GPM
Head	200 Ft.
Design Pressure	200 Psia
Design Temperature	600^{o}F
Material	304SS
Rating	15 HP
Heat Exchangers	
Quantity	2
Type	Primary Cold Trap Regenerative Shell/Tube
Fluid	Primary Na/Primary Na
Flow	100/100 GPM
Design Pressure	100 Psia
Design Temperature	970^{o}F
Thermal Rating	8.59 * 10^6 BTU/HR
Material	304SS
Weight	
Heat Transfer Area	150 Ft.^{2}
Quantity	4
Type	Intermediate Sodium, Regenerative Shell/Tube
Fluid	Intermediate Na/Intermediate N
Flow	100/100 GPM
Design Pressure	100 Psia
Design Temperature	640^{o}F
Thermal Rating	8.59 * 10^6 BTU/HR
Material	304SS
Weight	
Heat Transfer Area	150 Ft.^{2}
Tanks	
Quantity	1
Primary Overflow	
Fluid	Primary Coolant
Design Pressure	5 Psia
Design Temperature	950^{o}F
Size	25' x 20'ϕ
Volume	58,752 gallons
Material	304SS
Weight	

TABLE 6.1 (Continued)

DESCRIPTION	LMFBR TARGET PLANT
HTS NaK Expansion Tanks	
Quantity	4
Design Pressure/Temperature	65 Psia/400^{o}F
Fluid	NaK
Size	2'ϕ x 3'
Volume	70 Gallons
Filters	
Quantity	3
Type	Primary Cold Traps
Fluid	Primary Coolant
Flow	100 GPM
Design Pressure	100 Psia
Design Temperature	400^{o}F
Mesh	
Material	304SS
Weight	
Quantity	4
Intermediate Sodium Cold Trap	
Fluid	Intermediate Sodium
Flow	70 GPM
Design Pressure	200 Psia
Design Temperature	400^{o}F
Mesh	
Material	304SS
Weight	
Quantity	5
NaK Diffusion Cold Trap	
Fluid	NaK
Flow	
Design Pressure	25 Psia
Design Temperature	250^{o}F
Mesh	
Material	Carbon Steel
Weight	
Valves	
Quantity/Type	6/2" Globe, SC2 8/3" Globe, NNS
Piping	200'/3"ϕ - 304SS 400'/2"ϕ - 304SS

TABLE 6.1 (Continued)

220.27 INSTRUMENTATION AND CONTROL SYSTEM EQUIPMENT

DESCRIPTION	QUANTITY
Data Processing System	
Plant Monitoring Computer	1
Plant Protection System (PPS)	
Sensors	
BF_3 Counters	4
BF_3 Counter Preamps	4
Startup Channel Safety Channel Drawers	4
Fission Chambers (3 Section)	4
Fission Chamber Preamps	4
Wide Range Safety Channel Drawers	4
Isolation Amplifiers	4
PHTS EM Flowmeters - 36"	4
IHTS EM Flowmeters - 36"	4
IHTS Venturi Diff. Pressure Transmitters	4
PHTS Pressure Transmitters	32
PHTS Temperature Transmitters (RTD)	32
PHTS Level Transmitters	16
I/I Converters (Isolation)	320
Power Supplies	92
Indicators	92
Safety Process Protective Cabinets	4
Core Monitoring Computers	2
Plant Protection System Cabinets	4
Reactor Trip Switchgear System	2
Remote Display & Control Modules	4
Annunciators	48
Supplementary Reactor Protection System	
Sensors	
Temperature Transmitters (RTD)	48
Level Transmitters	16
SRPS Cabinets	4
SRPS Reactor Trip Switchgear Cabinets	4
Remote Display Modules	4
Annunciators	24
Containment Isolation System	
Sensors	
Gamma Monitors	8
Gas Monitors	8
Particulate Monitors	8
Cell Atmosphere Monitors	8
Cover Gas Monitors	8
ESF Logic Cabinets	4
Remote Display and Control Modules	4

TABLE 6.1 (Continued)

DESCRIPTION	QUANTITY
In-Vessel Flux Monitoring System	
Fission Chambers	3
Pre-Amplifiers	3
Subcriticality Monitors	3
Ex-Vessel Flux Monitoring System	
Bio Ion Chambers	2
Linear Control Channel Drawers	2
Vessel and Internals Monitoring	
Temperature Elements (In-Core TC)	1624
Level Transmitters	4
CEA Pos. Transmitters	60
In-Vessel Accelerometers	4
Temperature Indicators	24
Equipment Operating Surveillance	
Acoustic Transducers	40
Signal Conditioners	40
Pressure Transducers	40
Temp. Elements (TC)	112
Accelerometers	24
Speed Sensors	8
Torque Transmitters	8
Mass Spectrometers	2
Gamma Spectrometers	1
BF-3 Counters	8
Delayed Neutron Monitor	1
Data Handling System	1
LD Contact Detectors	24
LD Cable Detectors	12
Aerosol Monitors	4
Level Transmitters	8
Hydrogen Detectors	4
Hydrogen & Gas Chromatograph	1
Oxygen Detectors	4
Disc-Rupture Sensors	48
Pressure Elements (Disc)	12
Radiation Monitoring Equipment	
Plutonium Monitors	4
Radio Iodine Monitors	4
Tritium Monitors	4
Liquid Monitor	1
Gamma Area Monitors	20
Particulate Monitors (3 ch)	6
Health Physics Monitoring Package	1

TABLE 6.1 (Continued)

DESCRIPTION	QUANTITY
Control Systems	
Recorder Indicator Controllers	27
Controllers	13
Pressure Transmitters	5
Temperature Transmitters (RTD)	4
Process Instrumentation/PHTS and IHTS	
Temperature Elements (TC)	80
Pressure Transmitters	36
Level Transmitters	24
Process Instrumentation/SG Systems	
Temperature Transmitters (RTD)	8
Pressure Transmitters	32
Level Transmitters	64
Flow Transmitters	4
Temp. Rec. Controllers	8
Flow Rec. Controllers	24
Flow Meters	24
Level Rec. Controllers	16
Level Indicators	64
Pressure Indicators	32
Hand Ind. Controllers	72
Hand Switches	80
Annunciators	576
Control Switches	400
Temp. Indicators	8
Process Instrumentation/Intermediate Sodium Purification System	
Temperature Elements	41
Level Transmitter	4
Flow Transmitters	4
Temp. Indicators	21
Press. Indicators	15
Flow Indicators	10
Temp. Indicator Controllers	8
Level Indicators	4

TABLE 6.1 (Continued)

DESCRIPTION	QUANTITY
Process Instrumentation/Intermediate Sodium Purification System	
Temperature Elements	41
Level Transmitter	4
Flow Transmitters	4
Temp. Indicators	21
Press. Indicators	15
Flow Indicators	10
Temp. Indicator Controllers	8
Level Indicators	4
Process Instrumentation/Primary Sodium Purification System	
Pressure Indicators	12
Temp. Indicators	16
Pressure Transmitters	16
Flow Indicators	6
Level Indicators	4
Level Transmitters	6
Temp. Indicator Controllers	8
Flow Transmitters	12
Temp. Transmitters	44
Process Instrumentation/Sodium & NaK Receiving System	
Temp. Indicators	2
Pressure Indicators	3
Temp. Sensors (TC)	4
Pressure Transmitter	1
Process Instrumentation/Primary Sodium Storage and Processing	
Level Indicators	5
Level Transmitter	5
Temp. Elements	37
Temp. Transmitters	6
Flow Indicators	2
Flow Transmitters	2
Temp. Indicator Controllers	2
Process Instrumentation/Ex-Vessel Storage	
Temp. Indicators	4
Temp. Transmitters	8
Temp. Sensors	44
Level Indicators	5
Level Transmitters	5
Flow Indicators	2
Flow Transmitters	2
Temp. Indicator Controllers	2

TABLE 6.1 (Continued)

DESCRIPTION	QUANTITY
Process Instrumentation/Primary Sodium Cold Trap	
Temp. Elements (TC)	12
Temp. Transmitters	6
Temp. Indicators	4
Flow Transmitters	2
Temp. Indicator Controllers	2
Flow Indicator	1
Level Indicator	1
Level Transmitters	1
Process Instrumentation/Intermediate Sodium Processing System	
Temp. Indicators	4
Temp. Elements	80
Temp. Trans. (RTD)	36
Pressure Transmitters	8
Level Indicators	4
Level Transmitters	4
Flow Transmitters	8
Pressure Indicators	4
Pressure Transmitters	4
Component Control System	
Solid State Component Cabinet	1
Control Element Drive Mechanism Control System	
CEDMCS Cabinet	1
Piping and Equipment Electrical Heating System	
Heaters	50,000 ft.
Thermocouples	2,000
Temperature Controllers	750
Panels	250
Heat-Up Control Computer	1

TABLE 6.1 (Continued)

DESCRIPTION	QUANTITY
Remote Shutdown System	
Remote Hot Shutdown Panels	12
Handswitches	100
Temperature Indicators	16
Pressure Indicators	4
Level Indicators	6
Control Transfer Switch	1
PPS Status Panel	1
Temperature Recorders	4
Annunciators	40
Control Panels	
Control Panels	60