3.3 SOMBRERO POWER CONVERSION AND PLANT FACILITIES

3.3.1 Heat Transport System

Primary Coolant Loop. The heat transport system proposed for the SOMBRERO reactor concept is shown in Fig. 3.57. The primary coolant selected is lithium oxide granules fluidized with gaseous helium. It operates between 550°C and 700°C. The primary loop consists of four coolant circuits including one heat exchanger in each circuit. The number of circuits was based on the size of the heat exchangers. A state-of-the-art heat exchanger design was assumed.

Intermediate Coolant Loop. The need for an intermediate loop has been discussed for the OSIRIS case. A similar rationale applies to the case of SOMBRERO. The intermediate loop consists of two circuits including one steam generator in each circuit. This selection was based on the projected steam generator capacity. Each steam generator capacity needed for the SOMBRERO plant is 1450 MWt. Although this capacity level has not been demonstrated to date, no show stoppers are anticipated in the development of steam generators of this power level.

Intermediate Heat Exchanger. There are four intermediate heat exchangers (IHX), and each is sized for 25% of the thermal capacity of the plant. Thus, each IHX has a rated capacity of 725 MWt. The key parameters of each IHX are shown in Table 3.14.

Table 3.14. IHX Design Parameters

Number of IHX	4
Duty (MWt)	725
Core Height (along Li_2O flow) (m)	5.68
Core Depth (along lead flow) (m)	3.0
Core Width (m)	4.1
Tube Outside Diameter (cm)	2.54
Tube Inside Diameter (cm)	2.22
Heat Transfer Area (m^2)	
Outside	18,300
Inside	16,000
Lead Pressure Drop (MPa)	0.27

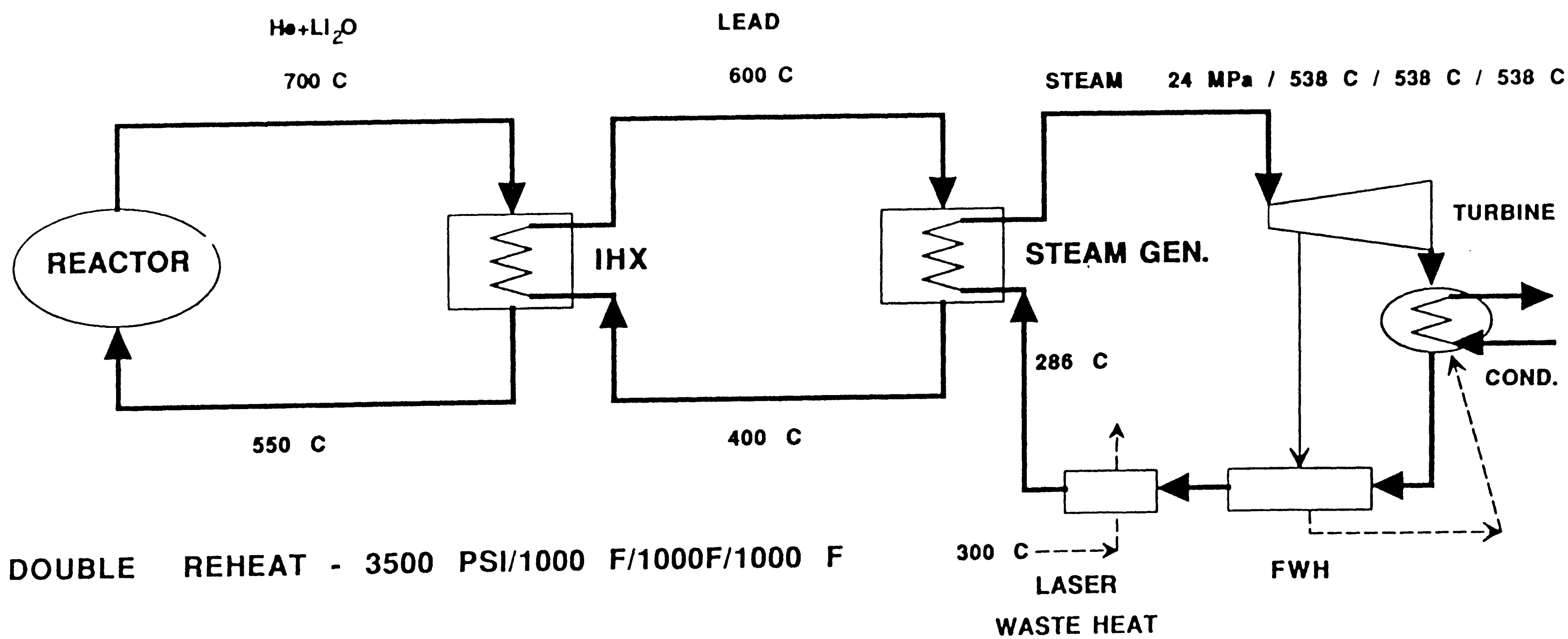

Fig. 3.57. SOMBRERO power conversion cycle diagram.

3.3.2 Power Conversion System

Power Cycle. To achieve a high efficiency power conversion, a high-pressure, high-temperature steam cycle was adopted for the SOMBRERO reactor concept. The steam pressure and temperature conditions chosen are consistent with the intermediate coolant temperature. These conditions also represent the state-of-the-art steam conditions used for fossil-fired steam power plants. A supercritical pressure double reheat steam cycle is used with the following steam conditions:

24.2 MPa / 538°C / 538°C / 538°C
[3,500 psig / 1,000°F / 1,000°F / 1,000°F]

The above pressure and temperature conditions refer to the steam conditions at the turbine inlet. The three temperature values stand for initial superheat, first reheat, and second reheat, respectively. These conditions are similar to those of the Osiris plant and provide a net cycle efficiency of 45 percent. The SOMBRERO plant has an additional source of heat for the power cycle. The waste heat from the laser system amplifiers is rejected at a reasonably high temperature such that it can be used to supplement the heat required to preheat the feedwater before it enters the steam generator. 270 MWt waste heat is rejected from the amplifiers at 300°C. The result of this additional heat is to effectively improve the steam cycle efficiency from 45% to 47%. The heat transport and power cycle schematic for SOMBRERO is shown in Fig. 3.57.

Steam Generator. There are two steam generators, and each is sized for 50% of the thermal capacity of the plant. Thus, each steam generator has a rated capacity of 1450 MWt. As in the case of Osiris, to accommodate the double reheat feature of the power cycle, each steam generator is made up of three stages, and each stage is provided with a separate vessel. These stages are the superheater, first reheater, and second reheater. These steam generator vessels are supplied with liquid lead from the intermediate heat exchangers (IHXs). There are two IHXs. These two IHXs are supplied with the fluidized lithium oxide coolant from the four primary coolant circuits. The key parameters of each steam generator are given in Table 3.15.

Turbine-Generator. The SOMBRERO reactor plant is provided with a turbine-generator capable of generating the required gross electrical power (1360 MWe). The turbine-generator is supplied with steam from the two steam generators. The turbine-generator consists of one high-pressure section, one intermediate-pressure section, and two low-pressure sections arranged in a cross-compound configuration. Turbine-generator has a size limitation, however. The largest turbine which has been built for advanced steam conditions was a 325 MWe machine. Currently, all of the techniques needed to build much larger capacity turbines do not exist in the

Table 3.15. Steam Generator Design Parameters

Parameter	Superheater	1st Reheater	2nd Reheater
Thermal Duty (MWt)	1064	241	122
Shell Inside Diameter (m)	3.7	2.1	2.1
Tube Bundle Length (m)	19.5	18.0	19.2
Number of Tubes	11862	4634	4983
Tube Size (cm)	1.27	1.27	1.27
Tube O.D. (cm)	2.13	2.13	2.13
Tube Wall Thickness (cm)	0.374	0.277	0.277

United States; they exist to a large extent in Europe. Thus for units 800 MWe or larger, a cross-compound configuration may very well only be practical at a much higher cost.

3.3.3 Plant Facilities

The facilities for the SOMBRERO plant are shown in Figs. 3.58 through 3.63. The Plot Plan, shown in Fig. 3.58, shows the major structures of the plant. These structures include:

- Reactor Building
- Laser Buildings
- Hot Cell (Maintenance) Building
- Auxiliary Building
- Target Fabrication Building
- Steam Generator Building
- Turbine-Generator Building

Figure 3.59 shows an isometric view of the optics configuration within the reactor building. The final focusing mirrors as well as the grazing incidence mirrors are arranged in a near-uniform illumination form. The grazing incidence mirrors are all located 30 m from the center of the reactor chamber, and the final focusing mirrors are all 50 m from the center of the chamber. The plan and cross-sectional views of the Fusion Island, primarily consisting of the reactor building, hot cell building, and steam generator building, are shown in Figs. 3.60 and 3.61.

Reactor Building. The reactor building is the most important building for which a concept has been developed for the SOMBRERO plant. The building provides housing for the

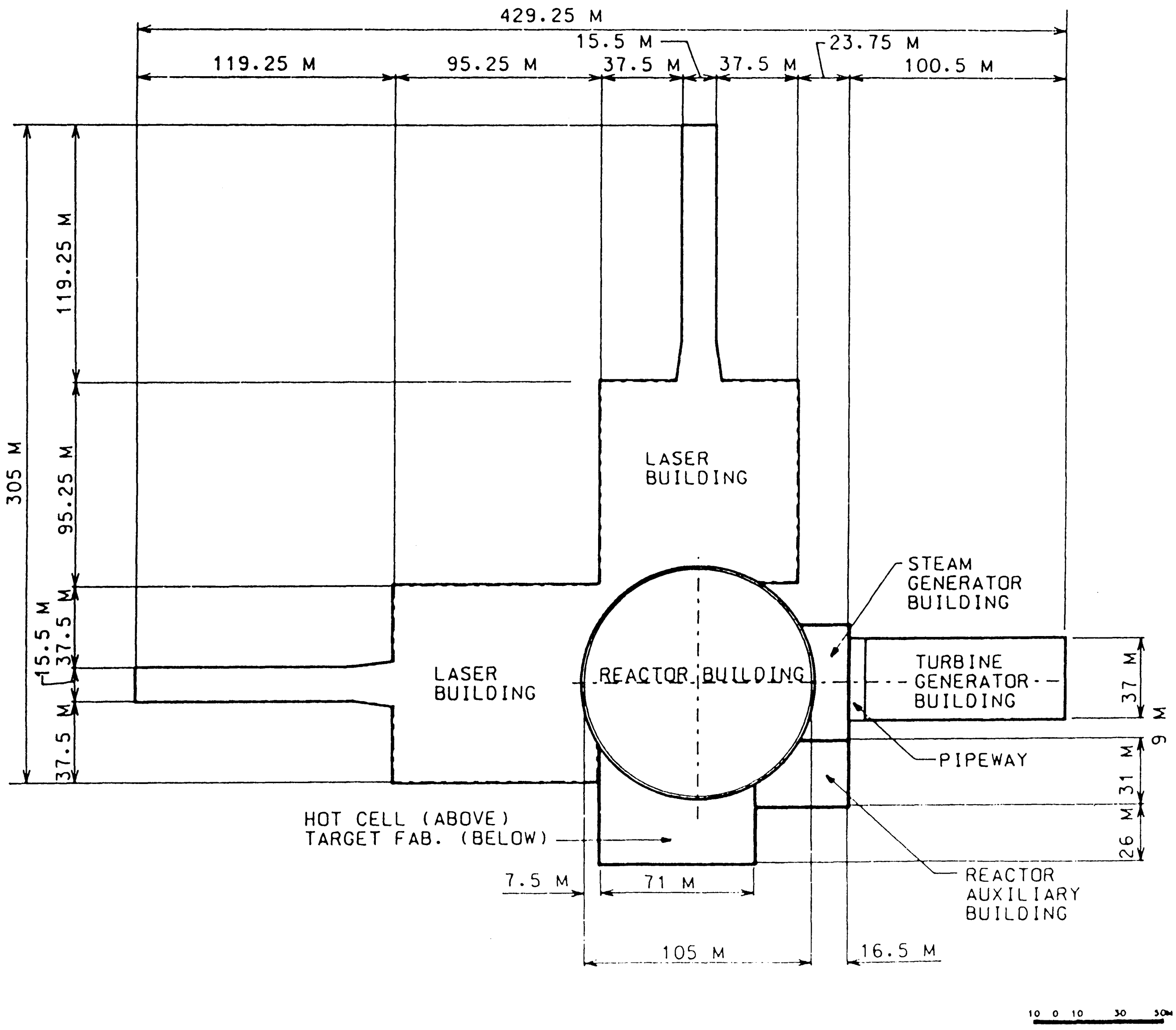

Fig. 3.58 Plot plan for SOMBRERO power plant.

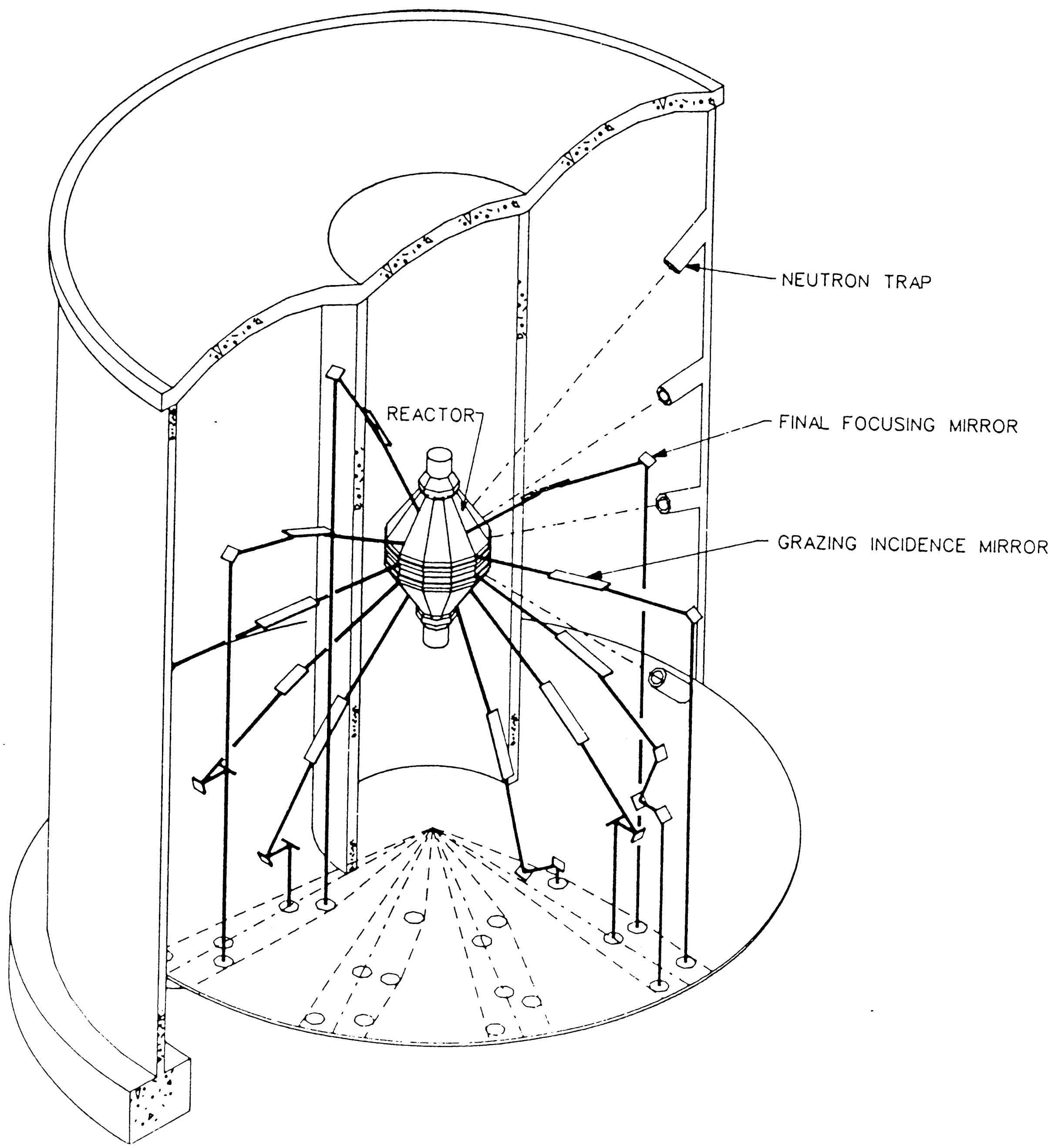

Fig. 3.59. Isometric view of the optics configuration in the SOMBRERO reactor building.

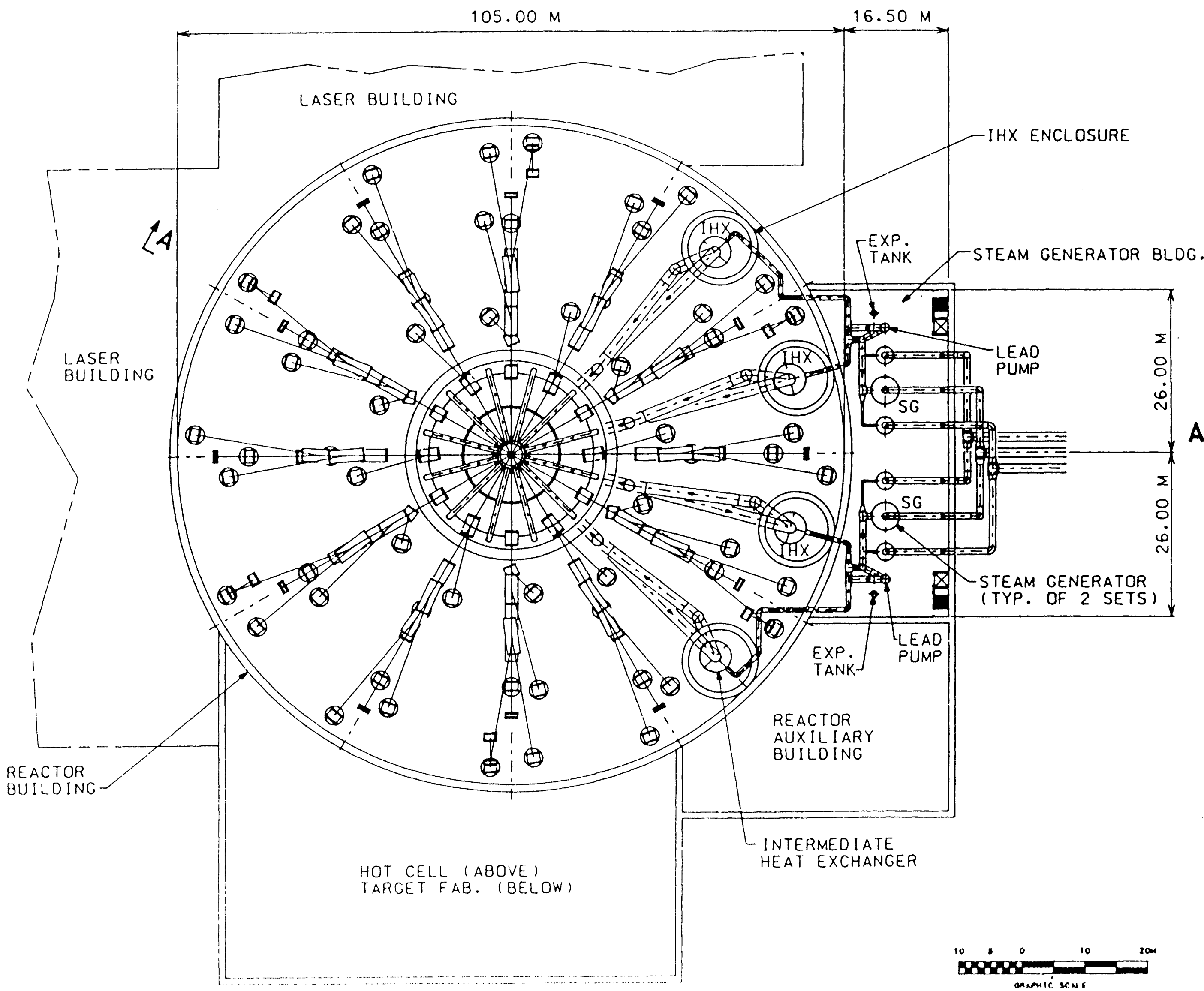

Fig. 3.60 Plot plan for SOMBRERO reactor building.

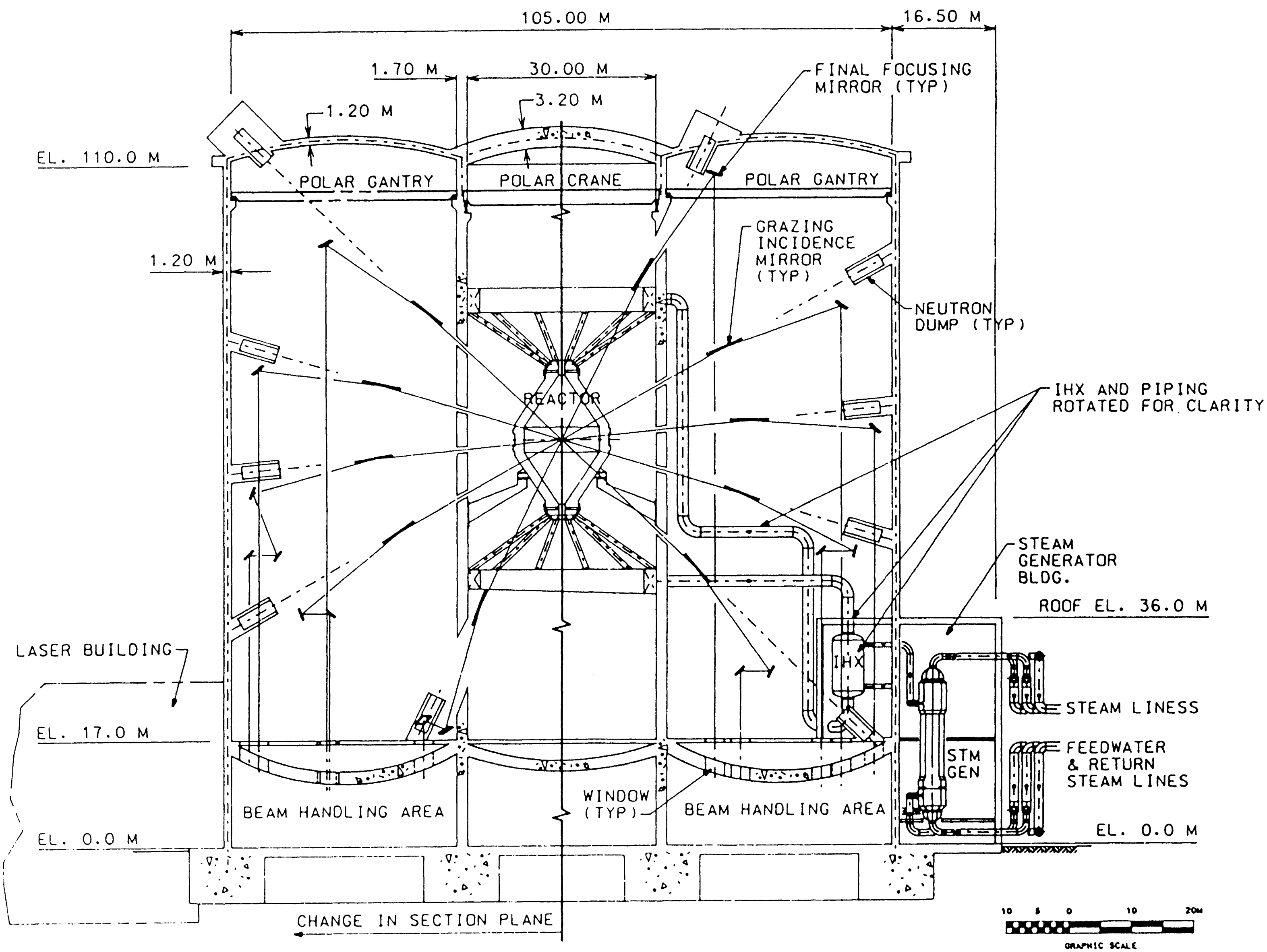

Fig. 3.61 Elevation view of SOMBRERO (Section A-A of Fig. 3.60).

reactor and the final optics, shielding of the public from fusion neutrons, and confinement barrier to the accidental release of tritium. In addition, the building also accommodates remote maintenance of the reactors. The size of this building is primarily dictated by the requirements for housing the final optics of the laser driver. It accommodates 60 beam lines that offer a near-uniform illumination. All the beam lines penetrate the reactor building through a basement level called "Beam Handling Area." The building vacuum boundary is located at the building floor where the beam lines penetrate the floor through "windows" (see Fig. 3.61). The other vacuum boundaries are the reactor building walls located at a radius of 52.5 m and the building ceiling.

Final Optics. The layout of the final optics adopted for this design is determined by the requirement for reasonable lifetimes of the final turning and focusing optics. It was determined that a dielectric mirror in the line of sight of the target would not have a reasonable life (i.e., one year) for a reactor operating at the design power unless it is placed at an impractically long distance from the target. Therefore, it was decided to introduce an aluminum mirror operating at grazing incidence as the first optic with the dielectric focusing mirror located out of the line of sight. There are almost no data on radiation damage of either metal or dielectric optics in high neutron fluences. The choice was thus made based on reasonable model assumptions.[3.45] This has led to the location of the grazing incidence mirrors at 30 m from the target and the first dielectric mirrors 20 m beyond them. The grazing angle on the aluminum mirror is limited to less than six degrees by the absorption of the incident laser beams. The angle of incidence on the dielectric mirror was also chosen to less than 45° to minimize the fabrication cost of these optics. It is clear that the damage threshold of these optics under neutron illumination is one of the major uncertainties in this design. If the optics were to have higher fluence tolerances than assumed then the optics could be placed closer to the target and the whole structure reduced in size. This might reduce the cost of the SOMBRERO reactor building significantly. As a result of the 45° limitation, up to two mirrors, in addition to the final focusing mirror, are needed to direct some of the beam lines to the floor of the reactor building. These additional mirrors are needed only for some of the beams which penetrate the reactor chamber below the reactor mid-plane.

To minimize the neutron activation of the optics, a neutron dump is provided to trap the primary neutrons escaping the reactor chamber through each opening for the beam lines. This subjects the equipment within the reactor building only to the secondary neutrons. The grazing incidence mirrors are of course subject to the primary neutrons. In addition to the neutron dumps, the reactor building is also provided with a shield floor below the lowest reflecting mirror to reduce the impact of neutrons on the windows as well as on the equipment in the beam handling area.

The IHXs are located within the reactor building. However, they are housed in their respective cylindrical chambers at atmospheric pressure. This arrangement accommodates the 0.1 MPa differential pressure (between the IHX chambers and the rest of the reactor building) and at the same time allows limited access to the IHX chambers during normal power operation. The steam generators are located in a separate building outside the reactor building.

Several unique features are incorporated in the reactor building structural concept. Since the building is required to maintain a vacuum (approx. 10 Pa), its internal pressure is assumed to be 0 MPa (for structural design purposes), and it is subject to an external pressure of about 0.1 MPa. Thus a cylindrical shaped building is chosen for an efficient structural design. The following requirements and design features characterize the reactor building (Fig. 3.61):

- Codes and Standards - ACI-349 (American Concrete Institute) applicable to Seismic Category I Structures:

Operating Basis Earthquake (OBE)	0.15 g
Safe Shutdown Earthquake (SSE)	0.30 g

- Building Pressure - Pressure within the building is dictated by the operations and maintenance requirements.

Normal Operation	0.0 Pa (approx.)
Maintenance	0.1 MPa

These pressure conditions apply to the spaces above and below the building floor. In addition, the conditions can occur in either space independent of the other.

- Building Size - The size of the building is determined by the requirements for the final optics layout.

Overall Height	110.0 m
Height of the Beam Handling Area	17.0 m
Internal Diameter of the Inner Shield Wall	30.0 m
Internal Diameter of the Outer Wall	105.0 m

- Wall, Floor, and Roof Thicknesses - These thicknesses are controlled by the shielding requirements (not by the structural requirements).

Inner ShieldWall	1.7 m
Outer Wall	1.2 m
Building Floor (below inner shield chamber)	1.7 m
Building Floor (below annular space)	1.2 m
Shield Floor	0.6 m
Roof Over the Inner Shield Chamber	3.2 m
Roof Over the Annular Space	1.2 m

- Floor and Roof Configuration - To resist the external pressure efficiently, the floors and roofs are designed as curved surfaces:

Floor and roof of the inner cylindrical space	Spherical
Floor and roof of the annular space	Toroidal

- Buckling - A factor of safety of 7.3 was applied to the outer cylindrical wall to resist the external 0.1 MPa pressure against buckling.

- Seismic Design - The building has been designed as Seismic Category I Structure. The operating basis earthquake (OBE) events control the design over the safe shutdown earthquake (SSE) events due to the load factor and damping differences.

	OBE	SSE
Acceleration (g's)	0.15	0.30
Load Factor	1.9	1.0
Damping (%)	4	7

Optics Support Concept. A concept for the support of the grazing incidence and final focusing mirrors has been developed. As shown in Figs. 3.62 and 3.63, each mirror is separately supported. However, for structural rigidity, some of the supports are also tied together. Each support is a combination of reinforced concrete members. The supports are also configured such that the remote maintenance equipment can access the mirrors without interference for replacement or refurbishment. Although not shown in the figure, each support is configured to accommodate alignment of the supported mirror. A continuous alignment may be required for each mirror to accommodate thermal movement of the supports as well as of the building.

The following requirements and design features characterize the optics support concept:

- Major criteria
  - Extremely high rigidity
  - Avoid interferences with laser beams, cranes, and equipment
  - Avoid neutron streaming
  - Minimize activation by minimizing metals
  - Facilitate maintenance

- Structural concept for mirrors that are not close to the building structure (i.e., wall, floor, or ceiling):
  - For grazing incidence mirrors, a ladder-type structure is envisaged. Each mirror is

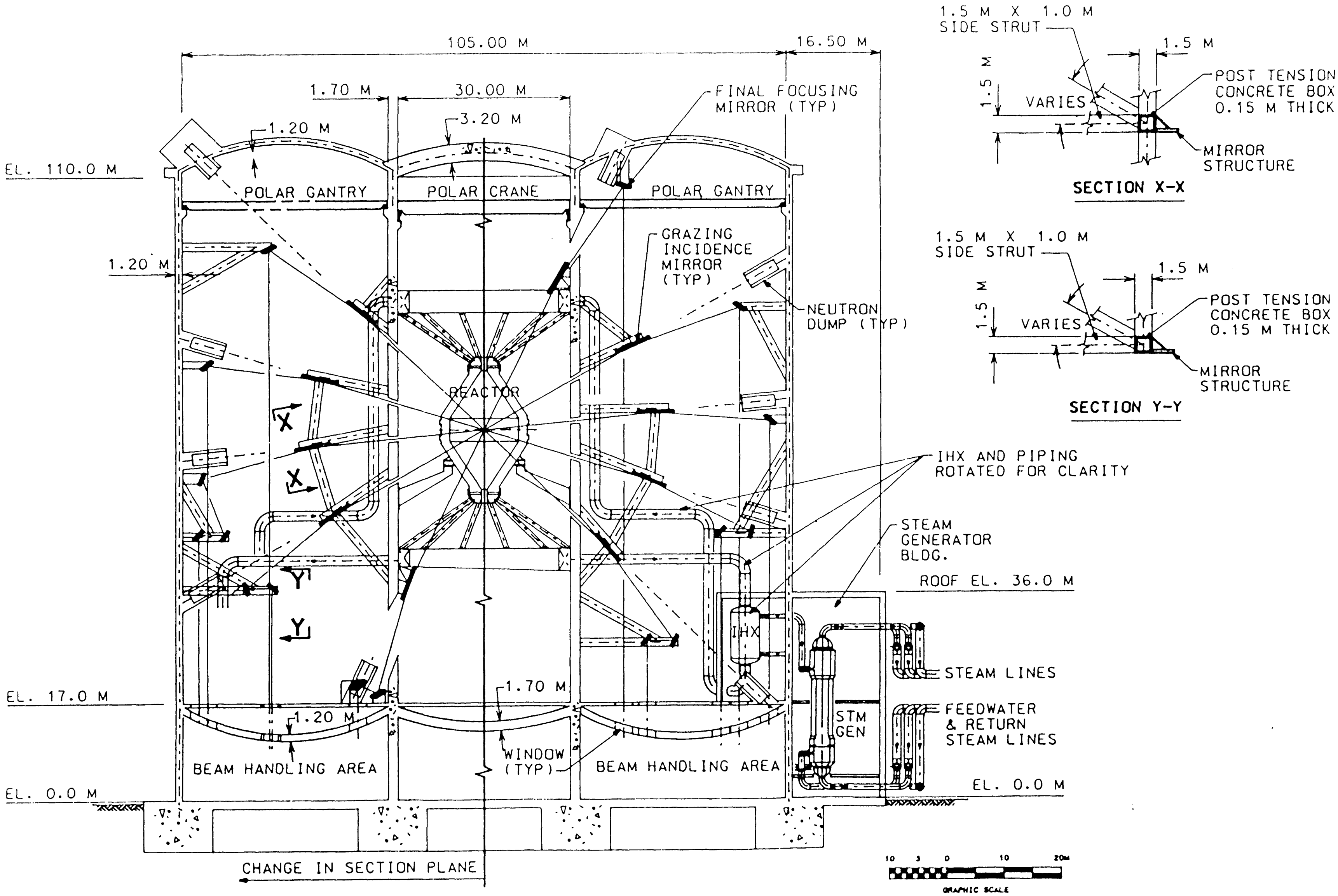

Fig. 3.62 Reactor building optics support concept.

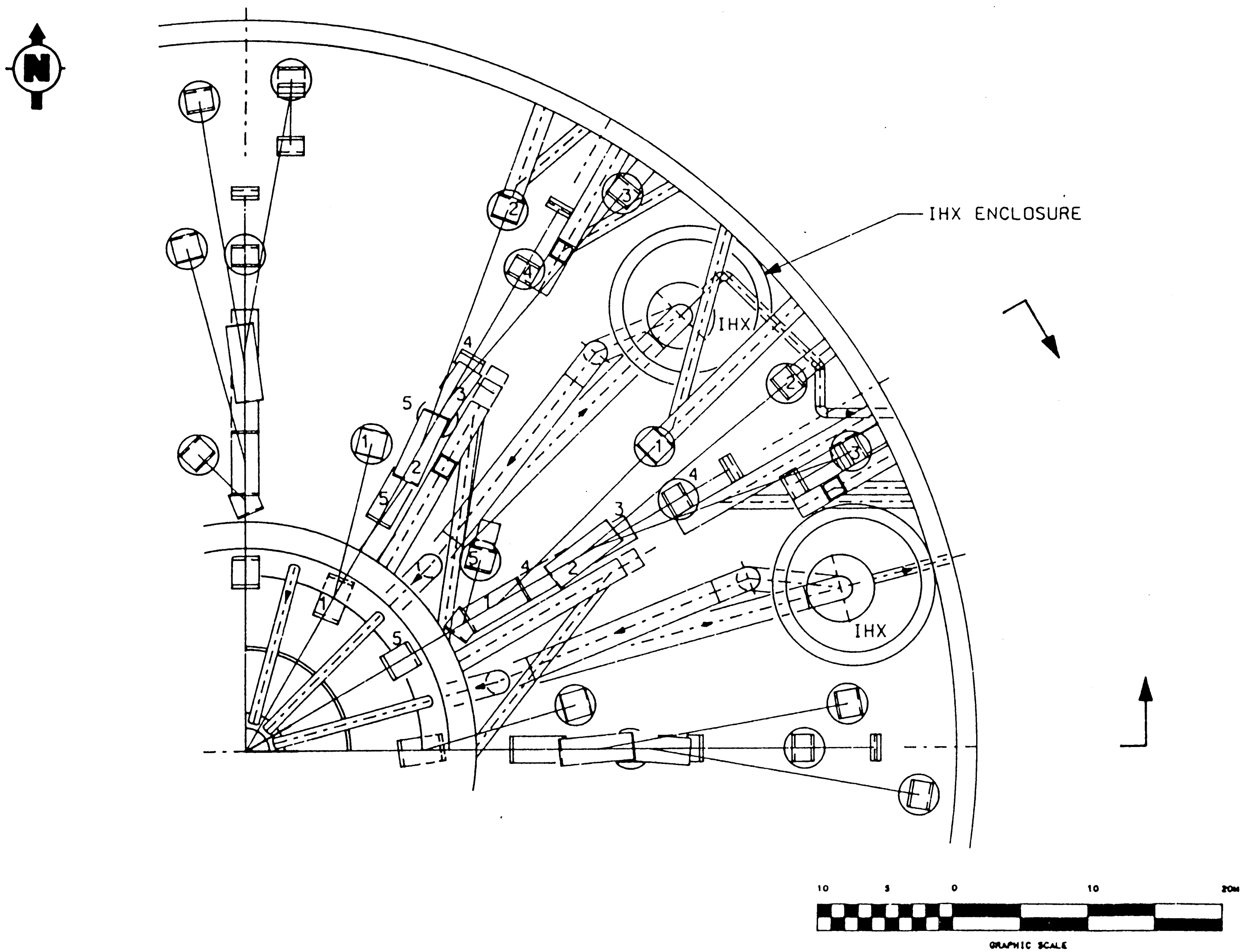

Fig. 3.63. Optics support concept.

supported by a "rail" and a radial "ring", both in a vertical pane, and a strut that lies in a plane that contains the ring and is perpendicular to the plane that contains the rails and the rings.

- For each final focusing mirror, a tripod structure consisting of three struts is provided.
- All struts, rails, and rings are precast concrete box modules. These modules are assembled to the required lengths by pulling steel tendons through tendon sheaths embedded longitudinally in precast modules. The tendons are tensioned by jacking creating a strong, economical structural element.

- Structural concept for mirrors that are close to the building structure (i.e., wall, floor, or ceiling):
  - For each of these mirrors, a strut made of precast concrete box module is used. The strut is supported from the nearest structure and the configuration of each strut is tailored to the location of the respective mirror.

- All mirrors are located on one side of the concrete box module as shown in the Sections X-X and Y-Y on the Fig. 3.62. This facilitates maintenance, prevents interference between the support structure and the laser beam, and keeps the support structure away from the neutron path.

Tritium Confinement Barrier. The reactor building provides a leak-tight barrier to tritium leakage into the environment. The leakage from the building can be reduced to limit the tritium leak rate to an acceptable level. The leakage from the building is generally controlled by properly sealing the penetrations, access doors, and equipment hatches. In addition to this, all the interior surfaces of the building walls, floors, and ceiling are coated with epoxy paint to minimize tritium permeation into the concrete. Similarly, all equipment surfaces are also painted with suitable coatings to minimize tritium permeation.

Vacuum Pumping System. As indicated earlier, the walls, floor, and the ceiling of the reactor building constitute the vacuum boundary (i.e., the entire reactor building is evacuated to a pressure of 10 Pascal (0.08 torr)). Since this is not a very high vacuum and falls under the "medium" vacuum category, roughing vacuum pumps, such as roots blower, are adequate for initial pumpdown as well as for maintaining the vacuum during normal operation. Six vacuum pumps are provided to initially pumpdown the building from atmospheric pressure to 10 Pa in 24 hours. Each pump is nominally rated at 2 m^3/sec pumping capacity. The building gaseous effluent from the vacuum pumping system exhaust is sent to the atmosphere cleanup system for further processing.

Atmosphere Cleanup System. To maintain an equilibrium tritium concentration as well as to cleanup the tritium following an accidental leakage within the reactor building, an atmosphere cleanup system is provided. The system also maintains the tritium concentration within the building well below the maximum permissible level during maintenance operations. After processing by the system, the recovered tritium is pumped back into the tritium processing system provided to recover tritium from the blanket and coolant systems.

Laser Building. There are two laser buildings. The plan and cross-section views of the buildings are shown in Figs. 3.64 and 3.65, respectively. The buildings house the KrF driver system components including:

- Temporal and spatial pulse shaping components
- Intermediate amplifying and multiplexing stages
- Demultiplexing arrays
- Penultimate amplifiers
- Final amplifiers

The first two items of the above list are housed in a laser support building located between the two laser buildings. This support building is common to both the laser buildings and also houses common electrical equipment associated with the first two items.

To maintain the quality of the beams, three alternative building environments were considered:

- Helium-filled building
- Evacuated building
- Evacuated beam tubes

A helium-filled building arrangement would require tightly sealed enclosures to minimize helium leakage. In addition, helium temperature must be maintained within a very tight tolerance. These aspects would make the building very expensive and would impose difficult maintenance requirements. Thus, this alternative was not chosen. The second alternative, a completely evacuated building, was also not chosen because it will require a tightly-sealed building to minimize leakage. This would make the building expensive. In the third alternative, a conventional steel-framed structure is provided. Here all the beamline components are housed in evacuated beam tubes. This allows the buildings to be always accessible and provide easier maintenance. Thus this alternative is selected as this also provides the least expensive building.

Other Facilities. A brief description of the other major facilities is given here. Only outlines of these facilities are shown in the Plot Plan (Fig. 3.58) to indicate that facilities are needed to support the operation of the plant. No design has been developed for them at this stage.

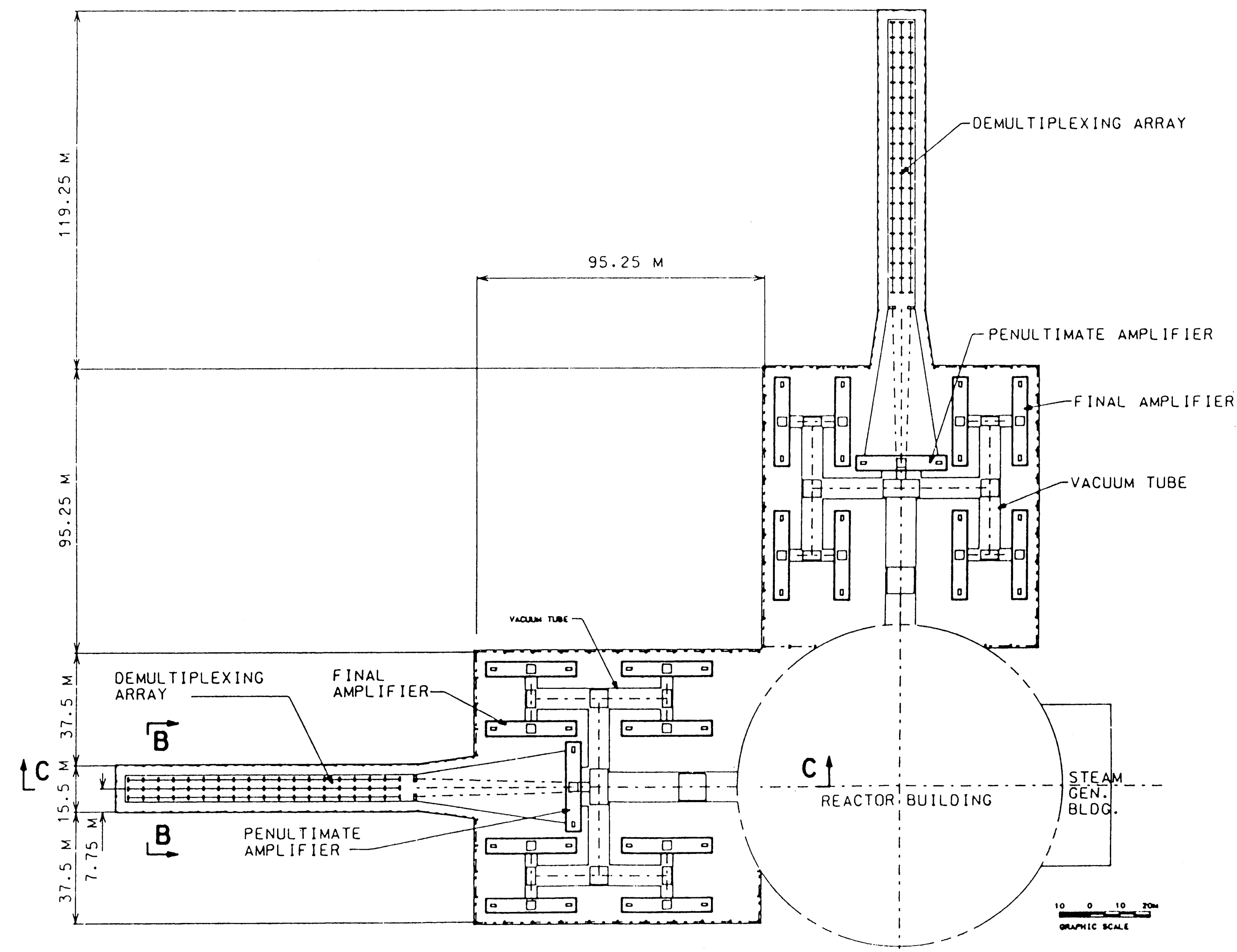

Fig. 3.64. Top view of KrF laser building.

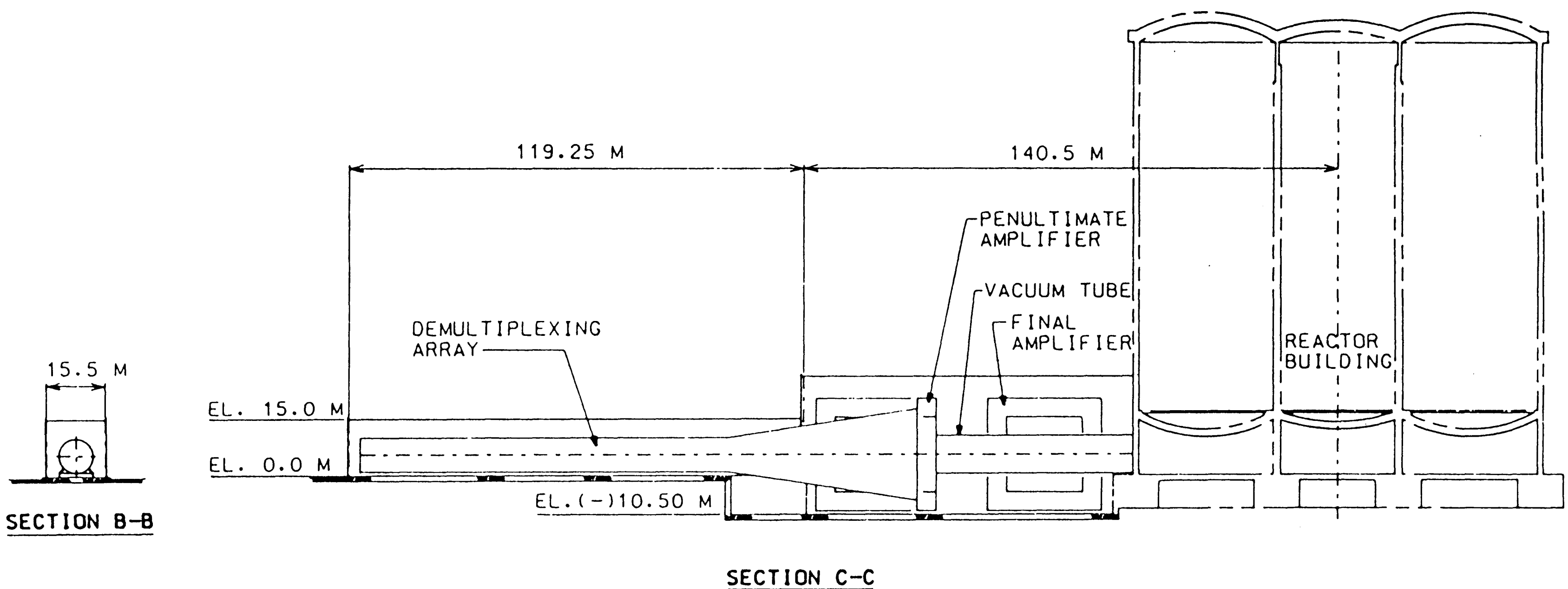

Fig. 3.65. Cross-sectional view of KrF laser building.

Maintenance Building. The maintenance building houses the equipment for assembly and disassembly of the SOMBRERO components and provides space for both irradiated and refurbished modules. The building is designed as a earthquake and tornado hardened structure.

Auxiliary Building. This building houses the reactor and heat transport system auxiliary equipment. These include auxiliary cooling system, plant electrical systems, heat tracing system, coolant handling system, heating, ventilation, and air conditioning (HVAC) system, vacuum system as appropriate, etc. The building is designed as an earthquake- and tornado-hardened structure.

Target Fabrication Building. This building houses all the systems and components necessary for storage, fabrication, and delivery of the fuel pellets. The building is located below the maintenance building. The building is designed as an earthquake- and tornado-hardened structure.

Steam Generator Building. A concept has been developed for this building as shown Figs. 3.60 and 3.61. The tall structure of this building is dictated by the height of the steam generator. The building is designed as an earthquake- and tornado-hardened structure.

Turbine-Generator Building. The building is sized to house the 1360 MWe cross-compound turbine-generator and its auxiliaries, steam system components, feedwater heating and condensing system components, etc. The building is envisaged as a conventional building similar to that of fossil-fired plants.