6.3 Configuration and Maintenance Approach

The configuration and maintenance approaches for both the Prometheus-L and Prometheus-H reactor concepts are described in this section. Prometheus-L is a 1000 MWe IFE power plant using a KrF excimer laser driver to deliver 4 MJ of energy through 60 beamlines 5.6 times per second to direct drive targets in the center of a cylindrical reactor cavity. Prometheus-H is a similar sized plant utilizing a heavy ion driver to deliver 7.8 MJ of energy through 14 beamlines 3.5 times a second to indirect drive targets in a similar reactor cavity.

A top down approach describes these two IFE plant configurations. A general site plan explains the overall arrangement of each power plant. Most of the plant buildings (administration, auxiliary, turbine, steam generator, target factory, and tritium processing) and sizes used in both concepts are similar; only the reactor and driver buildings differ in size and design approach. Descriptions of the driver systems, reactor systems, and heat transport system are provided Plan and elevation drawings define interfaces between these major subsystems with drawings illustrating major components arrangements.

The maintenance approach used to service reactor and driver systems vary depending on the location within the plant. The maintenance of all reactor systems within the bulk shielding walls will be totally remote. In both concepts, the reactor cavity is essentially the same. Therefore, common maintenance methods are employed. A vertical maintenance approach for all operations within the reactor vacuum vessel is envisioned. All interfacing systems which penetrate the bulk shielding walls are provided with enclosed, local shielding. Therefore, reactor systems and interfacing driver systems within the reactor building walls but outside the bulk shielding walls are maintained with a combination of remote maintenance and limited hands-on maintenance equipment. The maintenance method would depend on the type of maintenance to be performed.

6.3.1 Reactor Design Integration - This section presents design integration of the major subsystems in the two inertial fusion energy (IFE) reactor concepts. Detailed descriptions of the subsystems are presented in Sections 6.4 through 6.11.

6.3.1.1 Prometheus-L - Site plans for the Prometheus-L reactor design power plant are shown in Figures 6.3.1-1 through 6.3.1-3. These figures present a trimetric view of the plant site, a plan view of the plant site, and a building definition plan view, respectively. Prometheus-L site plans show the typical IFE power plant buildings (administration, auxiliary, turbine, steam generator, target factory, and tritium processing) arranged around the circular KrF laser driver building. This annular-shaped building is 153 m in outer diameter and contains all the laser driver

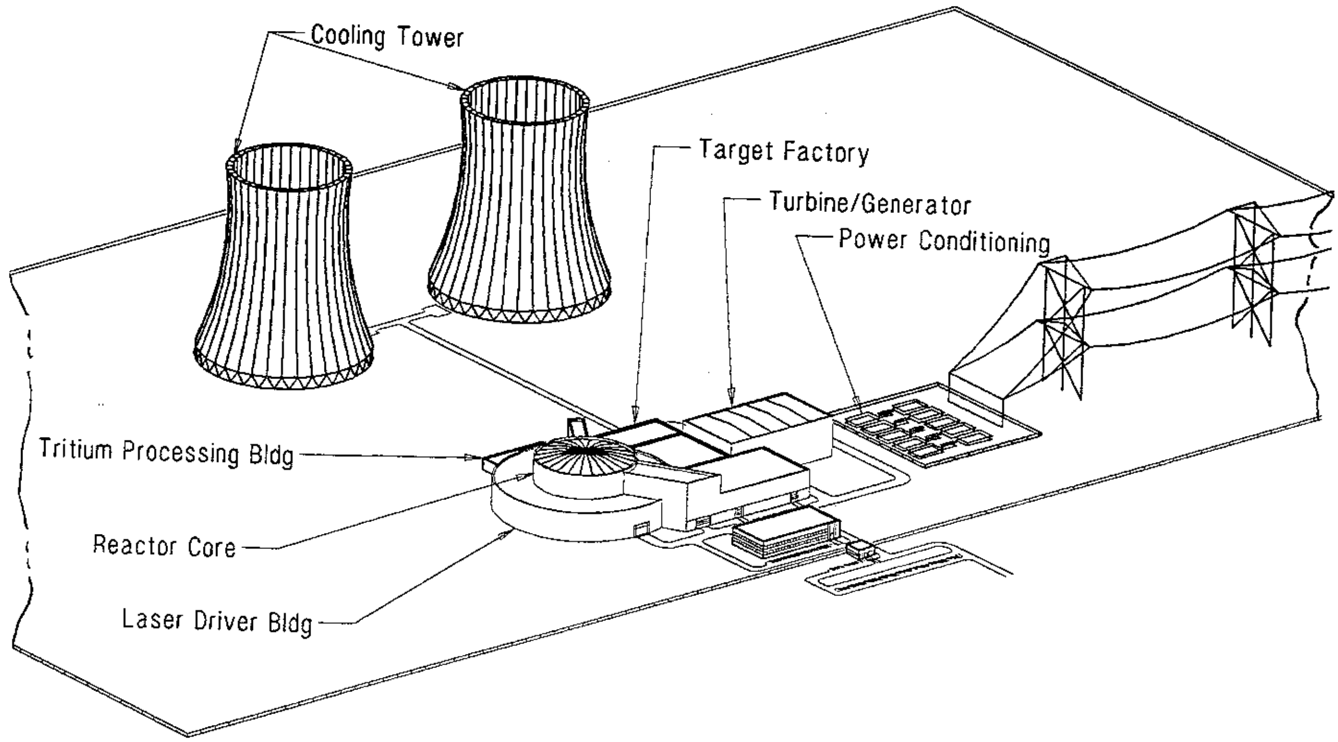

Figure 6.3.1-1. Prometheus-L Plant Site Trimetric View

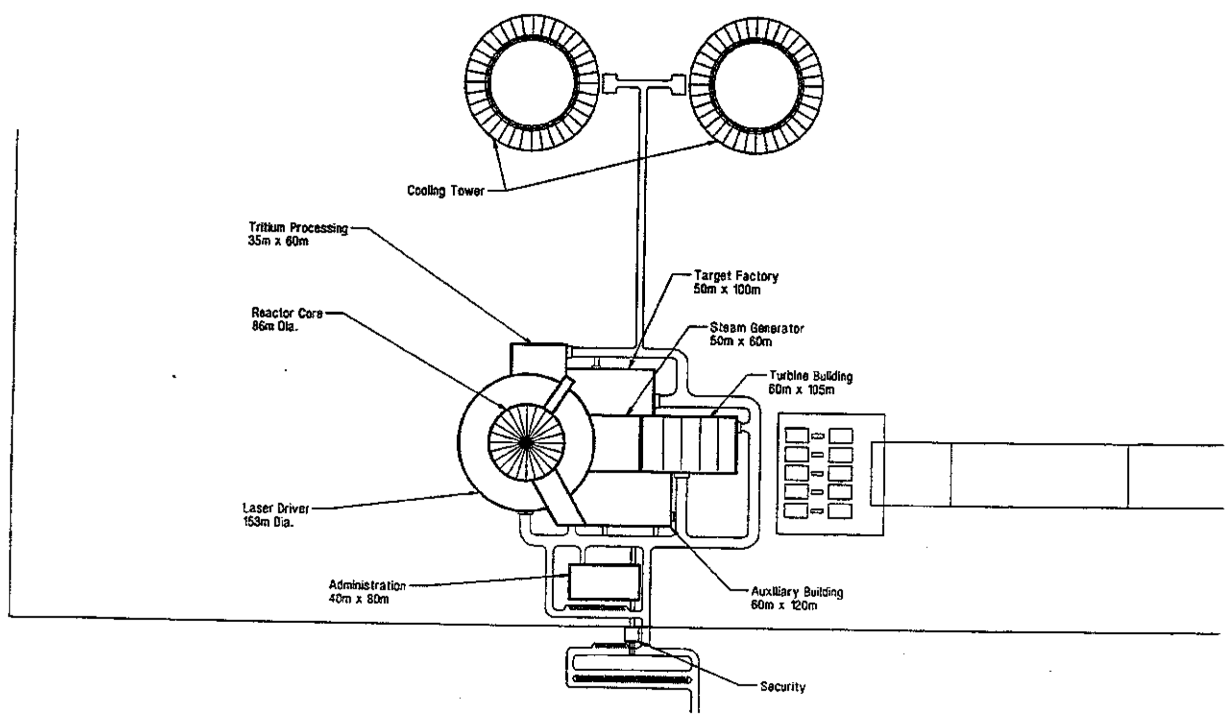

Figure 6.3.1-2. Prometheus-L Plant Site Plan View

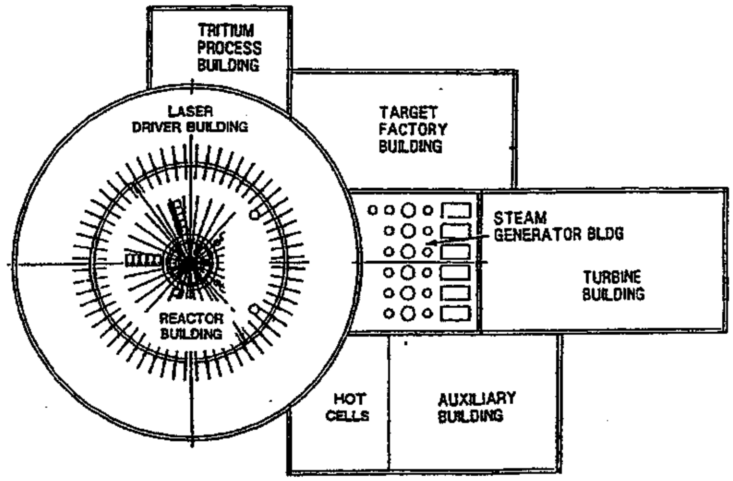

Figure 6.3.1-3 Prometheus-L Building Plan View

components to generate 60 individual laser beams. These 60 beamlines are arranged in an equally-spaced radial array and penetrate the inner wall of the driver building which is also the outer wall of the reactor building. The Prometheus-L reactor building is 86 m in diameter.

<u>KrF Laser Driver-General Overview</u> - The Prometheus-L reactor design concept employs a KrF excimer laser driver and a nonlinear-optical (NLO) system. This NLO system features an electric discharge laser subsystem, crossed forward Raman accumulator cells, and stimulated Brillouin scattering (SBS) cells. Upstream are typical front end elements which complete the 60-beam network including the master oscillator for all the beams, the beam splitter system, and the preamplifier/amplifier stages for each beamline. Theoretical and operational aspects of the overall system are described in detail in Section 6.5.1.

The laser driver delivers 4 MJ of energy to a target through 60 optical laser beamlines each with a gross energy of 67 kJ. Sixty (60) identical sets of driver output components (laser module, Raman accumulator, and SBS cell) are arranged in an equally-spaced radial array (6°) in the annular driver building and about the reactor building vertical centerline. Inside the reactor building, the 60 beams converge to enter the reactor cavity with two beams equally spaced every 12° as seen in the plan view. A plan view of the KrF laser and reactor buildings is shown in Figure 6.3.1-4.

Inside the driver building, the electric discharge lasers output beams are routed to the Raman accumulators and then to the SBS cells. Output beams from each of the 60 SBS cells are then directed to the cylindrical section of the reactor cavity. The

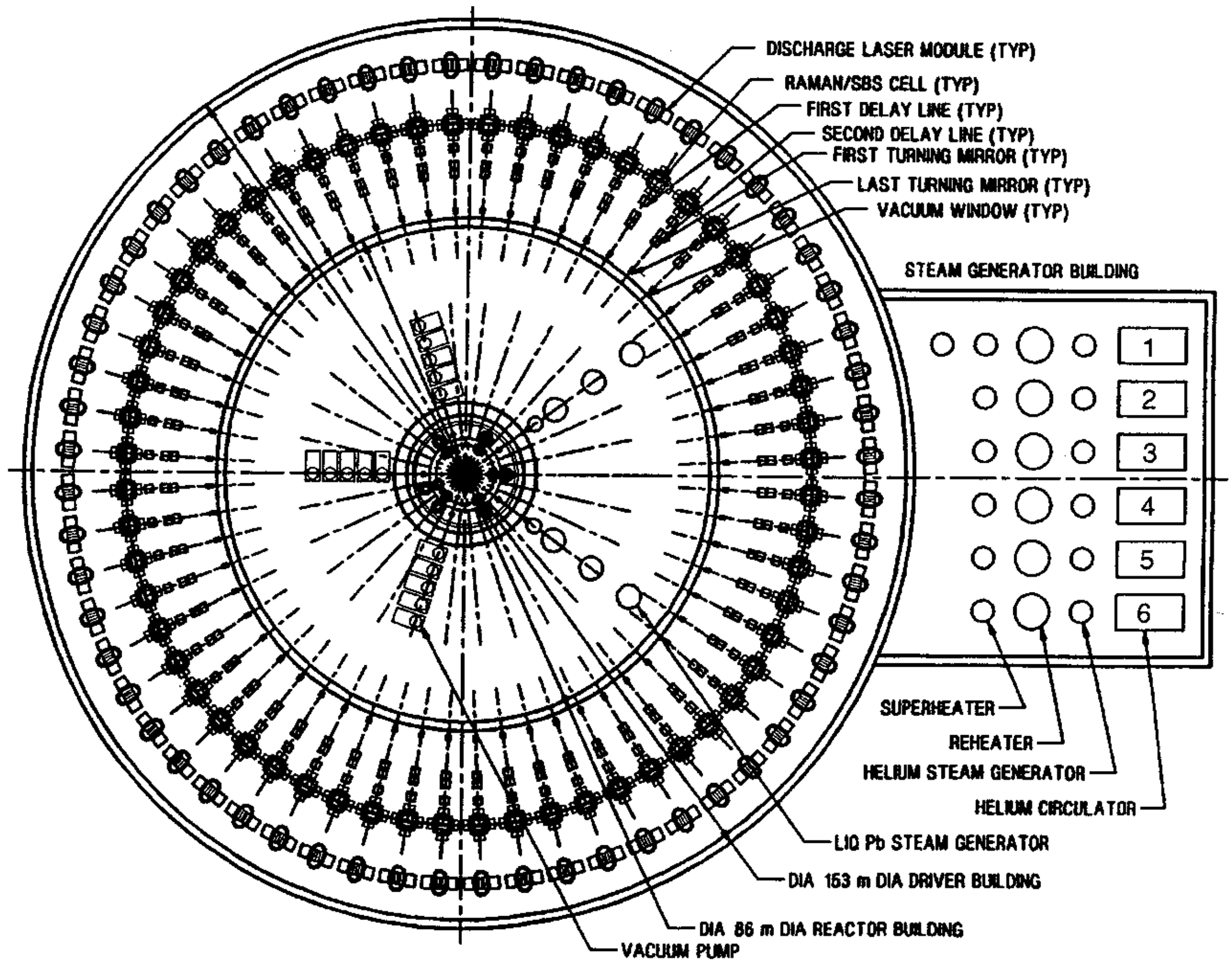

Figure 6.3.1-4. KrF Laser and Reactor Buildings – Plan View

location and orientation of the 60 beamline penetrations in the reactor cavity (to be discussed below in the Final Optics Subsystem Description) results in eight unique beamline routes from the SBS cell to the center of the reactor cavity. The eight unique beamline routes occur repetitively around the reactor cavity. These routes are shown in Figure 6.3.1-5 (typical five places) and Figure 6.3.1-6 (typical ten places), which are two cross-sectional elevation views. Some license has been taken with correct technical drawing of the these two views since the four routes in each figure upstream of the final focusing mirrors actually lie slightly out of the plane of the cross-sectional cut (along different radial arrays). The 90° doglegs in the beamlines are rotated either slightly into or out of the plane of the drawing. The route from final focus mirror to the center of the cavity on both figures lies in plane and is shown correctly.

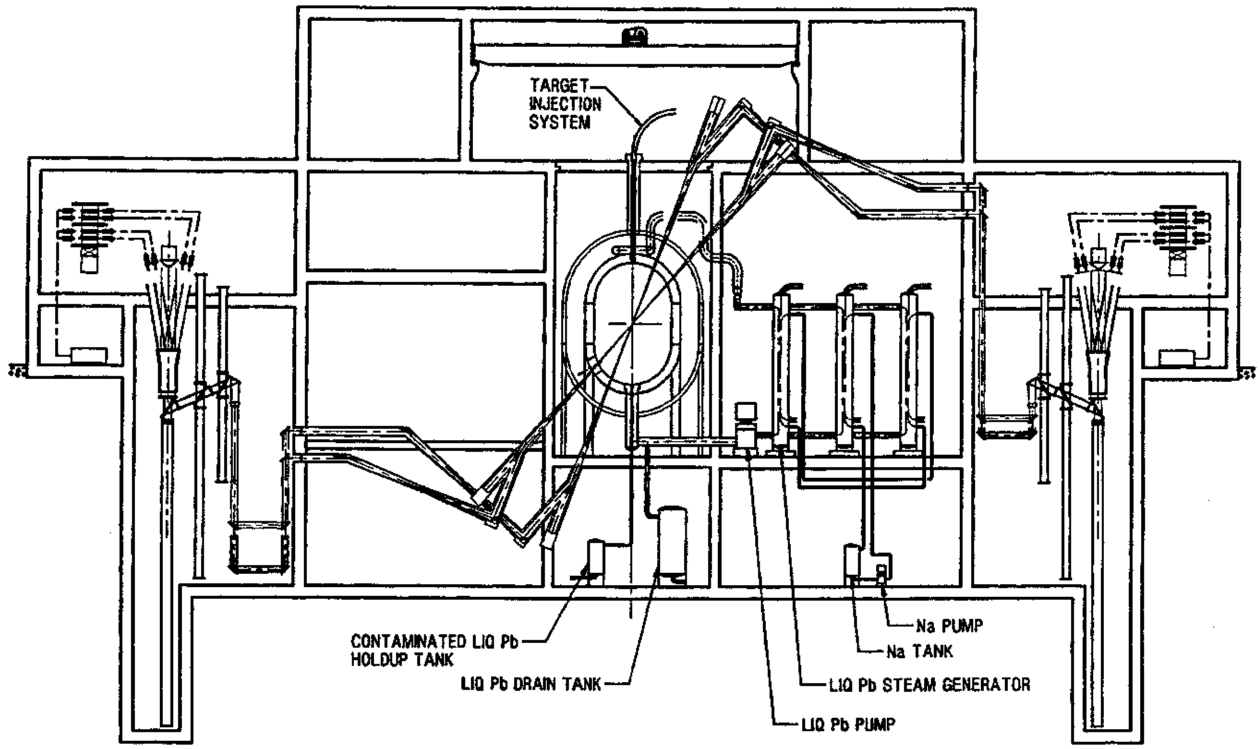

Figure 6.3.1-5. Elevation View - Typical Laser Beam Routing-5 Places

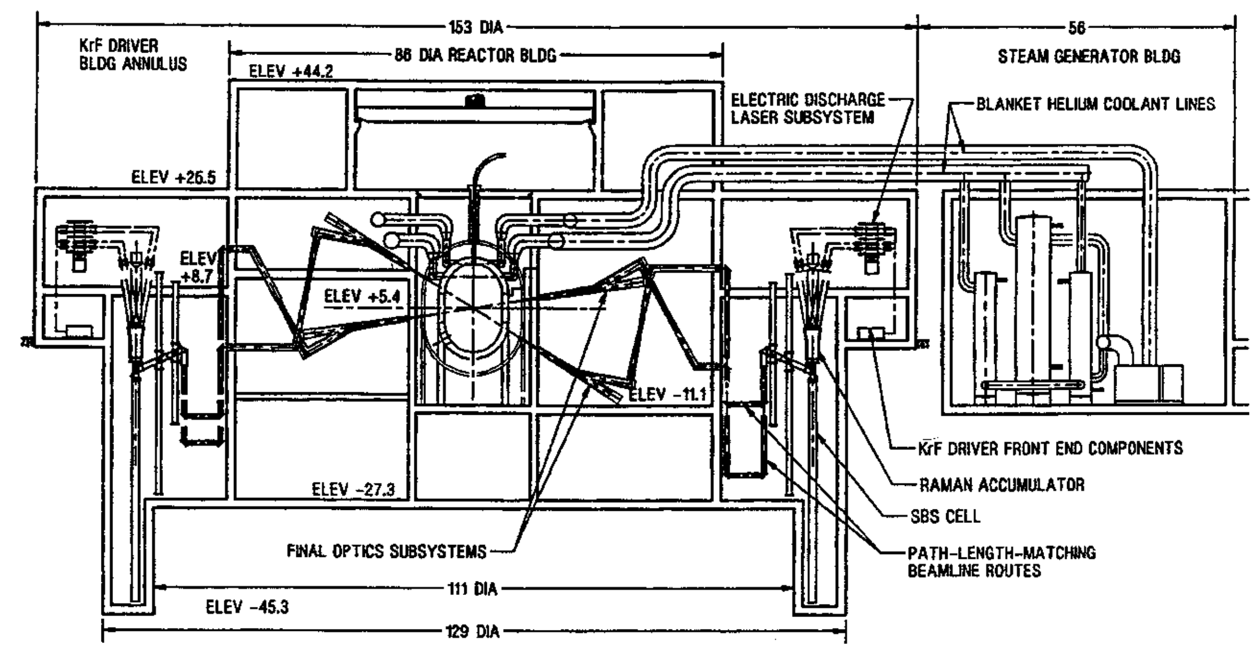

Figure 6.3.1-6. Elevation View - Typical Laser Beam Routing-10 Places

The output beam from each SBS cell is routed through four turning mirrors along a path within the driver building that will match the path lengths for all eight beams from the SBS cell to the center of the reactor cavity. From this path-matching route, the beams enter the reactor building through penetrations running radially inward toward the center of the reactor cavity. The wall penetration contains the vacuum window for each beamline. The driver building is pressurized with argon at ambient pressure. The operating pressure downstream of the vacuum window is 3×10^{-3} torr.

KrF Laser Driver-Electric Discharge Laser Subsystem - There are 60 electric discharge laser subsystems in the KrF driver system—one for each beamline. This subsystem consists of two electric discharge laser modules, three sets of stabilization coils, and the KrF gas flow system and is shown in Figure 6.3.1-7. The KrF gas flow system consists of inlet and outlet ducts, a helium-cooled heat exchanger, and a circulating fan. It circulates a mixture of KrF gas through four parallel paths in the two electric discharge laser modules. Each of the two discharge laser modules contains eight electric discharge lasers for a total of 16 lasers for each beamline. Thus, there is a total of 960 electric discharge lasers in the KrF driver. Each of the electric discharge lasers has a gross energy output of 4.2 kJ.

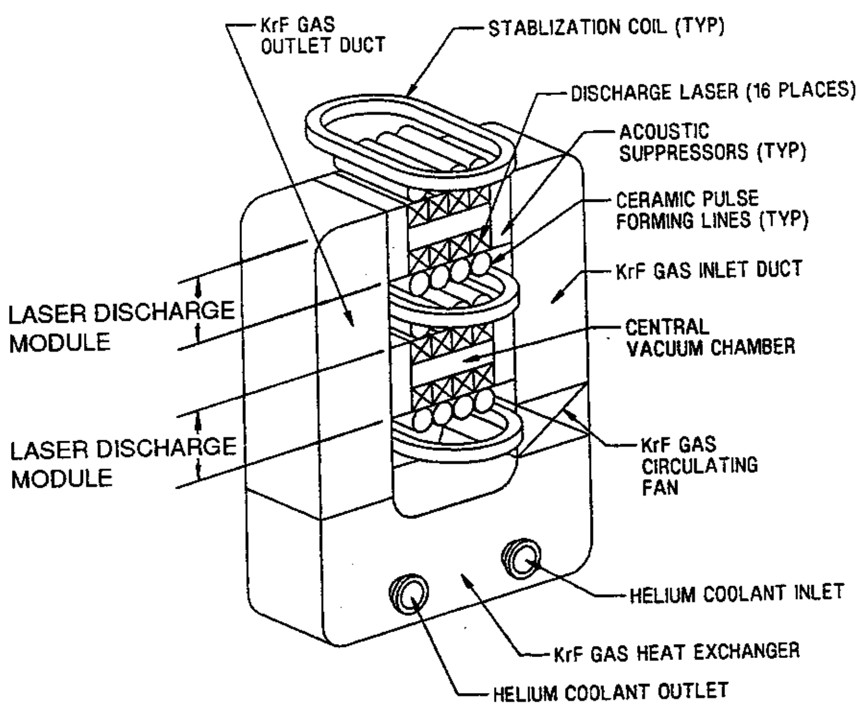

Figure 6.3.1-7. Electric Discharge Laser Subsystem

The KrF gas flow paths are shown schematically in Figure 6.3.1-8. To assure proper thermal control of the laser gas, a slug of KrF gas circulates through and clear each of the four parallel paths once for each of the 5.6 pulses per second. This yields a gas flow velocity of 15 m/s. The KrF gas is circulated by the fan through the lasers and then through the heat exchangers. The laser inlet gas temperature is 400°C and the outlet is 650°C. A cooler mixture of gas is assumed to be injected along the inner surface of the inlet and outlet windows of each laser to protect the windows from the higher temperature gases. Helium coolant is circulated through the heat exchanger to recover the resulting waste heat from the lasers. The helium is routed to a feedwater heat exchanger in the thermal transport system in the steam generator building where a total of 193 MW is recovered as feedwater preheat.

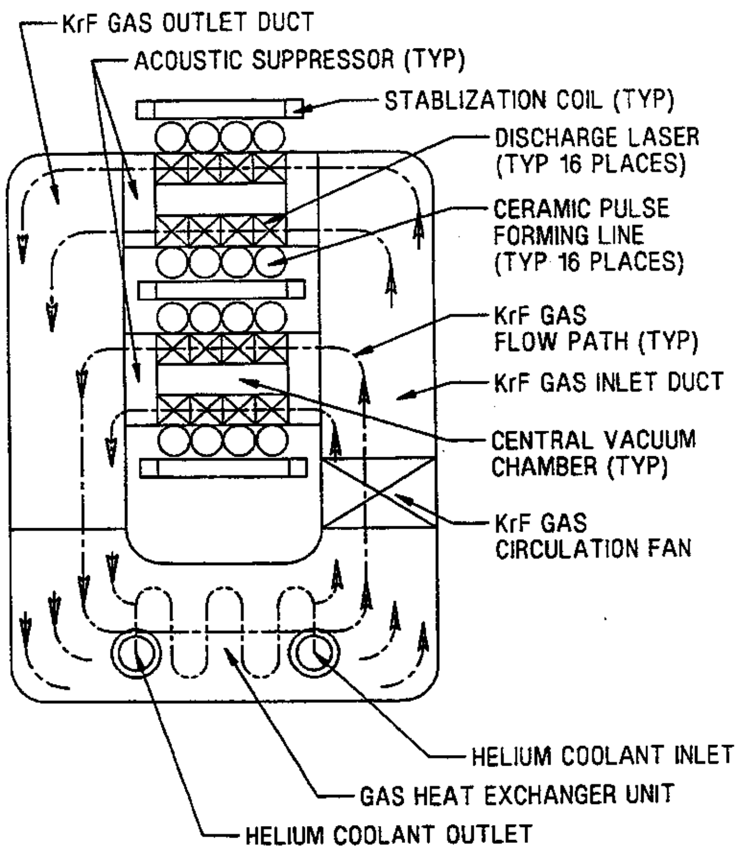

Figure 6.3.1-8. KrF Gas Flow Schematic for Waste Heat Recovery

Each electric discharge laser module contains eight discharge lasers arranged in four groups of two as shown in Figure 6.3.1-9. The discharge lasers are first clustered in groups of two lasers around a central vacuum chamber containing a pair of cathodes, one for each laser. Ceramic pulse forming lines and anodes (shown as the cylinders in Figure 6.3.1-9) are located on the outside of each laser. Stabilization coils are

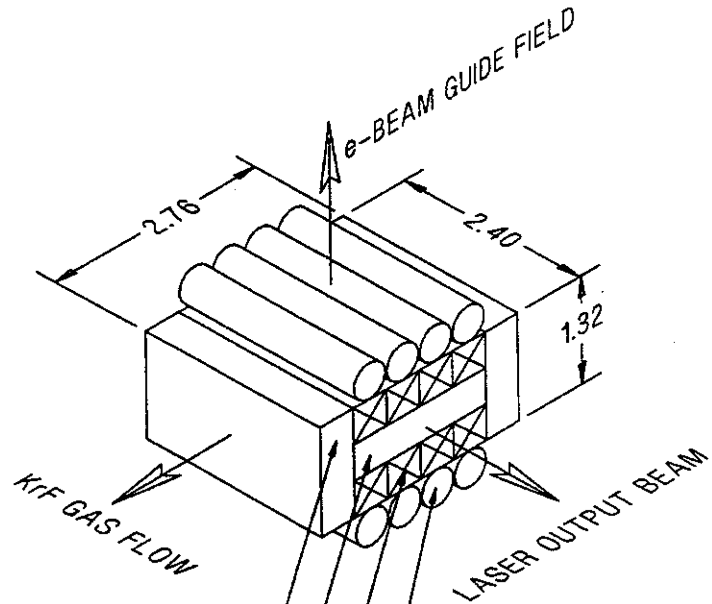

Figure 6.3.1-9. Electric Discharge Laser Module

located on the outside of the ceramic pulse forming lines as shown in Figure 6.3.1-7 forming a stabilizing magnetic field perpendicular to both the KrF gas flow direction and the laser beam direction (shown in Figure 6.3.1-9). Acoustic flow suppressors are located at the entrance and exit of the gas flow paths to maintain flow stability. A similar arrangement for discharge lasers has been suggested in previous KrF laser system studies.[1]

KrF Driver—Raman Accumulator/SBS Cell/Delay Line- Downstream of the electric discharge laser subsystem, the 16 discharge laser output beams are routed into the Raman accumulator (four beams on each of four sides) at an angle of 10° off the axial centerline. The Raman accumulator, SBS cell, and related components are shown in Figure 6.3.1-10. A larger Stokes seed beam (derived from the excimer pump beams upstream of the electric discharge laser subsystem) enters the Raman accumulator on the centerline of the Raman accumulator. Interaction of the 16 laser beams with the Stokes seed beam in the hydrogen gas environment of the Raman accumulator results in a highly amplified, long pulse Stokes beam exiting the downstream end of the Raman accumulator.

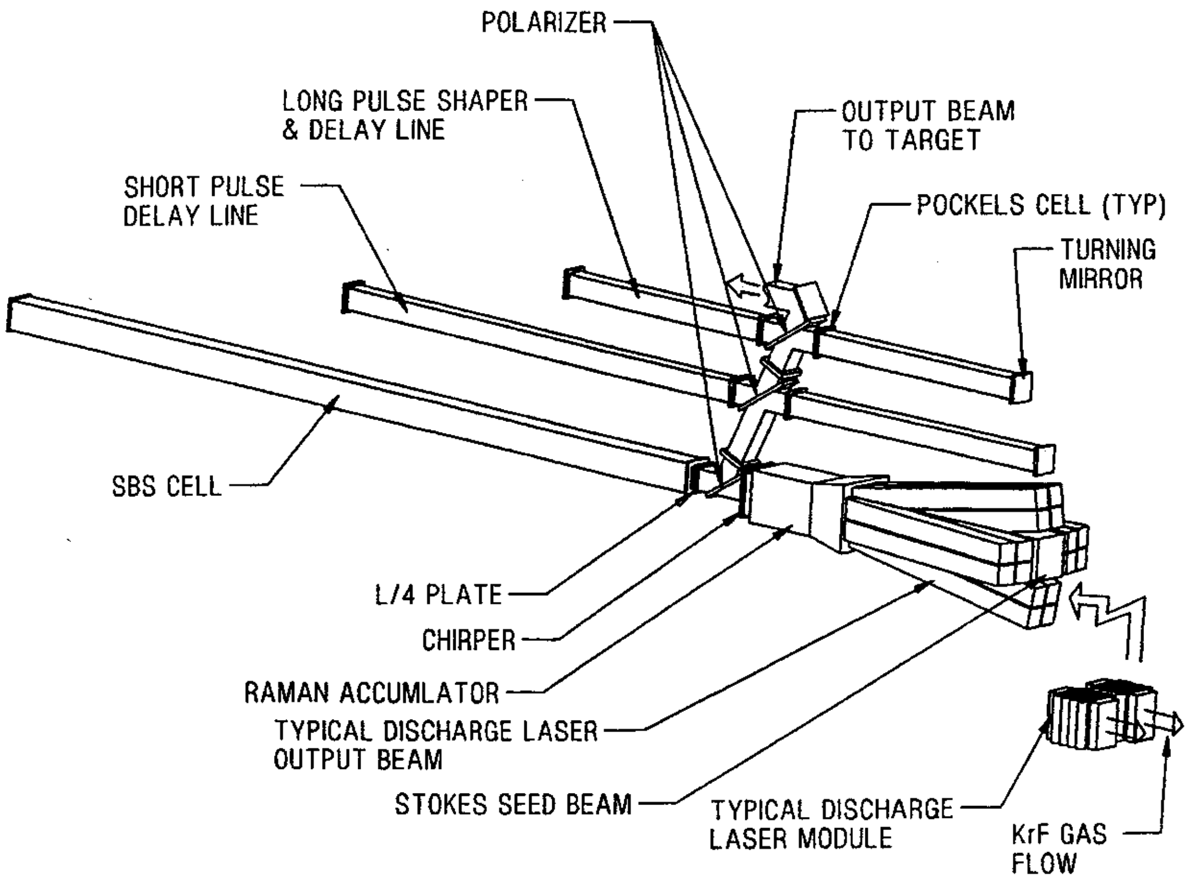

Figure 6.3.1-10. Raman Accumulator/SBS Cell/Delay Line

From the Raman accumulator, the long pulse Stokes beam passes through a chirper, a polarizer, and a quarter wave plate and enters the SBS cell. This 37.5-m long cell is filled with SF_6 gas and has a mirrored surface on the other end to reflect the entering beam back out the entrance window. The combination of these components produces a short pulse (6 ns) beam followed by a longer pulse length, depleted Stokes beam. (See Section 6.5.1 for a more complete description of this process.) The short pulse beam is the desired 6-ns pulse main beam with an energy of 70 kJ, while the longer pulse beam will be utilized to form a prepulse beam. When these beams come back out of the SBS cell and pass through the quarter wave plate, a frequency shift has occurred and the polarizer plate then reflects the beams off-axis in the direction of the short pulse delay line. (Since the 6-ns pulse main beam is in front of the longer, prepulse beam, the short pulse delay line inverts the time order of these beams.) Leaving the polarizer plate, the short pulse beam passes through a Pockels cell and strikes and is reflected off the next polarizer plate, this time into the short pulse delay line. Before the long prepulse beam enters this Pockels cell, the cell voltage is changed, which changes the polarity of the long prepulse beam such that it passes through the polarizer plate in the short pulse delay line, proceeding on line toward the long pulse shaper and delay line.

The long prepulse beam now preceeds the short pulse main beam. Downstream, a combination of three Pockels cells are utilized to shape the prepulse beam to meet the prepulse requirements by alternately switching portions of the prepulse beam into and out of the long pulse shaper and delay line. The resulting prepulse beam (80 ns) continues downstream toward the target followed by the main beam (6 ns).

Turning mirrors route the prepulse and main beams from each of the 60 SBS cell/Raman accumulator arrangements in the KrF laser driver building into the reactor building beamlines. Delay lines allow path-length matching of all 60 beam paths. The 60 beamlines enter the reactor building through penetrations containing vacuum windows. The eight unique beam path routes discussed earlier are shown in Figures 6.3.1-5 and 6.3.1-6.

<u>KrF Laser Driver - Final Optics Subsystem</u>- The 60 beamlines enter the reactor cavity at angles defined by radial lines passing from the vertices to the center of a truncated icosahedron platonic solid with a pentagon/hexagon edge length ratio of 1.2. This orientation provides nearly uniform target illumination (<1% nonuniformity). This orientation of beamlines was envisioned for the Omega Upgrade facility at the University of Rochester. The resulting angular interface locations of the 60 beamlines with the reactor cavity are shown in the elevation view of the reactor cavity in Figure 6.3.1-11. Typical beams at each angular location off the vertical axis are rotated into view on both sides of the vertical axis to provide a visual indication of the beam orientations around the reactor cavity. If viewed from the top (plan view), two beams would be located on each radial plane approximately 12° apart as shown in the 3-D cavity/beamline drawing in Figure 6.3.1-12. A similar trimetric view is shown in Figure 6.3.1-13.

Typical final optics configuration contained within each beamline in the reactor building is shown in Figure 6.3.1-14. The optical characteristics of the mirrors within this region are presented in Section 6.5.1.6. From the outer diameter reactor building wall, each beamline enters on a horizontal radial array from the reactor vertical centerline. This penetration contains the vacuum window. Downstream of this window, the beams pass through a collimating mirror which focuses the beam to a point as it goes through a pinhole opening with an area of a few cm^2. This small opening allows the beam to enter the shielded region of the beamlines without releasing a significant amount of radiation. Each beamline contains an outer layer of shielding which is 25-cm thick. The shielded region runs from the pinhole opening to the beamline penetration in the bulk shielding wall. The shielding analyses for this region is presented in Section 6.8.4.1.

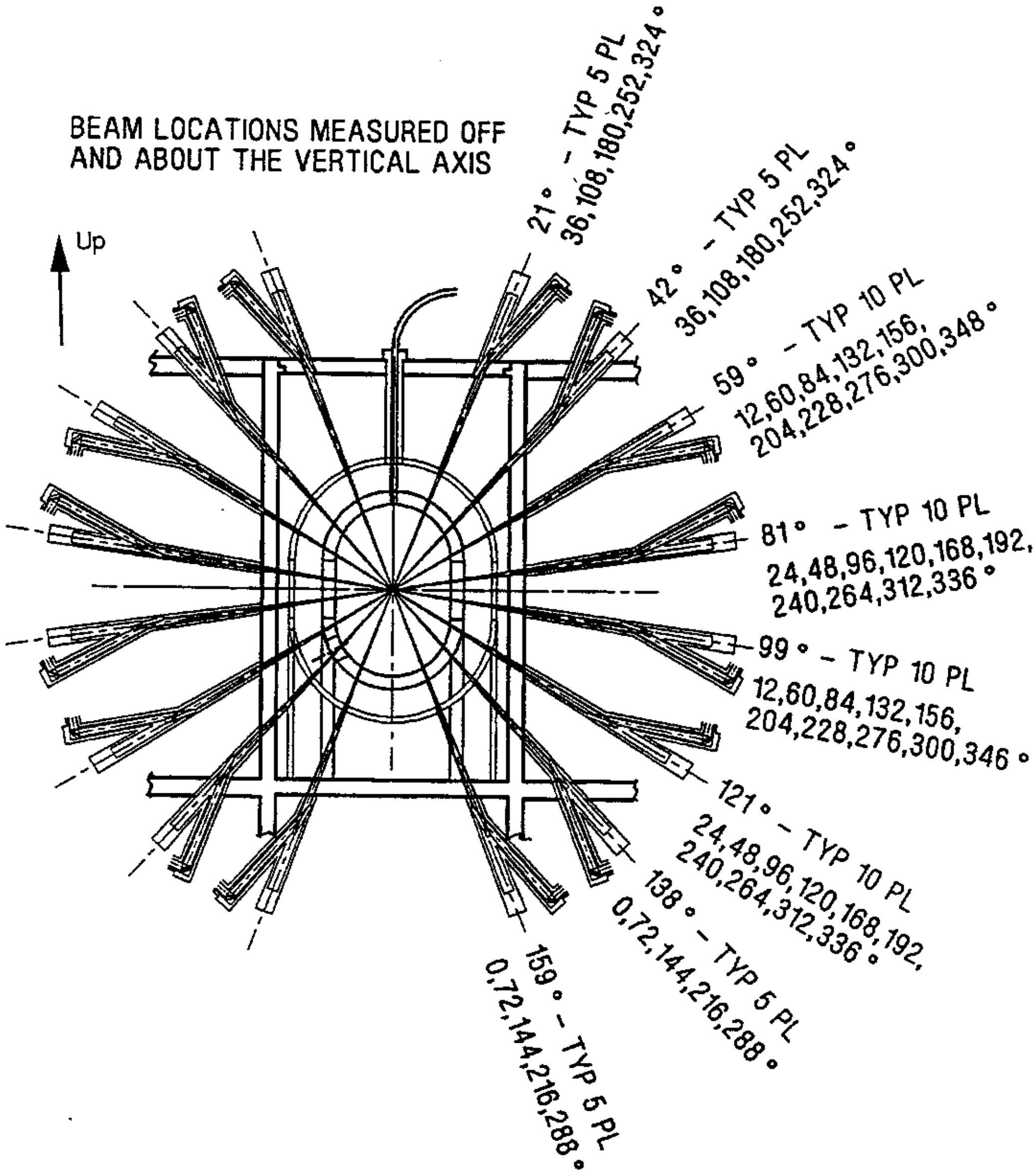

Figure 6.3.1-11. Angular Beamline/Reactor Cavity Interface Locations

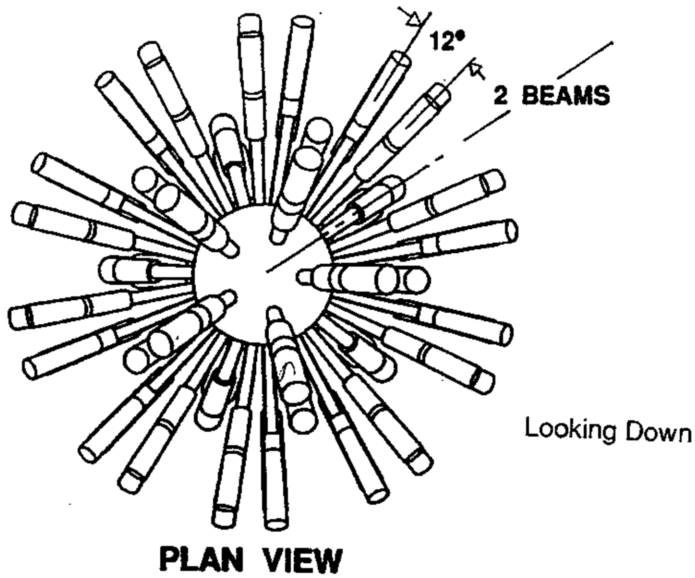

Figure 6.3.1-12. 3-D Beamline/Reactor Cavity Interface–Plan View

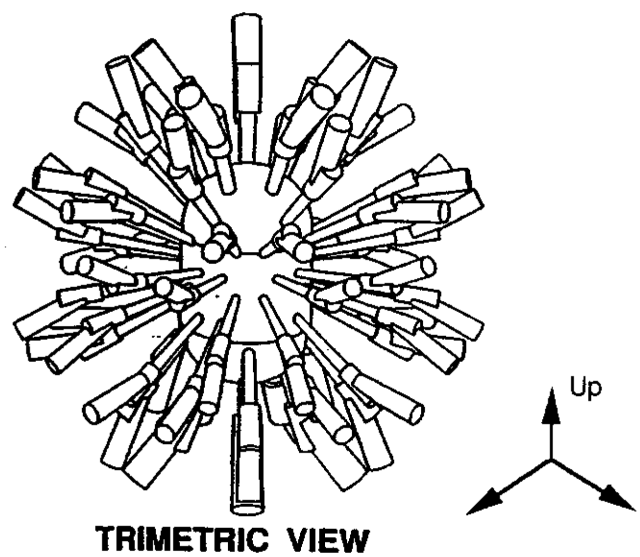

Figure 6.3.1-13. 3-D Beamline/Reactor Cavity Interface–Trimetric

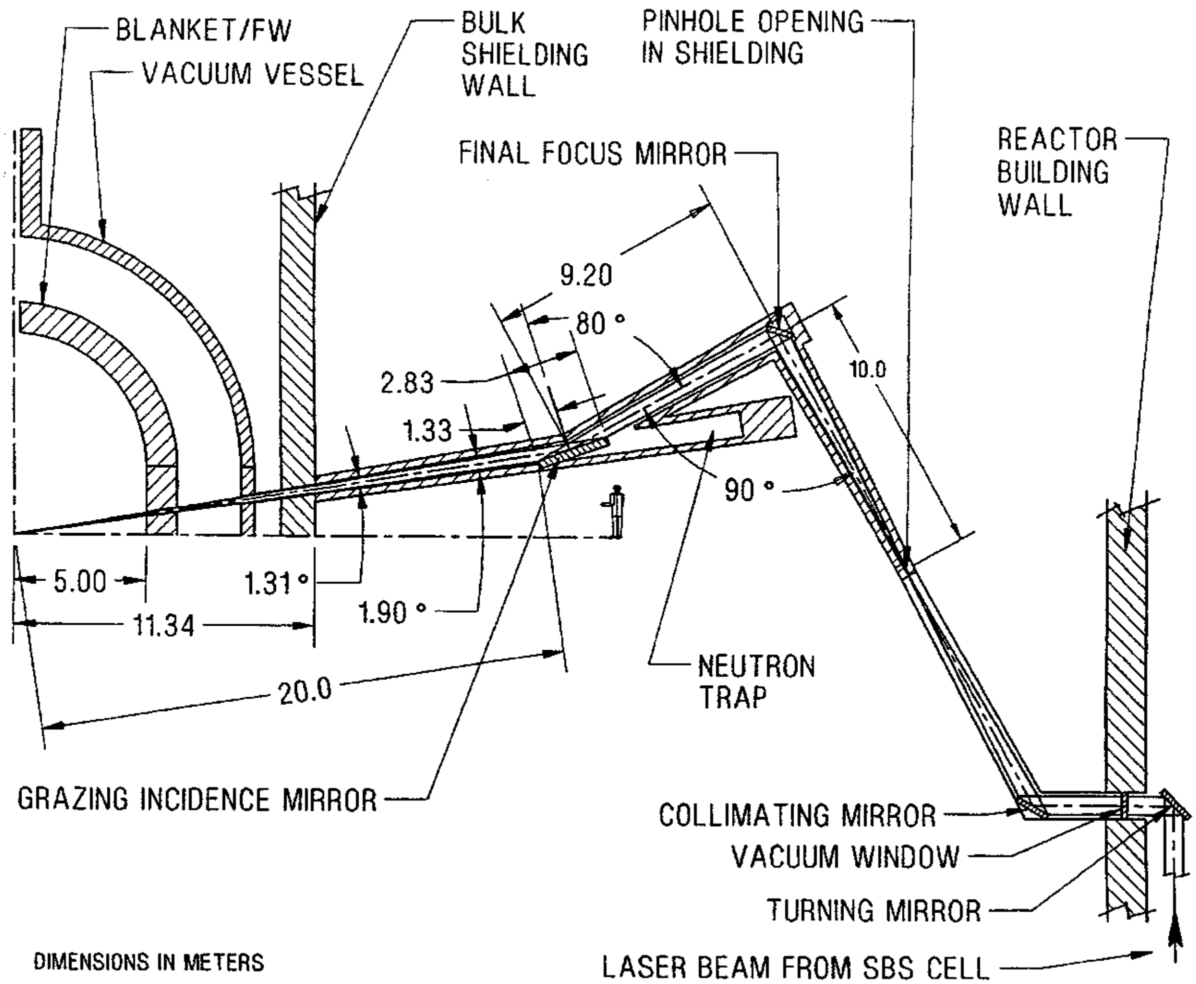

Figure 6.3.1-14. Final Optics Configuration–Reactor Building

After the pinhole, the beams tare directed downstream to the final focus mirror. This aspherical-shaped mirror, located 30 m from the center of the reactor cavity, serves to focus the beam to achieve a tangential illumination on the target at the cavity center.

The final mirror configuration is a grazing incidence metal mirror (GIMM) which is located 20 m from the cavity center. The GIMM uses a high reflective aluminum surface (1-2 mm thick) bonded to a silicone carbide ribbed structure with coolant channels. The angle of incidence of the GIMM in the beam path is 80°. This mirror is positioned in the direct line of sight with the first wall (FW) beamline openings (0.18-0.26 m in diameter). It protects the upstream final focus mirror from the radiation damaging environment. A neutron trap is located between the GIMM and the center of the reactor cavity. Shielding at the end of the neutron trap is 2 m thick. Analyses of the

GIMM and final focus mirrors suggest they are life-of-plant components; however remote maintenance methods are provided for mirror replacement and maintenance.

Protection for the GIMM and the final focus mirrors (as well as beam port walls) have been identified as a key development issue for the laser driver (see Section 5.4). The mirrors and ports must be protected from heating, blast, and radiation damage effects while not interfering with the laser beam propagation. Evaluation of this issue explored a number of protection methods as shown schematically in Figure 6.3.1-15. Protection methods include:

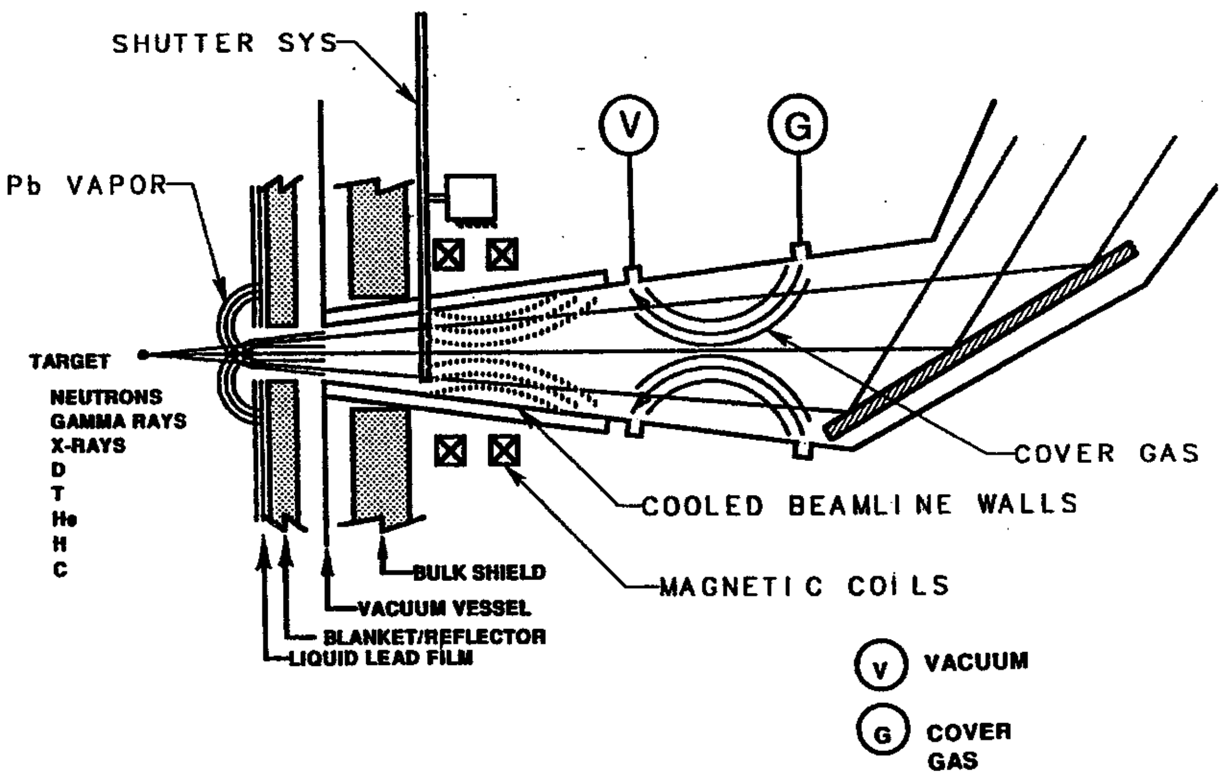

Figure 6.3.1-15. Schematic of Final Mirror Protection Methods

(1) Silicon carbide beam ports in a configuration similar to the FW panels with flowing liquid lead. The temperature of the lead would be maintained high enough to produce a lead vapor that protects the wall and mirror surfaces. Any condensed vapor on the GIMM surface would be vaporized by the prepulse beams.
(2) Residual lead vapor from the cavity could help attenuate the debris and x-rays before they reach the port area.
(3) A magnetic field could be provided by small magnet coils around the beamlines to deflect ions and electrostatically-charged particles.

(4) A cover gas, such as neon, injected in front of the GIMM could stop remaining x-rays and then be removed with vacuum pumps.
(5) Cooling the beamline walls below the GIMM surface temperature would help assure the condensable gases adhere to the walls instead of the optics.
(6) A shutter system could intercept lead droplets before they reach the optics, especially in the lower beamlines.

The baseline design employs a multilayer defense using all the above methods except the cover gas and cooled wall approaches. A neon cover gas resulted in extremely difficult vacuum pumping requirements. Instead, the baseline design provided a lead vapor cover gas by flowing hot lead through porous beamport walls and depending on the laser prepulse to remove any recondensing lead from the optic surfaces.

Prometheus-L Reactor Subsystems Overview - The subsystems that make up the reactor subsystem include the reactor vacuum vessel, vacuum pumping system, target injection, first wall, blanket, and the primary coolant systems. A wetted-wall reactor cavity concept is common to both the Prometheus-L and Prometheus-H reactor designs. The common cavity concept will be described in some detail for the Prometheus-L concept, and only the differences will be noted in the Prometheus-H description. All aspects of the cavity design are presented in detail in Section 6.8.

An elevation view of the central reactor cavity configuration is shown in Figure 6.3.1-16. The radial and elevation builds of the cavity are defined in this figure as is the dimensional configuration of the vacuum pumping system discussed below. Dimensions of the bulk shielding walls (1.3 m thick) are also defined.

Prometheus-L FW/Blanket Subsystem - The cavity first wall (FW) system employs liquid lead (Pb) which both cools and protects the silicon carbide (SiC) FW structure. Liquid lead bleeds through the porous first wall reactor facesheet, forming a protective liquid film on the surface. The microexplosion of the DT targets release three forms of fusion energy: neutrons, x-rays, and target debris ions. The energies from x-rays and target debris ions induce in surface heating of the Pb film, evaporating a portion of the film. As the film surface cools, the evaporated Pb condenses on the surface where the energy is conducted through the porous FW and is removed by convection into the flowing liquid Pb coolant. Also, a portion of the neutron energy is collected in the flowing Pb coolant as volumetric heating.

The SiC composite FW is 6 cm thick, with 5 cm diameter coolant channels. The film thickness of liquid Pb on the FW surface is 0.5 mm. Liquid Pb is pumped through the steam generator located in the reactor building to the top of the reactor cavity where it is distributed to the FW panels and flows downward to the collection header at the bottom of the reactor cavity. The general arrangement of the pumps, steam generator,

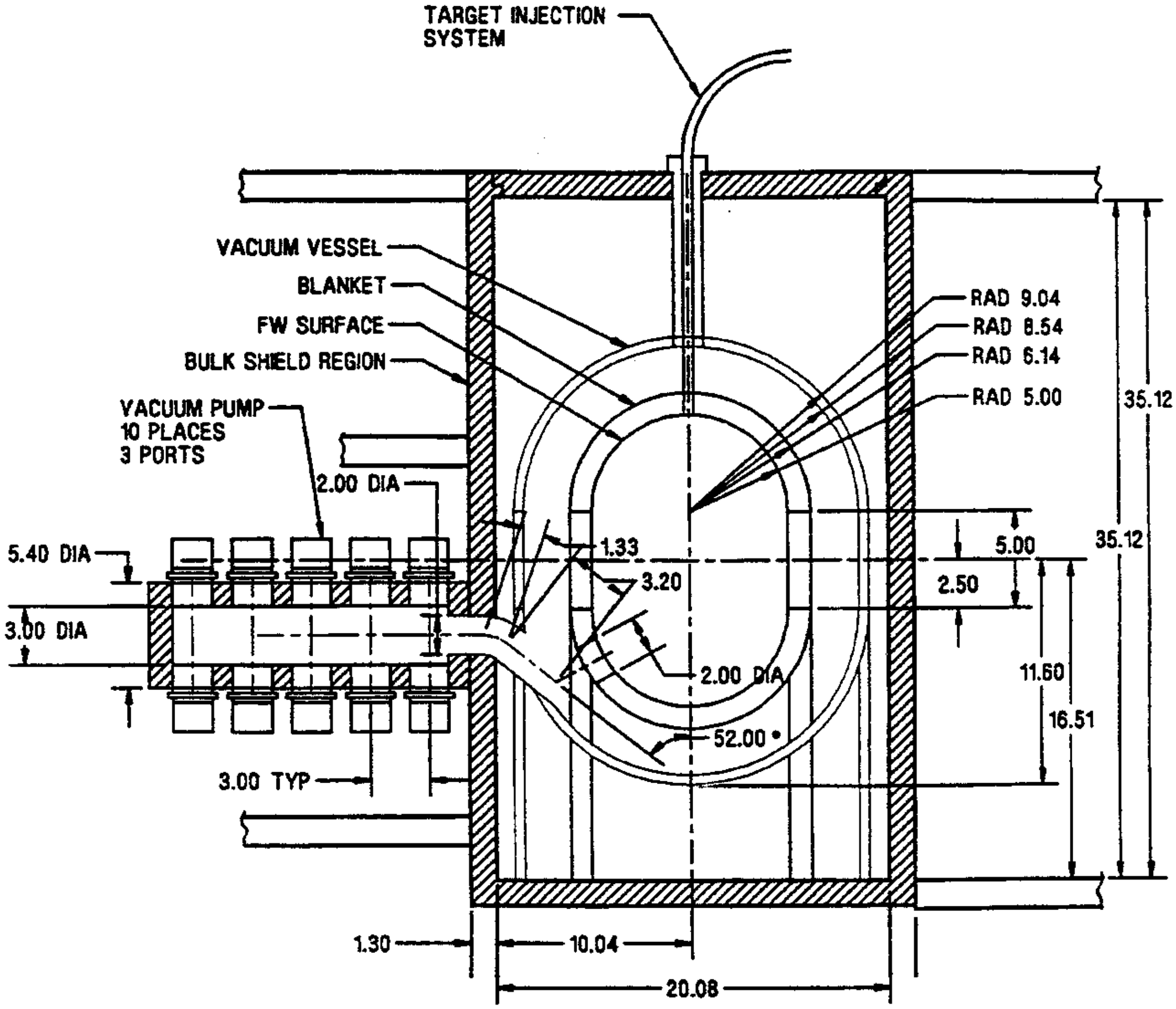

Figure 6.3.1-16. Elevation of Central Reactor Cavity Region

and inlet and outlet manifolds is shown in Figures 6.3.1-5 and 6.3.1-6. The liquid lead inlet/outlet temperatures are 375/525°C with pressures of 2.0/1.5 MPa, respectively.

The remaining useful neutron energy is captured in the blanket system. This helium cooled, solid breeder blanket system features SiC composite structure for a Li_2O peeble bed breeder with helium purge. The blanket section of the cavity is composed of stacked ring modules , each connected to helium manifolds in back of the blanket modules. Vertical supply and return headers supply helium coolant to/from the top of the reactor where inlet and outlet helium lines are located. (This configuration is shown in detail in the maintenance section of the report in Figures 6.3.2-4 and 6.3.2-5). Helium outlet lines connect the vacuum vessel to the helium steam generation components in the steam generator building. The general arrangement of these components is shown in Figures 6.3.1-4 and 6.3.1-6. The hot helium flows through the steam generator releasing its energy to feedwater which is converted to steam for the power conversion system. A helium circulator driven by a steam turbine returns the helium back to the reactor blanket system via the helium inlet lines to the top of the reactor cavity. Tritium is bred in the breeder zones of the blanket and is collected by a separate helium purge system. The blanket tritium breeding ratio is 1.20.

The blanket inlet/outlet helium temperatures are 400/650°C with a inlet pressure of 1.5 MPa. The total pressure drop within the helium coolant system is 85 kPa with 33 kPa in the blanket. The total blanket thickness is 104 cm which is made up of 60 cm breeder zone, 20 cm reflector zone, 6.5 cm for inner/outer SiC structure, and 17.5 cm for internal plenum manifolding.

<u>Prometheus-L Vacuum Pumping Subsystem</u> - The propagation of the laser light beams within the reactor cavity required that the vacuum system pump the cavity to a base pressure of 1-3 mtorr prior to each pulse. Noncondensible gases of hydrogen, helium, deuterium, and tritium from each target implosion are pumped by a system of 30 vacuum cryopumps. These pumps are arranged in clusters of ten pumps, each at three radial locations around the reactor cavity. The detail configuration is shown in Figure 6.3.1-16. A reactor building cross-section in Figure 6.3.1-17 shows the vacuum

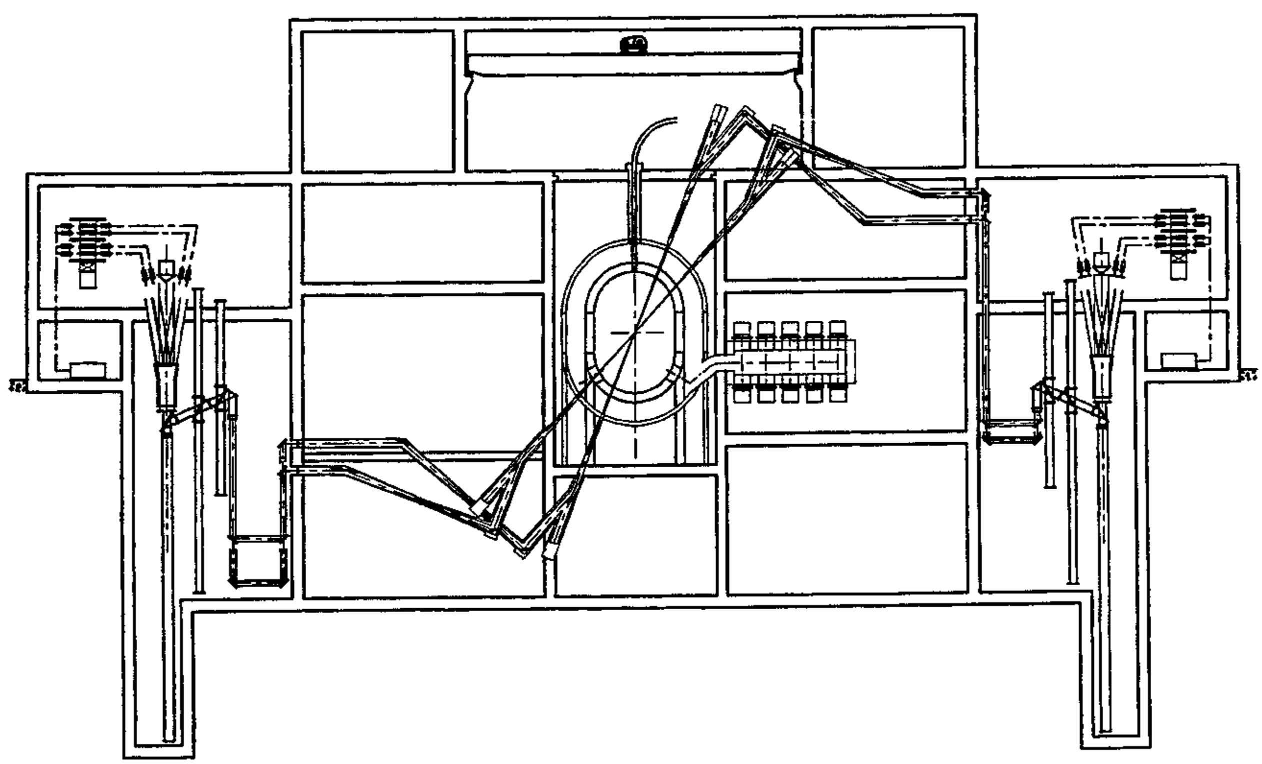

Figure 6.3.1-17. Vacuum Pumping/Reactor/Final Optics Systems Interface

pumping system relative to the cavity and laser beam lines. Pumps are attached to a 3-m diameter plenum which is connected to the vacuum vessel by a 2-m diameter duct attached to the vacuum vessel at each location. Radiation shielding 1-m thick surrounds this enclosure. Vaporized lead and carbon are assumed to recondense within the cavity or at the vacuum pump duct inlets. The design aspects of the vacuum pumping system are discussed in detail in Section 6.6.

Prometheus-L Target Injection System Reactor Interface - The Prometheus-L concept uses the direct-drive targets. An electromagnetic injection system injects targets into the reactor cavity at a rate of 5.65 per second (484 x 10^3 per day). The single shell targets are 6 mm in diameter. The target injection interface with the reactor cavity is shown in Figure 6.3.1-16. This injection system is discussed in detail in Section 6.4.4.

Prometheus-L Reactor Vacuum Vessel - The reactor vacuum vessel shown in Figure 6.3.1-16 provides the required pressure boundary for the reactor. A vessel radial build of 0.5 m is allocated for the overall structural arrangement although the overall actual vessel pressure boundary thickness will be only a few cm. The material for the vessel is a low activation ferritic steel material. There is some power loss through the FW/blanket system, thus the vessel will require heat removal capability. This could be an active, liquid cooled system or perhaps a passive, convective system over the outside of the vessel.

6.3.1.2 Prometheus-H - The Prometheus-H reactor power plant employs a single-beam linear induction accelerator (LINAC) driver design to deliver the necessary energy to the indirect drive targets. Site plans for the Prometheus-H reactor design power plant are shown in Figures 6.3.1-18 through 6.3.1-20. Presented are a trimetric view of the plant site, a plan view of the plant site, and a building definition plan view, respectively. These figures show the configurational arrangement of the heavy ion beam driver components and the interface with the 59-m diameter IFE reactor building. The heavy ion beam driver components are located in a network of tunnel complexes with a total length of 2700 m. Two main beam bundles enter the reactor building from two sides, 180° apart. Typical IFE power plant buildings (administration, auxiliary, turbine, steam generator, target factory, and tritium processing) complete the site complex. Notice that Figure 6.3.1-20 shows the routing of the LINAC with broken lines. Figures 6.3.1-18 and 6.3.1-19 show the site plan with the full 2700-m length of the heavy ion driver shown to scale.

Prometheus-H Driver - General Overview - This driver is a single-beam induction linear accelerator (LINAC) design which generates and accelerates a sequential series of 18 heavy ion beamlets with a total energy output of 7.8 MJ. The technical, theoretical, and operational aspects of this driver system are discussed in Section 6.5.2.

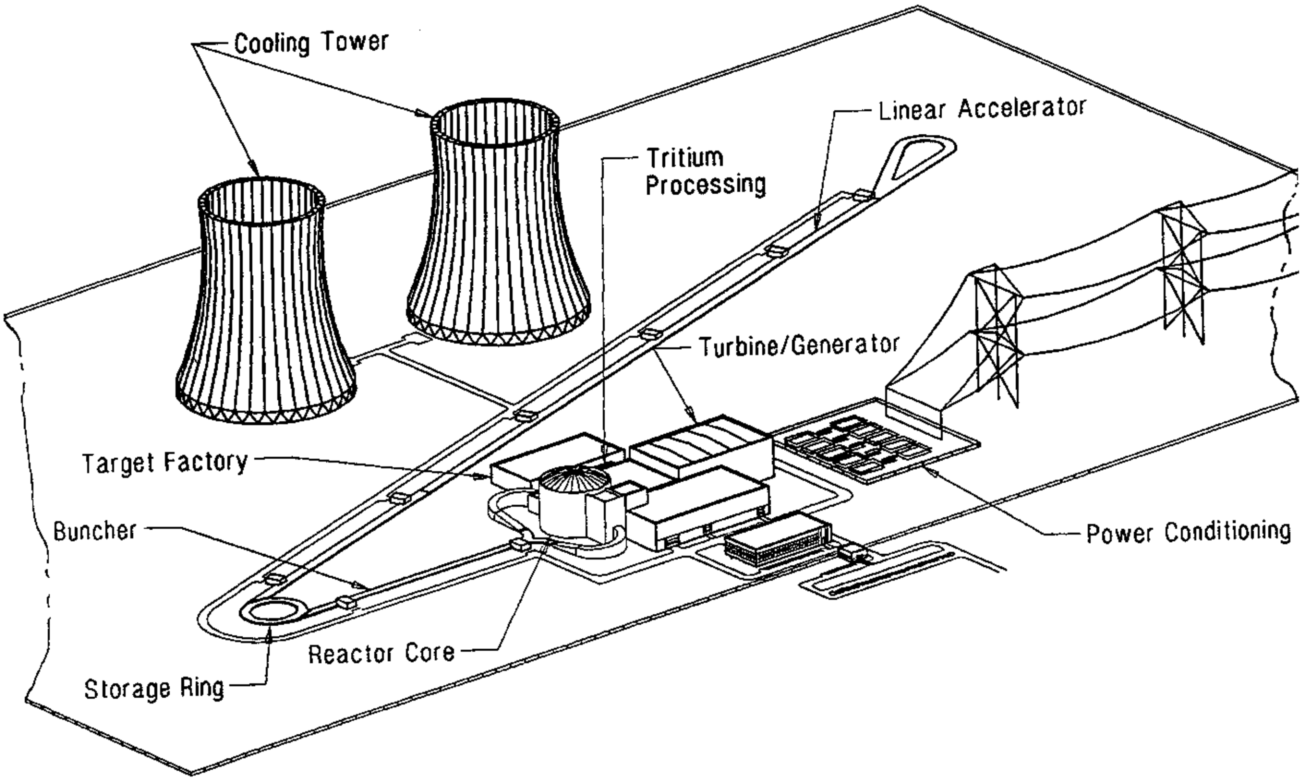

Figure 6.3.1-18. Prometheus-H Plant Site Trimetric View

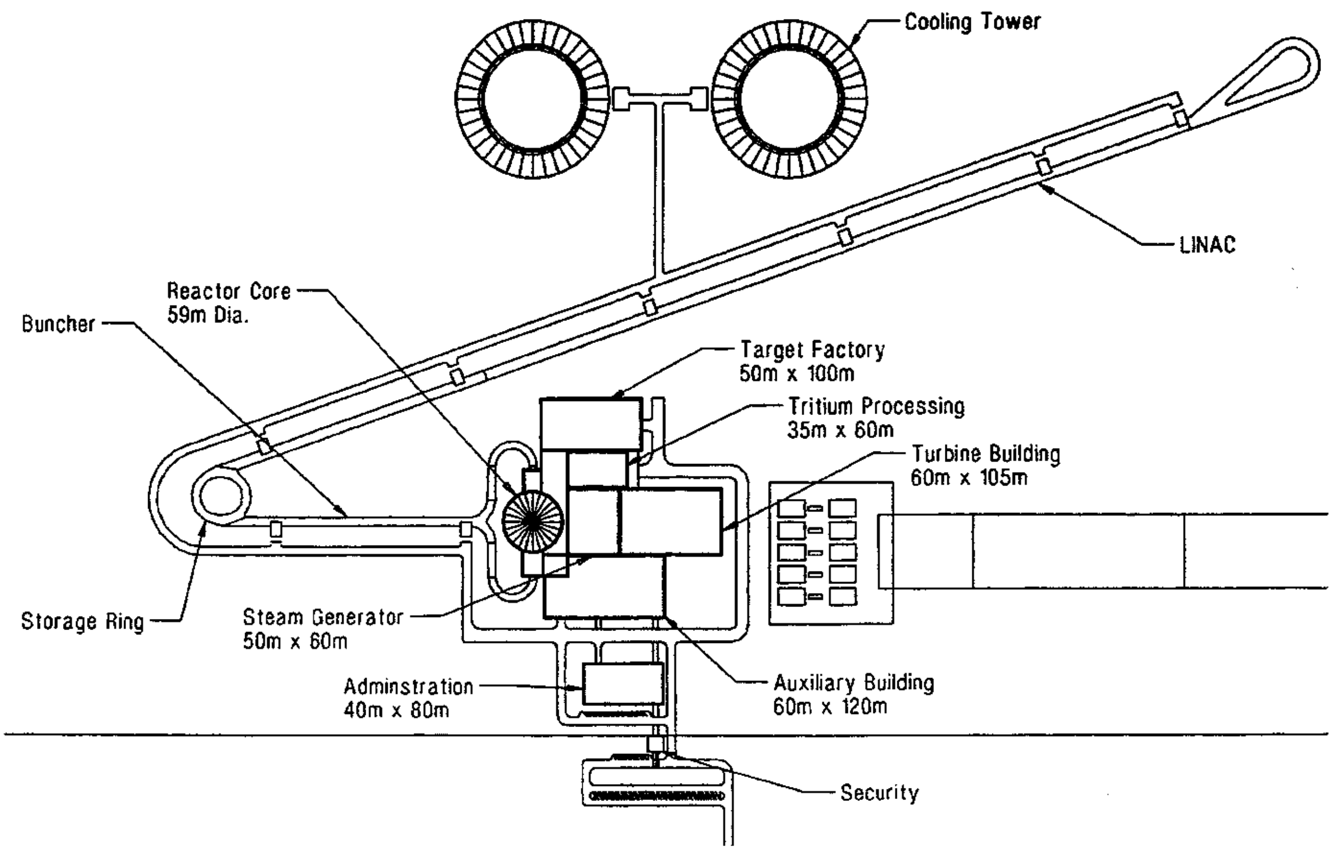

Figure 6.3.1-19. Prometheus-H Plant Site Plan View

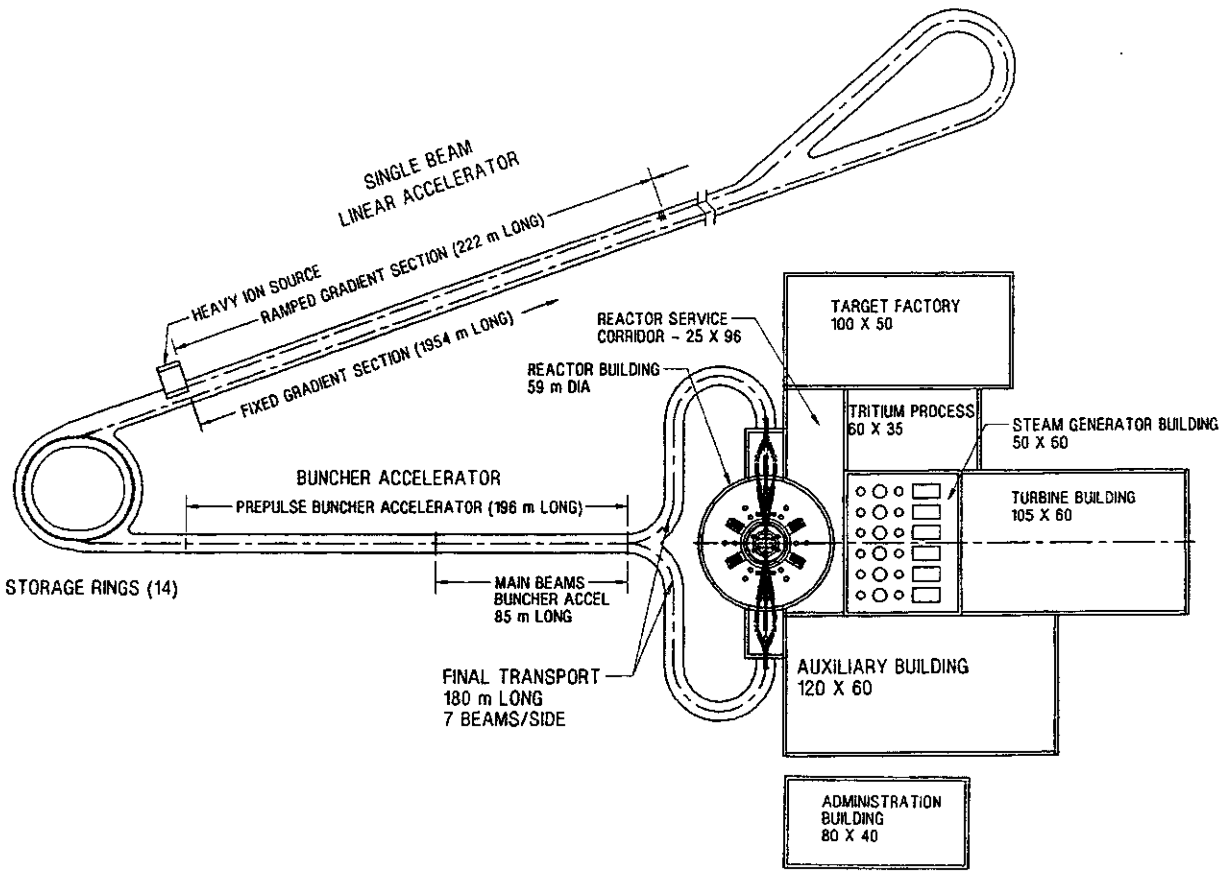

Figure 6.3.1-20. Prometheus-H Building Plan View

The major subsystems are the heavy ion LINAC, storage rings, buncher accelerator, final transport, final focus, and channel formation sections. The major components and general arrangement of these subsystems are shown in a sketch in Figure 6.3.1-21 with the final focus and channel formation subsystems located inside the reactor building not shown in detail. These subsystems will be discussed in the sections below. A heavy ion source on the front end of the LINAC generates and injects the 18 heavy ion (Pb) beamlets into the single-beamline LINAC section where they are accelerated to the desired energy state. From the LINAC section, the 18 beamlets are stored in a set of 14 vertically-stacked storage rings which store the beamlets (12 main and 6 prepulse beamlets) until the proper time for release. The six prepulse beamlets are stored in two storage rings with three sequential beamlets in each storage ring (one storage ring for each set of prepulse beamlets going to each side of the reactor). At the proper time, the beamlets from first the prepulse and then the main beamlet storage rings are simultaneously released into 14 parallel beamlines leading to the buncher accelerators. There are two separate buncher accelerators—one for the prepulse beamlets (196-m long) and one for the main beamlets (85-m long). The buncher accelerators compress the beamlet lengths to achieve the required pulse lengths for both the prepulse (30 ns) and main (7.3 ns)

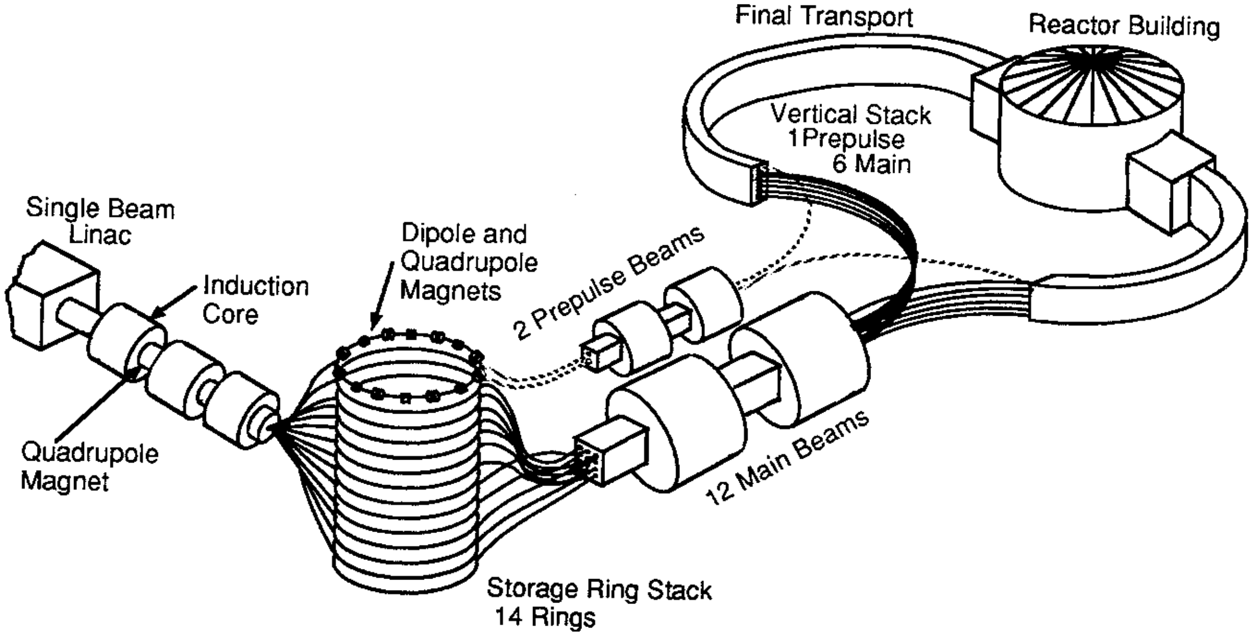

Figure 6.3.1-21. Schematic of Heavy Ion Driver Subsystems

beamlets. The buncher accelerator consists of 14 parallel beamlines—two for the prepulse beamlets and 12 for the main beamlets.

From the buncher accelerators, the prepulse and main beam routes separate into two identical 180 m long routes to the center of the reactor cavity. The typical routes enter the reactor building 180° apart with each route containing a vertical stack of seven parallel beamlines—six for the main beamlets and one for the prepulse beam (made up of three sequential beamlets). At the entrance to the reactor building system, the six main beams on each side are routed from the vertical stack to a conical array with a half angle of 8.54°, allowing all beams to be focused to a midplane point on the outer diameter face of the blanket cylindrical section. The prepulse beam line on the top of the vertical stack is routed to the horizontal, axial centerline of the conical array focusing on the same point. At this point, a lead-vapor gas jet forms an aero window over the 2-cm diameter cylindrical opening through the blanket module to the reactor cavity. This aero window serves as an electron stripping cell, allowing the beams to become one beam which is a highly charged, high current, self-pinched beam for transport through the final 5.64 m of cavity environment to the target at the center of the cavity. The prepulse beam arriving first forms a plasma channel for the following six main beams. All seven beams from each side (prepulse beams first, then main beams) strike the ends of an injected, indirect drive target in the center of the reactor cavity. The target implodes, releasing 719 MJ of energy to the reactor cavity at the rate of 3.5 pulses per second.

LINAC Subsystem - The LINAC subsystem consists of the heavy ion source/injector, ramped gradient sections, and fixed gradient sections. These components are located in a tunnel system with a nominal width of 10 m. In order to minimize the length of the tunnel network, a "hair-pin" arrangement of the tunnel system is used to house the 2200-m LINAC subsystem. The front end of this system is the heavy ion source and injector which contains all the components necessary to deliver heavy ion beams with the required properties to the ramped gradient portion of the LINAC. Representations of the source/injector portions of the LINAC subsystem were not developed in this study other than to represent the general location of the heavy ion source location on the site plan in Figure 6.3.1-20. The source/injector operates in "burst" mode, injecting a sequential set of 18 beamlets into the ramped gradient section at a repetition rate of 3.5 cycles per second. Specific parameters for the injector are discussed in Section 6.5.2.

The ramped and fixed gradient sections of the LINAC both accelerate and compress the injected beams traveling down the 2200-m length of the LINAC. The main components of the single beam LINAC are induction core modules and superconducting quadrupole magnets. These components are arranged in alternating fashion along the single beamline as shown in the schematic in Figure 6.3.1-21. The LINAC baseline configuration of the induction cores and the quadrupole magnets is shown in Figure 6.3.1-22. Note that the outer diameter and the length of the induction cores and the effective width of the superconducting quadrupole magnets change along the length of the LINAC system. Figure 6.3.1-22 shows those dimensions at three points—at the injector, at the transition between the ramped and fixed gradient sections, and at the end of the LINAC.

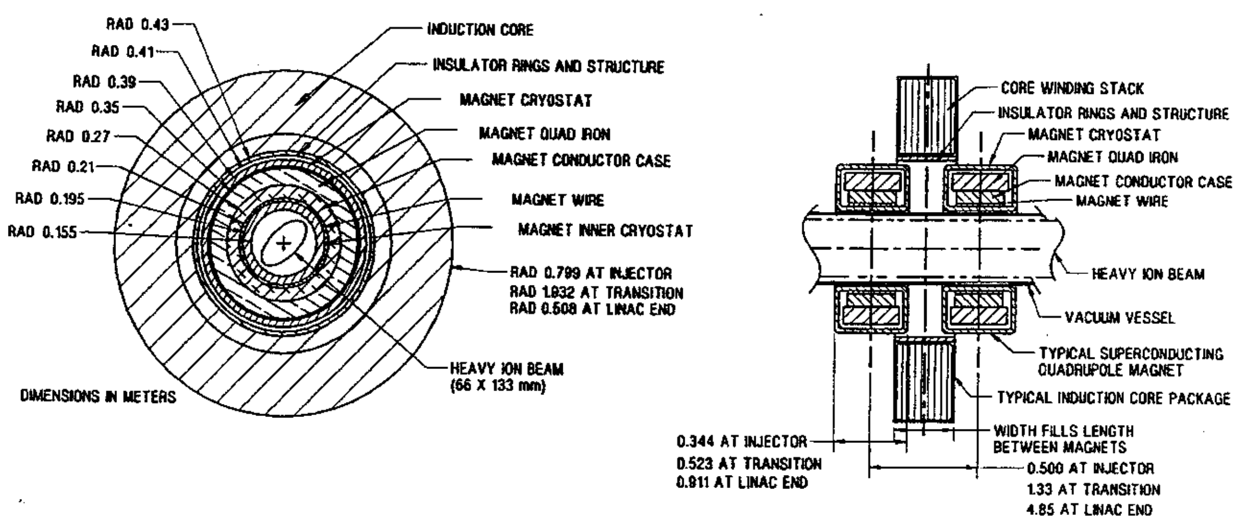

Figure 6.3.1-22. Configuration of Induction Cores and Quadrupole Magnets

The induction core modules function to accelerate the injected beamlets while the quadrupole magnets form the transport channel in between the induction cores. The ramped and fixed gradient sections function identically but differ in the allowed voltage gradient as a function of position along the accelerator length. The end of the ramped gradient section is defined as the point where the maximum gradient is reached. Section 6.5.2 describes the technical characteristics of these sections in more depth.

A typical cross-section of the LINAC subsystem tunnel complex at one of the maintenance buildings along the LINAC is shown in Figure 6.3.1-23. The maintenance buildings are located 200 m apart as shown in the site plans in Figures 6.3.1-18 and 6.3.1-19. These figures shows the single beamline, folded LINAC going in both directions—first down the tunnel system away from the heavy ion source and then back toward the storage ring tunnel complex.

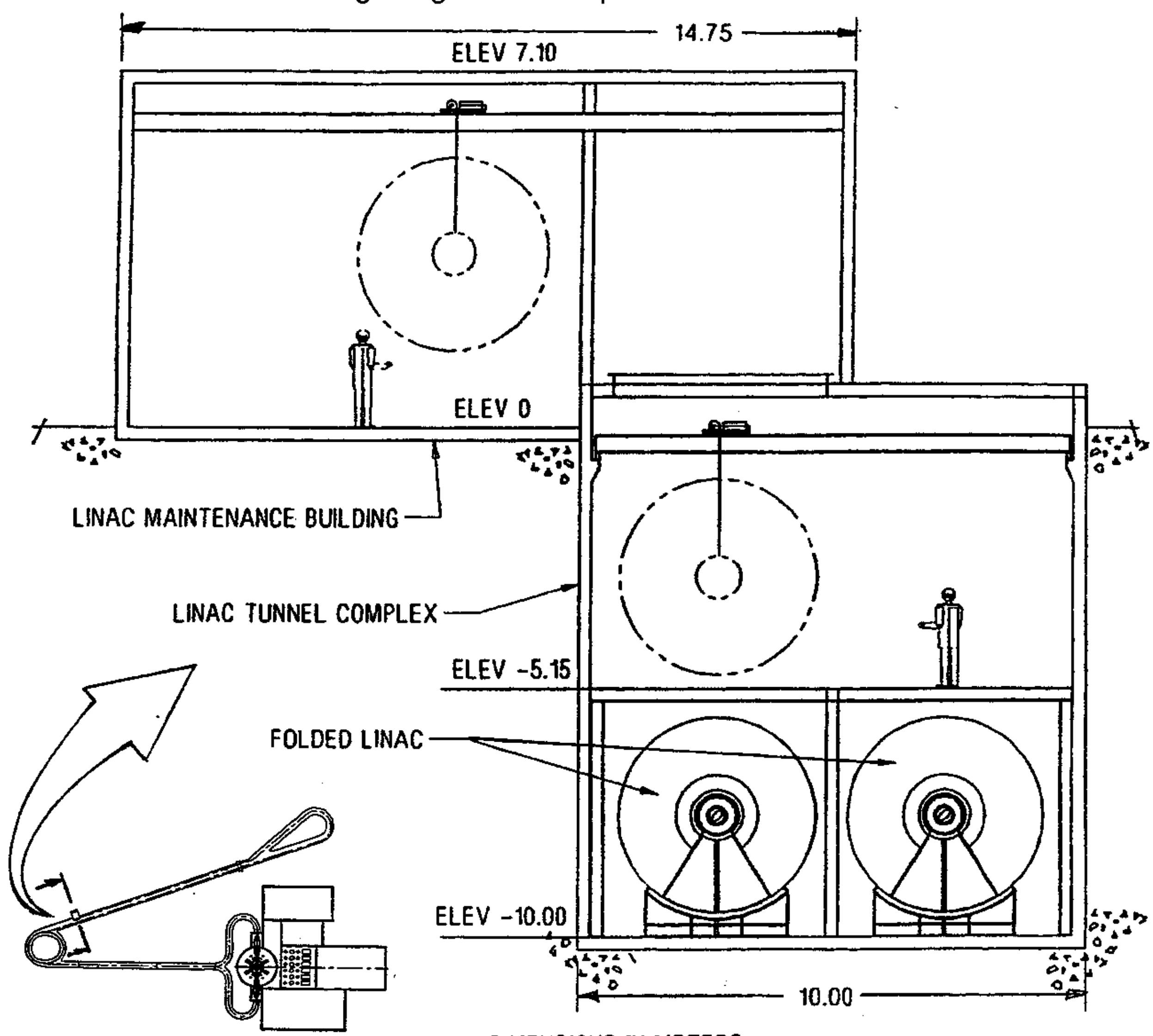

Figure 6.3.1-23. Typical Cross-Section LINAC Tunnel Complex

Storage Ring Subsystem - The single beam LINAC outputs the sequential array of 18 beamlets to a vertical stack of 14 storage rings as discussed above in the overview description. The storage rings store the beamlets until the proper timing for release toward the target in the reactor cavity. A network of beamlines with switching magnets routes the single beam output of the LINAC to the proper storage ring. A plan view of the storage ring is shown in Figure 6.3.1-24 which shows the arrangement of quadrupole and dipole magnets in two semi-circular arrangements with a short

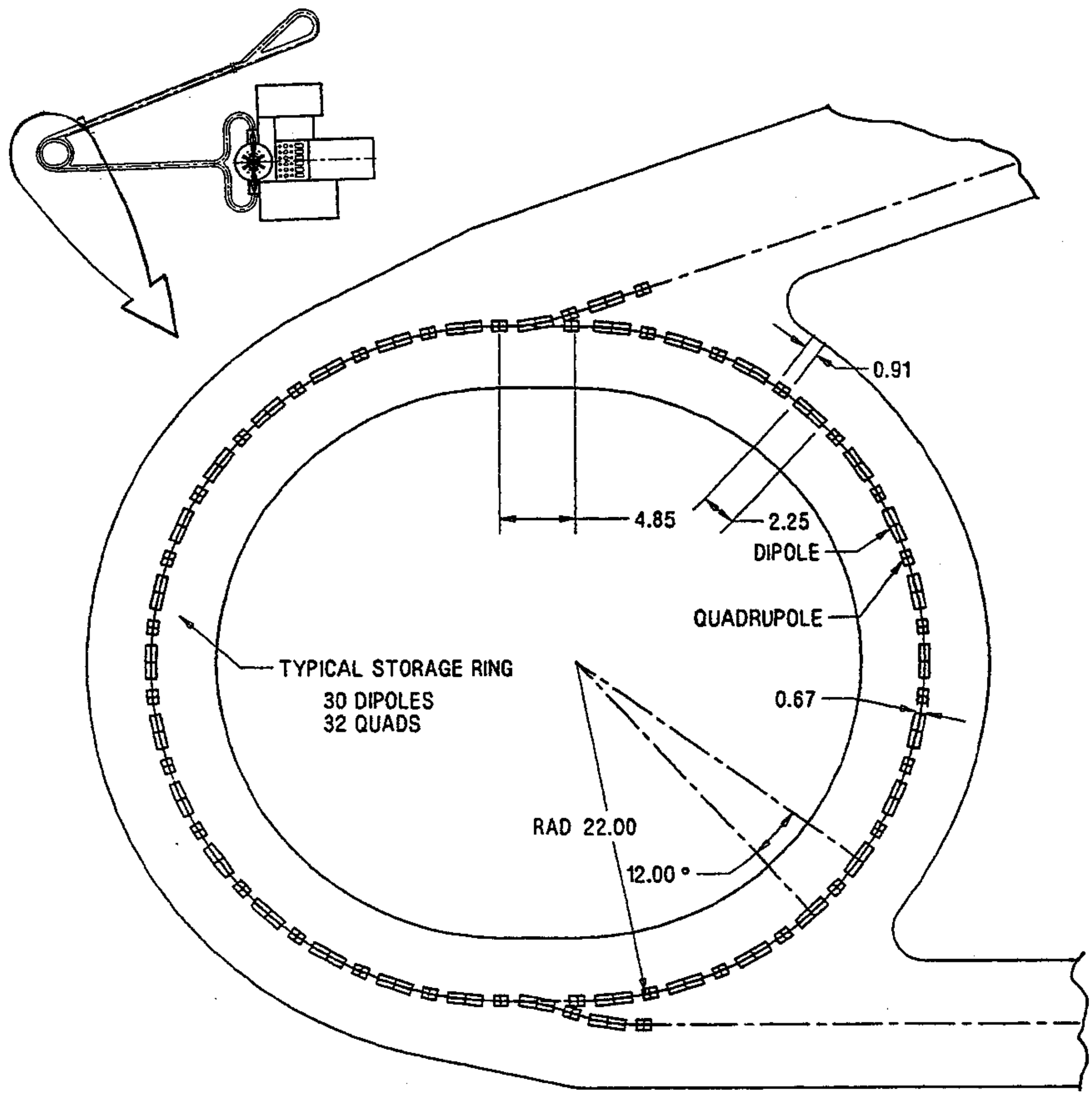

Figure 6.3.1-24. Storage Ring Plan View

straight section in between for switching the beamlines into and out of the storage rings. The vertical stack of 14 parallel beamlines in the storage ring is shown in the cross-sectional view of the storage ring tunnel complex in Figure 6.3.1-25. A detail in this figure shows the general arrangement of beamline components around the beamline.

Buncher Accelerator Subsystem - This subsystem functions to compress the overall length (head-to-tail length) of beamlets released from the storage ring complex to achieve the proper beam length at the time of impact with the target. Two sets of buncher accelerators are included in this subsection—one for the 2 prepulse beams (196 m long) and one for the 12 main beams (85-m long). The buncher accelerator components are identical in functional arrangement as the components in the main LINAC; i.e., the components again consists of a repeating arrangement of an induction core in between quadrupole superconducting magnets. However in the buncher accelerators, there are multiple, parallel beamlines. To reduce the number of induction cores, the parallel beamlines are grouped together and are run through a common induction core around all the parallel beams. Within the prepulse beam buncher accelerator, there are two parallel beam running through a common induction core. Similarly, within the main beam buncher accelerator, there are 12 parallel beamlines running through a common induction core. This is shown in the cross-section of the buncher accelerator tunnel complex in Figure 6.3.1-26.

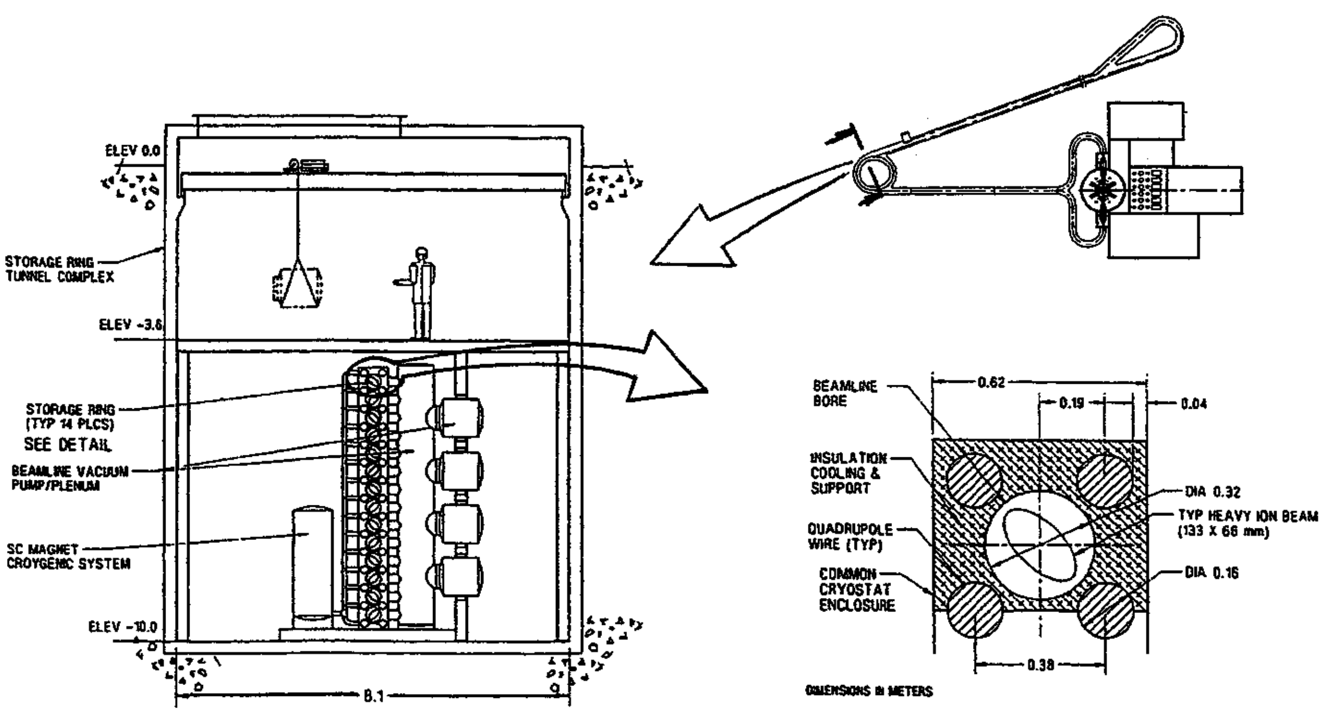

Figure 6.3.1-25. Storage Ring Tunnel Cross-Section and Typical Beam Detail

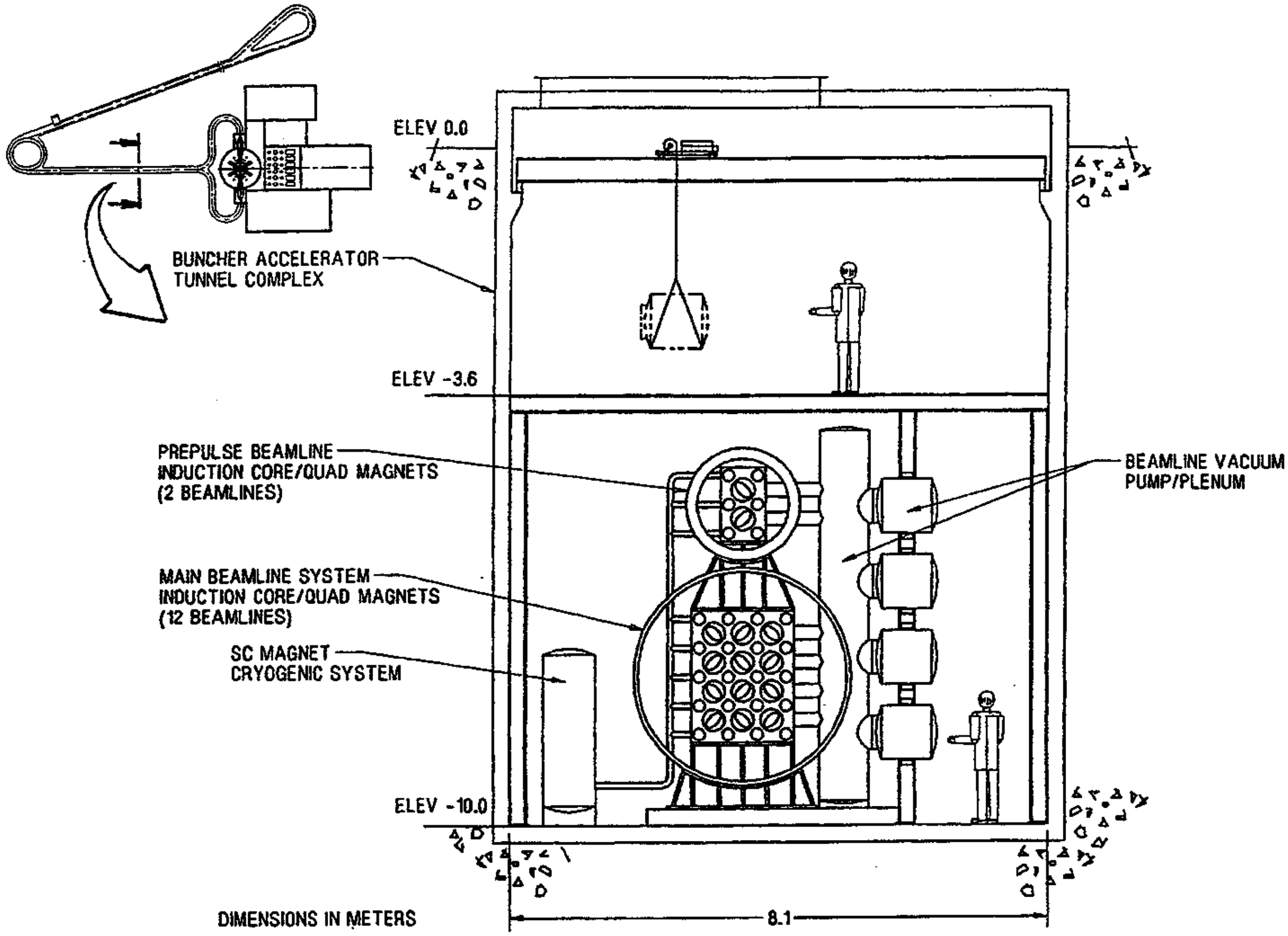

Figure 6.3.1-26. Buncher Accelerator Cross-Section

The beamlines exit the buncher accelerators at a common point and then divide up with one prepulse beam and six main beams routed to each side of the reactor building. The configuration and routing from LINAC to reactor is shown schematically in Figure 6.3.1-27 by the arrangement of the typical cross-sectional configurations of the beamlines in each major area. The configuration of components along the routes from each major area to the next consists of the parallel beamlines with alternating arrangement of quadrupole and dipole magnets. The quadrupole magnets maintain the channel transport and focus, and the dipole magnets are used to bend the beamlines along the curved paths. In pure straight sections with no bends, only quadrupole magnets are needed.

Final Focus Subsystem - The final focus subsystem consists of a triplet set of superconducting, quadrupole magnets in each beamline, and a final focus vacuum

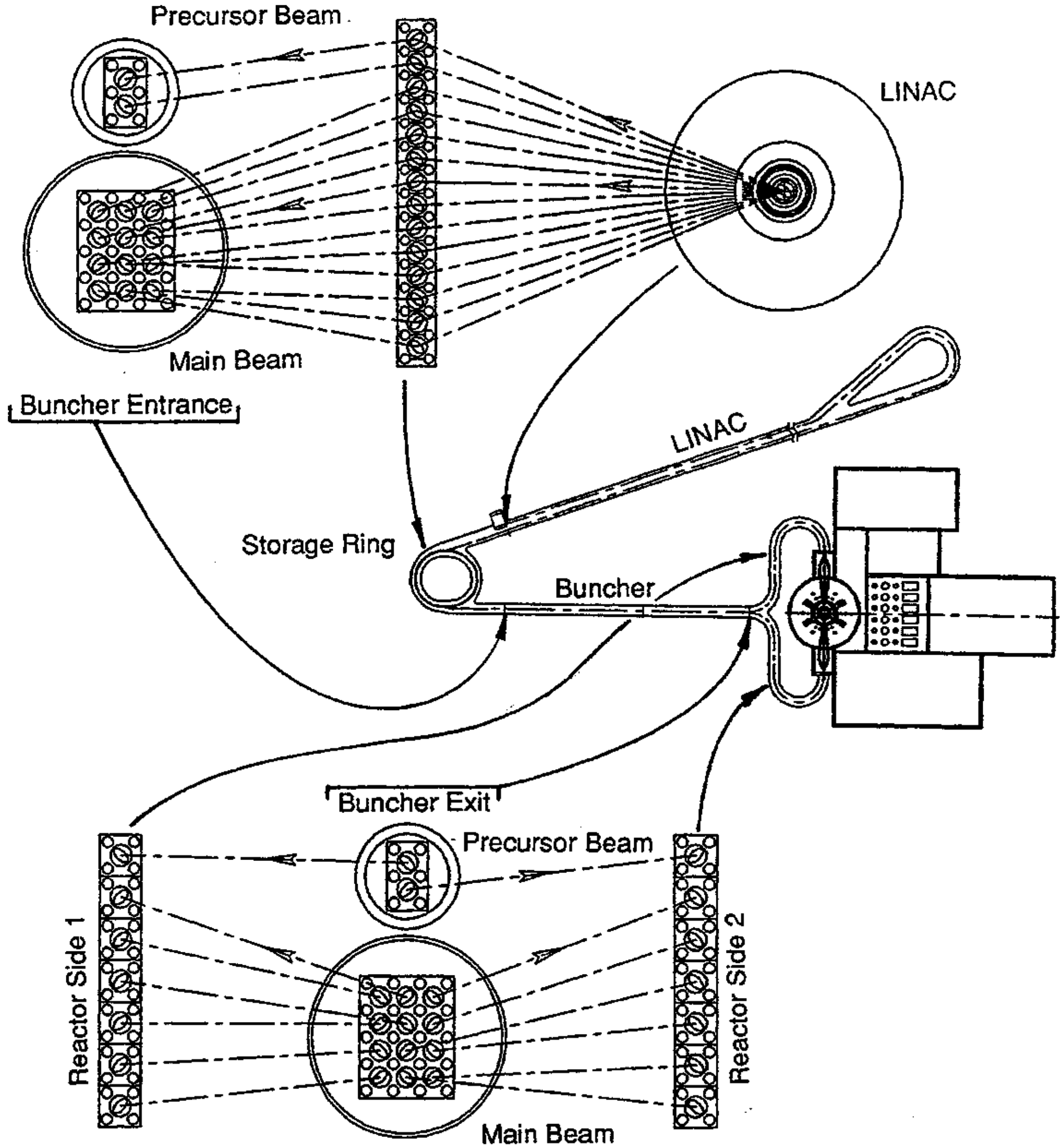

Figure 6.3.1-27. Beamline Configuration – Routing from LINAC to Reactor

enclosure. Components within this subsection are shown in Figure 6.3.1-28. The function of this subsystem is to accept the set of seven beams (six main and one prepulse) arriving from the last quadrupoles in the final transport section and to focus the beams on a common focal point which is on the outer diameter of the blanket cylindrical section. After passing through the triplet final focusing magnet sets, the beams proceed by ballistic transport to the focus point. To final focus the seven beams to a common point, the prepulse beam is routed from the vertically-stacked beamlines to a horizontal, on-axis position and the six main beams are routed from the vertical stack to an equally-spaced conical array around the center prepulse beamline. The

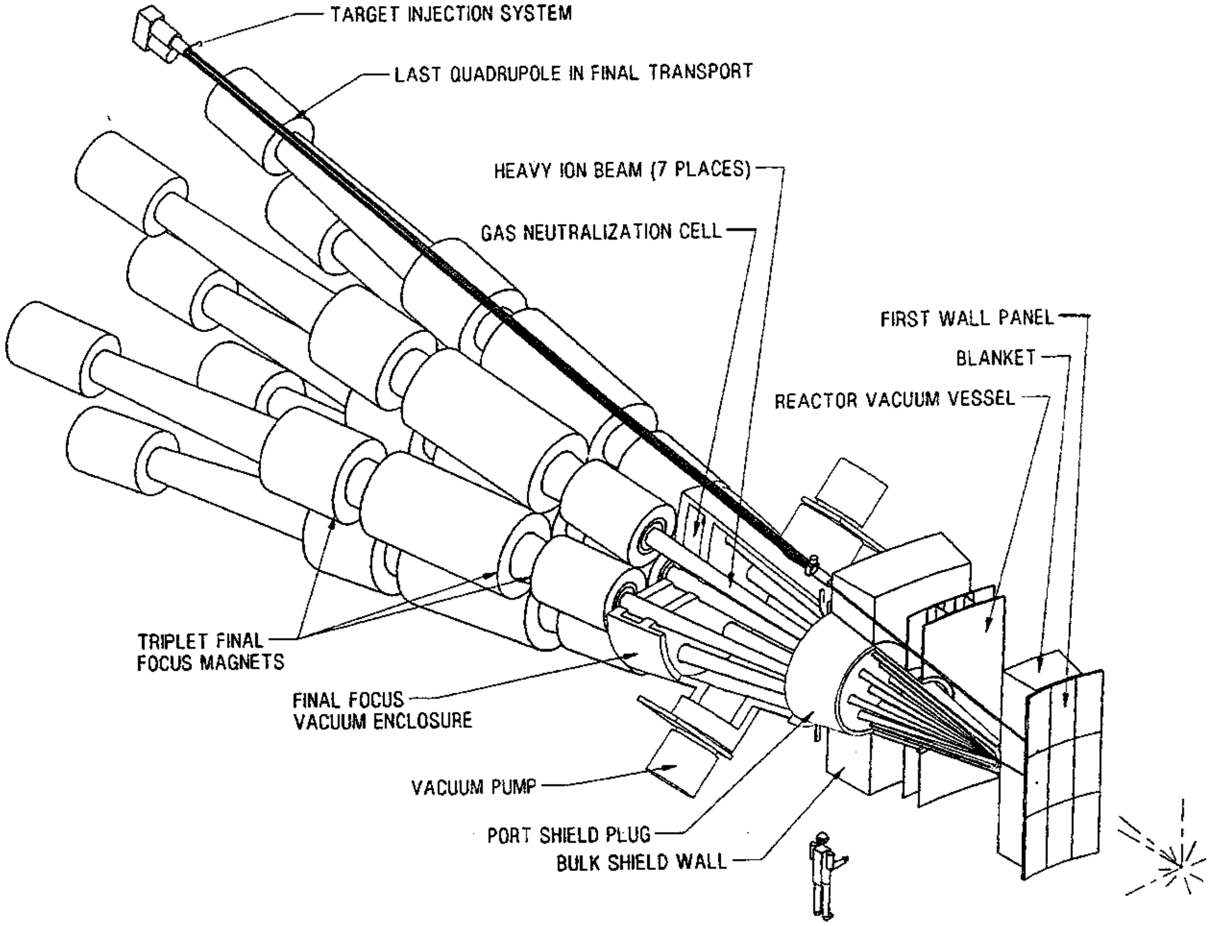

Figure 6.3.1-28. Heavy Ion Beam Final Focus Subsystem Configuration

conical array of six main beams has a half angle of 8.54°. The resulting interface with the reactor cavity is also shown in an elevation view in Figure 6.3.1-29 and in a plan view in Figure 6.3.1-30. The main beams in the conical array and the final focus vacuum pumps in Figure 6.3.1-29 and the vacuum pumps in Figure 6.3.1-30 have been rotated about the conical centerline into view for clarity.

The final focus vacuum enclosure provides an interface between the triplet magnet sets in each beamline and the outboard face of the cylindrical blanket modules at the midplane of the reactor cavity. This shielded, conical shaped enclosure forms an intermediate pressure boundary where a base vacuum pressure of 10^{-5} torr is maintained by a set of two cryopumps. The pressure boundary of the enclosure interfaces with the reactor vessel port extension at a flanged interface outside the bulk shielding wall as shown in Figure 6.3.1-31. The reactor vacuum vessel operates at a base vacuum pressure of 10^{-1} torr provided by a vacuum pumping system to be discussed below. The base vacuum pressure maintained within the beamlines

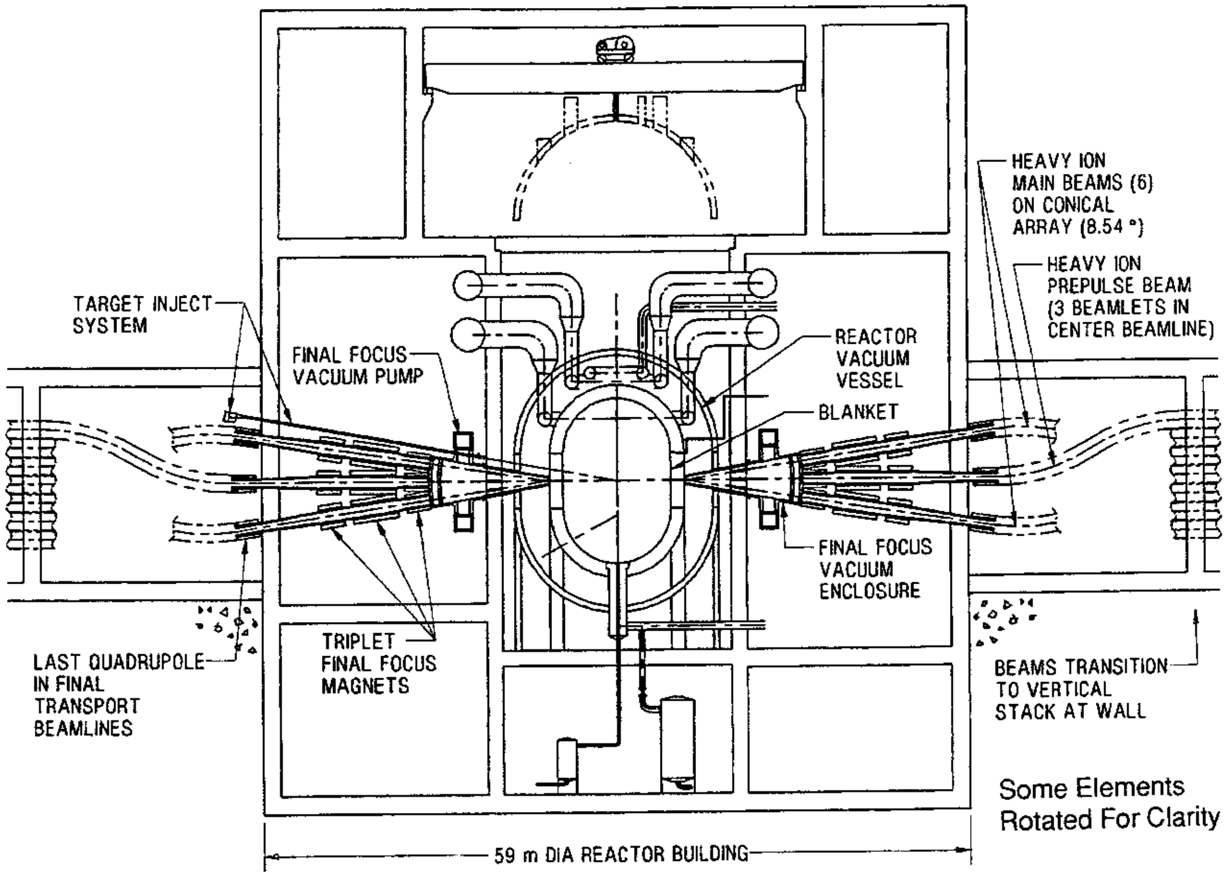

Figure 6.3.1-29. Elevation View – HI Beams/Reactor Systems Interface

passing through bore of all the magnets in the driver (from LINAC through final focus) is 10^{-9} torr. Thus, the final focus vacuum enclosure provides the intermediate vacuum pressure boundary between reactor cavity pressure of 10^{-1} torr and the beamline vacuum pressure of 10^{-9} torr.

As the seven beams enter the base of the final focus vacuum enclosure, they will pass through a gas neutralization cell formed by a double-bottom in the vacuum enclosure. Lead vapor gas will be puffed into this cell prior to the arrival of each set of beams in the 3.5 Hertz repetition rate. The gas neutralization cell functions to neutralize the charged, heavy ion beams allowing the beams to be focused to a small diameter (6 mm) focal spot just outside the blanket.

Channel Transport Subsystem - The final subsystem in the Prometheus-H driver system is the channel transport subsystem which is shown in Figure 6.3.1-31. It consists of a lead vapor gas jet system employed to form an aero window at the final focus point of the seven beams on each side of the reactor cavity. The aero window

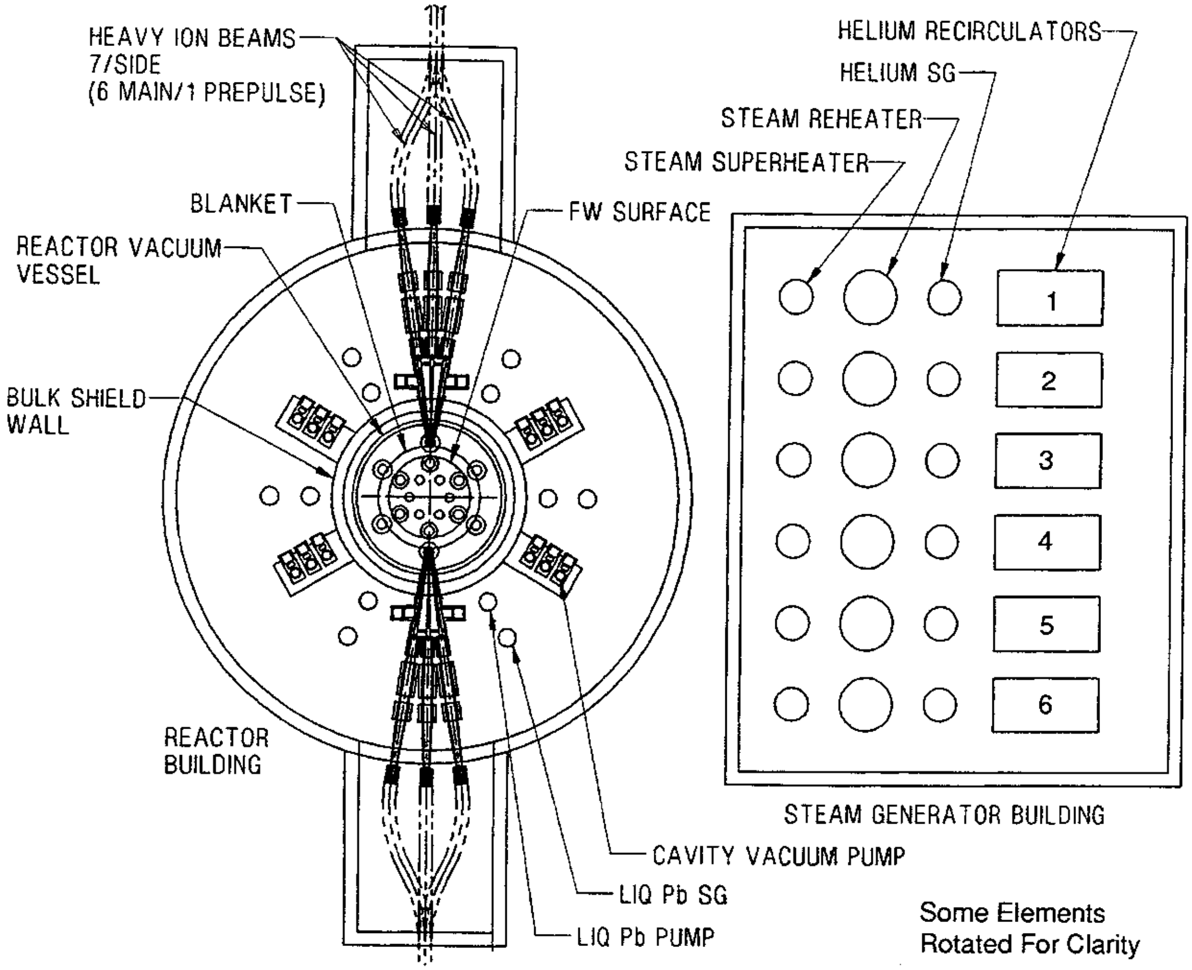

Figure 6.3.1-30. Plan View – HI Beams/Reactor Systems Interface

provides two functions. First, it provides a stream of lead gas vapor which serves as an electron stripping cell. This allows first the prepulse beam and then the six main beams to become a highly charged, high current, self-pinched beam for transport through the final 5.64 m of cavity environment to the target at the center of the cavity. Secondly, it separates the pressure boundary inside the reactor cavity from the pressure boundary inside the final focus vacuum enclosure.

The lead vapor gas jet line enters the final focus vacuum enclosure on the outside of the bulk shielding wall and is routed parallel to the main beam path. At the focus point, the 4x10-cm rectangular line bends on a 25-cm bend radius and intercepts the beam path at the focus point. The gas jet line is positioned to fit snugly against the outer face of the blanket module. At the focus point, the gas jet line has a 2-cm diameter hole through and at 90° to the gas jet flow path. The gas jet line contains a center 2x2-cm line containing the lead vapor gas. The center line is surrounded by an outer cell containing helium gas at 400°C to prevent the lead vapor from solidifying on the inner walls of the center gas jet line.

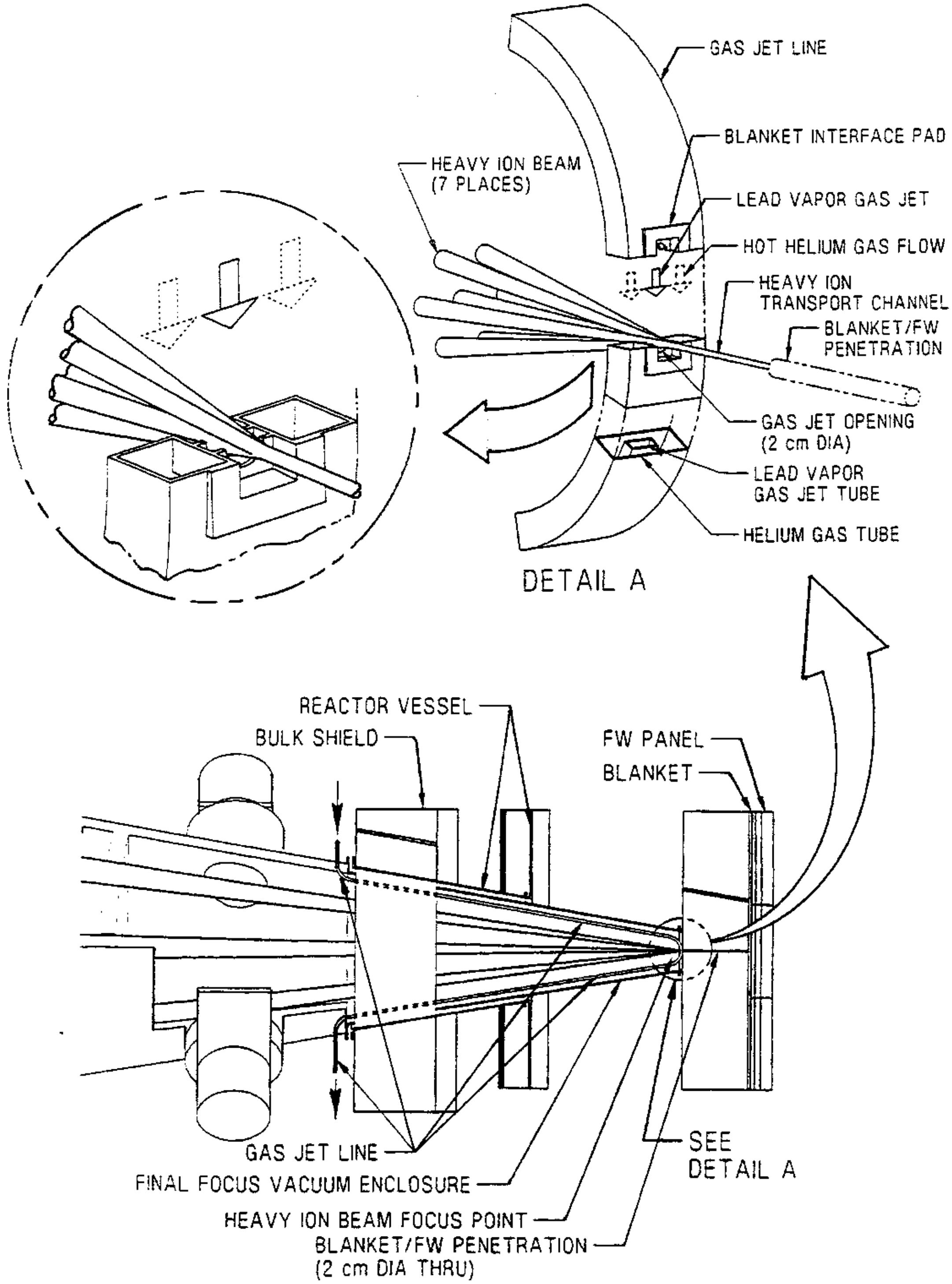

Figure 6.3.1-31. HI Beam Channel Transport Configuration

Prometheus-H Reactor Subsystems Overview - Since the type of cavity and heat transport designs for Prometheus-H are identical to the designs for Prometheus-L except for the overall, detail dimensions, the reactor subsystems for Prometheus-H will not be discussed in the same detail as for Prometheus-L. The discussions here and below will simply discuss the differences between the two designs. All aspects of the cavity and heat transport designs are presented in detail in Section 6.8 and 6.9, respectively.

An elevation view of the reactor systems is shown in Figure 6.3.1-32. This figure shows all the interfaces between the reactor cavity, vacuum pumping, and heat transport systems within the reactor and the steam generator buildings. The reactor building for Prometheus-H is smaller (59-m diameter and 66-m height) than the Prometheus-L building due to differences in number of beams and final focus subsystem differences between the two systems.

Prometheus-H FW/Blanket Subsystem - These systems are identical in design to the systems for the Prometheus-L design except for the dimensional differences. (See the subsystem description for Prometheus-L above for further definition.) The radial and veritical builds for Prometheus-H are shown in the elevation view of the central reactor cavity region in Figure 6.3.1-33. This figure is comparable to Figure 6.3.1-13 for Prometheus-L.

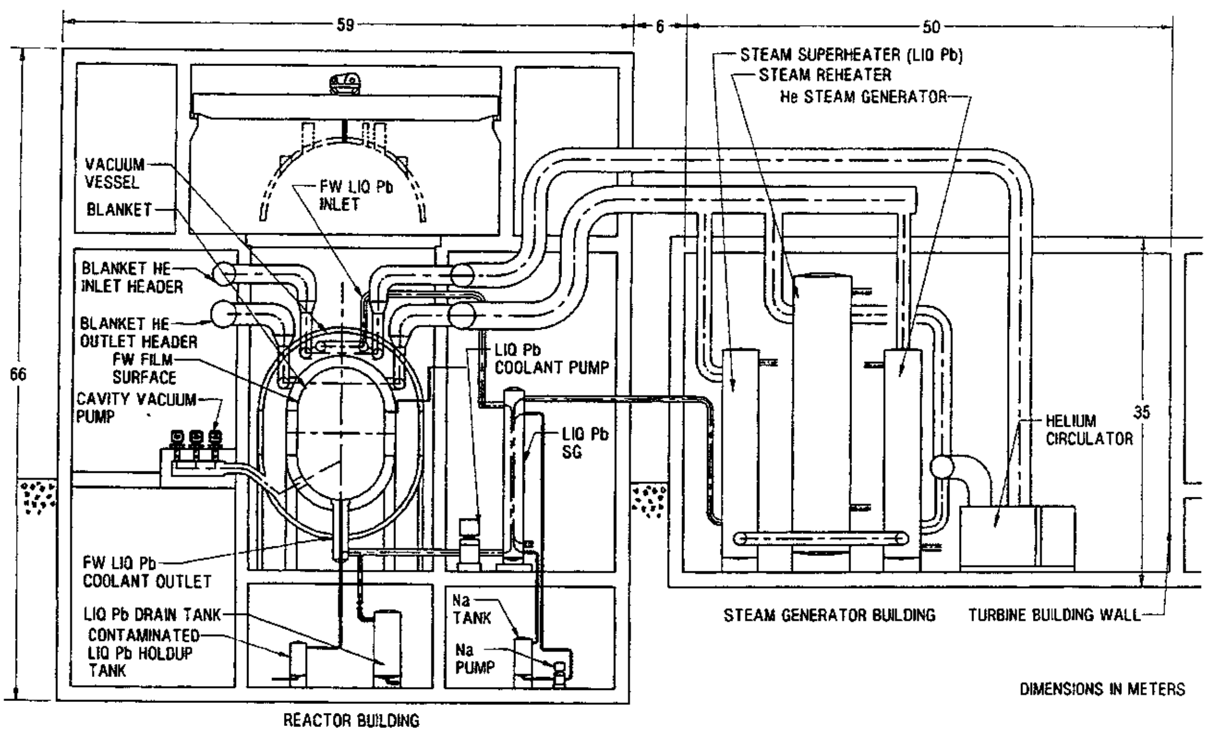

Figure 6.3.1-32. Elevation View – Reactor Systems/Heat Transport Interface

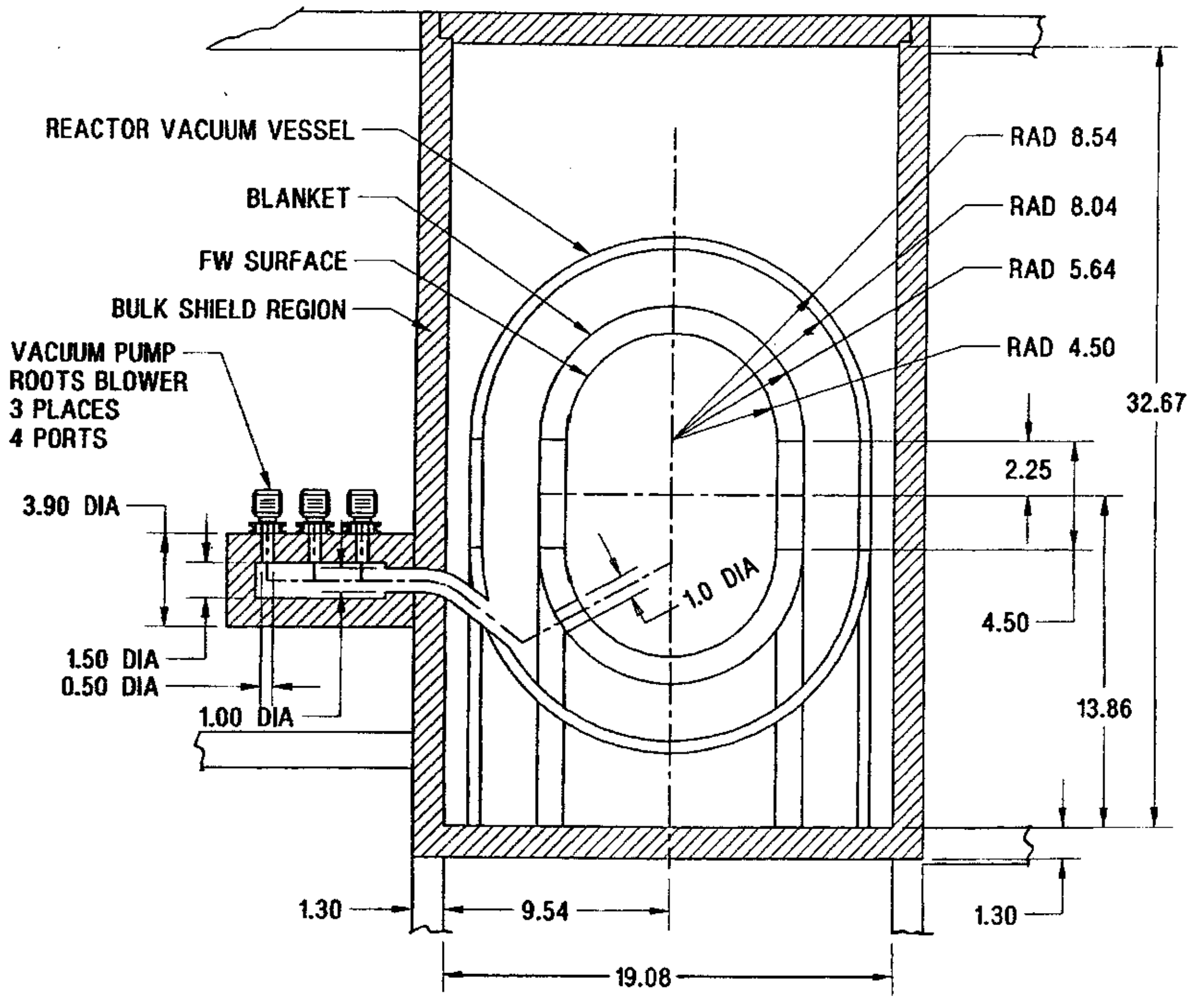

Figure 6.3.1-33. Prometheus-H Elevation of Central Reactor Cavity Region

Prometheus-H Vacuum Pumping Subsystem - The configuration of the vacuum pumping system for the reactor cavity is also defined by Figure 6.3.1-33. A system of three vacuum pumps on each of four ports pump the reactor cavity down to a base pressure of 10^{-1} torr, removing noncondensible gases of hydrogen, helium, deuterium, and tritium. The vacuum pumps are Roots blower pumping systems. The pumps are attached to a 1.5-m diameter plenum which is reduced to a 1.0-m diameter duct attached to the vacuum vessel at each port location. The inlet diameter for each pump is 0.5-m diameter. Four 1.0-m diameter holes through the blanket/FW subsystem complete the vacuum duct system to the inner cavity. For a technical description of the vacuum system operation, refer to Section 6.6

Prometheus-H Target Injection System Reactor Interface - The targets selected for the Prometheus-H concept are indirect drive targets. A pneumatic target injection system injects targets at the rate of 3.5 per second (302,400 per day). The injection system is described in more detail in Section 6.4. The target injection system is depicted by

Figure 6.3.1-34. The system feeds, loads, and pneumatically injects targets with an acceleration of 100 g's through rifled barrels 20-m long. Multiple barrels permit complete evacuation of each barrel prior to the next shot. A fast-acting gate valve on the muzzle end prevents the accelerating gas from entering the vacuum environment of the reactor cavity. A diagnostic chamber permits determination of the target position after launch down the ballistic guide tube. The guide tube provides a protected guide path through the bulk shield, vacuum vessel, blanket, and FW systems to the open cavity. This interface is shown in Figures 6.3.1-28 and 6.3.1-29.

Prometheus-H Vacuum Vessel - The reactor vessel design is the same as the design for Prometheus-L except for the dimensional differences due to the cavity radial and vertical build differences.

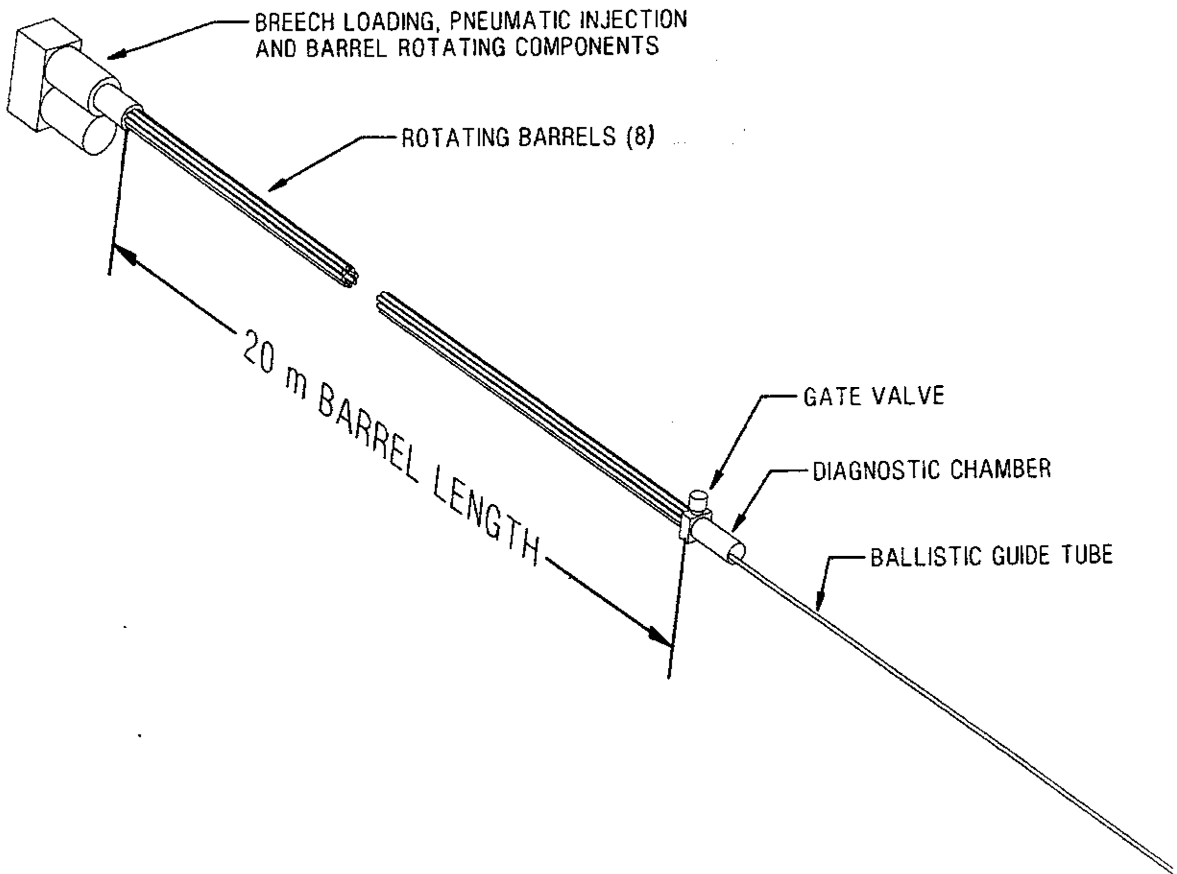

Figure 6.3.1-34. Prometheus-H Target Injection System

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