3.0 SOMBRERO LASER-DRIVEN POWER PLANT

3.1 OVERVIEW OF SOMBRERO POWER PLANT DESIGN

3.1.1 Introduction

SOMBRERO (solid moving breeder reactor) is a conceptual design study of a 1000 MWe KrF laser-driven IFE power reactor utilizing direct drive targets in a near symmetric illumination configuration. Among the important goals of the study was the achievement of a safe and environmentally attractive reactor of relatively simple design. Thus, the chamber is constructed of a low activation carbon/carbon composite, and the blanket consists of a moving bed of solid Li_2O particles flowing through the chamber by gravity. The particles are transported through an intermediate heat exchanger (IHX) and around the loop in a fluidized state by He gas at 0.2 MPa. This very low pressure will exist in the blanket and thus distinguishes this breeding blanket from all other solid breeder schemes.

Solid breeding materials have always been considered front runners for use in fusion reactors with research and development programs in place investigating them in the U.S., Japan, and Europe. They offer the potential for high temperature capability, low activation, safety, no corrosion issues, and a good data base. Many of the recent tokamak studies both near term[3.1] and long term[3.2] have proposed static solid breeder blankets. Static solid breeder blankets, however, have some problems. Typically, they have to be cooled with a high pressure He gas at 5-8 MPa and require a separate loop of low pressure He gas for T_2 extraction. Temperature control in these blankets is difficult, because it depends on the effective thermal conductivity of the packed bed which can change with time and with radiation fluence in unpredictable ways. The operating temperature windows for solid breeders is relatively narrow. This tends to exacerbate temperature control. Further, static beds suffer from problems of Li burn-up, phase changes, swelling and hot spots. In the present design, the breeding material particles can be continuously reprocessed to insure size uniformity, to remove fractured particles, and to maintain the proper Li atom density. This can be done in a small side stream as is the practice in many liquid cooled systems. A moving bed of solid breeder particles retains all the advantages of static beds while eliminating the problems. This scheme has been proposed for tokamaks, but has not been taken seriously because of the geometric limitation due to the encumbering magnet systems.[3.3] A moving bed of solid Li_2O particles was used in the SOLASE CO_2 laser-driven conceptual reactor design (1977) at a time when relevant properties of Li_2O were not well characterized.[3.4] The issues that have to be dealt with in moving beds are the large inventory of solid breeder material, the large volumetric transport around the loop, break-up of particles, erosion of wall materials, and relatively poor heat transfer at the first wall, which also results in a large intermediate heat exchanger.

3.1.2 General Description

The SOMBRERO reactor a 1000 MWe commercial power plant utilizing inertial fusion energy (IFE) and driven with a KrF laser. The 3.4 MJ laser energy is divided into 60 beams to provide near symmetric illumination of direct drive targets giving a gain of 118 at a rep-rate of 6.7 Hz. The chamber is made of a 4D weave carbon/carbon composite and has a cylindrical central region with conical ends. The chamber has a minimum inner radius of 6.5 m at the midplane and a blanket/reflector thickness of 1.0 m at the midplane. Solid Li_2O particles 300-500 μm in size flow through the blanket by gravity from top to bottom. This blanket configuration gives a breeding ratio of 1.25 and an energy multiplication of 1.08. The coolant channel at the first wall (FW) has a constant flow area from top to bottom. Thus, it is wider at the conical extremities than at the midplane. This is done to insure a constantly high particle velocity at the FW where the surface heat load is high. The rear of the blanket/reflector region is divided into zones with increasing fraction of carbon. In this way, a reflector is incorporated into the blanket design and will not require a separate coolant. The particle velocity in the rear zones is progressively lower due to the reduced nuclear heating.

The Li_2O particles enter the chamber at 550°C and exit at an equilibrated temperature of 740°C. From the chamber, the particles go to the IHX where they exchange heat with liquid lead. The liquid lead at 600°C then goes to a steam generator and a double reheat power cycle, where the steam conditions are 538°C and 24 MPa. By recovering the laser waste heat, the efficiency is boosted by 2% giving an overall power cycle conversion efficiency of 47%. After going through the IHX, the particles are transported in a fluidized bed mode, using He gas, back to the chamber to start a new cycle.

3.1.3 Overall Reactor Layout

Figure 3.1 shows the layout of the reactor building with the reactor chamber shown in the middle. The target is illuminated by 60 beams in a near symmetric illumination configuration. There are beam ports lying on 10 horizontal planes with 6 beam ports in each plane forming a cone with the vertex at the chamber center. Such a configuration avoids the necessity of having beams at the north and south poles making the design simpler. The figure shows the upper manifold that feeds the solid breeder material through individual supply tubes to 12 wedge-shaped blanket modules. After going through the blanket, the breeding material exits from each module through individual tubes to a return manifold located below the chamber. From there the breeding material is transported in a fluidized bed mode to the IHX.

The chamber is surrounded by a 1.7 m thick shield wall at a radius of 10 m. This wall has several functions: it shields the area outside the wall such that it can have hands-on maintenance capability with 24 hours after shutdown in areas surrounded with an additional 1.0 m thick wall

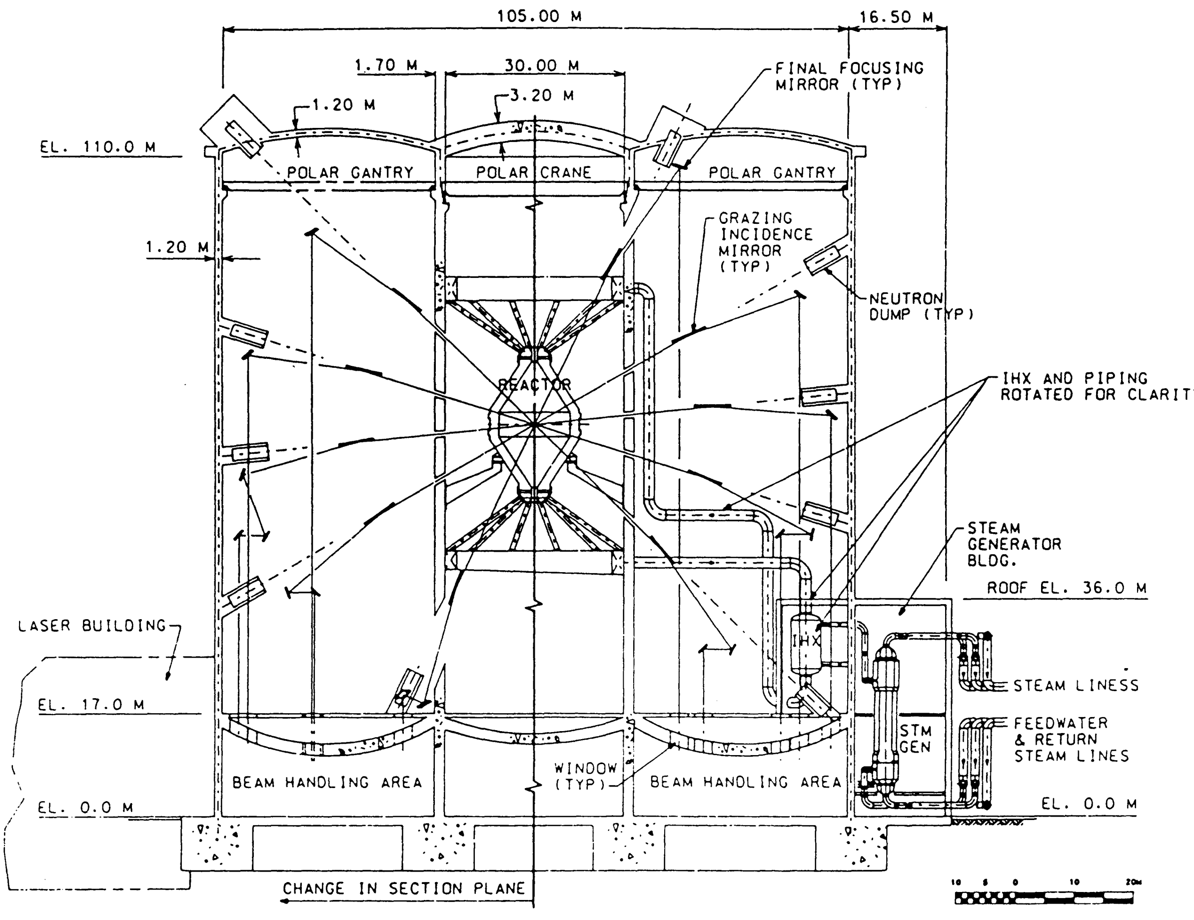

Fig. 3.1. Overall cross section of SOMBRERO reactor building.

such as the IHX area; it is the primary support for the chamber, and finally, it provides a central support column for the reactor building roof.

The laser beams are routed from the laser building to the reactor building through the lower level as shown in Fig. 3.1 and then reflected vertically through windows in the floor of the reactor building. These windows are the primary barriers against tritium diffusion into the laser building. Secondary windows located between the laser building and the lower level of the reactor building act as the back-up barriers. After going through the windows in the floor of the reactor building, the laser beams are incident onto the final focusing (FF) mirrors which focus the beam and direct them onto grazing incidence metal (GIM) mirrors which in turn deflect them into the chamber through ports in the shield wall and the chamber wall. The GIM mirrors are at a radius of 30 m and are subjected to primary neutrons coming through the beam ports. The lifetime of the GIM mirrors depends on the degree of damage recovery by annealing. The primary neutrons passing through the thin metal of the GIM mirrors are directed into neutron traps located on the wall of the reactor building. These high aspect ratio neutron taps act as black holes for neutrons allowing only a very small fraction of low energy neutron to backscatter. The FF mirrors which are at a radius of 50 m are out of line-of-sight of primary neutrons. These dielectric-coated mirrors are very susceptible to neutron damage and cannot be annealed. According to present thinking, the limiting fluence to dielectric coatings is $\sim 10^{18}$ n/cm^2. The estimated flux to these mirrors is 8.6×10^8 n/cm^2, which gives an approximate lifetime of 37 full-power-years. This is a significant development since up until now the FF optics has always been the Achilles heel in laser driven IFE reactors.

The reactor building which houses the chamber and beam optics is 110 m in diameter with an overall height of 115 m. Since there are no beam tubes, the building shares the same atmosphere as the chamber, namely ~0.5 torr of Xe gas. Roots type of pumps will be used to evacuate the building, and fresh Xe gas will be injected into the chamber continuously. Unburned tritium and target debris will be pumped through the vacuum system, and a side stream will be used for tritium recovery.

3.1.4 Tritium Considerations and Safety Assessment

Tritium extraction from the breeding material is accomplished by treating the He carrier gas. The predominant tritium species in the He carrier gas is maintained as HTO by the addition of H_2O such that the O_2 partial pressure of 10^{-5} Pa is achieved. Under these conditions the T_2 partial pressure will only be 2×10^{-6} Pa, and the T_2 permeation at the steam generator is manageable. Most of the carrier gas is disengaged from the breeder material, and only 10% of it goes through the IHX. Using this fact and taking credit for a tritium barrier of a factor of 100 due to the oxide layer on the steam generator tubes reduces the steady state T_2 permeation into the power cycle to only ~15 Ci/day. The amount of H_2O in the carrier gas has to be controlled carefully because of the danger of forming LiOH(T), which has a melting point of 417°C and could give problems with agglomeration. The required H_2O partial pressure of 64 Pa, however, is far below that needed to form LiOH(T), which is 3150 Pa. Tritiated water in the form of T_2O and HTO is recovered from the He carrier gas by adsorption on molecular sieves. The solubility of T_2 in Li_2O at 650°C is ~0.081 wppm and thus for the total 2000 tonnes of Li_2O in the reactor system, the T_2 inventory is ~162 g.

Activation and safety analysis has been performed for the chamber, shield, and breeder material. It is found that the total activities generated in the carbon/carbon composite of the chamber and in the steel-reinforced concrete shield are 0.054 and 10.12 MCi, respectively. Intermediate heat exchangers are located in the space between the reactor shield and the reactor building wall within circular enclosures which have a 1.0 m thick wall. Within these enclosures the biological dose rate drops down to 1.6 mrem/h 24 hours after shutdown making it possible to do hand-on maintenance on the IHX and other components. Radwaste classification has shown that the chamber and the shield will easily qualify as Class A low level waste according to the waste disposal ratings defined by 10CFR61 guidelines. The Li_2O breeding material, however, only qualifies as Class C low level waste. The maximum public dose from atmospheric effluents is 0.73 mrem/y, occurring at the reactor site boundary, which is 1 km from the reactor building. The results of a loss of coolant accident (LOCA) have also been assessed. If the back of the FW will no longer be cooled as a result of LOCA, some of the FW carbon will be evaporated. It has been estimated that a loss of ~0.44% of the FW due to evaporation will generate a high enough C atom density in the chamber as to prevent the laser beams from reaching the target, in this way achieving a self regulating shutdown. The afterheat in the shield will only raise its temperature by a few degrees over a prolonged shutdown period; therefore, there is no danger of it releasing activation products. During a totally improbable accident which will cause the release of all 162 g tritium inventory in the Li_2O, the estimated off-site whole body dose to the surroundings is 2.11 rem. This low off-site dose eliminates the need for N-stamp components for the reactor thus reducing the cost and making it easier to license. Table 3.1 gives the relevant SOMBRERO parameters.

Table 3.1. SOMBRERO Plant Parameters

Driver	KrF Laser
Driver Energy (MJ)	3.4
Driver Efficiency (%)	7.5
Illumination	Near Symmetric
Type of Target	Direct Drive
Target Gain	118
Target Yield (MJ)	400
Rep-Rate (Hz)	6.7
Overall Energy Multiplication	1.08
Chamber Construction	C/C Composite
Breeding Material	Li_2O Particles
Breeding Ratio	1.25
Fusion Power (MW)	2677
Thermal Power (MW)	2891
Power Cycle Efficiency (%)	47
Gross Electric Power (MWe)	1359
Driver Power (MWe)	304
Auxiliary Power (MWe)	55
Net Electric Power (MWe)	1000