LIBRA-LiTE: A 1000 MWe Reactor

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Introduction

The use of light ions to produce power from thermonuclear reactions was first proposed by Clauser in 1975 [1]. Since that time, considerable progress has been made in the production of intense proton beams and more recently, in the production of Li beams [2]. The advances in pulsed power technology has been truly impressive and Helia class drivers for commercial power plants are a relatively small extension of present day technology [2,3]. When it became apparent that light ions represented a viable option to generating commercial electricity from fusion, a conceptual design of a small (≈ 300 MW_e) commercial reactor was initiated in 1982. This effort involved scientists from Fusion power Associates, the Fusion Technology Institute at the University of Wisconsin, the Kernforschungszentrum Karlsruhe, Germany, and Sandia National Laboratories [4]. It culminated in the LIBRA (Light Ion Beam ReActor) report [5] published in 1989. Subsequent to that study, which was based on channel transport of the ion beams, it was obvious that another major variation to consider in the light ion fusion approach was the ballistic transport of ions to the target. Therefore, in 1990 the LIBRA-LiTE design, using Li coolant, was initiated to study the ballistic transport option. The purpose of this paper is to compare the main features of LIBRA with LIBRA-LiTE and to highlight where future research should be concentrated to demonstrate the viability of the ballistic transport approach. More detailed physics and technology papers will appear in the future (e.g., see [6]).

Key Features of the LIBRA and LIBRA-LiTE Designs

The main parameters of the two designs are listed in Table 1. Aside from the change in power levels, which was made for economic not physics reasons, the main difference between the two designs is the use of ballistic focussing and the use of Li as the breeder/coolant in LIBRA-LiTE design. This switch from PbLi alloys was necessary to avoid the high scattering cross section of the Pb atoms in the chamber which resulted in high loss rate from the ballistically focussed Li particle beams. Once Li was chosen, then the INPORT units, which protect the first wall from the shock wave and neutron damage [7], could not be made of SiC because of compatibility problems. This forced a change in the INPORT material from SiC to stainless steel. and also limited the maximum coolant temperature to < 600°C. The change in the secondary loop coolant from He to an organic fluid was done to increase the overall efficiency and had nothing to do with the ballistic transport mechanism.

Table 1
Key Parameters of Recent Light Ion Beam Fusion Power Plant Designs

Parameter	**LIBRA**	**LIBRA-LiTE**
Focus Mechanism	Channel Transport	Ballistic
Net Electrical Power, MW_e	331	1301
Li Ion Energy on Target, MJ	4	6
Target Yield, MJ/ Hz Rep Rate	320/3	600/5
Coolant/Breeder	PbLi	Li
INPORT Material	SiC	Stainless Steel
Secondary Heat Transfer Fluid	He	Organic

Schematic of LIBRA-LiTE Reactor

Figure 1 displays an isometric view of the LIBRA-LiTE drivers and reactor chamber. While the overall height (80 m) and diameter (90 m) of the reactor assembly in Figure 1 is indeed large, one should remember that this facility should be compared to the laser/cavity or heavy ion accelerator/cavity configurations of other ICF designs. The volume of a commercial KrF laser building alone, can be 4 times that of the entire LIBRA-LITE driver/cavity assembly [8]. A comparison to a heavy ion beam driver would require a completely different scale as a 10 GeV accelerator would be ≈1-2 km long and would presumably be folded to reduce the maximum dimension.

The shape and size of the reactor cavity can be better appreciated in Figure 2 where the 30 pulsed power driver assemblies have been removed. The "mushroom" shape of the reactor cavity is necessary to allow a dry wall upper roof configuration while retaining the INPORT unit protection [7] at the waist of the reactor. There are 12 vacuum lines connecting the reactor cavity to the the expansion chamber. The latter system is required in order to lower the residual cavity pressure after each shot to less than 1 torr on a 5 Hz rep rate.

Figure 3 is a cross sectional view of the target chamber which shows the placement of the final focussing lens, the INPORT units, the position of the diodes, the perforated bottom plate for draining the liquid Li pool, and the shape of the extended chamber roof. The final focussing lens are single turn, liquid Li magnets that generate 2T to bend the 30 MeV Li ions onto the target 1.5 m away.

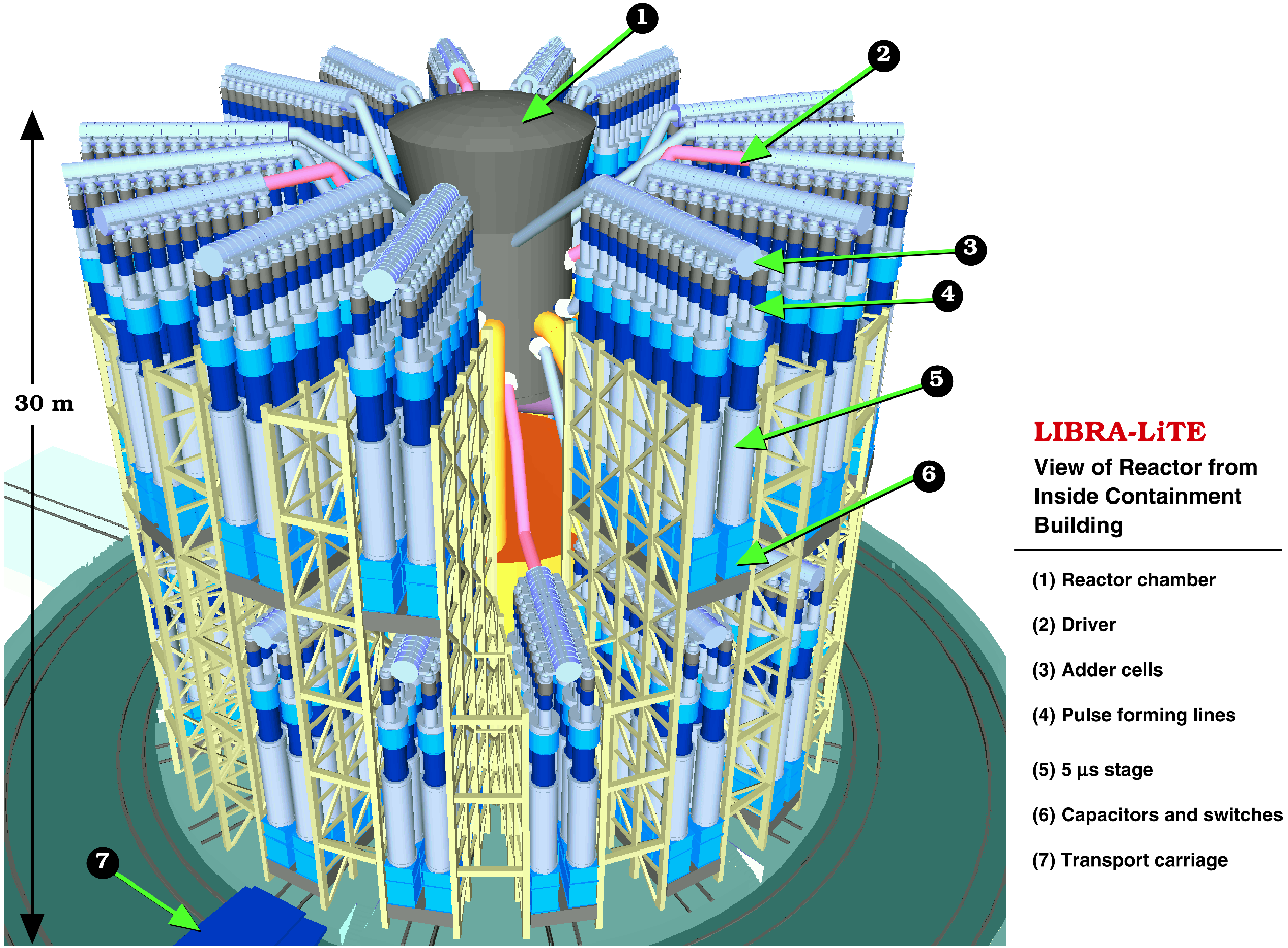

Figure 1. A view of the LIBRA-LiTE reactor from inside the containment building.

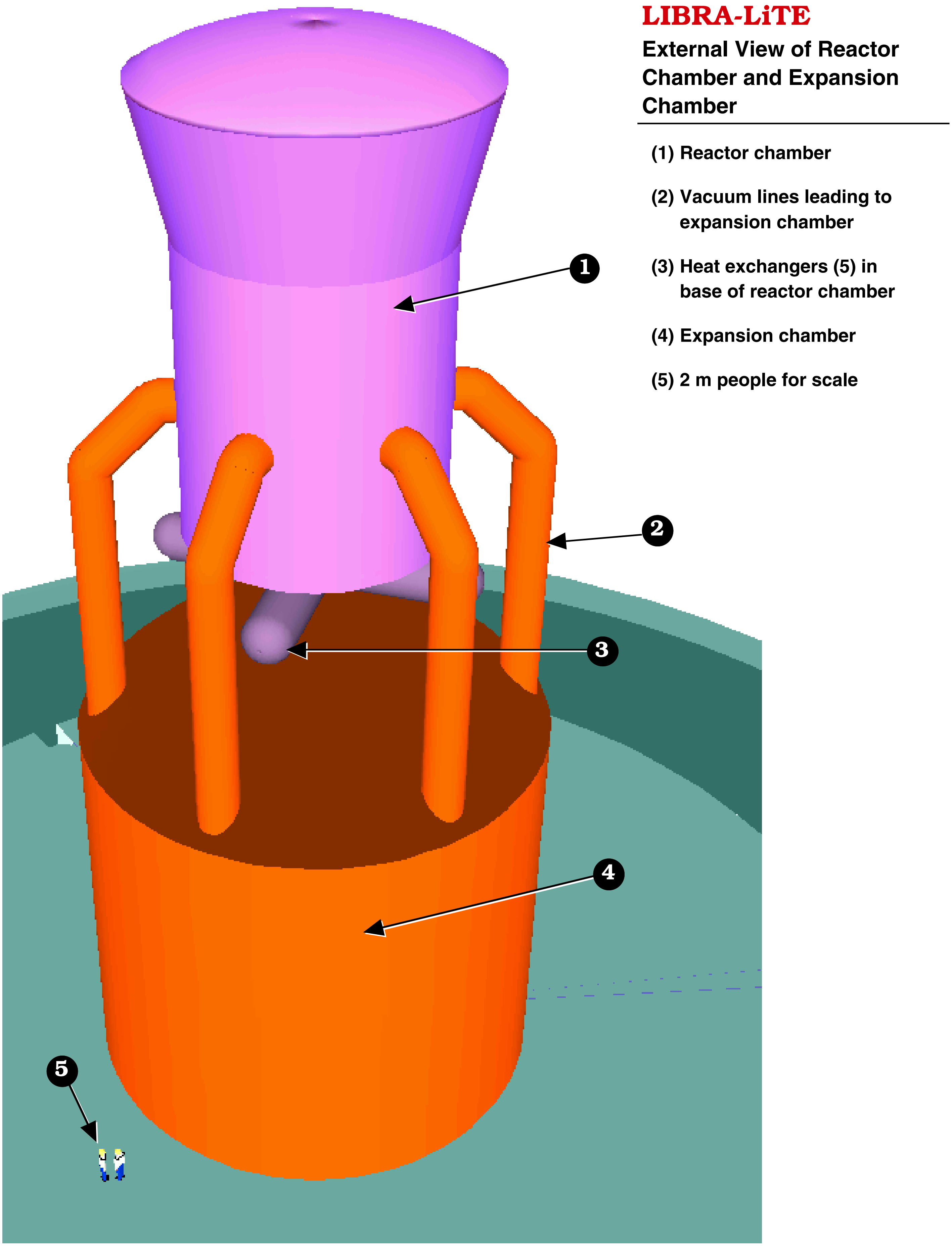

Figure 2. External view of reactor chamber and the expansion chamber.

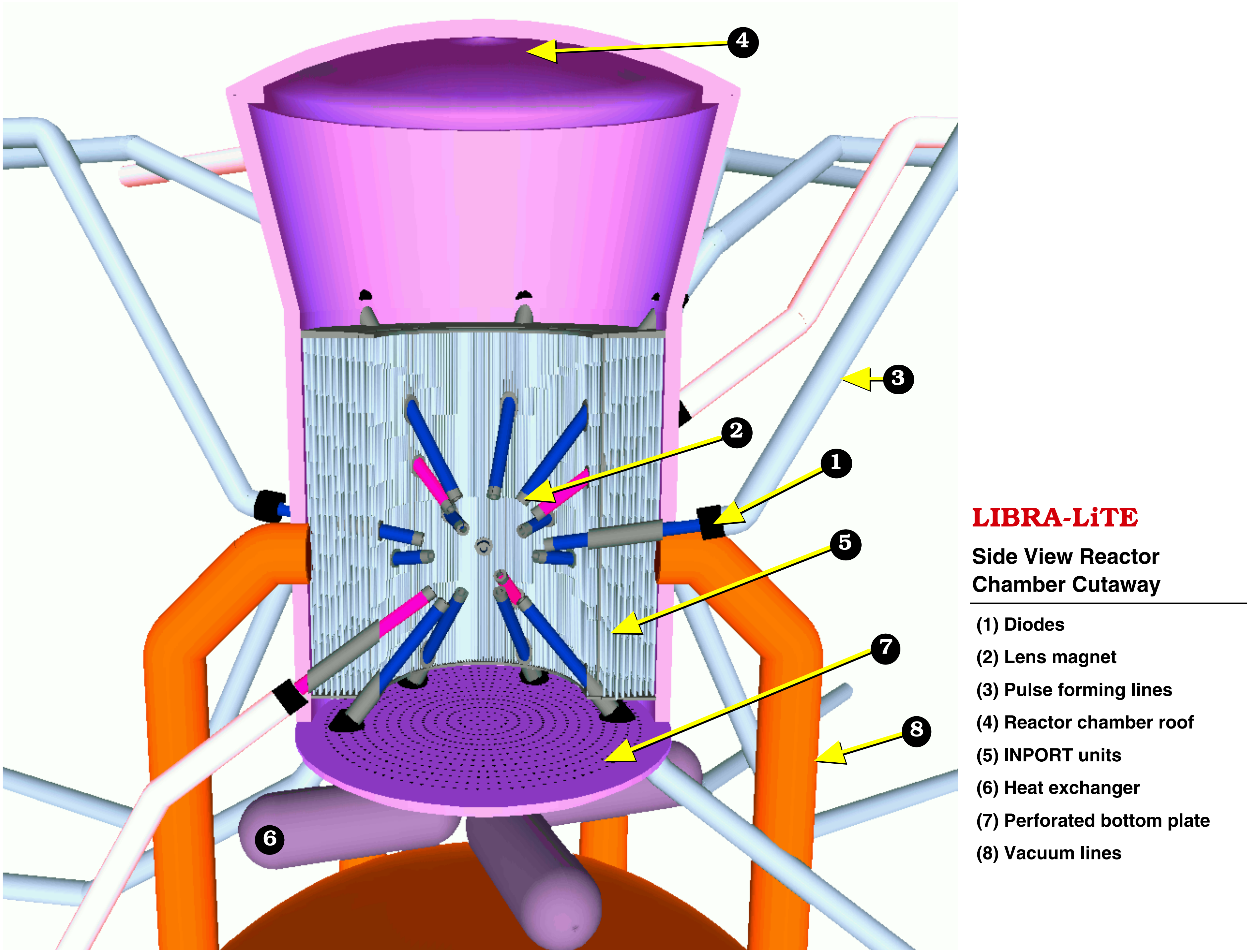

Figure 3. A cross cut view of the LIBRA-LiTE reactor chamber

Figure 4 is the view that one would get if the reactor chamber roof were removed. The cross section of the inner(smaller) and outer INPORT tube banks is shown along with a view of the 30 beam tubes (6 prepulse and 24 main driver beams)as they protrude through the INPORT units. The flow of Li is perpendicular to the plane of the figure and the hot Li collects in the bottom pool before draining to the heat exchangers below the reactor chamber (see Figure 2). The beam tube/lens magnet assembly is designed for rapid replacement on the order of once per calender year.

A set of key parameters for the LIBRA-LiTE design are given in Table 2. The target gain of 100 at 6 MJ gives a 600 MJ yield per shot. The use of a 5 Hz rep rate (determined by the vapor clearing rate) then yields a 3000 MW fusion power level. When the neutron energy multiplication (M= 1.22) and other sources of energy gain and loss are considered, the total thermal power level is 3380 MW. This thermal energy is converted through an organic coolant intermediate loop at 44% gross efficiency and when coupled with a recirculating power fraction of 12.5% (net driver efficiency = 22.6%), a net electrical power of 1301 MW_e is produced.

Perhaps one of the biggest challenges of the LIBRA-LiTE design is the close proximity of the final focussing lens to the source of neutrons. The required position of the lens means that it is subjected to over 13 MW/m^2 of neutron wall loading. Assuming that the maximum lifetime of the HT-9 lens case is ≈200 dpa, then the useful life of the lens is limited to ≈0.75 FPY (1 calender year at 75% capacity factor). Similarly, the closest small INPORT units (see figure 4) are subjected to a 4.5 MW/m^2 neutron flux which makes their useful lifetime ≈ 2.25 FPY's (3 CY's). It is felt that the ease with which both of these units can be replaced, will mitigate the problems associated with such high damage rates.

Table 2
Selected Parameters of the LIBRA-LiTE Reactor

Parameter	Value
Total Thermal Power	3380 MW
Li Coolant Outlet	500 °C
Gross Thermal Efficiency	44 %
Recirculating Power	12.5 %
Net Electrical Power	1301 MW_e
n Loading, Final Lens	13.6 MW/m^2
Max. n Loading, INPORT units	4.5 MW/m^2
Tritium Breeding Ratio	1.4
Magnet Lifetime	0.75 FPY
INPORT Lifetime	2.25 FPY
Vessel Lifetime	30 FPY

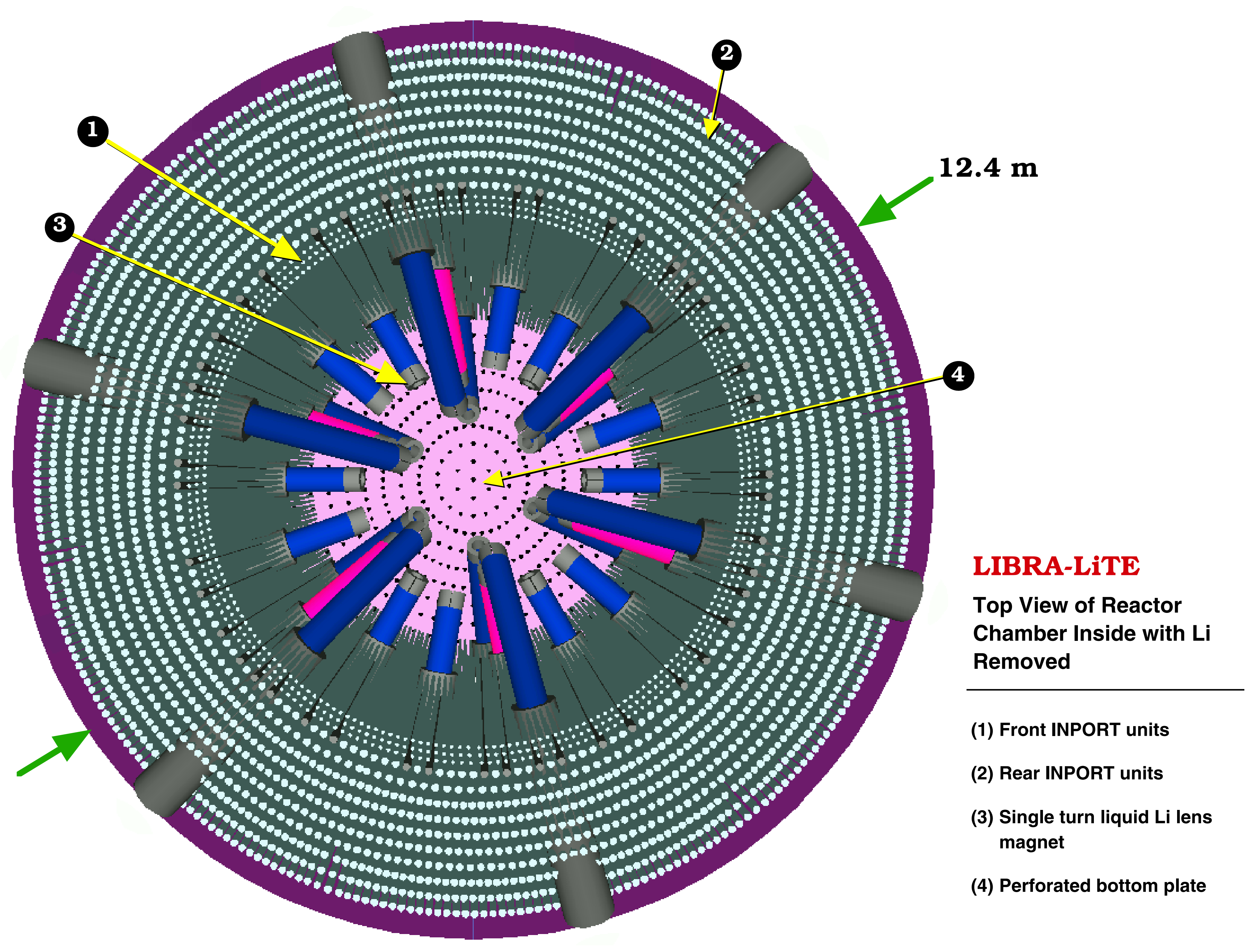

Figure 4. Top view of react chamber with roof and Li coolant removed.

Conclusions

The results from this study indicate that light ions can be a competitive factor in the race to commercial fusion power. The relatively simple and near term driver technology is particularly attractive compared to higher cost laser and heavy ion schemes. The cavity design and engineering operations can be tailored such that Utilities could envision a reliable and maintainable power plant. The major problem to be faced now is the method of beam propagation to the target. The LIBRA-LiTE design reveals that ballistic transport may be more attractive from a physics standpoint, but the severe neutron environment presents a challenge to materials scientists. Continued experimentation and research is needed to develop a truly attractive ICF power plant.

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