LIBRA, A Light Ion Driven Fusion Power Plant

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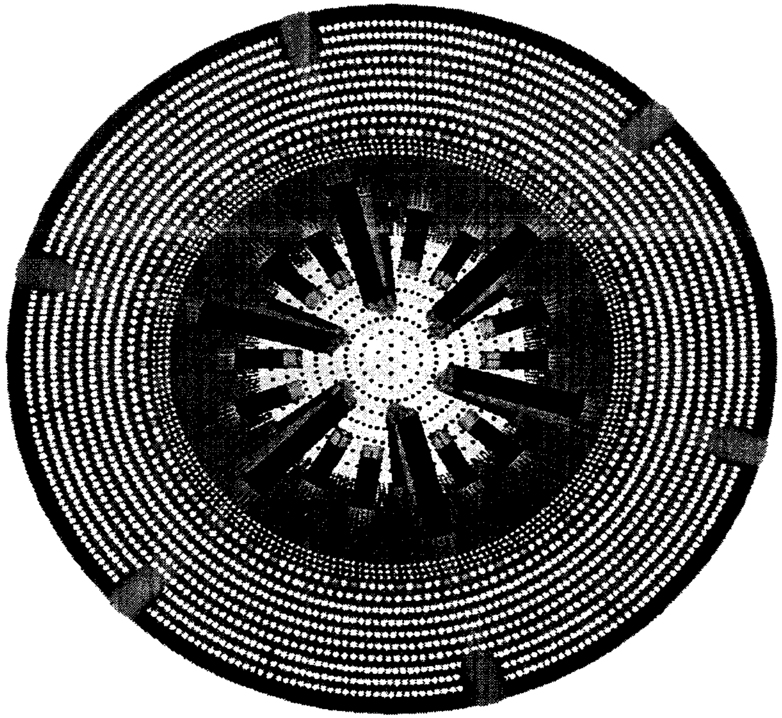

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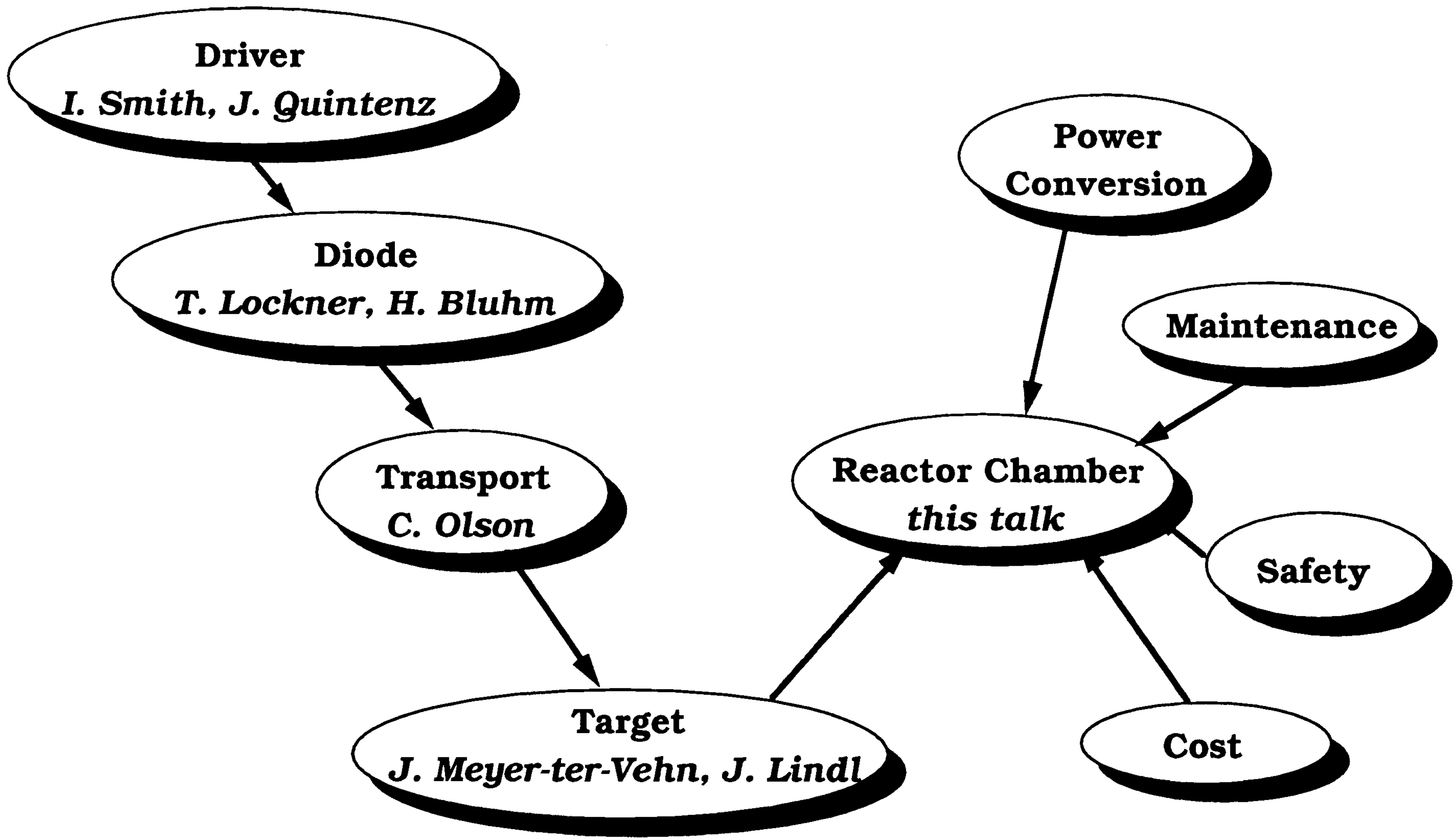
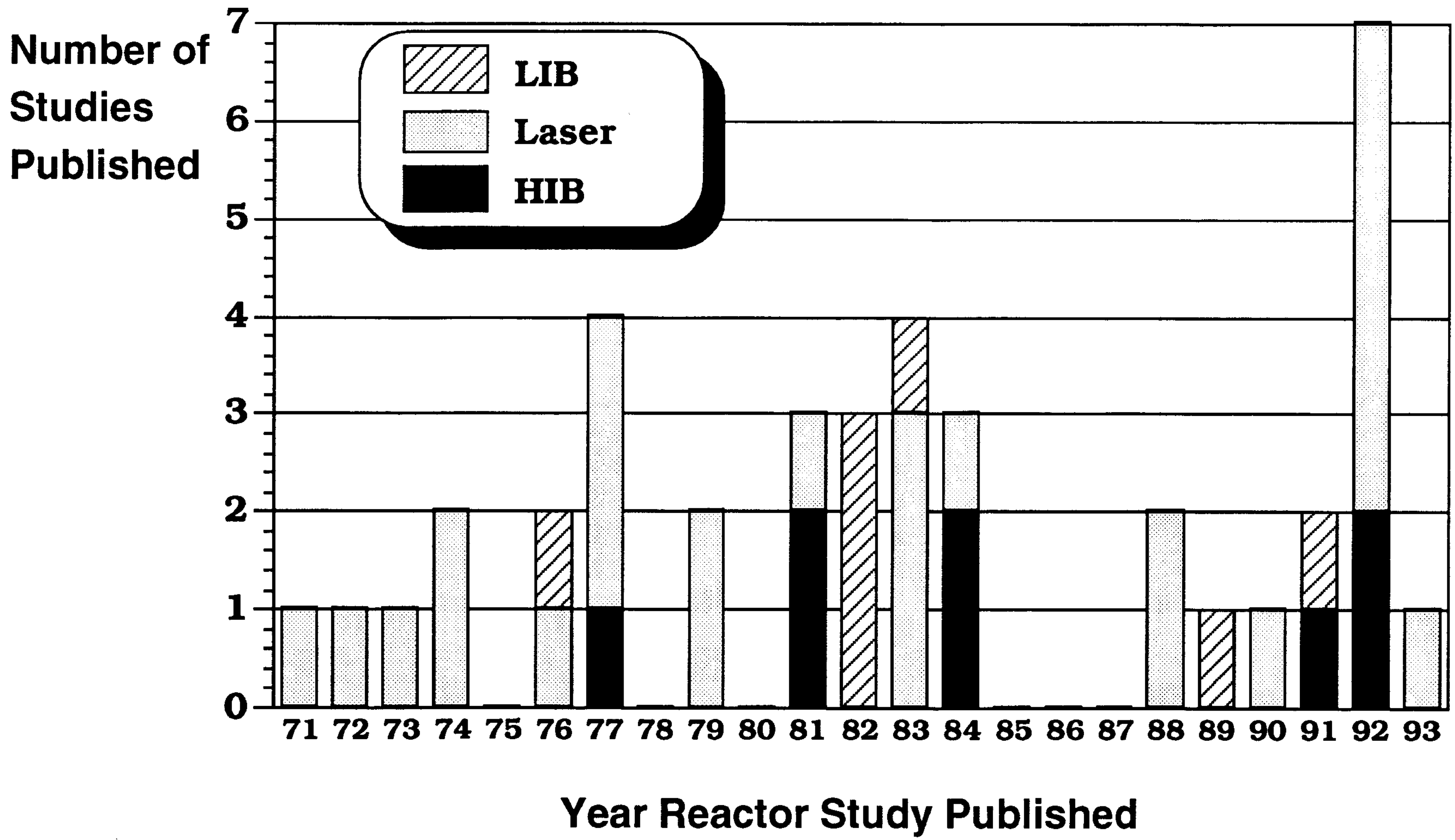
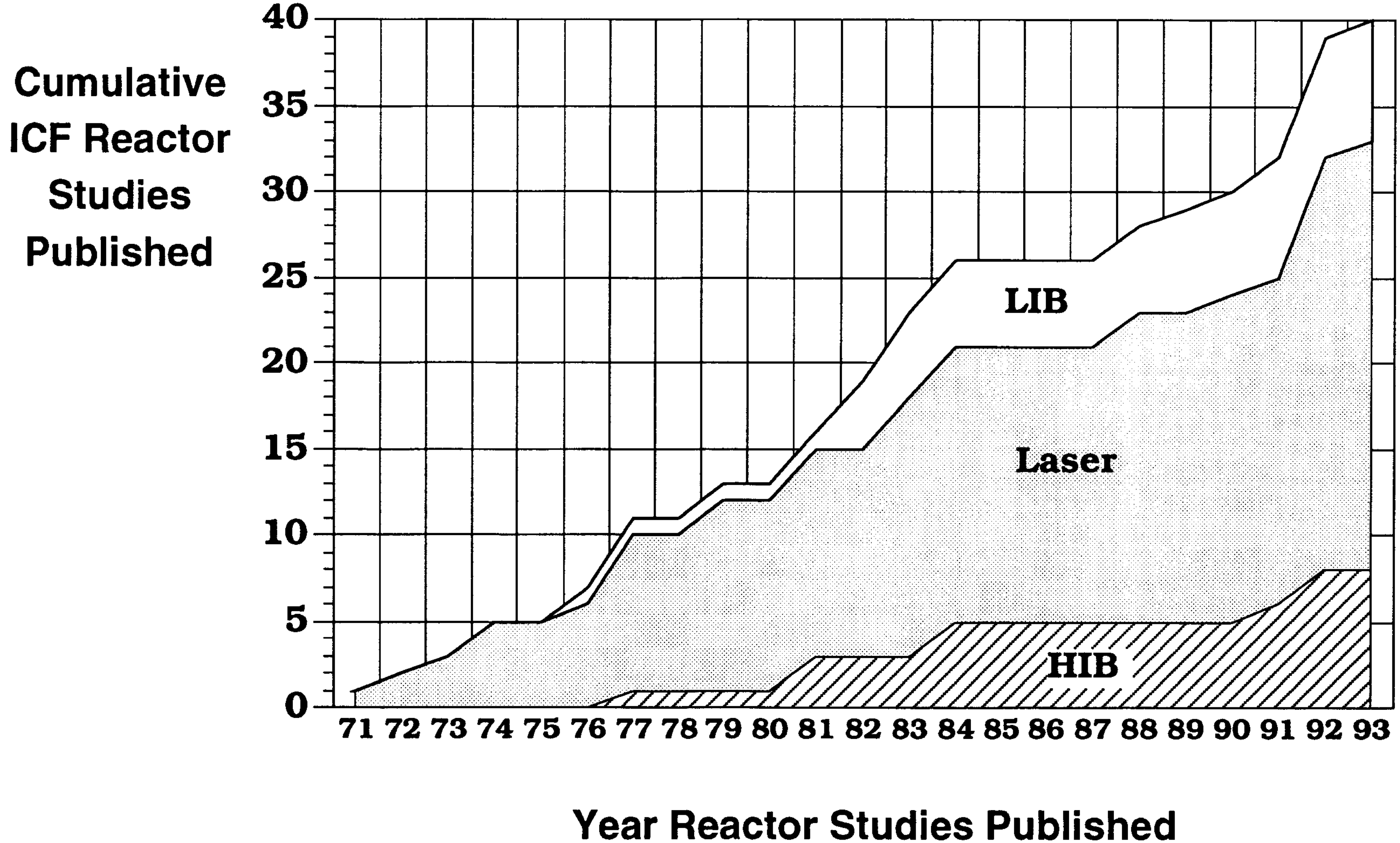
Context of Present Light Ion Fusion Power Plant Presentation



ICF Fusion Reactor Designs Have Begun Again in the Early 90's After a Prolonged Period of Inactivity in the Late 80's



The ICF Reactor Design Efforts Have Been Dominated by the Laser Approach Over the Past 20 Years



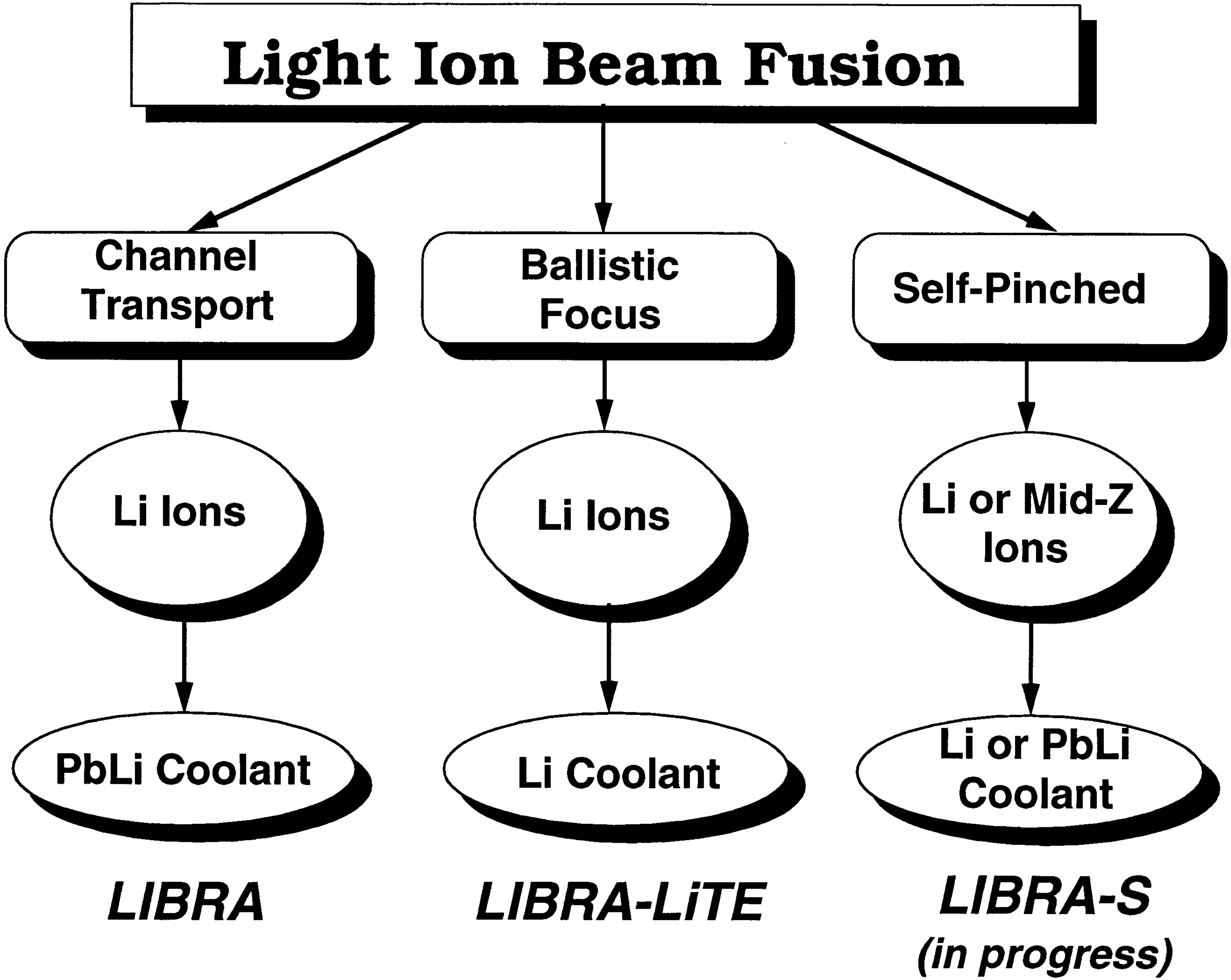
Historical Trends in Light Ion Beam Fusion Power Reactor Designs

	70's	80's	90's
Driver/Target Related	• Electron Beams • No Detail on Driver • High Rep Rate (35 Hz) • Low Yields (85 MJ)	• Hydrogen Isotope Beams (p,d) @ 6-8 MV • Lower Rep Rate (3-6 Hz) • Higher Yields (≈300-800 MJ) • Channel Transport	• Li & Welterweight Ion Beams • Helia Technology (30 MV) • Ballistic & Self-Pinched Transport • More Realistic LIB Targets
Reactor Chamber Related	• Li "Rain" FW Protection • "Moving Belt" FW	• Porous Tubes for First Wall Protection • High Pressure Gas Protection of FW • Cavity Size 4-5 m Radius	• Final Focusing Magnets Used in Chamber • Investigate Pb-Li Breeding Alloys • Smaller Cavity Size (3-3.5 m radius)

Goals of the LIBRA Study

- Develop a self-consistent conceptual design of a light ion beam fusion commercial power reactor.

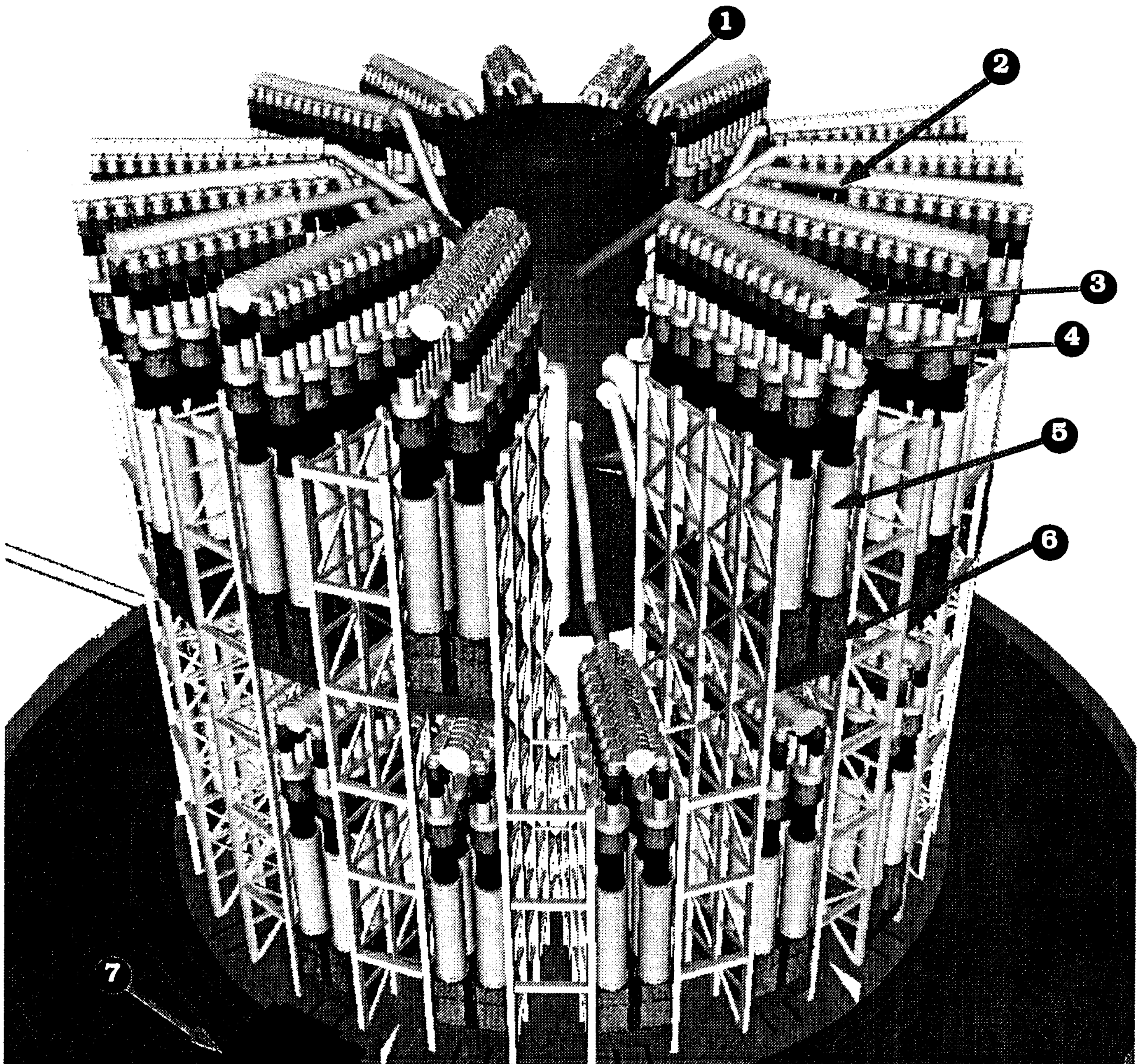
- Evaluate the potential of light ion fusion as the basis for economically attractive small power plants.


Light Ion Beam Fusion
Channel Transport
Ballistic Focus
Self-Pinched
Li Ions
Li Ions
Li or Mid-Z Ions
PbLi Coolant
Li Coolant
Li or PbLi Coolant
LIBRA
LIBRA-LiTE
LIBRA-S
(in progress)

Key Parameters for Recent Light Ion Beam DT Fusion Power Reactor Designs*

Parameter	LIBRA	LIBRA-LiTE	LIBRA-S
Focus Mechanism	Channel Transport	Ballistic	Self-Pinched
Net Electric Power, MWe	331	979	1078
Li Ion Beam Energy to Target, MJ	4	6	6
Target Yield, MJ/Rep Rate, Hz	320/3	600/3.9	600/3.9
Coolant/Breeder	PbLi	Li	Li/PbLi?
Inport Material	SiC	Steel	Steel
Secondary Heat Transfer Fluid	He	Organic	Organic

*Use 25–35 MeV Li ions from Helia type driver



LIBRA-LiTE

View of Reactor from Inside Containment Building

(1) Reactor chamber

(2) Driver

(3) Adder cells

(4) Pulse forming lines

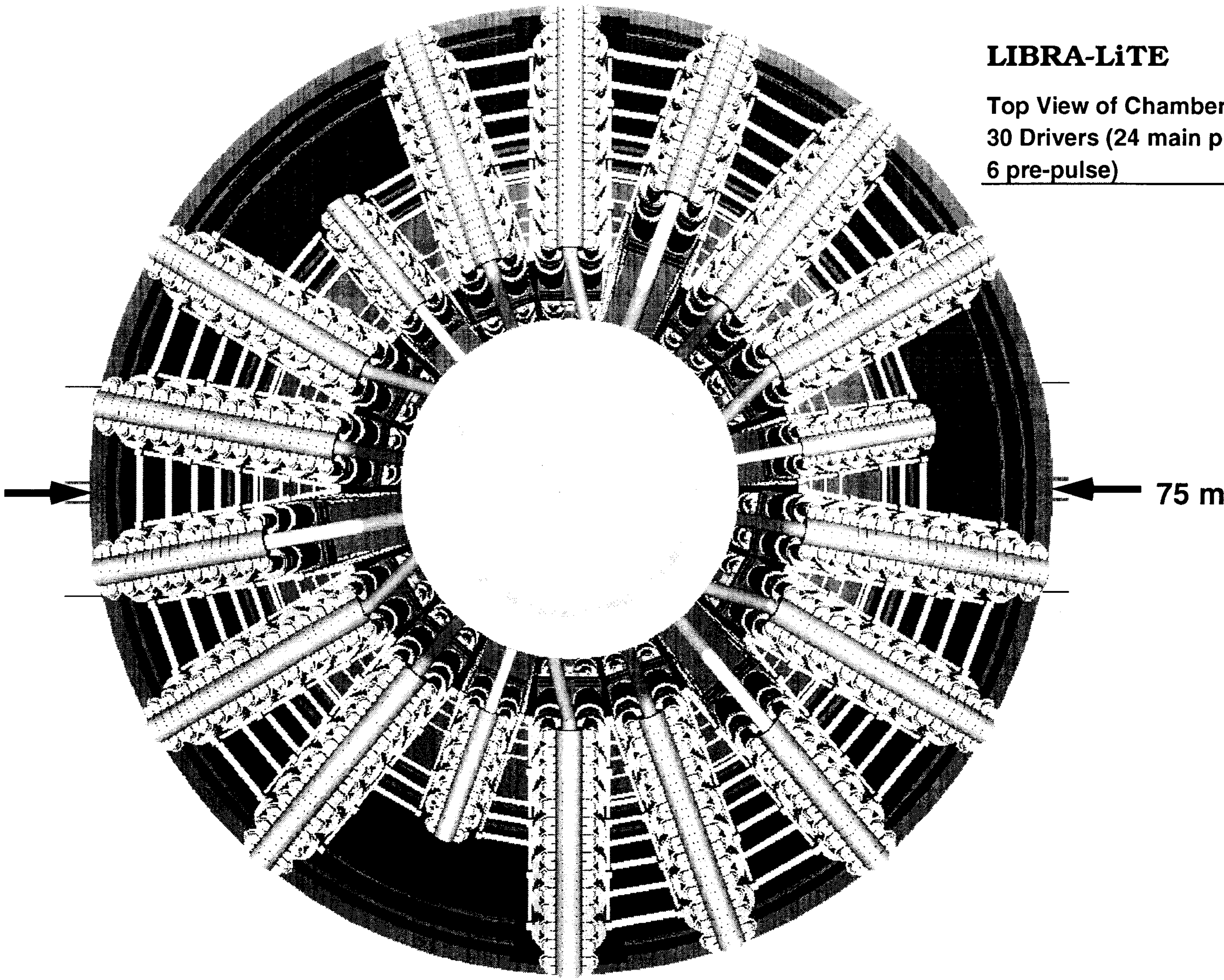
(5) 5 μs stage

(6) Capacitors and switches

(7) Transport carriage

LIBRA-LiTE

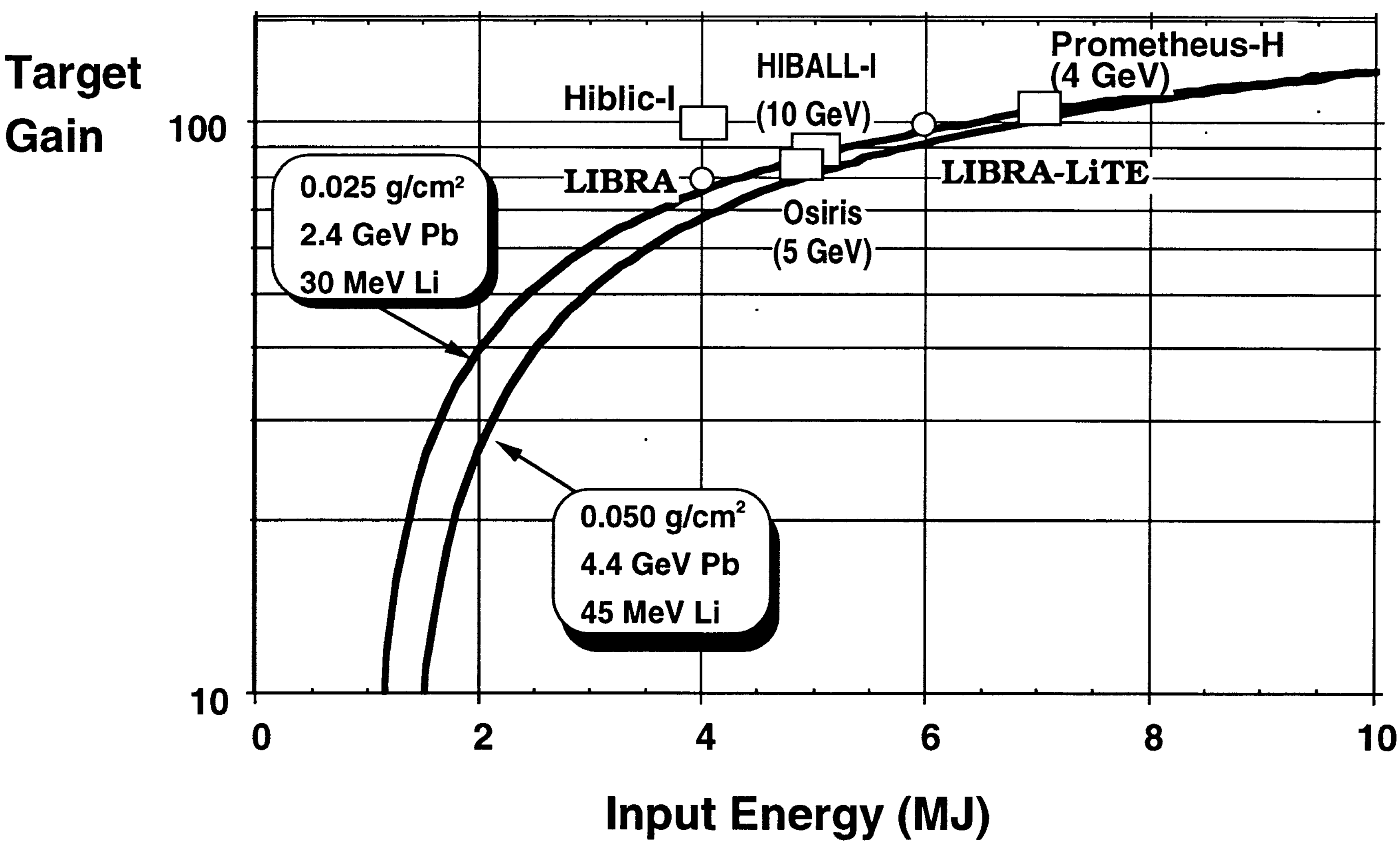
Top View of Chamber and 30 Drivers (24 main pulse, 6 pre-pulse)

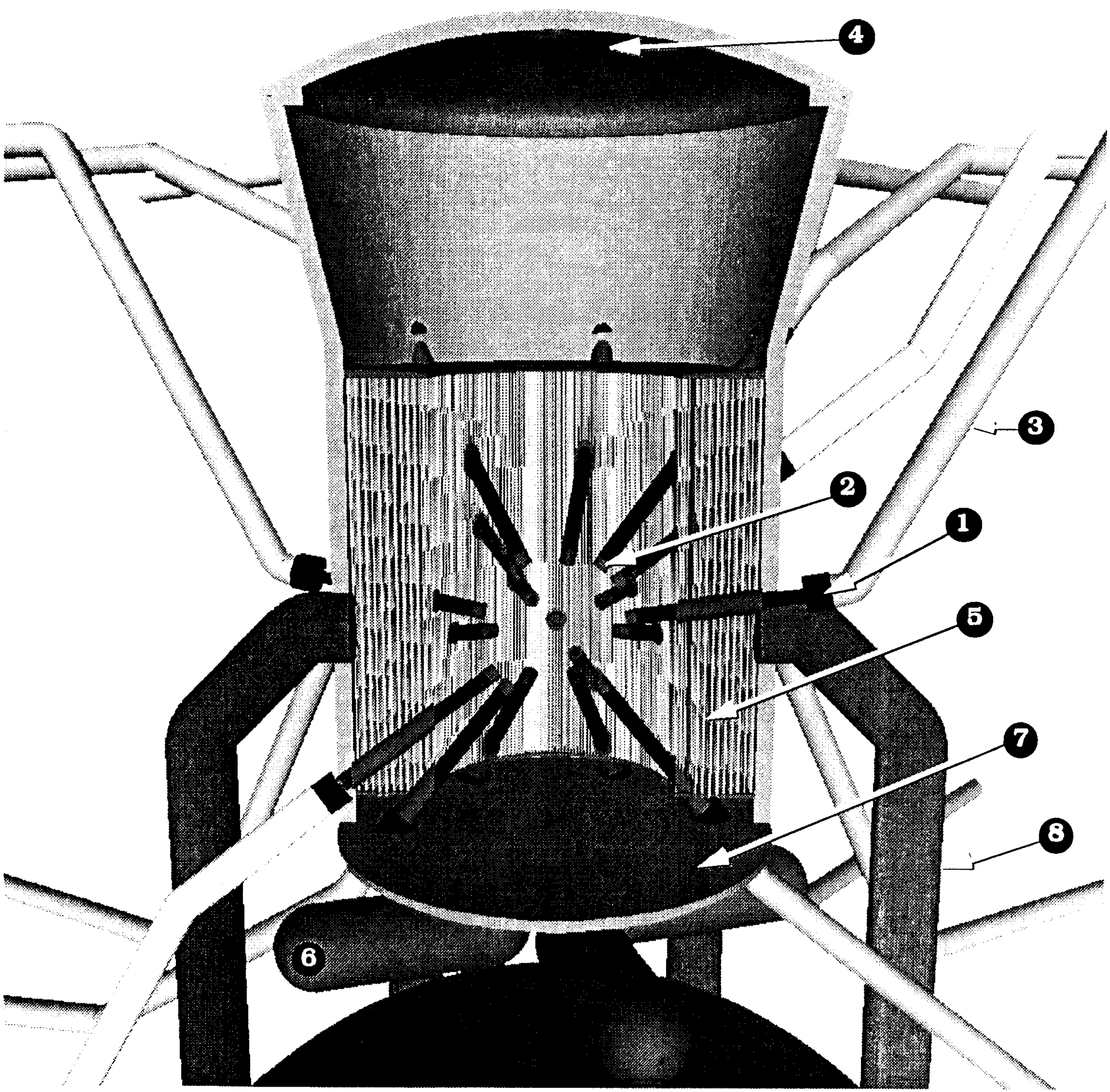


The Use of Helia Driver Technology and Li Ion Applied B Diodes Allow Efficient Energy Transport to the Target

	Prime Energy Storage (MJ)	η_D	Energy to Diode (MJ)	η_{DD}	Energy to Beam (MJ)	η_T	Energy on Target (MJ)	Net Driver Efficiency	Transport
LIBRA (18 beams)	18	47%	8.3	80%	6.7	60%	4	23.5%	*channel transport*
LIBRA-LiTE (30 beams)	30	38%	11.4	90%	10	60%	6	18.0%	*ballistic transport*
LIBRA-S (30 beams)	19.7	38%	7.4	90%	6.7	75%	6	25.4%	*self-pinch*

Indirect Drive Ion Beam Gain Curves are Lower than for Lasers



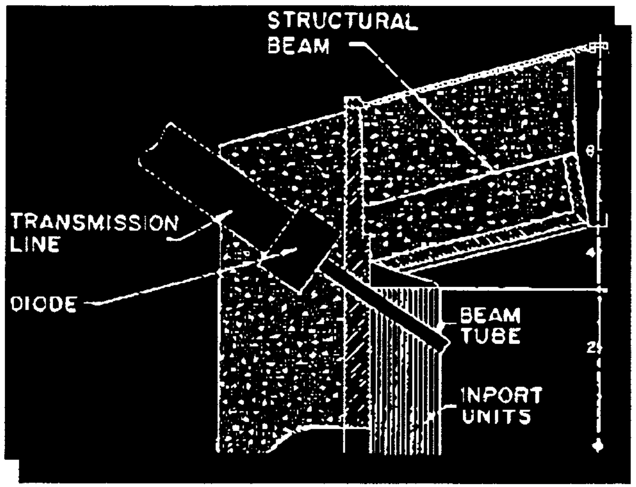


LIBRA-LiTE

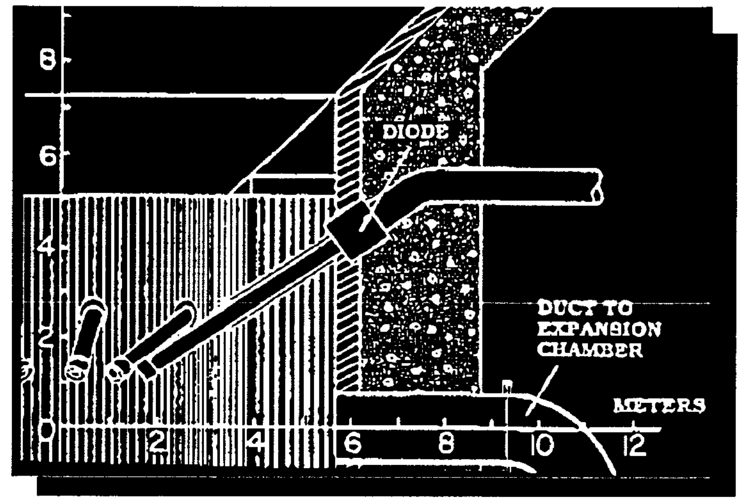
Side View Reactor Chamber Cutaway

(1) Diodes
(2) Lens magnet
(3) Pulse forming lines
(4) Reactor chamber roof
(5) INPORT units
(6) Heat exchanger
(7) Perforated bottom plate
(8) Vacuum lines

The Problem with Channel and Ballistic Transport is that Final Focusing Magnets Must Be Inside the Protective INPORT Units



LIBRA



LIBRA-LiTE

LIBRA		LIBRA-LiTE
18	Number of Beams	30
3 .6	Closest Distance to Magnet (m)	2.0
He/100 torr	Fill Gas	He/1 torr
153	Peak Impulse to the Magnet (Pa-s)	360
4	Neutron Wall Loading (MW/m^2)	29

Schematic Picture of Focusing Magnet

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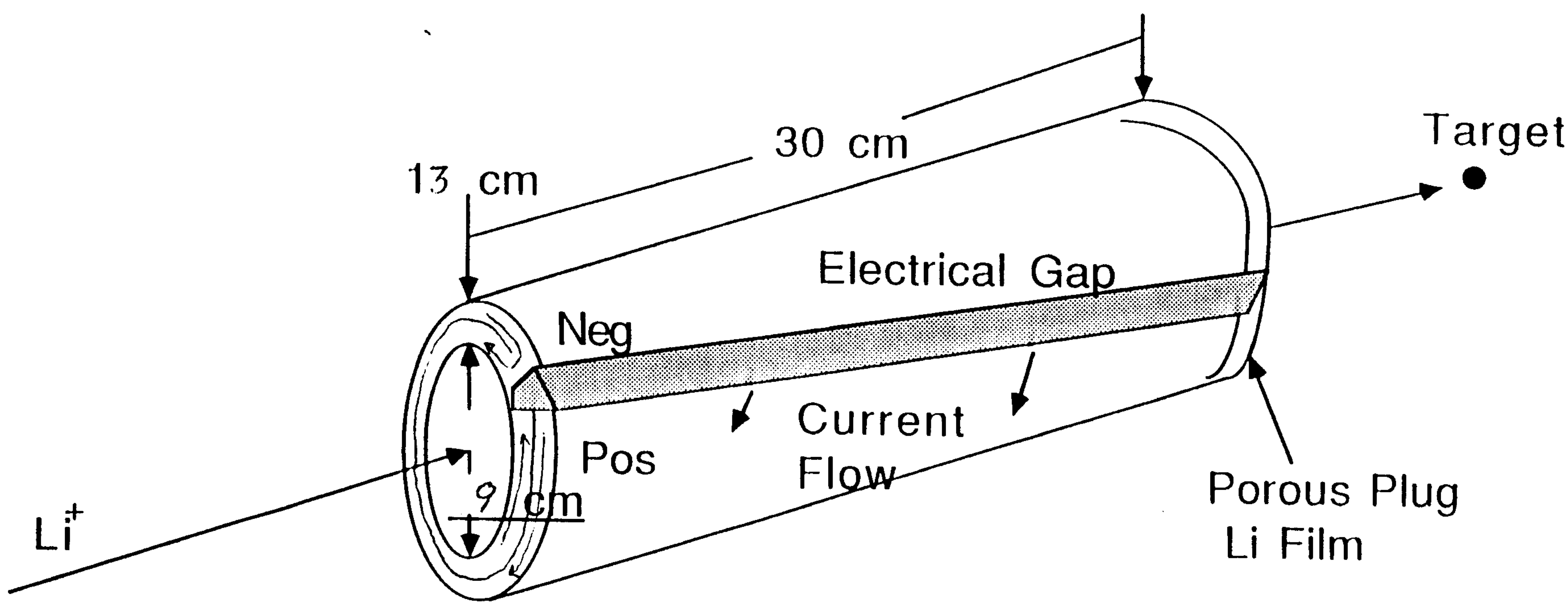
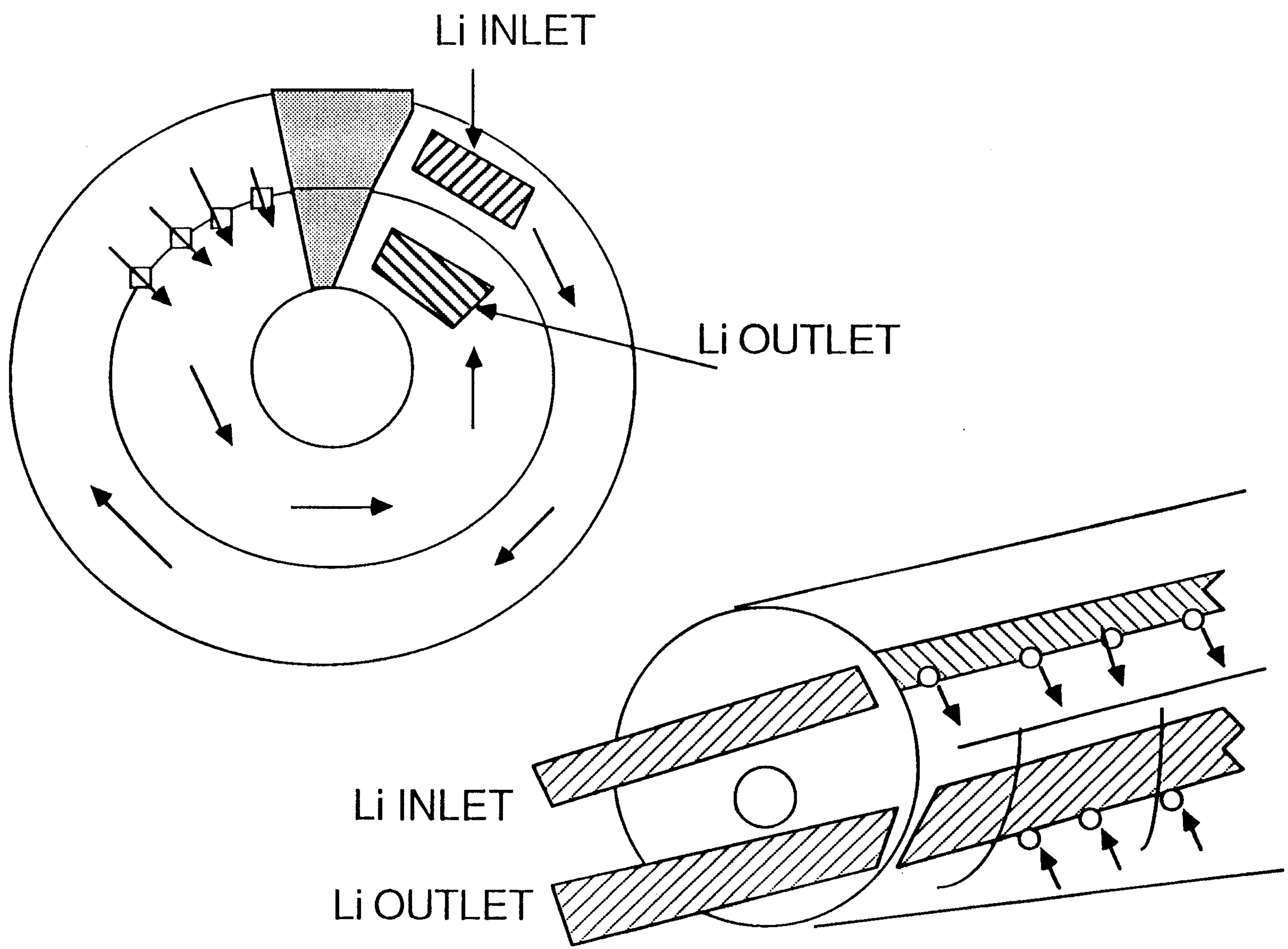
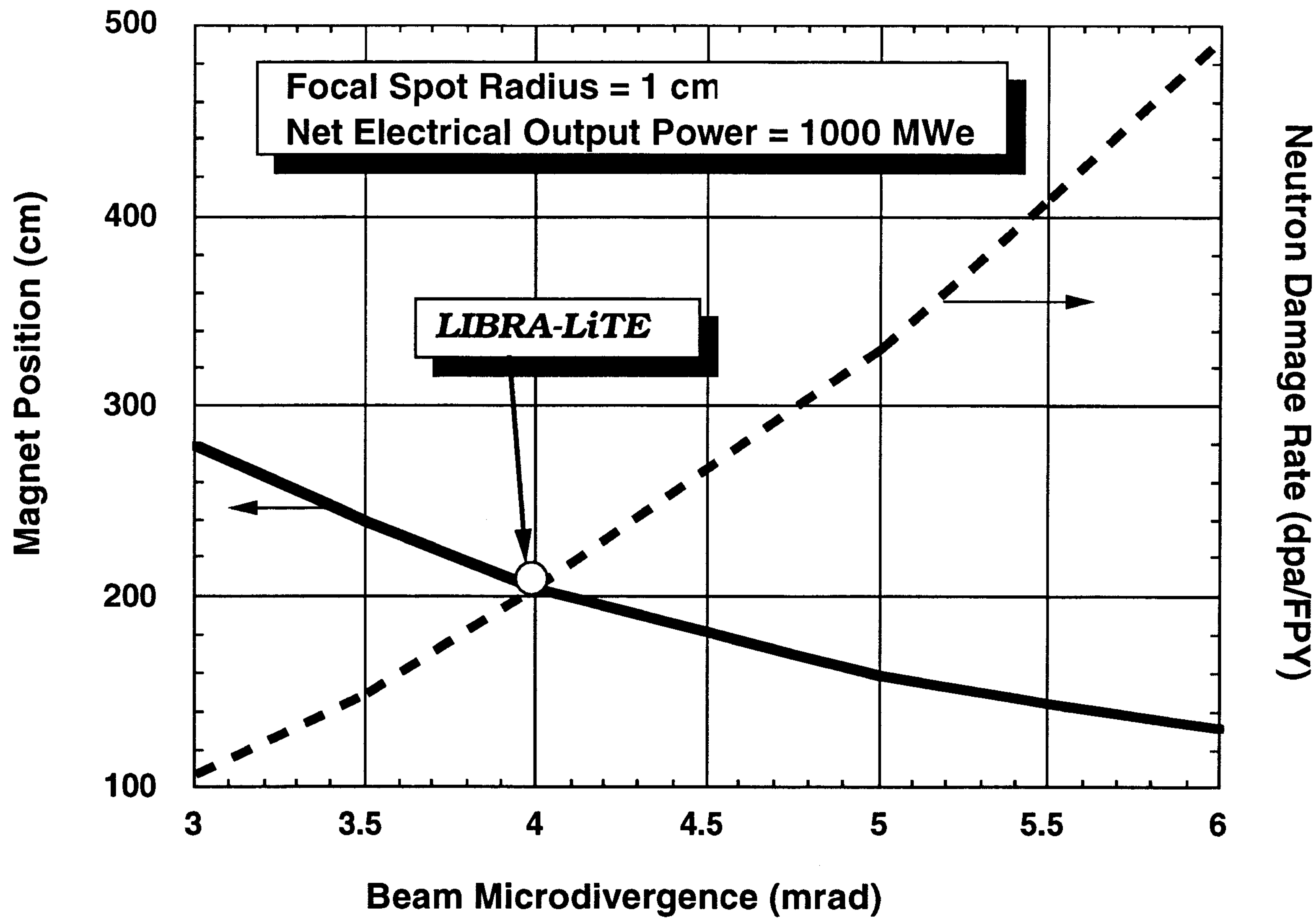
SINGLE-TURN SOLENOID MAGNET
FERRITIC STEEL CASE FILLED
WITH FLOWING LIQUID LITHIUM



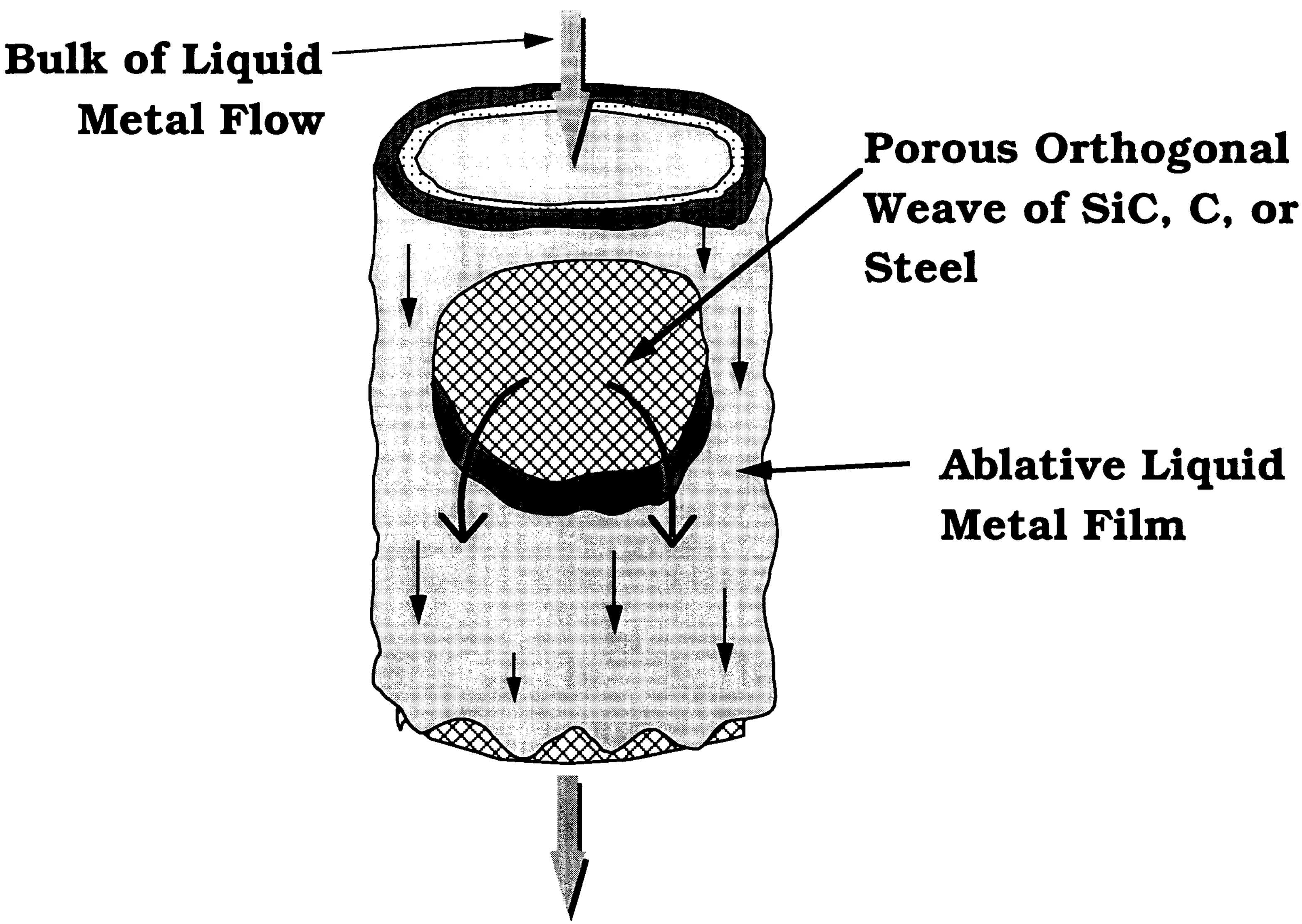
LIQUID LITHIUM CAN NOT FLOW ACROSS THE GAP BUT REVERSES FLOW AND EXITS AT THE INLET SIDE

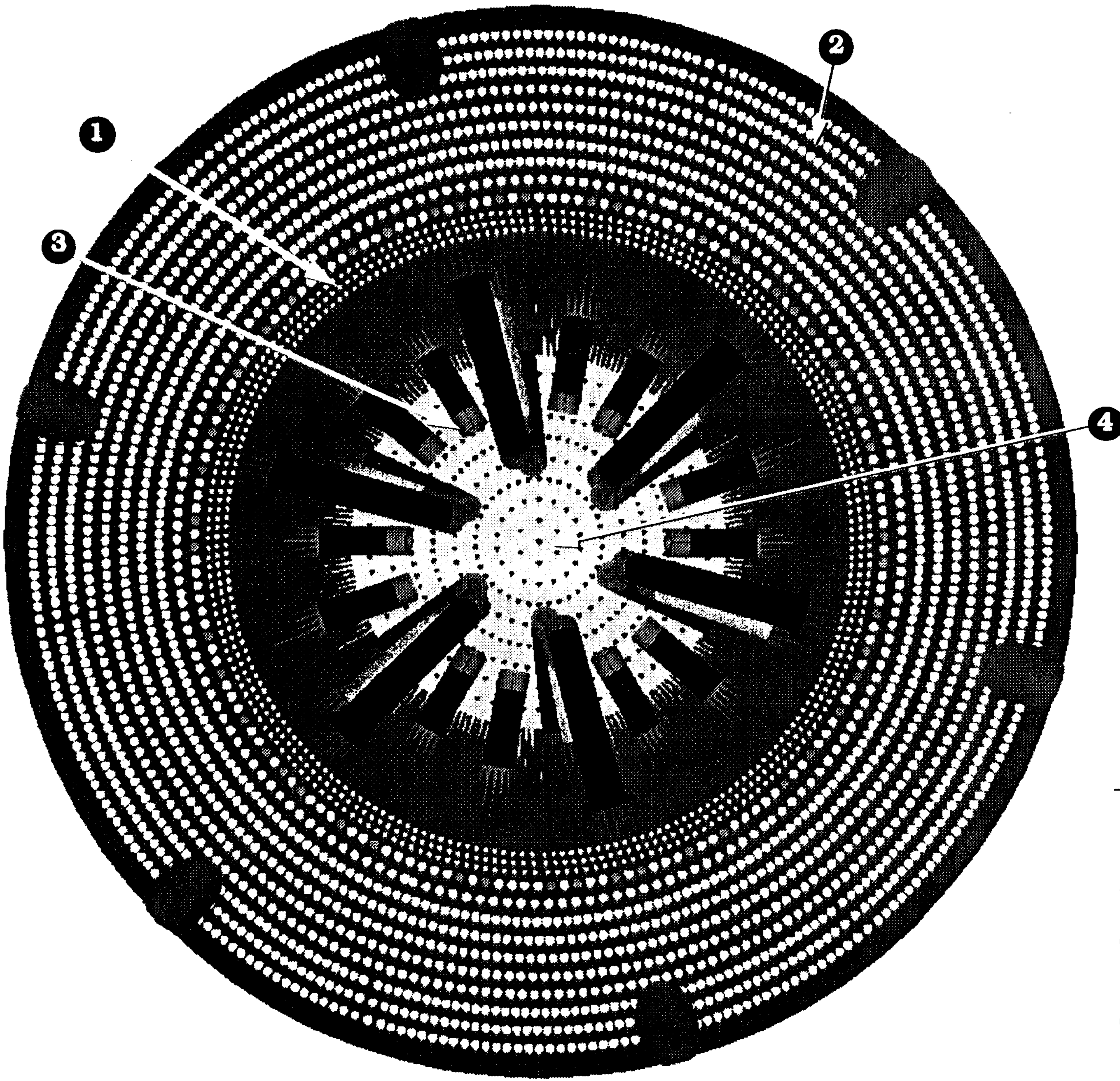


A Low Ion Source Microdivergence is Required to Place Final Focusing Magnets Farther Away from the Target



The Invention of the INPORT Unit Enabled Designers to Reduce the Cavity Diameter While Still Protecting the Structural Walls from Target Radiation





LIBRA-LiTE

Top View of Reactor Chamber Inside with Li Removed

(1) Front INPORT units

(2) Rear INPORT units

(3) Single turn liquid Li lens magnet

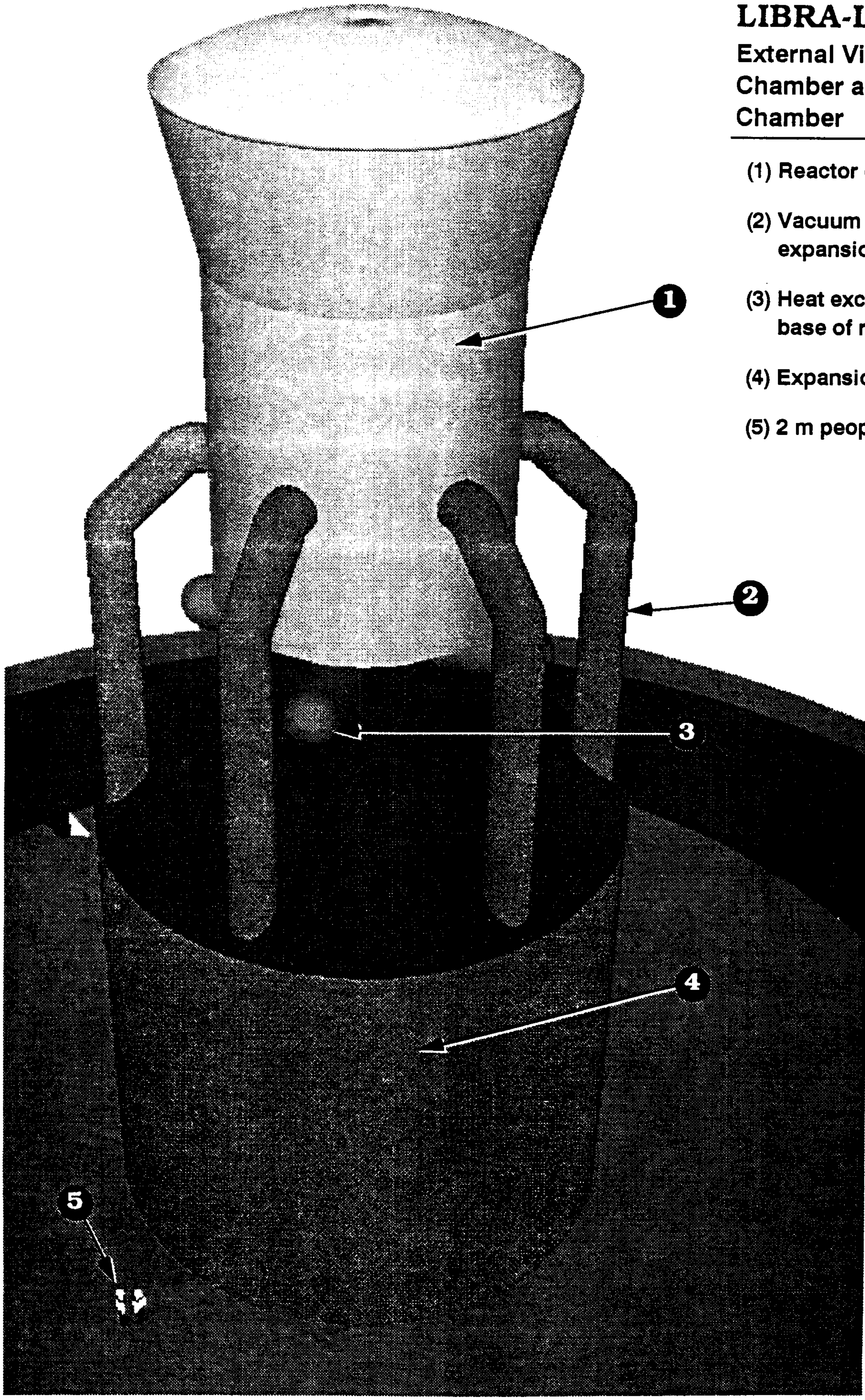
(4) Perforated bottom plate

Chronology of Events in a Single LIBRA Shot

- Target Injected
- Pulse Power Modules Apply Voltage to Diodes
- Diodes Generate Beams of Ions
- Ion Beams Transported to Target through Plasma Channels, Lens Magnets, via Self-Pinching Mechanisms
- Target Implodes, Releasing X-Rays, Ions, Neutrons and Debris
- X-Rays Reach Liquid Covered INPORT Units, Partially Vaporizing Liquid Coating
- Neutron Deposition in Blanket
- Vapor Blows Off INPORTs, Generating Impulse
- Debris and Ions Deposit in Expanding Vapor
- Vapor Reradiates to INPORTs, Vaporizing More Liquid Metal
- Vapor Expands throughout Chamber, Condensing and Losing Energy
- "Colder" Vapor and Background Gas Flow through Vent Pipes to Surge Tank

Reactor Cavity Conditions for Beam Propagation and INPORT Unit Performance

	LIBRA	*LIBRA-LiTE*
Initial Gas Conditions	T = 500°C Species = He # density = 3.55×10^{18} cm^{-3}	T = 500°C Species = He # density = 3.55×10^{16} cm^{-3}
Conditions at INPORTs	Peak Pressure = 100 GPa Pulse Width (FWHM) = 1 ns Total Impulse = 125 Pa-s Vaporization = 7 μm PbLi	Peak Pressure = 4.6 GPa Pulse Width (FWHM) = 8 ns Total Impulse = 100 Pa-s Vaporization = 66 μm Li



LIBRA-LiTE

External View of Reactor Chamber and Expansion Chamber

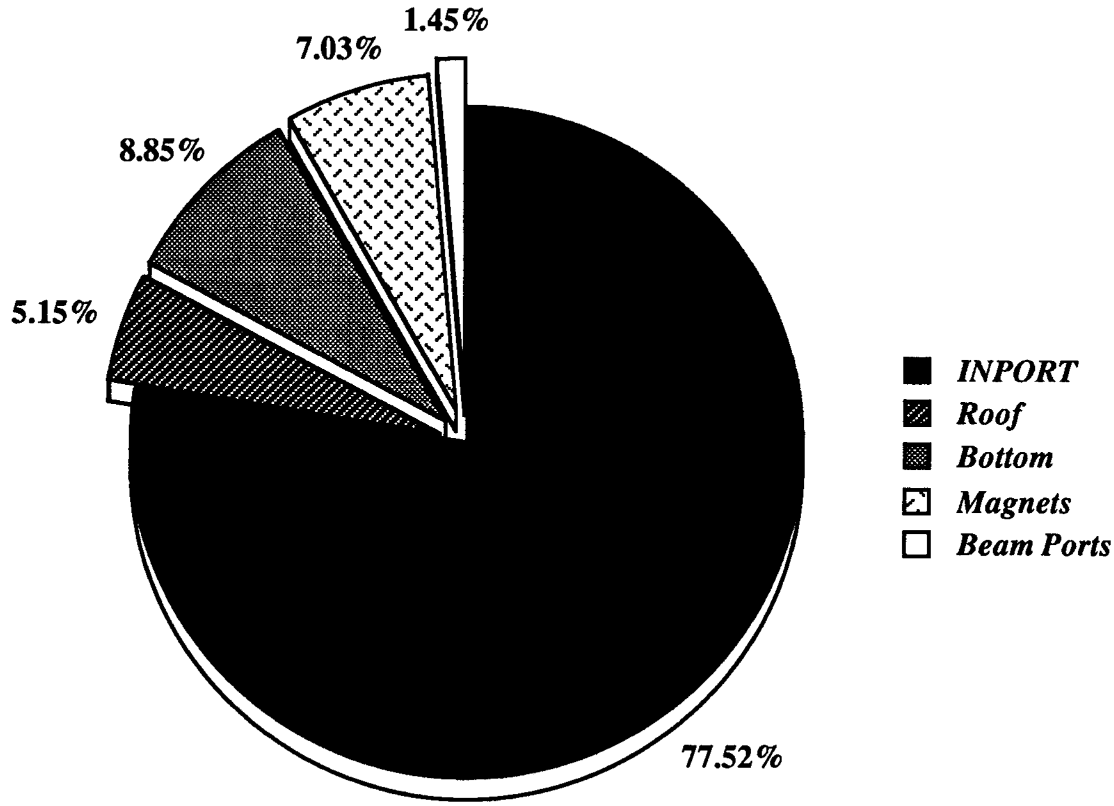
(1) Reactor chamber

(2) Vacuum lines leading to expansion chamber

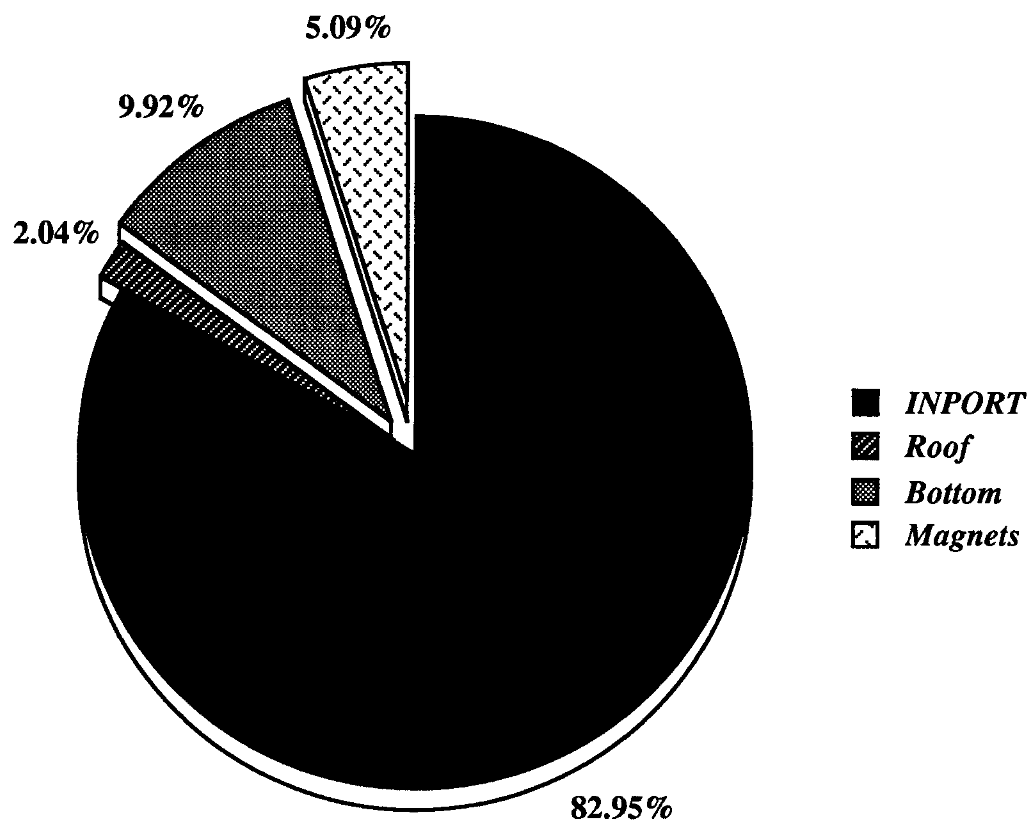
(3) Heat exchangers (5) in base of reactor chamber

(4) Expansion chamber

(5) 2 m people for scale

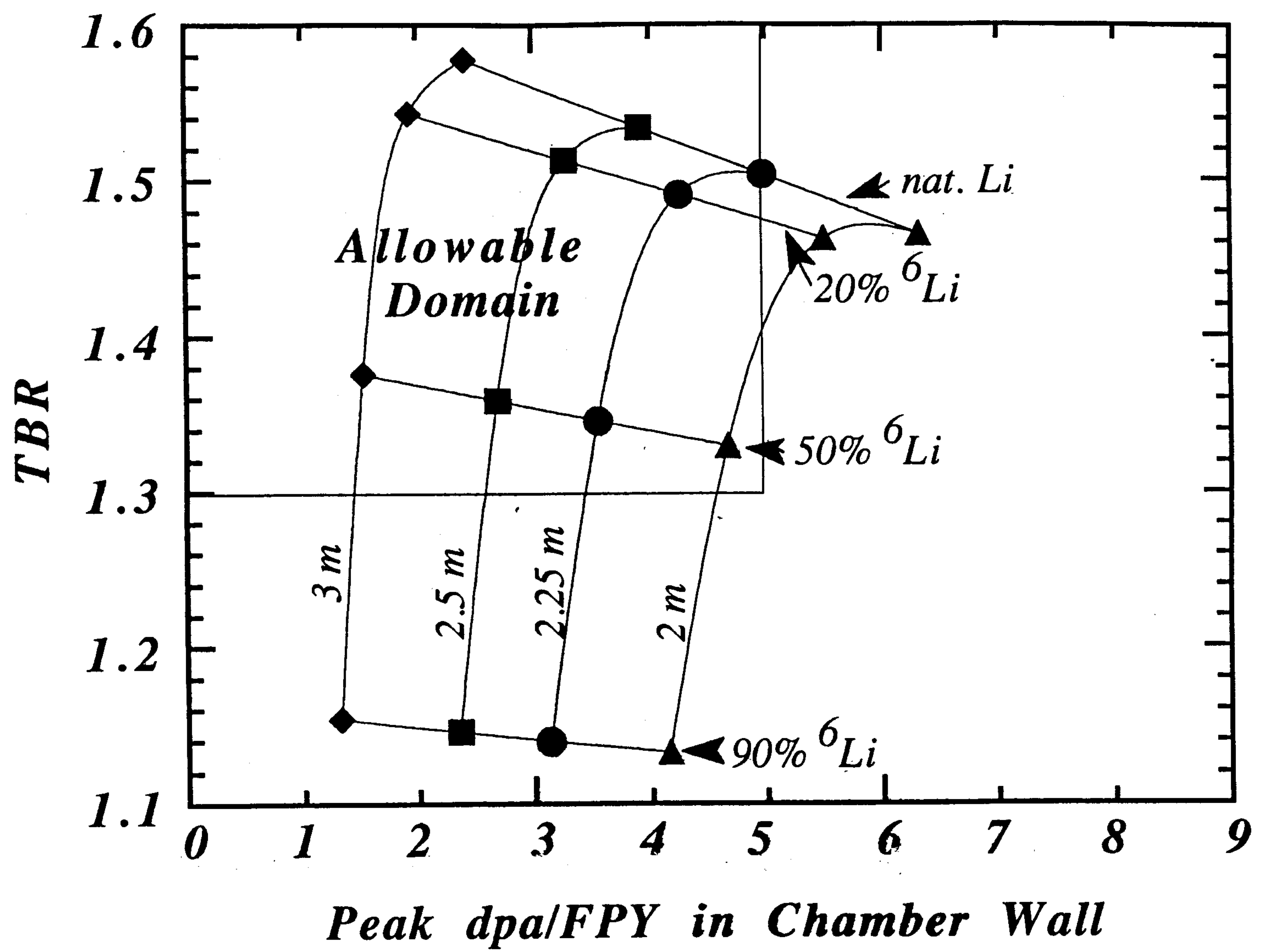


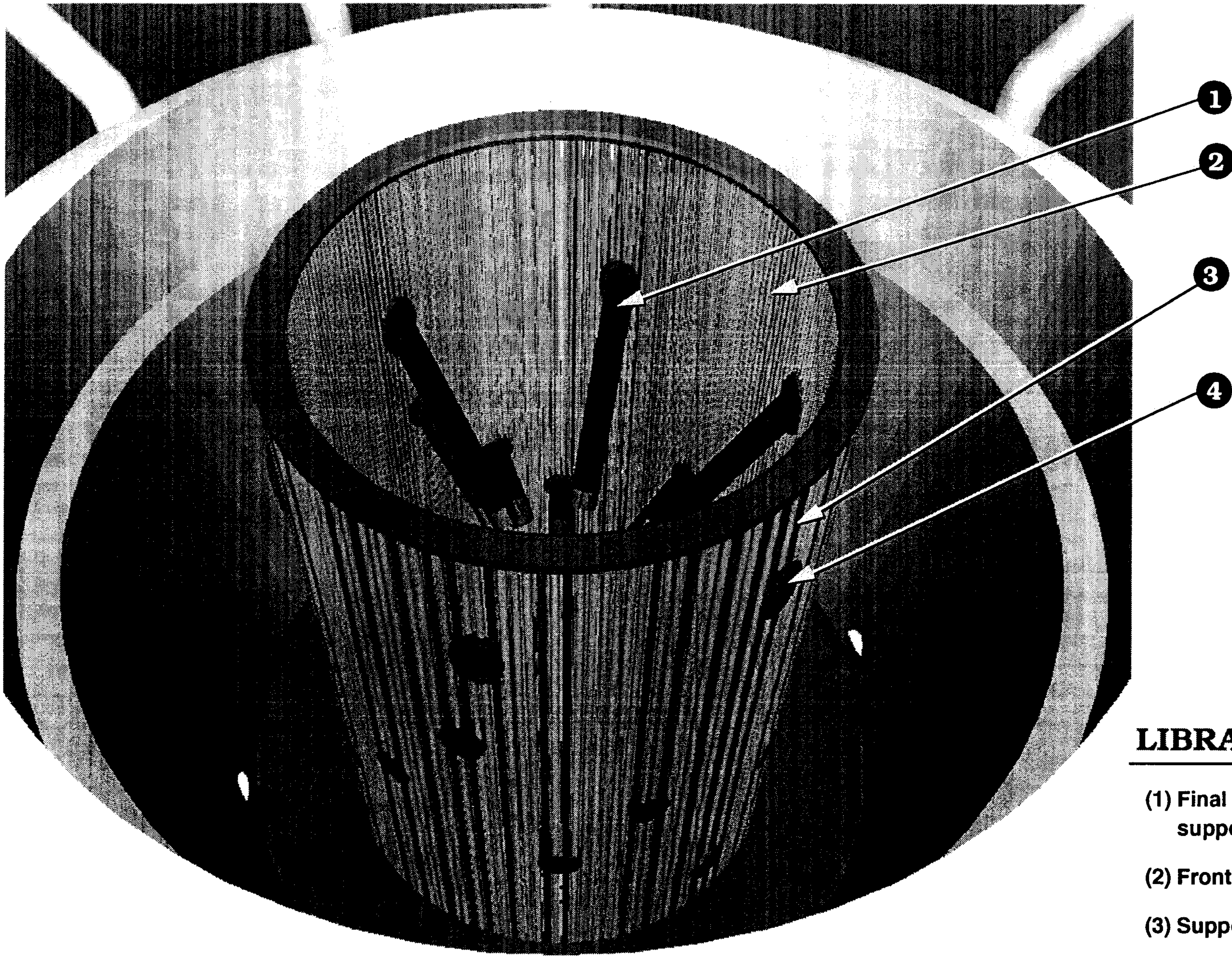
Fractions of Source Neutrons Going to Different Reactor Regions



Contributions from the Different regions to the Overall TBR (1.405)

The Trade-Off in dpa Damage vs. Tritium Breeding in LIBRA-LiTE Dictates ^{6}Li Enrichment and INPORT Thickness Values





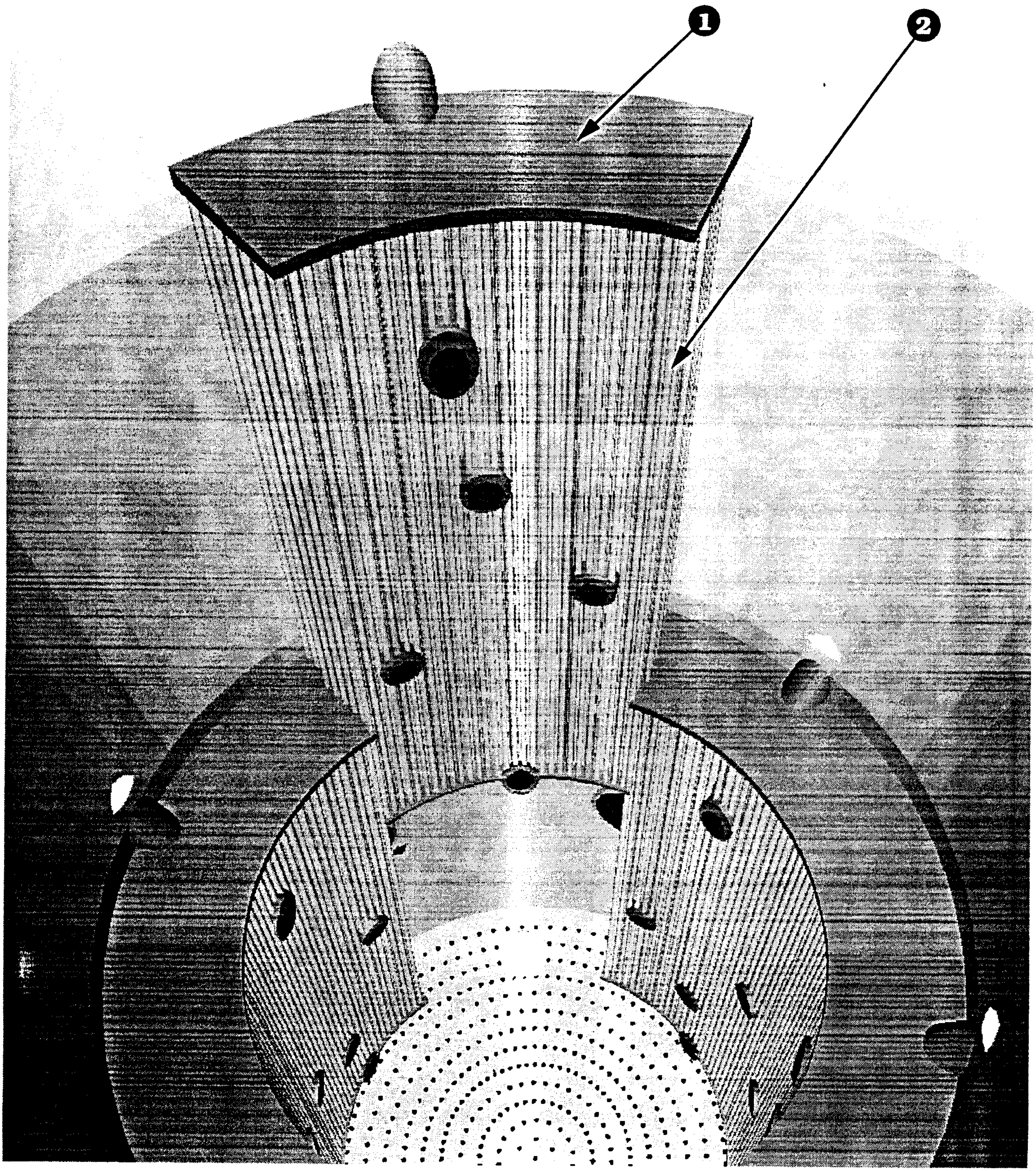
LIBRA-LiTE

(1) Final focusing magnet support

(2) Front INPORT units

(3) Support tube

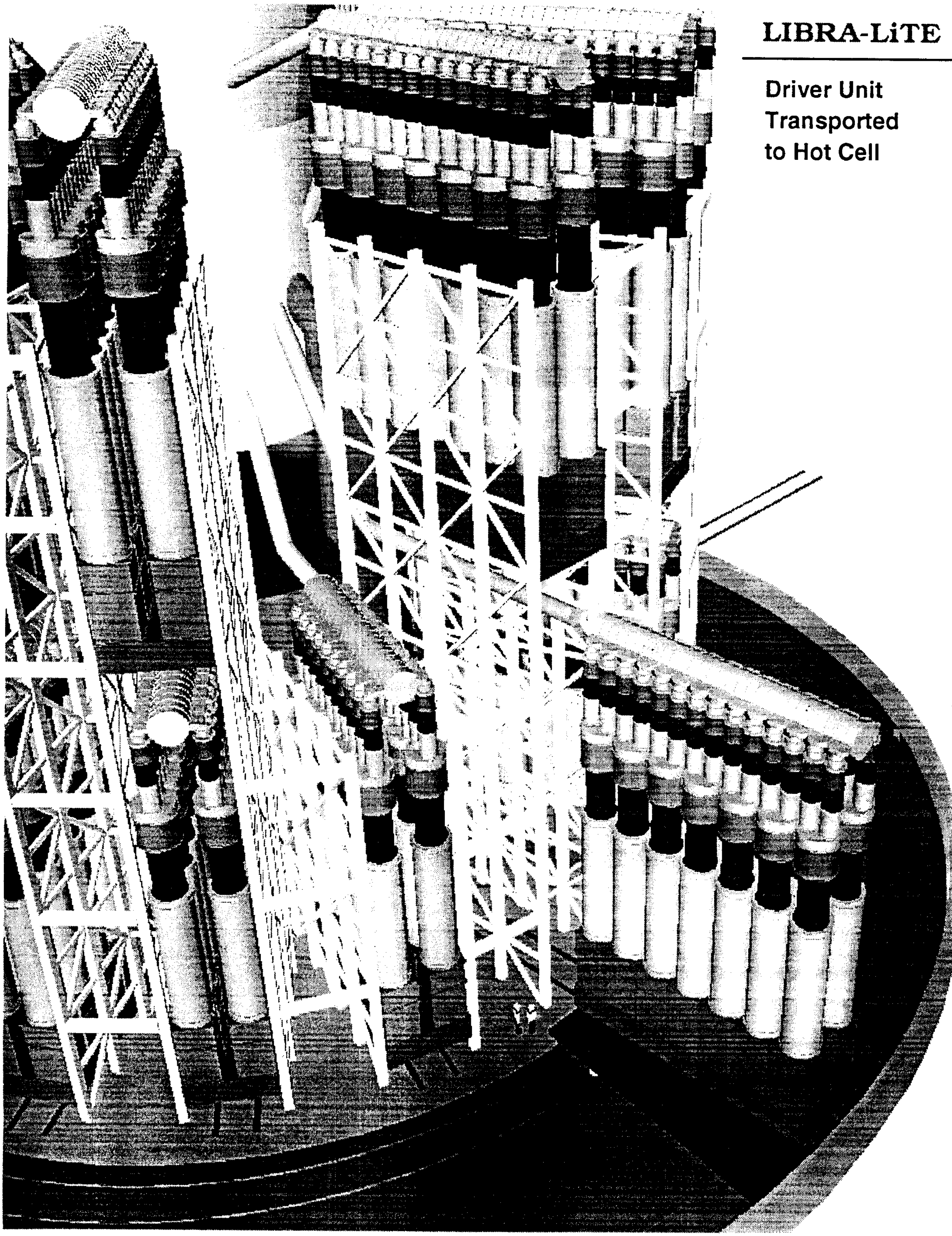
(4) Li shunt manifold around beam line



LIBRA-LiTE

(1) Rear INPORT Units' Assembly Being Removed from Reactor

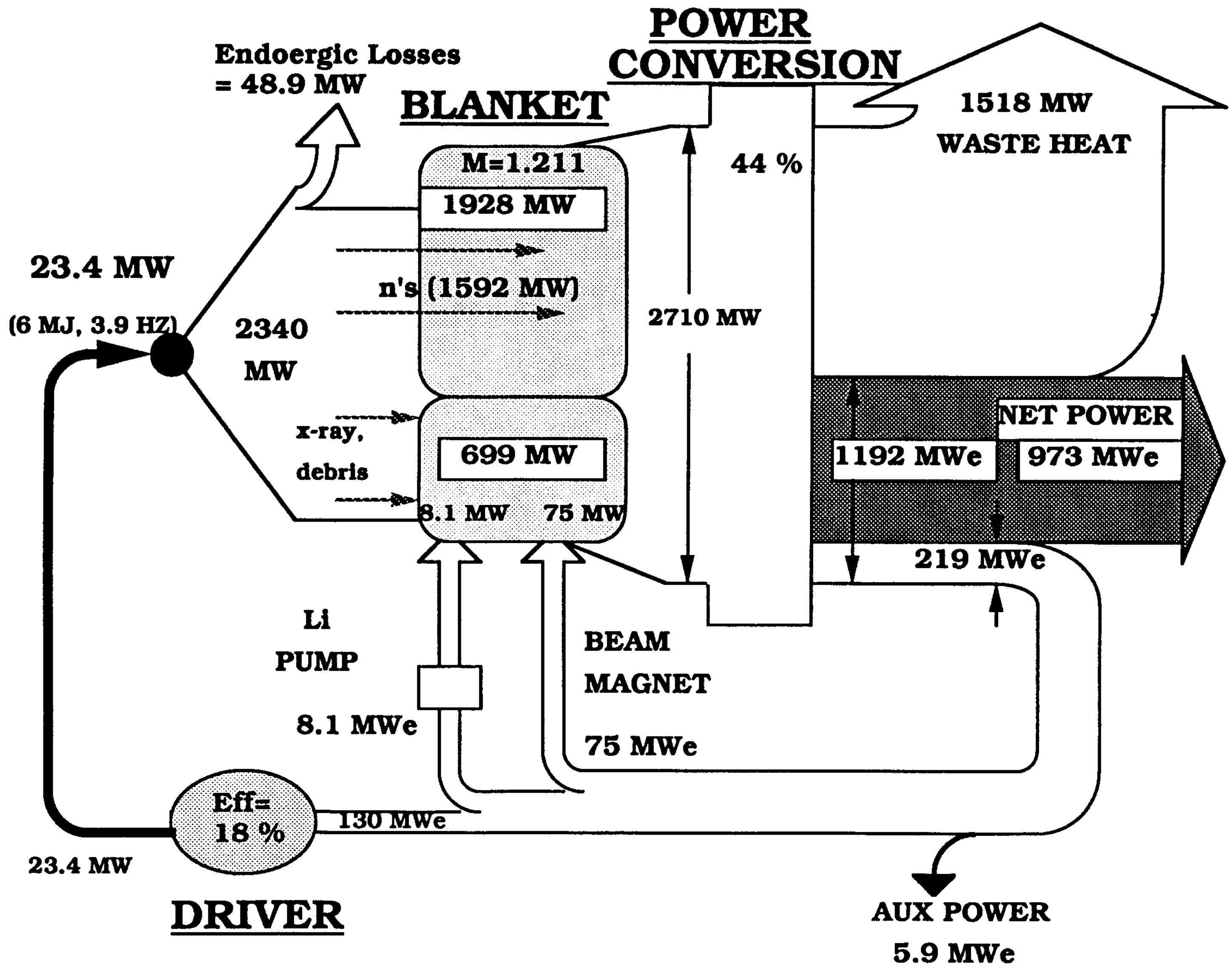
(2) Rear INPORT Units



LIBRA-LiTE

Driver Unit Transported to Hot Cell

POWER FLOW DIAGRAM FOR LIBRA-LiTE



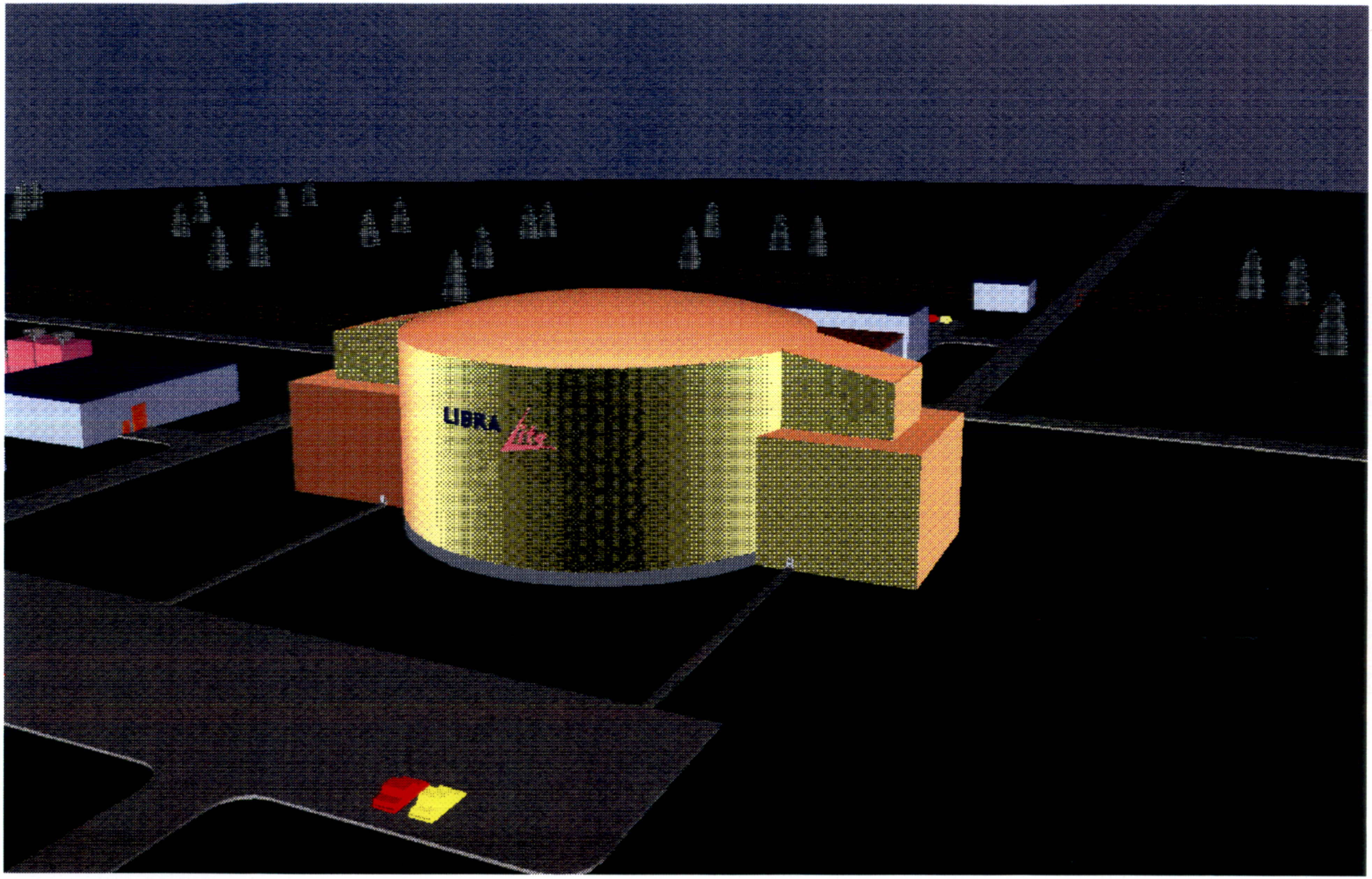
Active Tritium Inventories in LIBRA Reactors are Relatively Low

Location	*LIBRA (PbLi)*	*LIBRA-LiTE (Li)*
Target Fabrication Facility	**134**	**193**
Reactor Hall		
Targets (1 hr)	**21**	**50**
Breeder	**0.4**	**230**
INPORT Units	**150**	**~0**
Exhaust	**1.3**	**7**
	173	**287**
Fuel Processing		
Purification	**1.3**	**4**
Isotope Separation	**45**	**35**
	46	**39**
Total Active	**353**	**519**
Maximum Exposure at Fence if all T_2 were Released	**0.7 Rem (7 mSv)**	**1 Rem (10 mSv)**

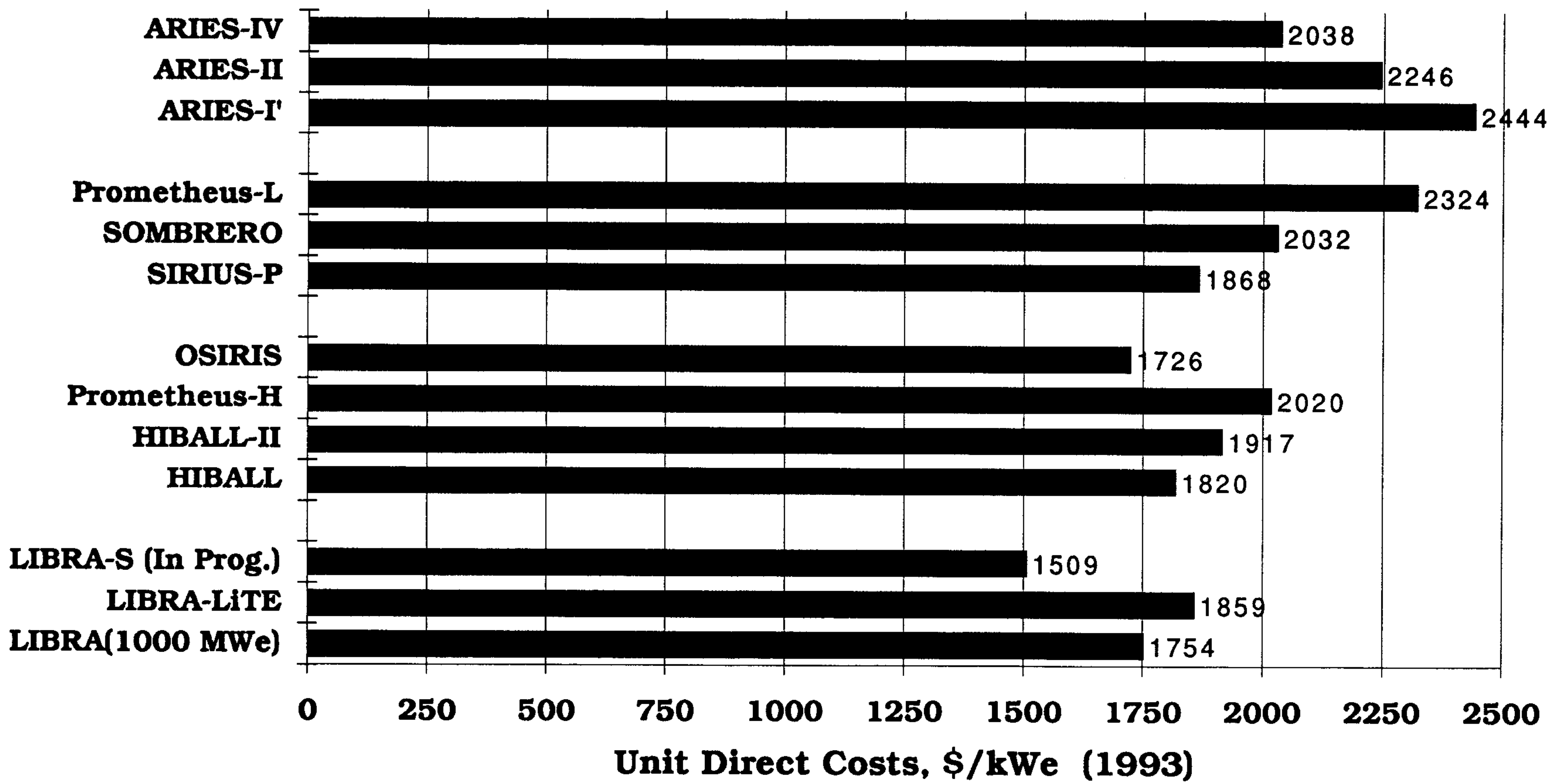
Direct Capital Costs for LIBRA Reactors are Quite Attractive

M$ (1993)

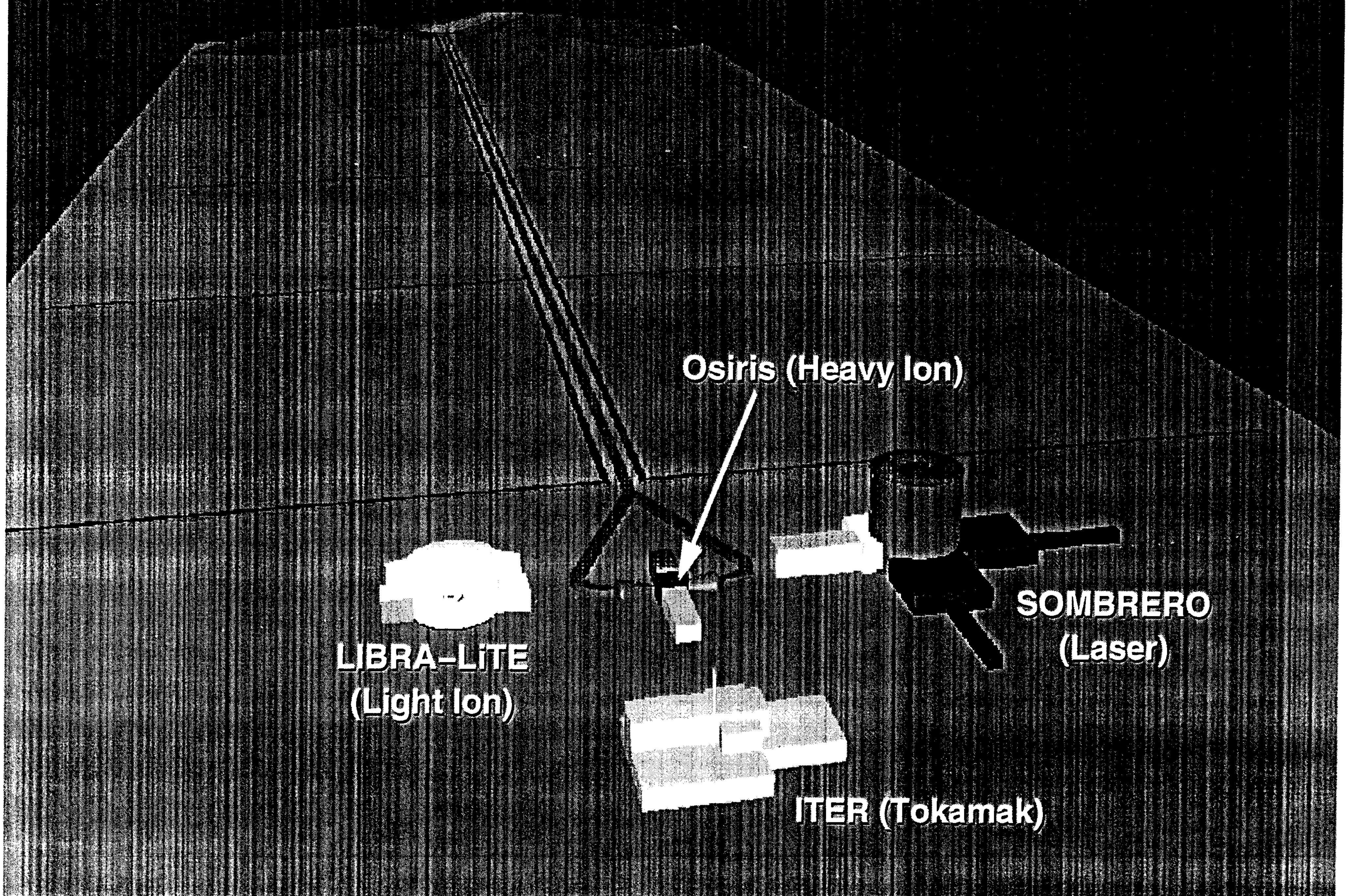
	LIBRA	*LIBRA-LiTE*	*LIBRA-S (est.)*
Driver	524	514	348
Total (incl. driver)	1157	1786	1592
Unit Direct Capital Costs ($/kWe)	3495	1835	1477
Net Power (MWe)	331	973	1078


LIBRA

The Direct Unit Cost of the LIBRA Reactors Compares Favorably With Other ICF and MCF Power Plants at the 1000 MWe Level



The Relative Size of Recent Inertial Fusion Power Plants is Comparable to the Magnetic Fusion Experiment ITER



Conclusions

1) Light Ion Beam Fusion Power Plants Display (compared to HIB and laser designs):

- Competitive Technological Readiness
- Adaptability to Low Power Levels
- Simplicity of Design
- Attractive Safety Features
- Potentially the Lowest Cost of Electricity

2) The major concern is the transport of ions at low microdivergence to the target on a repeatable basis (i.e., channel vs. ballistic vs. self-pinched transport).