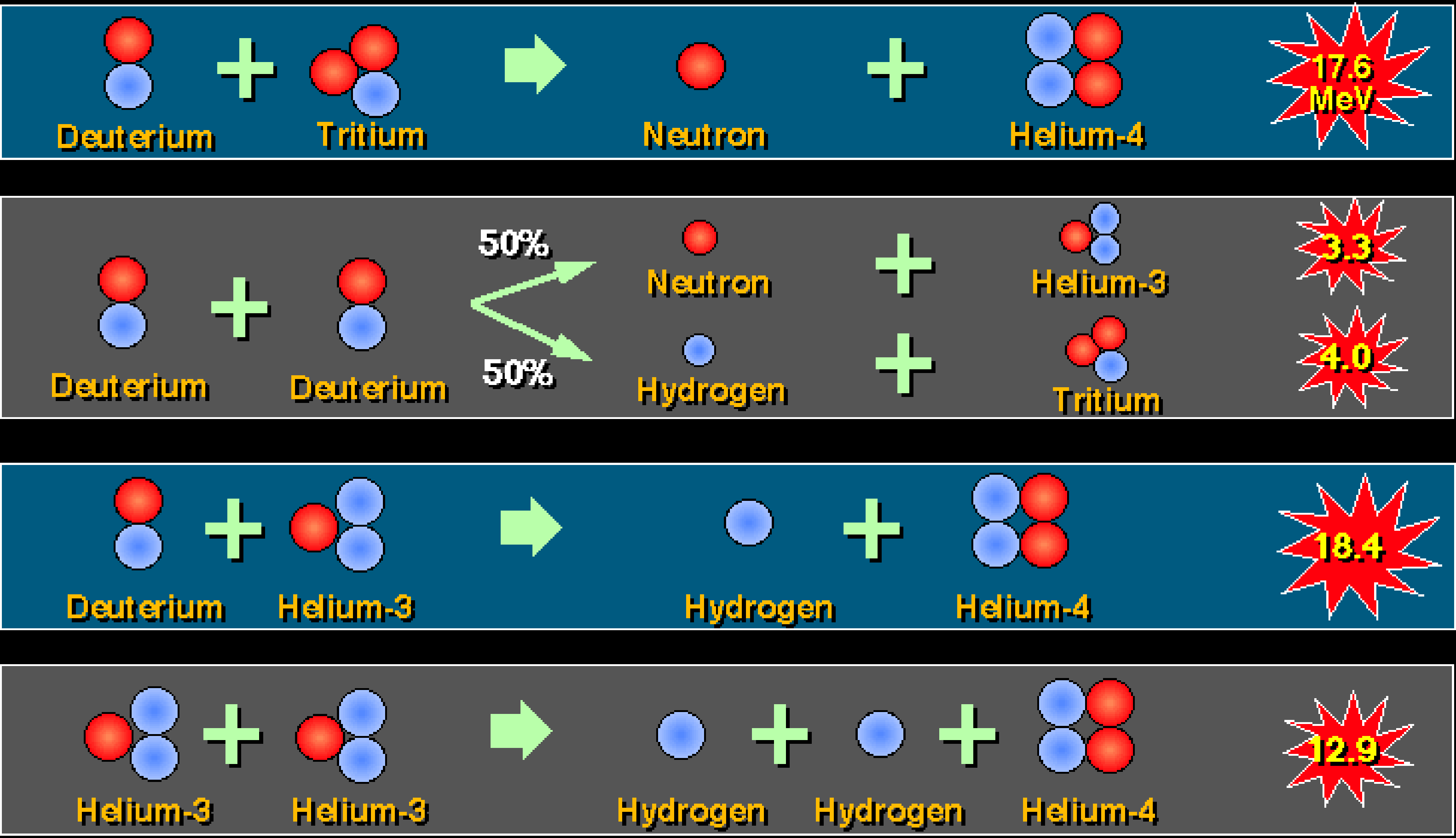
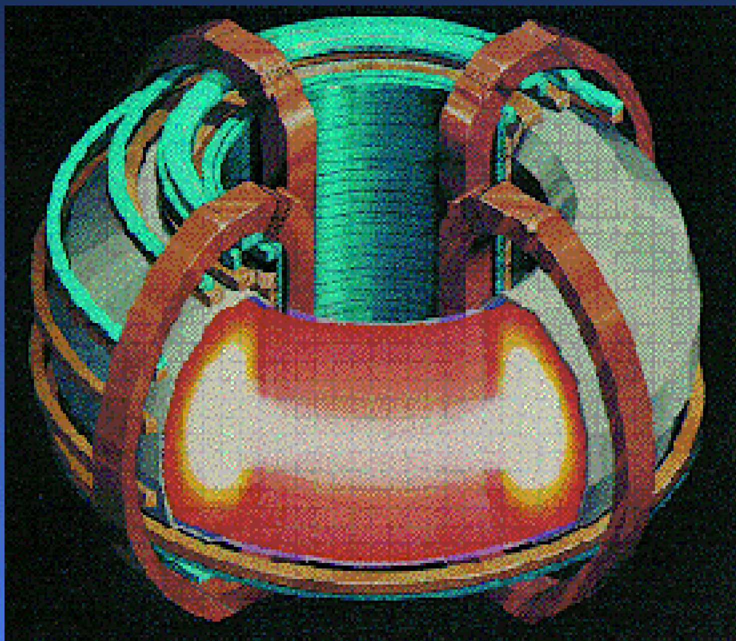
Fusion Fuel Cycles

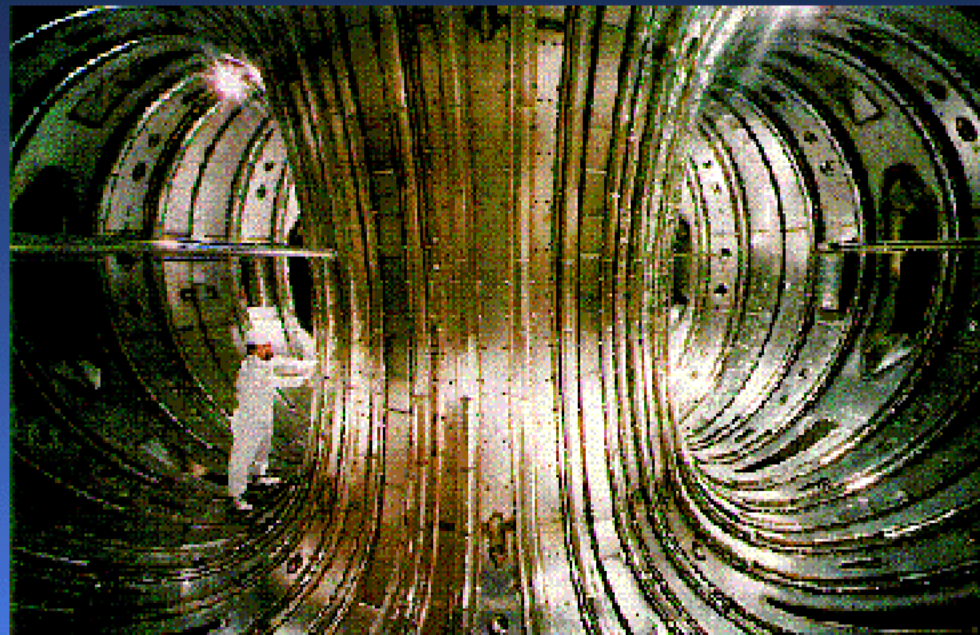


The Tokamak is the Leading Magnetic Fusion Concept for the DT Fuel Cycle

D + T -> n (14 MeV) + ^{4}He (3.5 MeV)



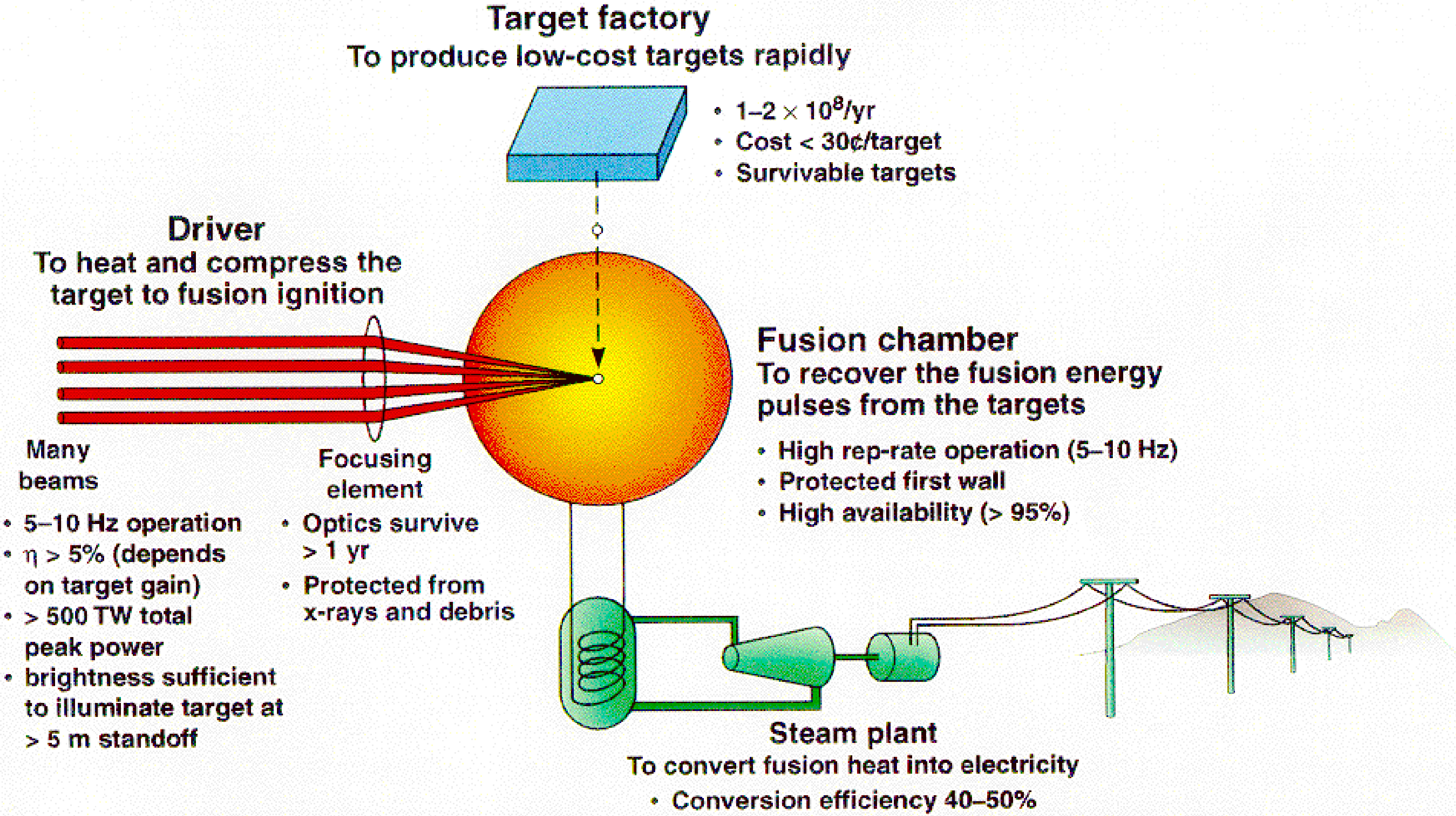
Schematic of a Tokamak



Joint European Torus – JET

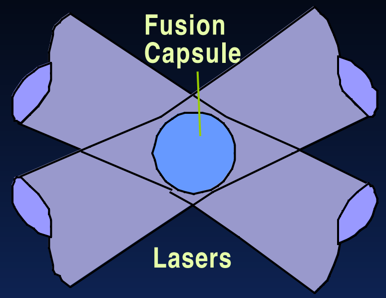
~ 40 MW

Inertial fusion energy (IFE) power plants of the future will consist of four parts

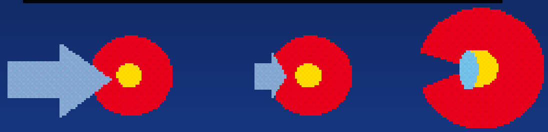


An IFE power-plant would ignite five to ten targets per second to produce as much electricity as today's one gigawatt power plant

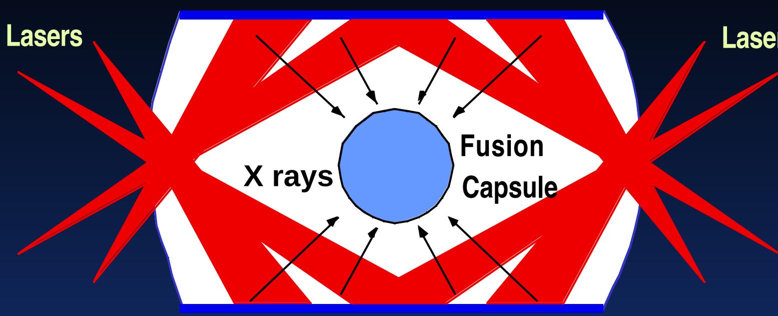
There Are Four Different ICF Target Designs



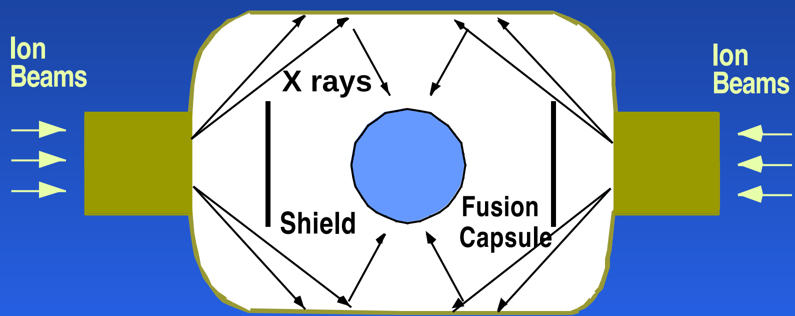
Direct Drive Lasers



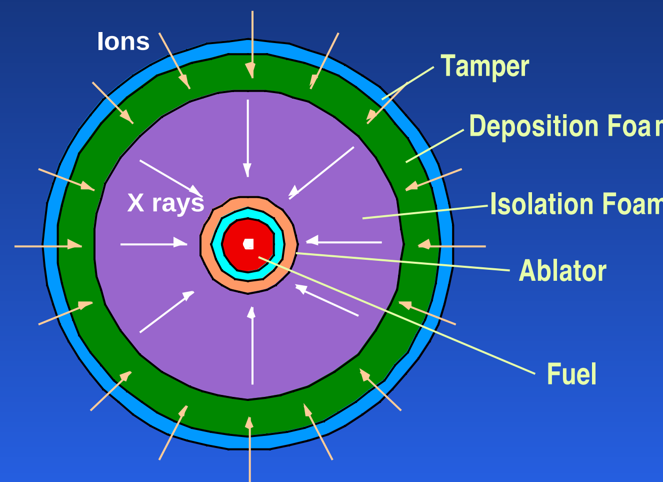
(Fast Ignitor Variation)



Indirect Drive Lasers



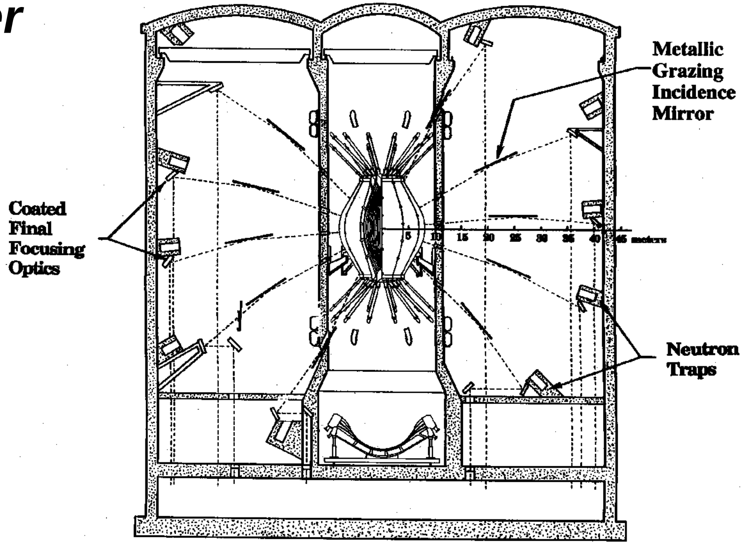
Indirect Drive Heavy Ions



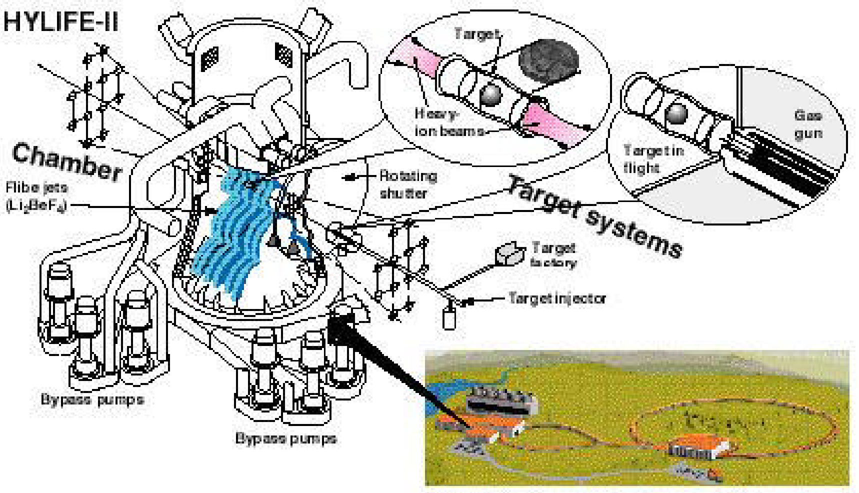
Indirect Drive Light Ions

There are 4 Current ICF Drivers

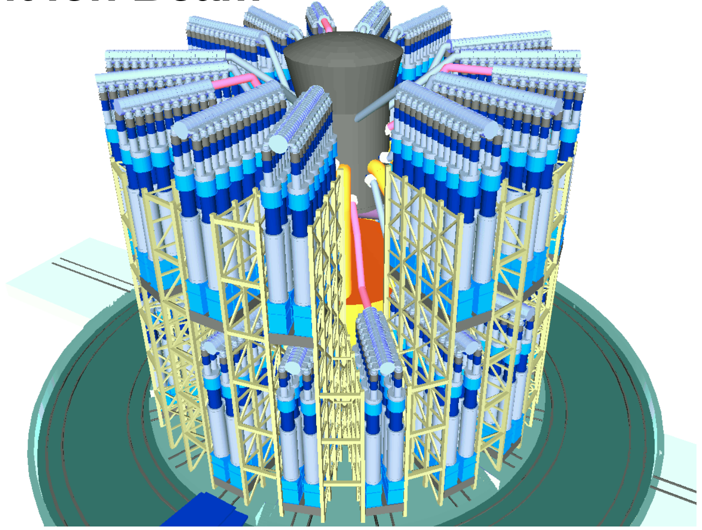
Laser



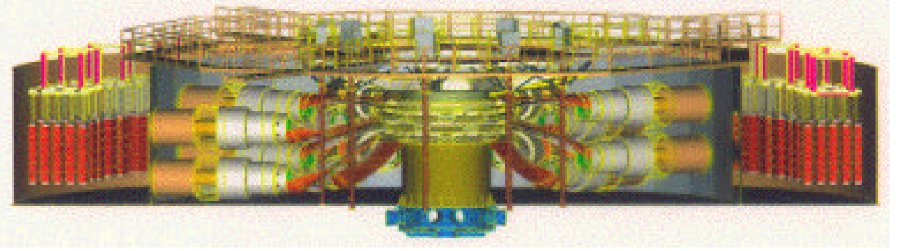
Heavy Ion Beam



Light Ion Beam

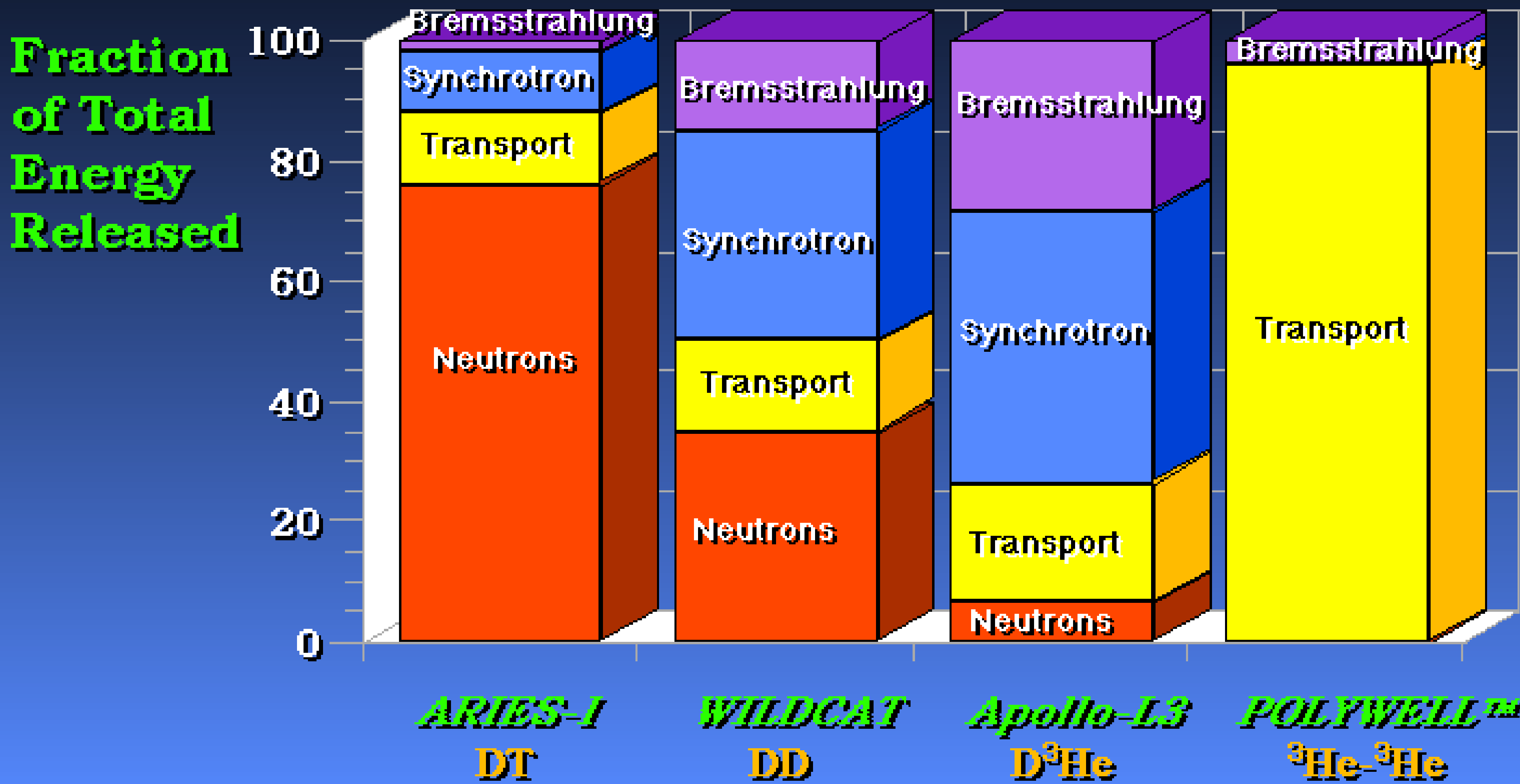


Z-Pinch – Energy application depends on finding a credible rep-rate concept

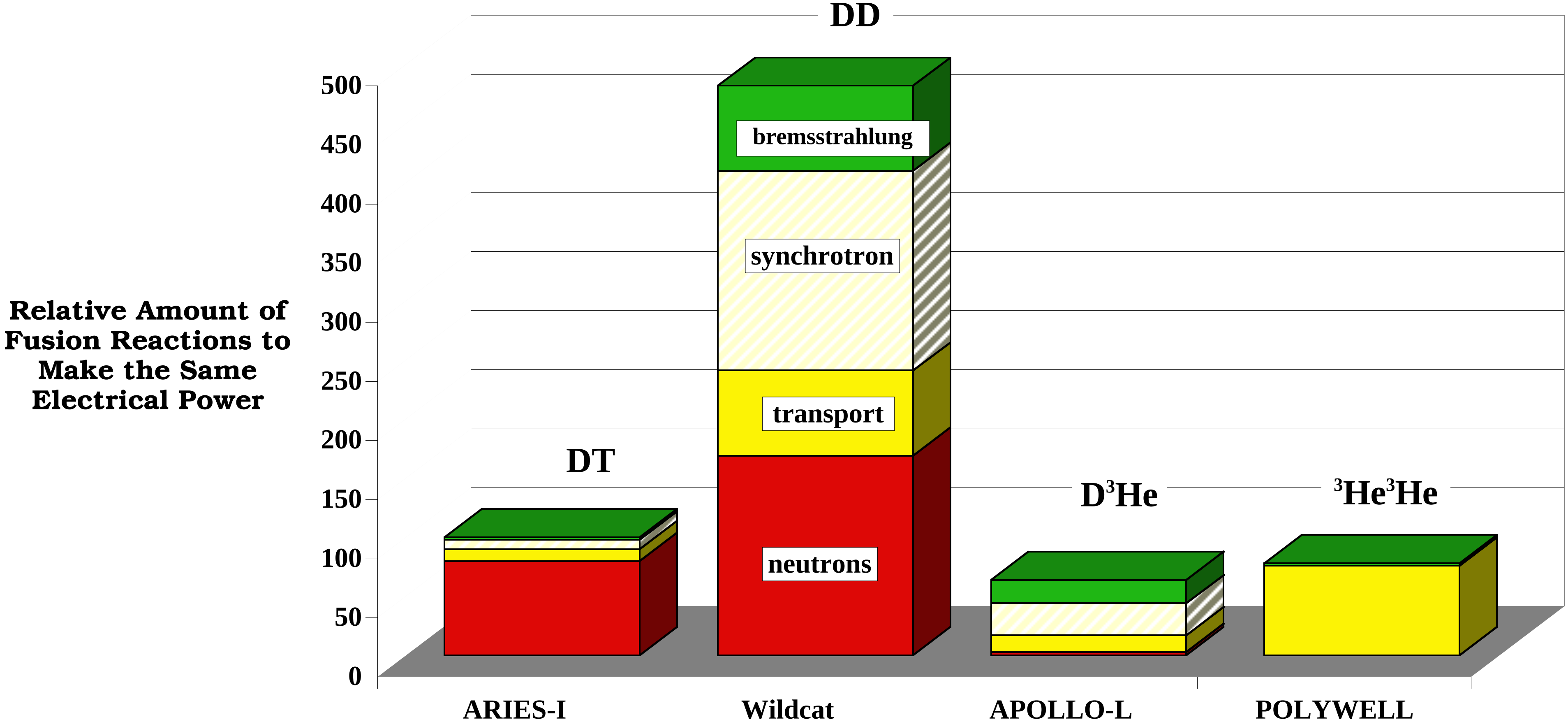


Light ion development currently on hold due to inability to focus adequately

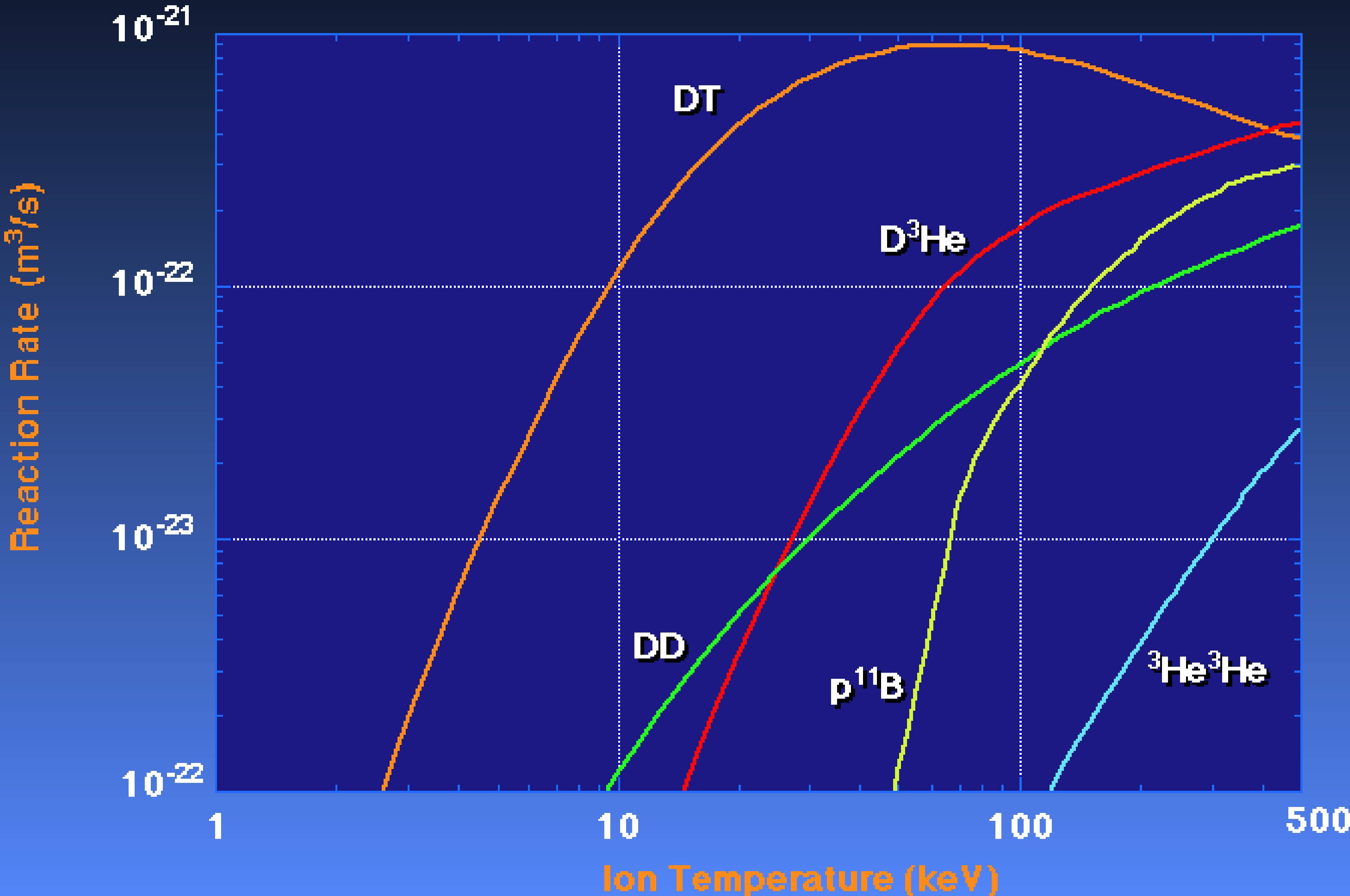
The Form of Energy Release is Quite Different in DT, DD, D^3He and ^3He-^3He Fuel Cycles



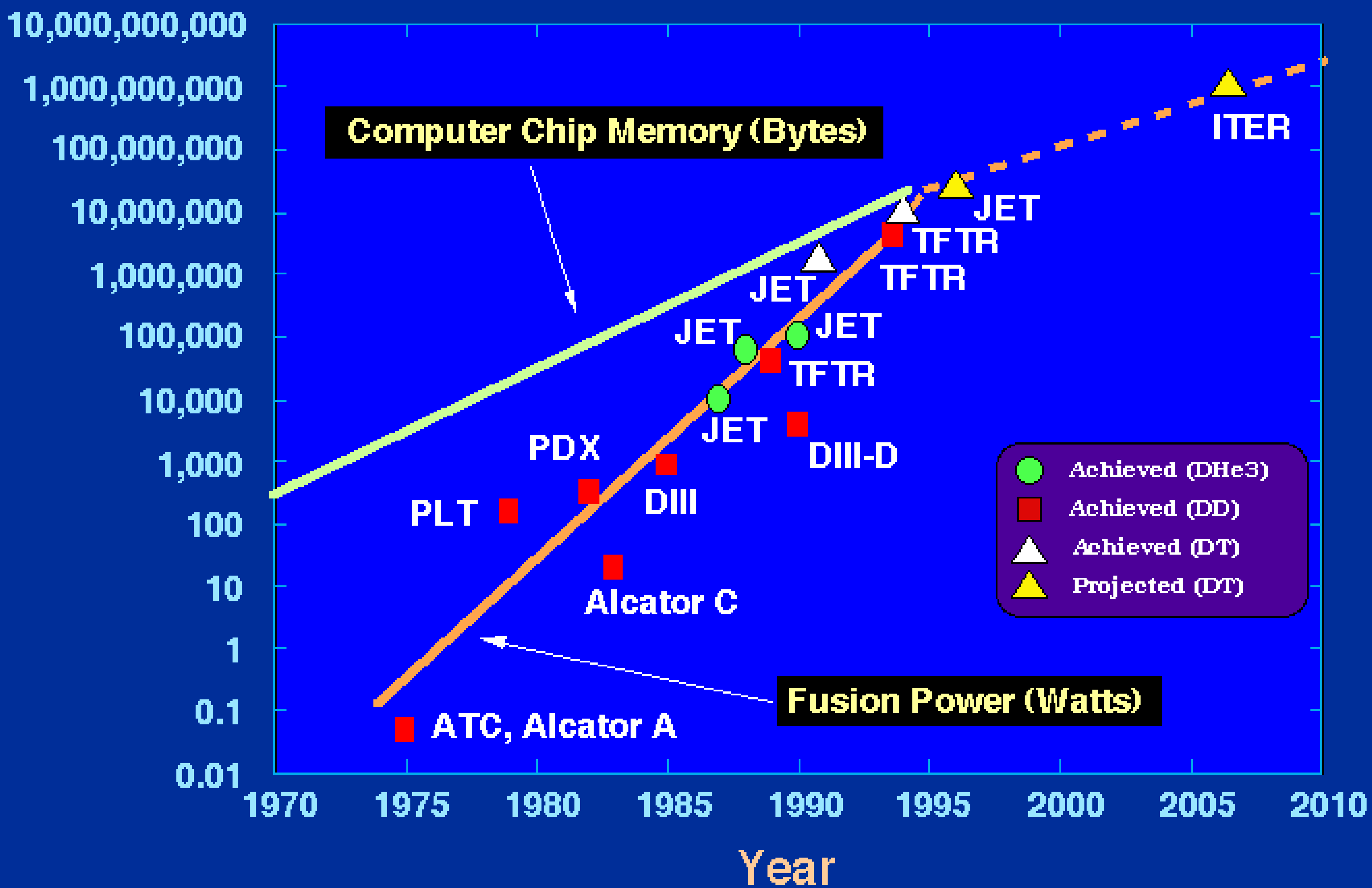
The Amount and Form of Energy Required to Make Fusion Power is Quite Dependent on the Fusion Fuel Cycle



Maxwellian Fusion Reaction Rates



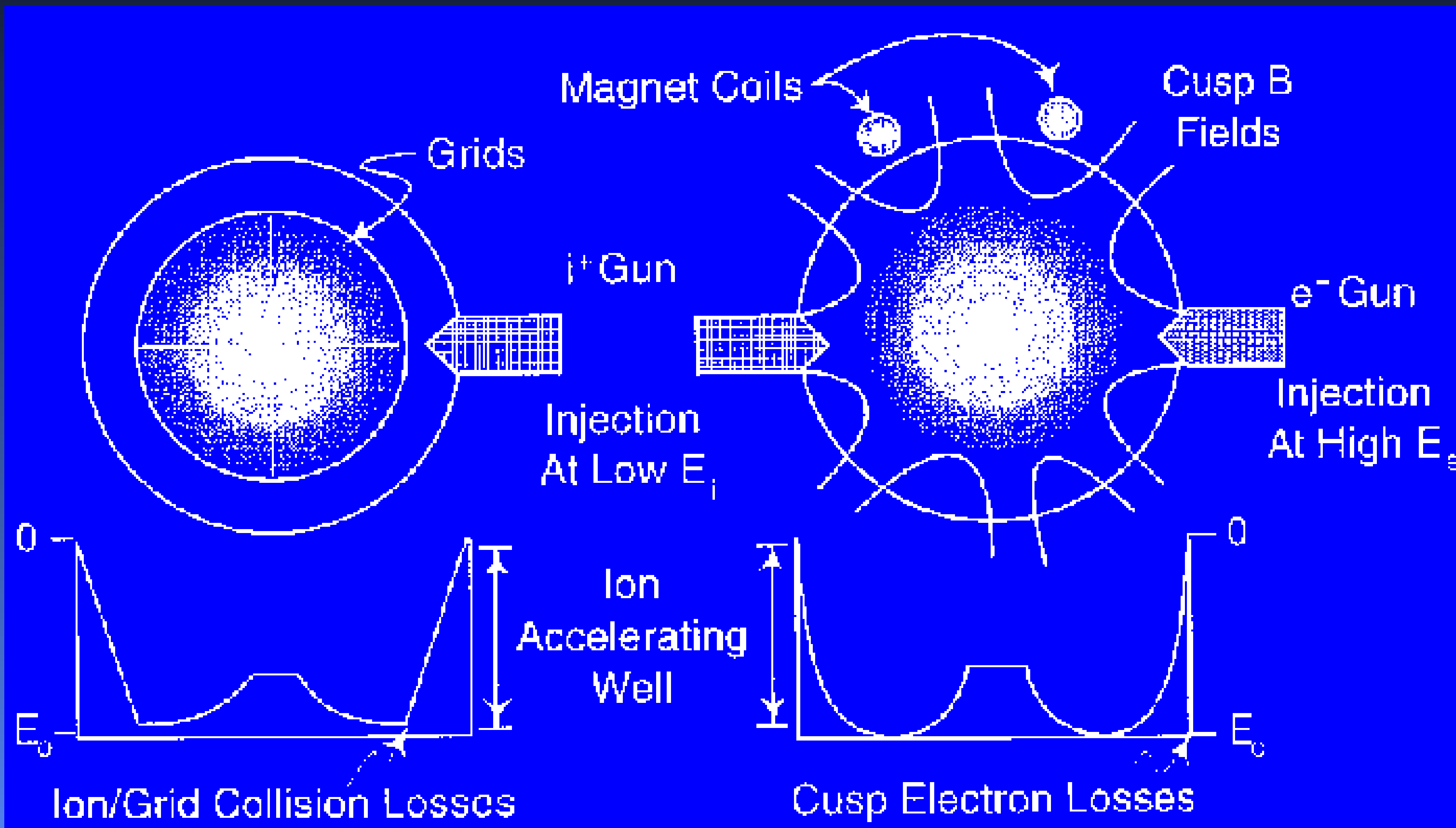
Magnetic Fusion Has Made Outstanding Progress During the Past 15 Years

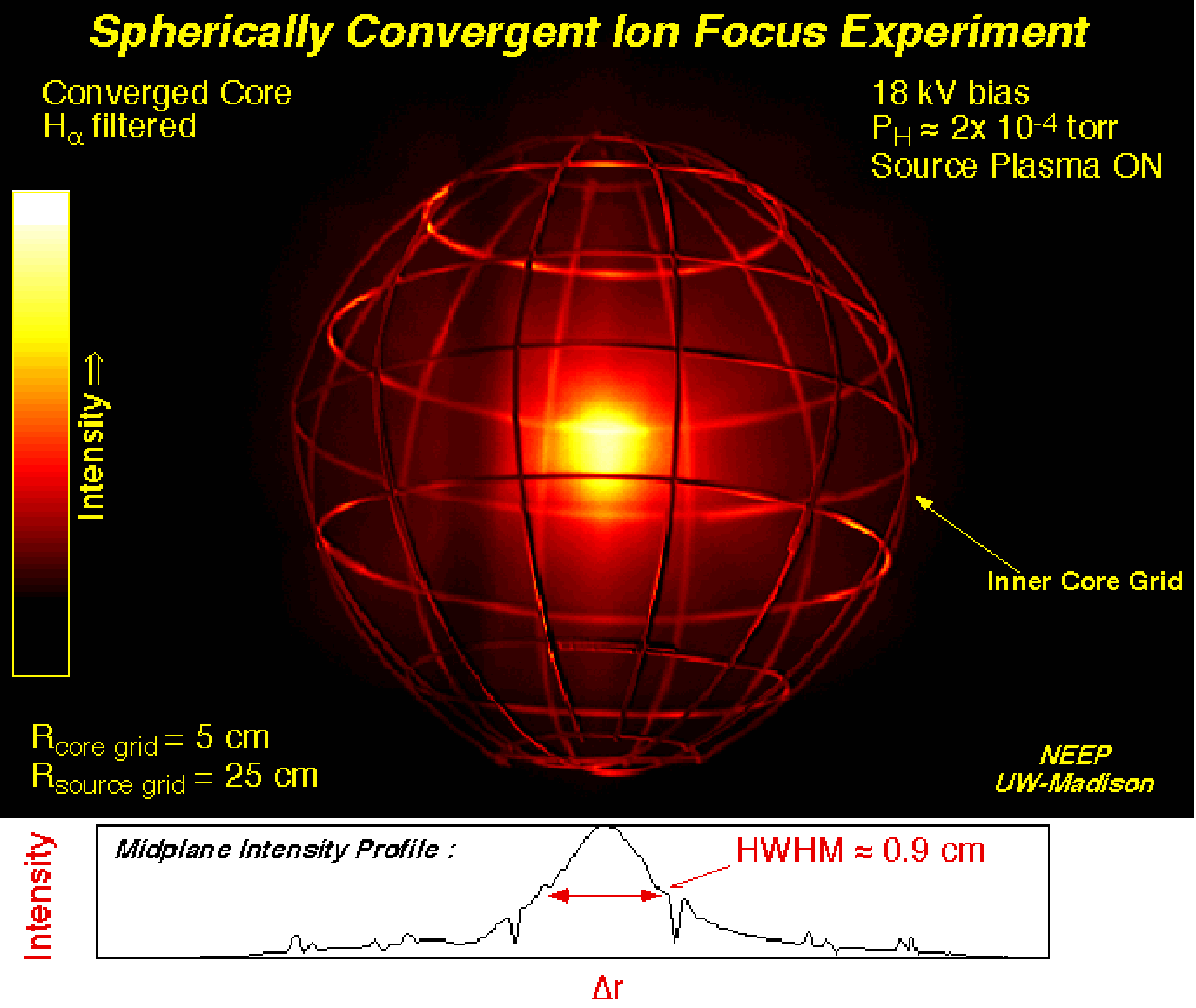


There Are 2 Basic Approaches to IEF

Purely Electrostatic

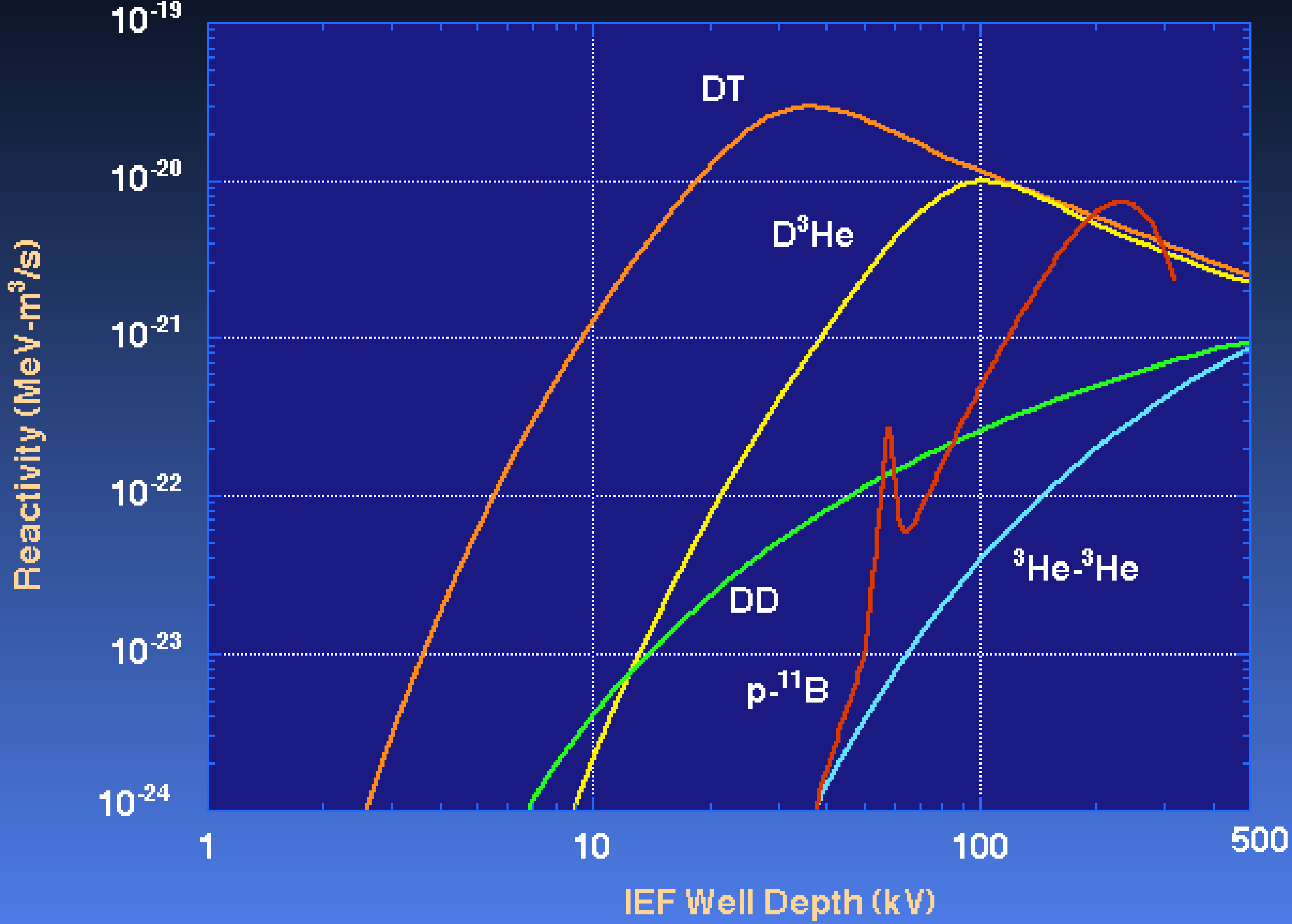
Virtual Cathodes (Established by Excess Electrons)





Spherically Convergent Ion Focus Experiment
Converged Core
H_α filtered
18 kV bias
$P_H \approx 2x\ 10^{-4}$ torr
Source Plasma ON
Intensity ⇒
Inner Core Grid
$R_{core\ grid} = 5$ cm
$R_{source\ grid} = 25$ cm
NEEP
UW-Madison
Intensity
Midplane Intensity Profile :
HWHM ≈ 0.9 cm
Δr

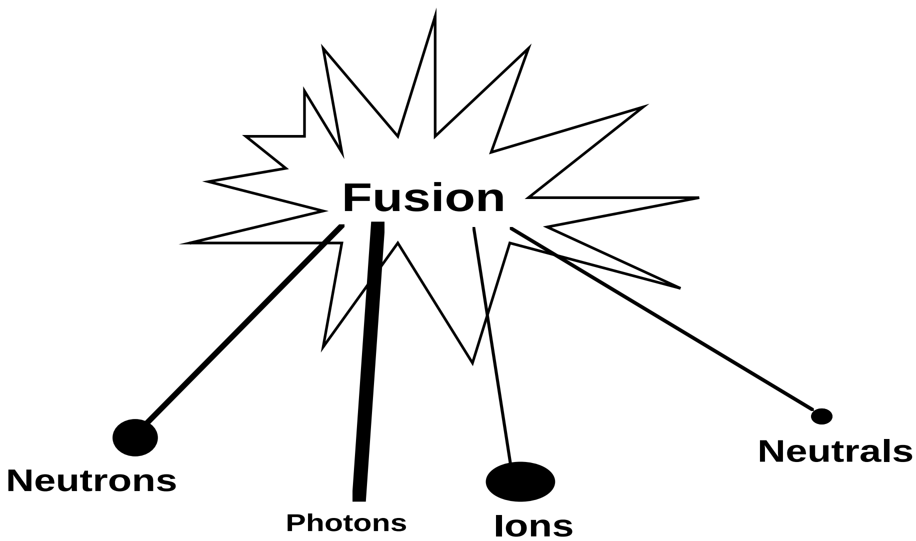
Reactivities ($\Sigma E_{fus} \sigma v$) versus IEF Well Depth

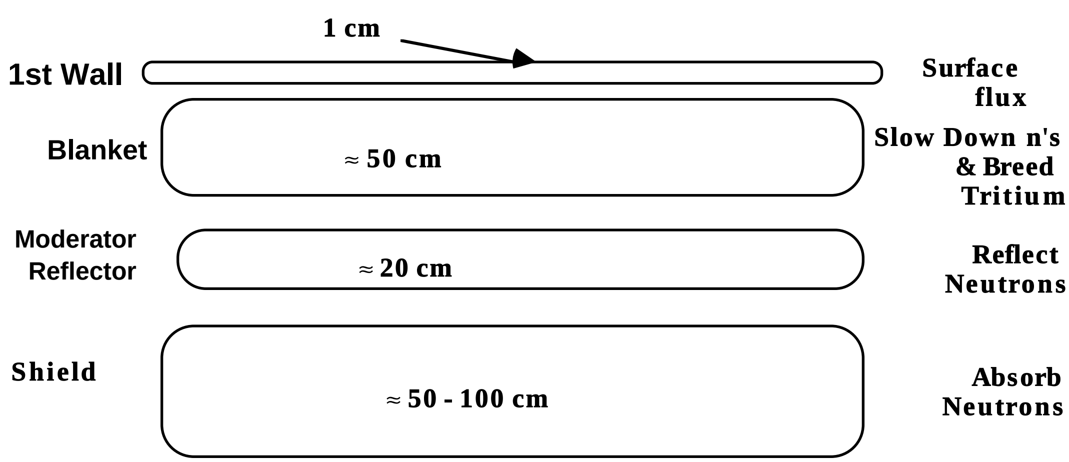


Blanket and Shield Design

Objective: ***To convert TN heat into useful energy, i.e.,***

Steam
Fissile Fuel
Synthetic Fuel
Electricity (directly)





Chamber Pressure

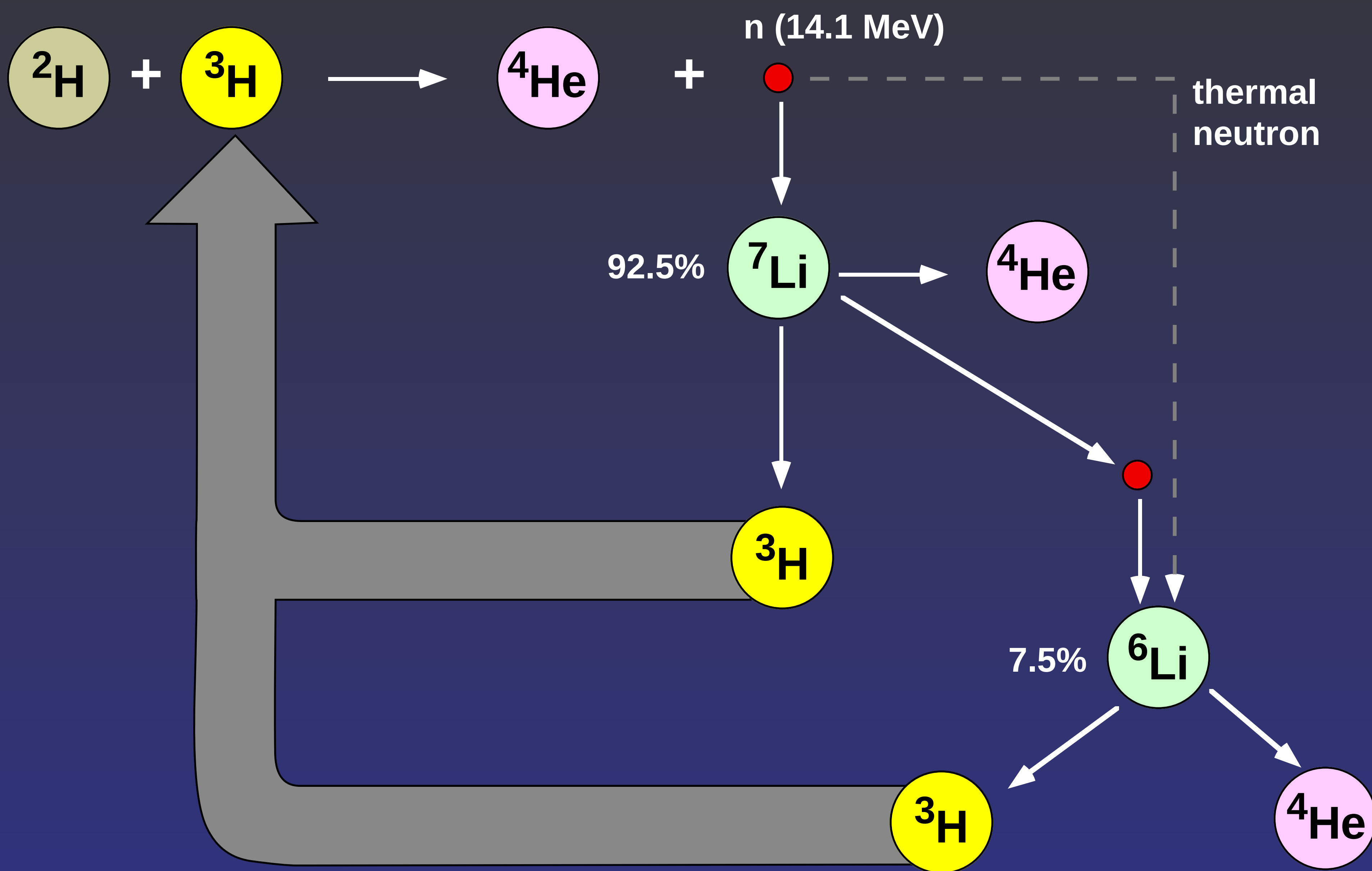
Magnetic ≈ 10^{-5} torr

Laser ≈ 1 torr
HIB ≈ 10^{-4} torr
LIB ≈ 1-100 torr

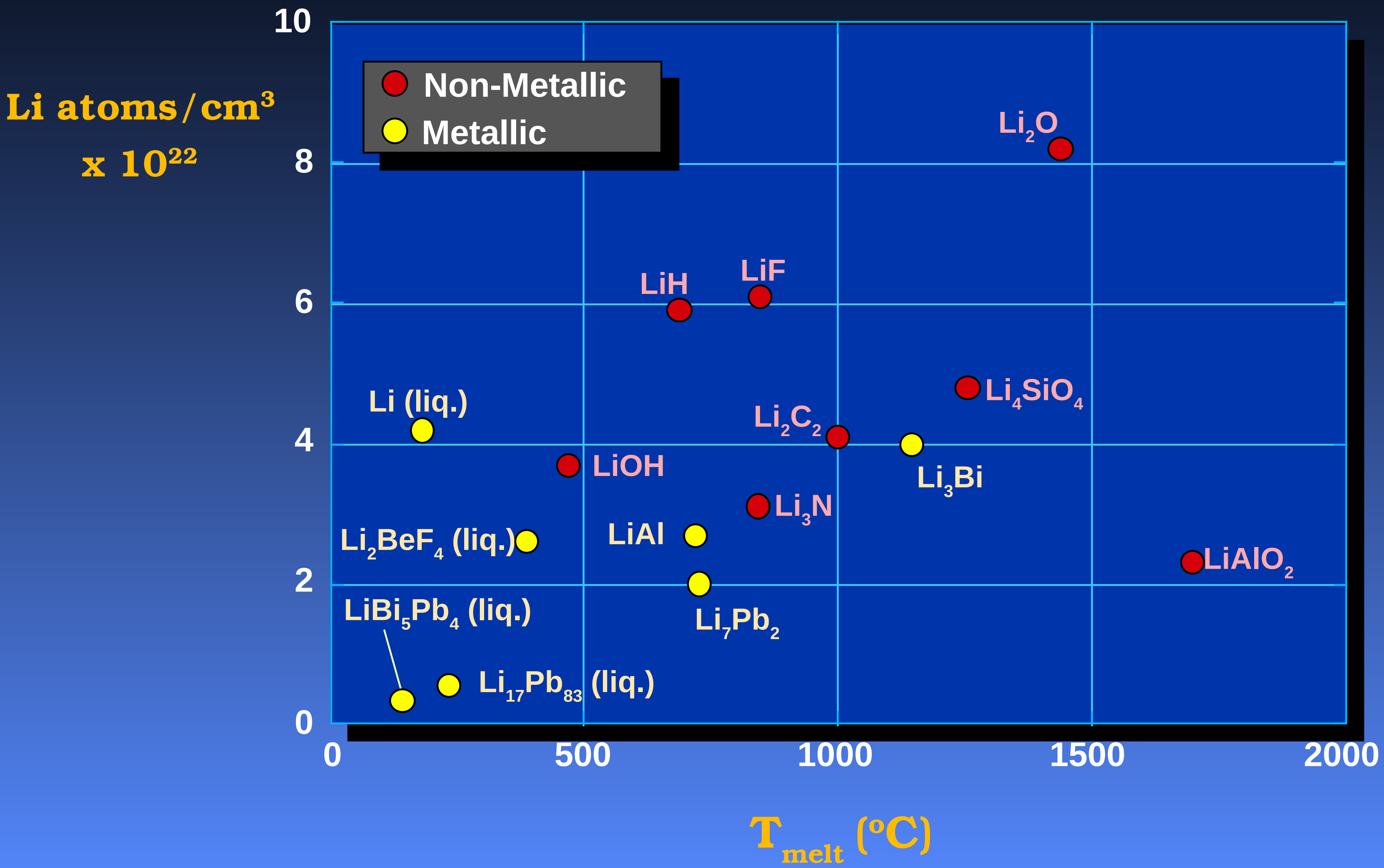
What Kind of Materials are in Fusion Reactors?

Chamber Gas		**He, Ne, Xe**
Blankets		
	Structure	**Steel, V, SiC, C, Ti Alloys**
	Breeder	**Li, Li_2O, $LiAlO_2$,Pb-Li.** **H_2O +LiOH**
	Coolants	**H_2O, Li, He, Pb-Li, Li_2O**
	n Multipilers	**Be, Pb, Zr**
Moderator/Reflector		**Steel, C**
Shield		**Steel, B, Pb, W, Concrete**

The DT Fusion Cycle Uses D and Li Fuels



Potential Lithium Containing Materials That Could Be Used to Breed Tritium



Information Summary of Candidate Breeder Materials								
	Li(liquid)	$LiPb_4$ (liq)	$LiBi_5Pb_4$ (liq)	Li_7Pb_2(s)	LiAl(s)	Li_2O(s)	$LiAlO_2$(s)	LiOH(liq)
Materials Data Base	Good	Poor	Zero	Fair	Fair	Fair	Fair	Fair
MP °C	180	235	125	726	700	1440	1600	0
T_{min} °C	230	285	175	270	250	500	450	10
T_{max} °C	400	550	400	330	310	800	850	200
Reason for T_{max}	Corrosion	Corrosion	Corrosion	<-----------------Sintering------------------>				Corrosion
Breeding Capability	Good	Good	Good	Excellent	Poor	Good	Poor	Good
Steady Tritum recovery	Excellent	Excellent	Excellent	Poor	Poor	Poor	Fair	Excellent
Reactor Relevant	Very Good	Very Good	Very Good	poor	Poor	?	?	Poor
Chemical Reactivity	Bad	Fair	Fair	Poor	Poor	Hygro-scopic	Best	Best

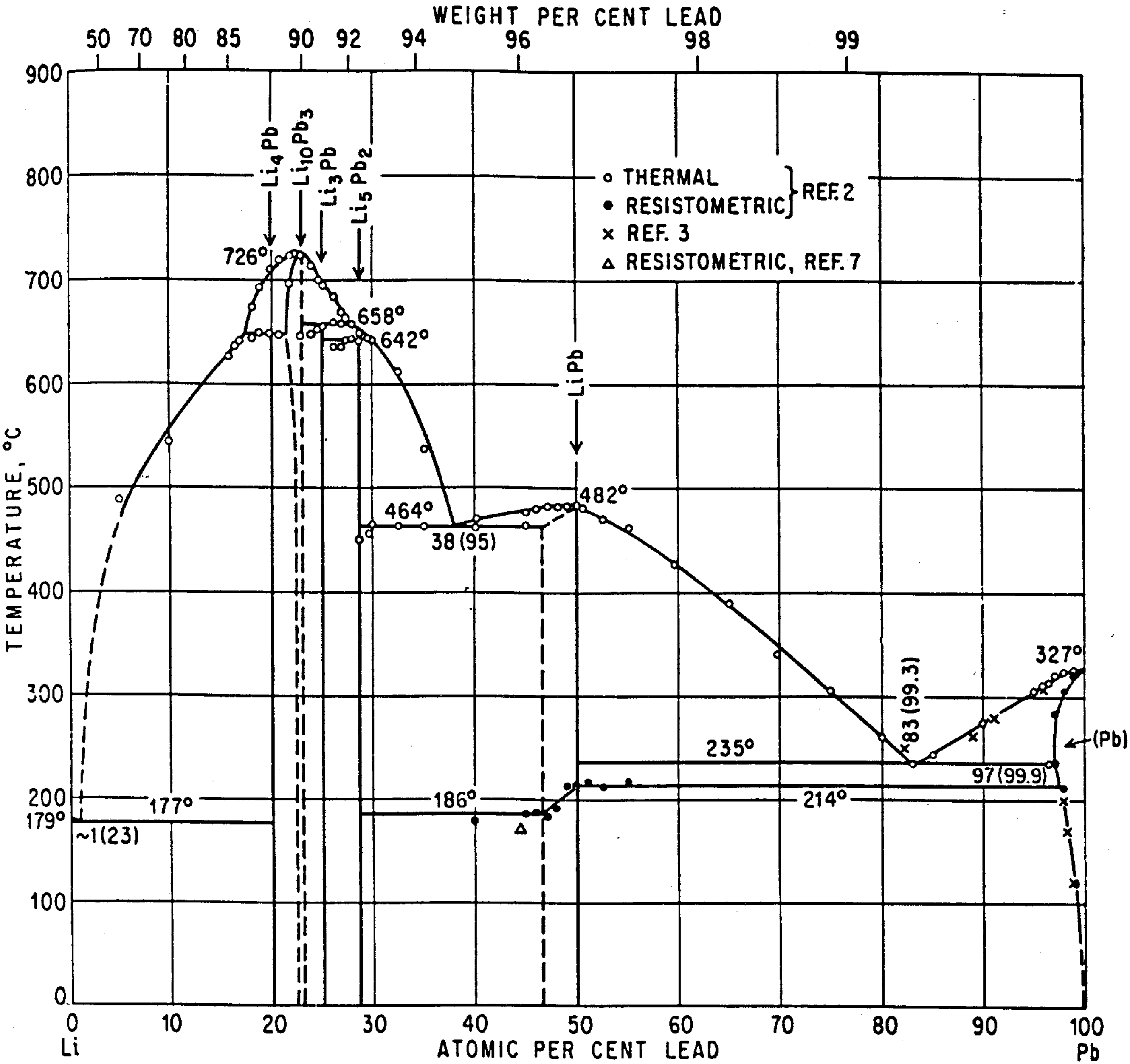
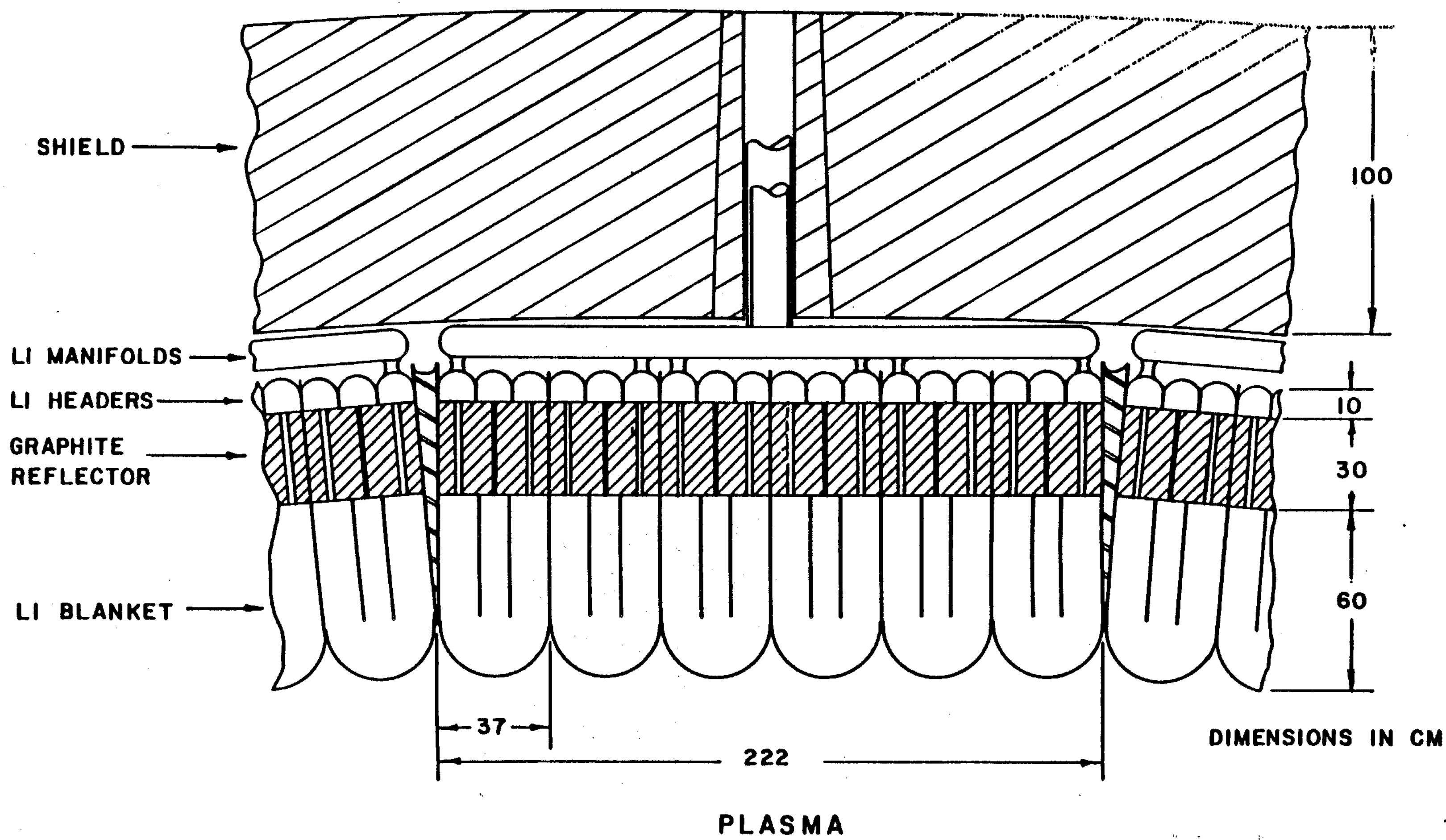


Fig. 497. Li-Pb. (See also Note Added in Proof.)

An Old Example of a Li Self-Cooled Blanket – UWMAK-III, 1976

University of Wisconsin



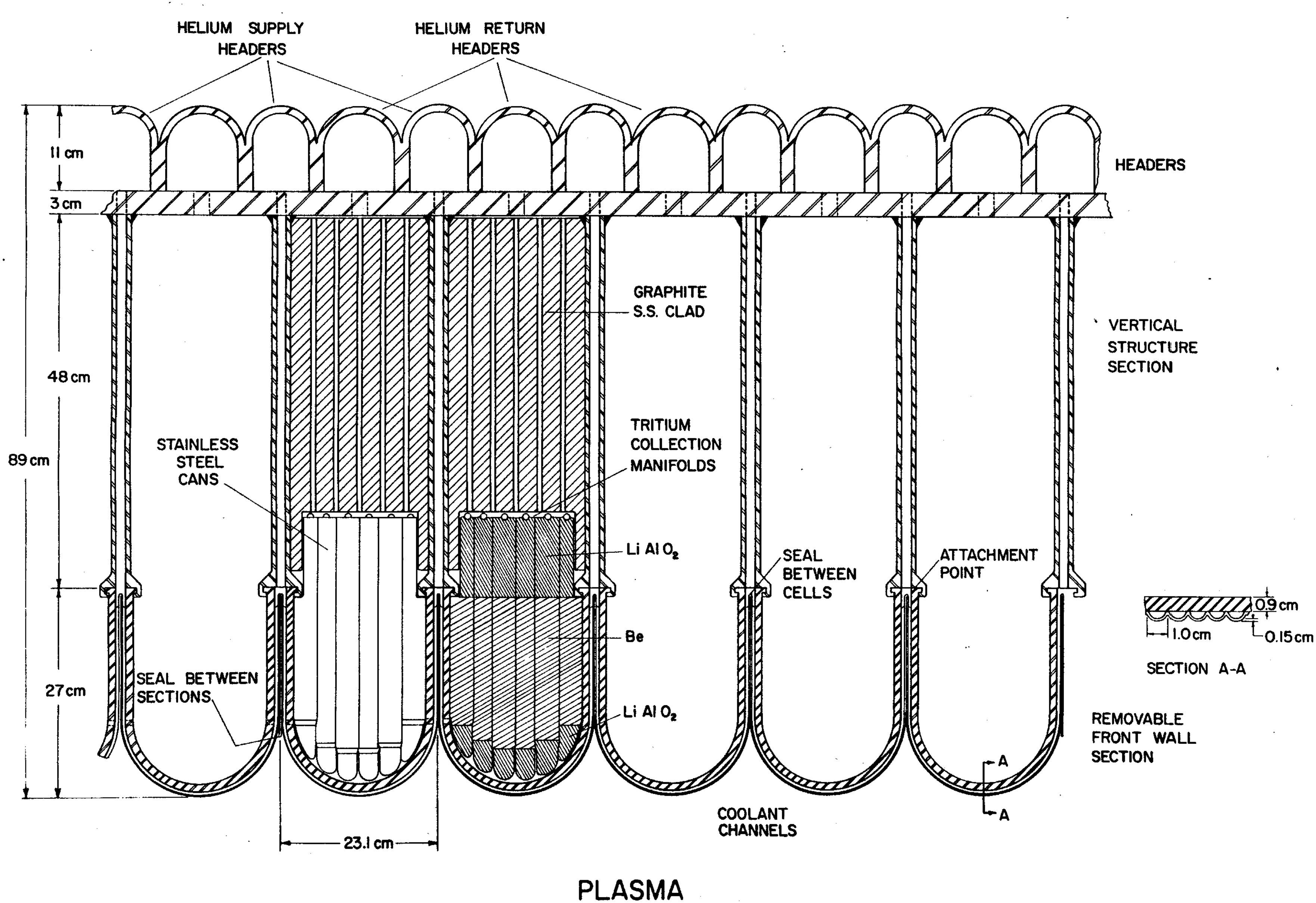
Structure: TZM

Breeder: Li

Coolant: Li

Reflector: C

BLANKET SECTION FOR UWMAK-II



Tritium Decay

^3H-->Beta (5.7 keV) + ^3He

$t_{1/2}$= 12.35 y 5.6% y^{-1}

Tritium Costs

Activity = 10,000 Ci/g
Cost ≈ $ 30,000/g 30$B/tonne

Biological Effects

- Biological half life ≈ 10 days
- Ingested Dose 1 Ci ≈ 70 mrem
- Maximum Permissible Body Burden ≈ 1 mCi
- Oxide forms (HTO, T_2O) greater hazard than gaseous forms

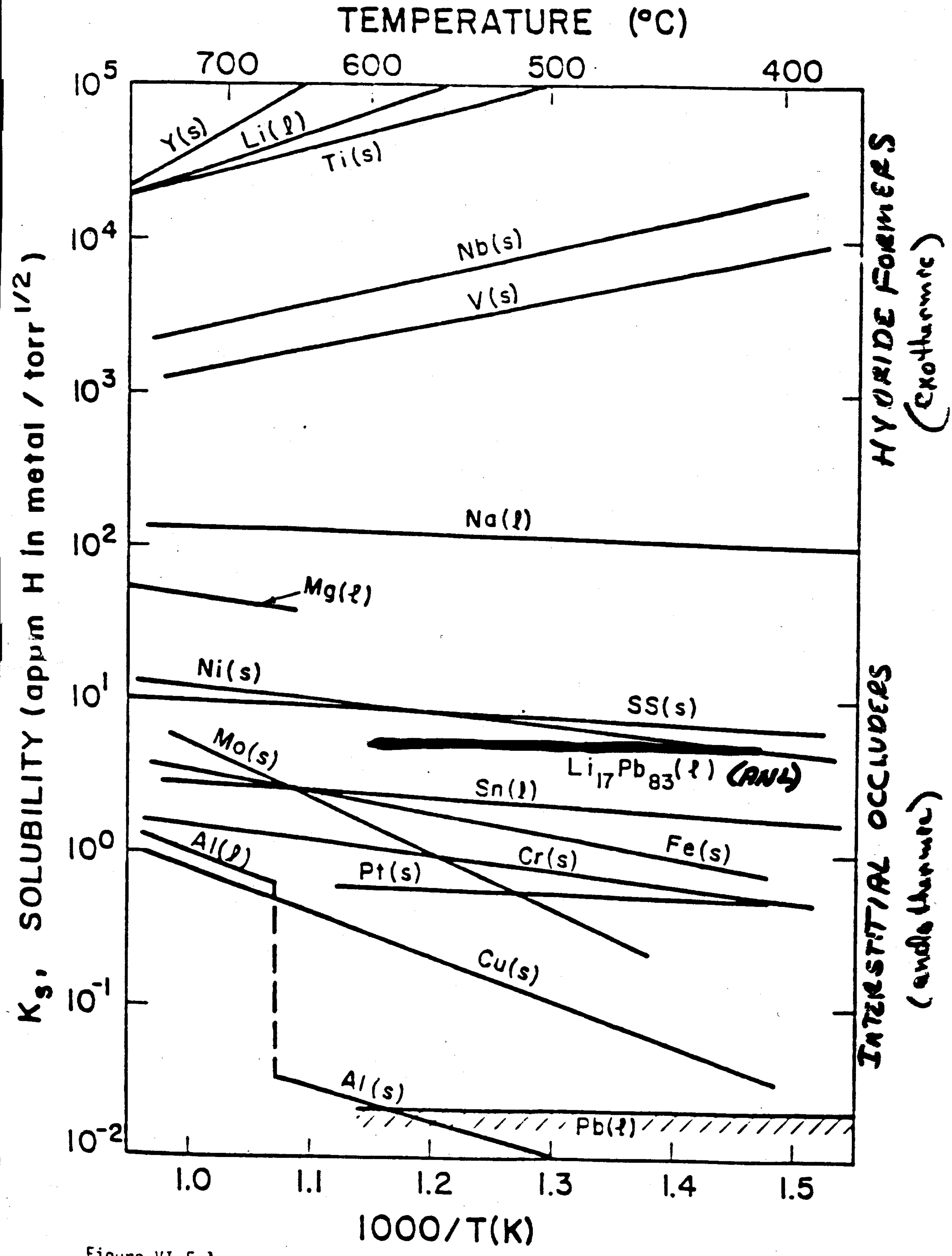


Figure VI.5-1 THE SOLUBILITY OF HYDROGEN IN SELECTED METALS AND ALLOYS AS A FUNCTION OF TEMPERATURE.

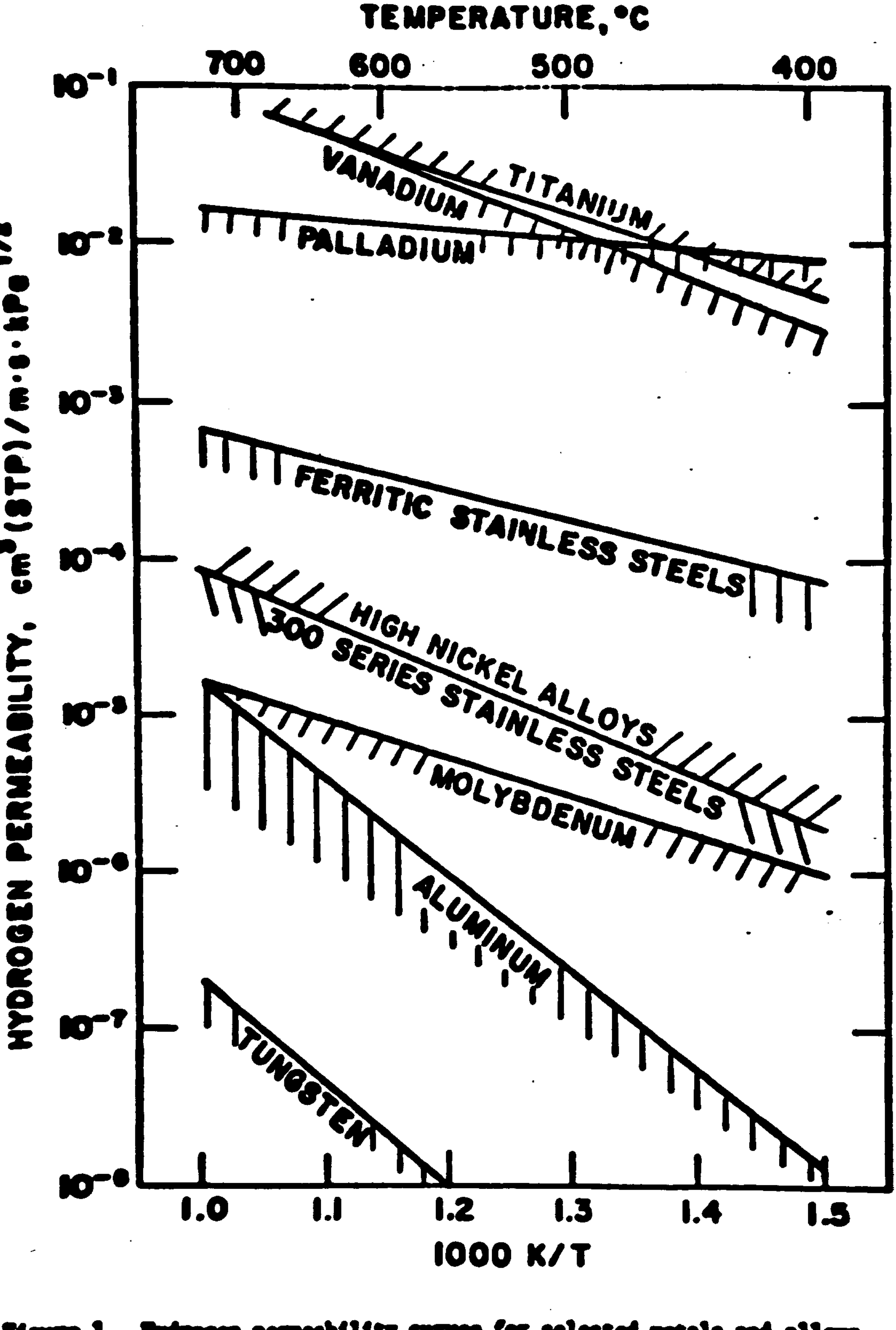


Figure 1. Hydrogen permeability curves for selected metals and alloys.

Radiological Hazards of Pu and T_2 in a 1 GW_e Power Plant			
	Units	Plutonium	Tritium
Inv. Outside Blanket	kg	900	25
Annual Flow Outside Blk.	kg/y	1600	32 (BR=1.25)
MPC (air)			
Insoluble ^{239}Pu, HT or T_2 gas	Ci/km^3	0.001	40,000
Sol. ^{239}Pu, HTO vapor	Ci/km^3	0.0006	200
BHP (air)			
Pure ^{239}Pu, T_2	km^3/g	63 to 1,000	0.25
Reactor Pu*, T in HTO	km^3/g	300 to 5,000	50
BHP (air)/GW_e• y			
Insoluble Pu, T_2	million km^3/y	450	0.008
Soluble Pu, HTO	million km^3/y	7,500	1.6
BHP (air) /GW_e			
Insoluble Pu, T_2	million km^3	270	0.006
Soluble Pu, HTO	million km^3	4,500	1.25
MPC (water)	Ci/km^3	5,000	3,000,000
BHP (water)			
Pure ^{239}Pu in Soluble Compound	m^3/g	12,500	
Reactor Pu* in Soluble Compound	m^3/g	62,500	
Pure Tritium in HTO	m^3/g		3,300,000
BHP/GW_e•y	km^3 water/y	94	110
BHP/GW_e	km^3 water	56	83

* ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu