Research Co-ordination Meeting on

Elements of Power Plant Design for Inertial Fusion Energy

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DESIGN CONCEPT OF FAST-IGNITION HEAVY ION FUSION POWER PLANT

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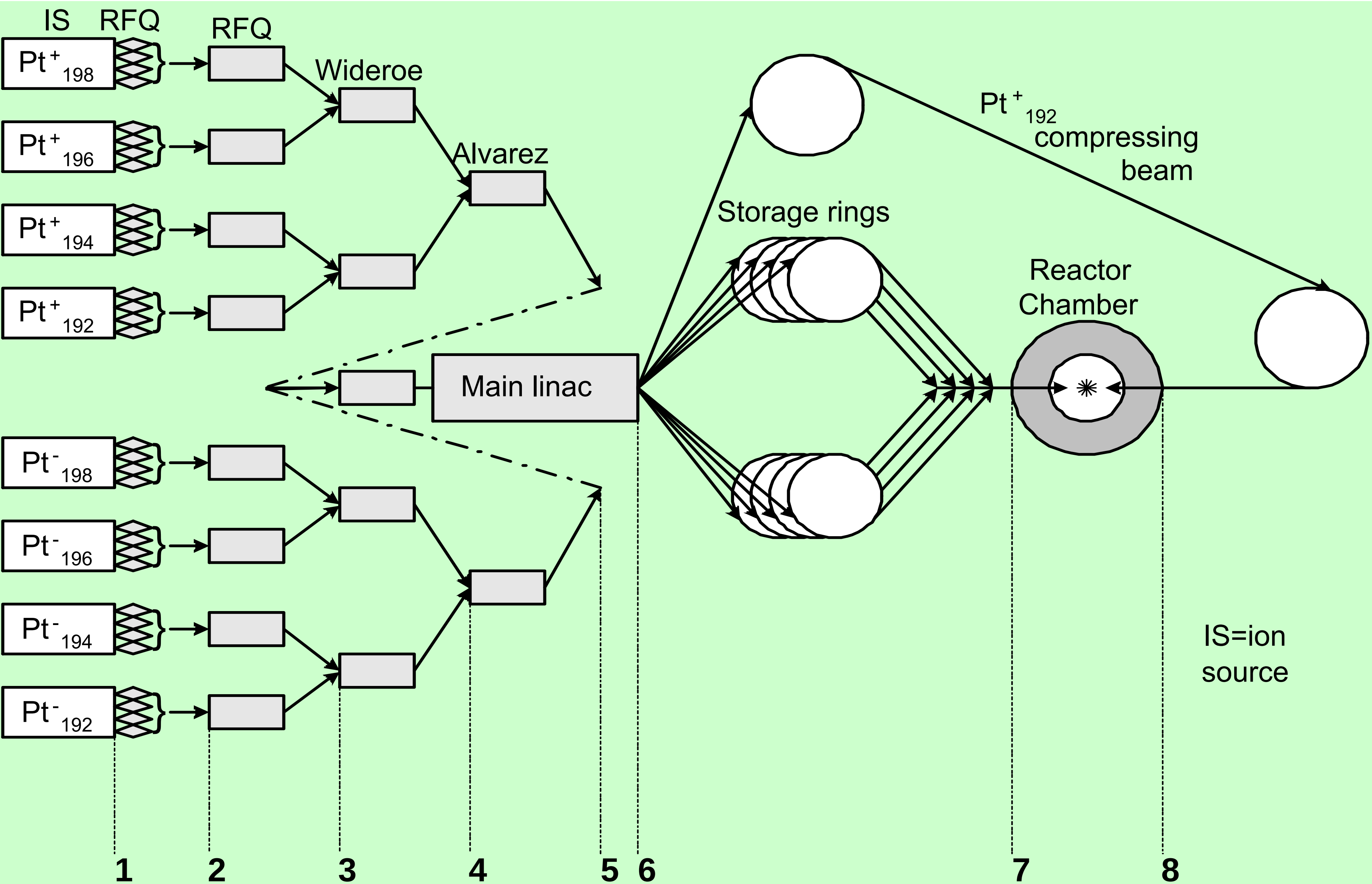
FIHIF Driver Scheme



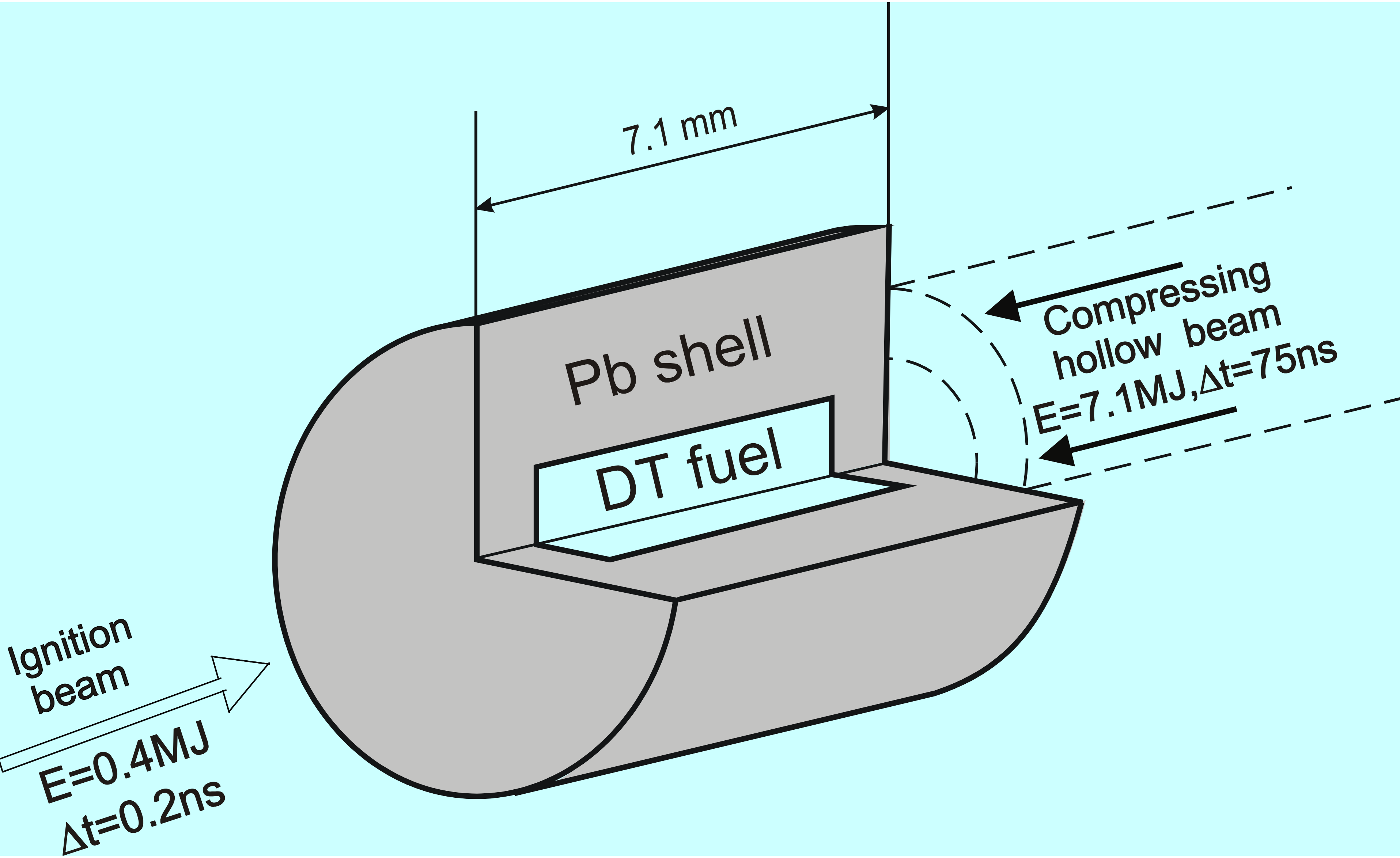
Beam parameters in HIF driver for fast ignition fusion						
Station number	Ion energy (GeV)	RF frequency (MHz)	Bunch current (A)	Momentum spread ($x10^4$)	Emittance (μm)	β=v/c
1	10^{-4}		0.04	±300	0.3	0.001
2	10^{-3}	6.25	0.16	±180	0.9	0.003
3	10^{-2}	12.5	0.4	±36	0.9	0.010
4	0.1	50	1	±37	0.9	0.033
5	0.2	200	4	±75	0.95	0.047
6	100	1000	230	±2	1	0.745
7	100	Single bunch	20000	±30	1	0.745
8	100	Single bunch	1600	±20	1	0.745

HIGH POWER HEAVY ION DRIVER

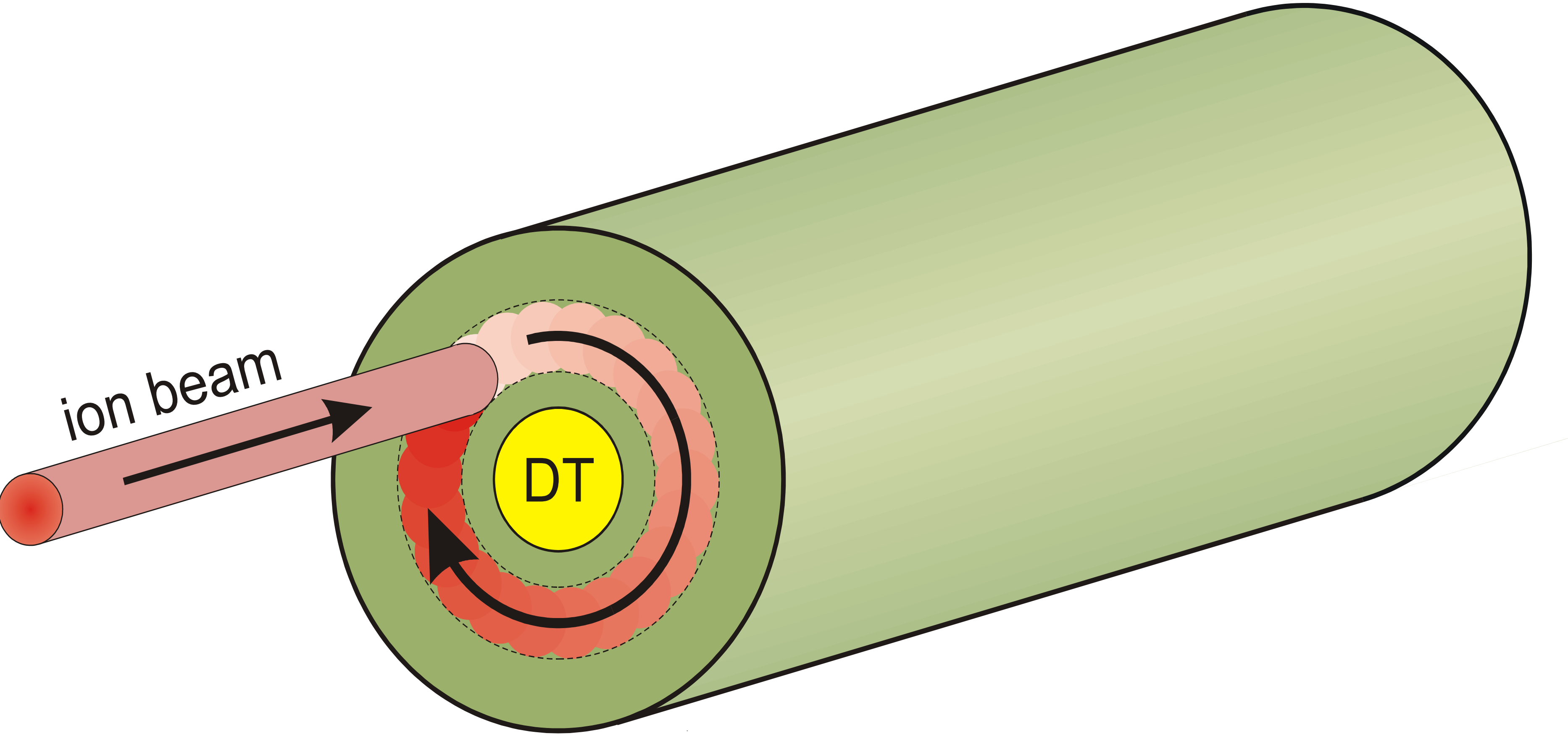
Ions		$Pt^{+,-}_{192,194,196,198}$
Ion energy	**(GeV)**	**100**
Hollow Compression beam		
Energy	**(MJ)**	**7.1 (profiled)**
Duration	**(ns)**	**75**
Rotation frequency	**(GHz)**	**1**
Ignition beam		
Energy	**(MJ)**	**0.4**
Duration	**(ns)**	**0.2**

Main linac length	**(km)**	**11**
Transmission line length	**(km)**	**5**
Driver efficiency		**0.25**

Cylindrical FIHIF Target



Cylindrical FIHIF Target



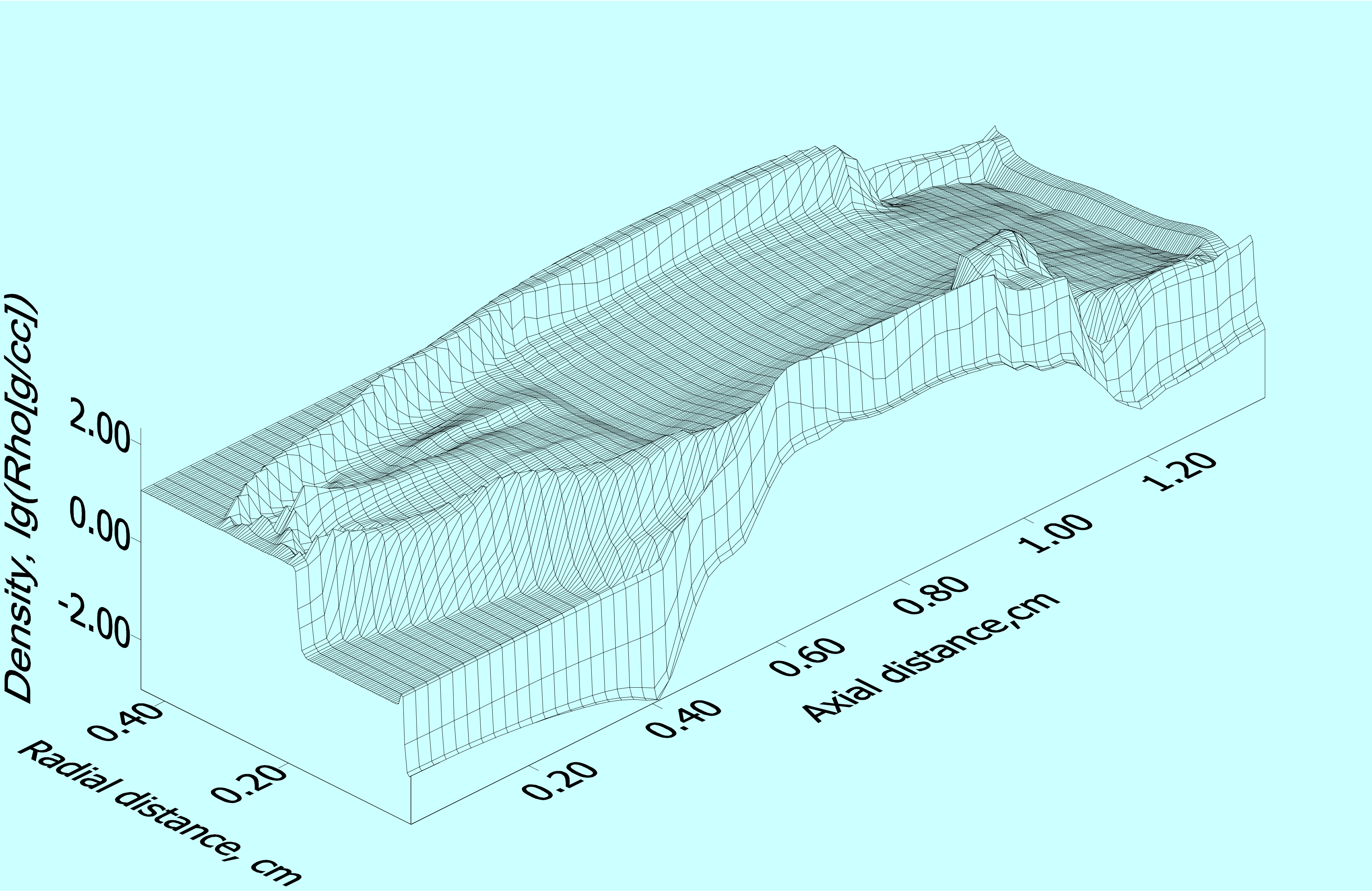
CYLINDRICAL TARGET

DT fuel mass	(g)	0.006
Total mass	(g)	3.696
Length	(mm)	7.1
ρR parameter	(g/cm^2)	0.5
Burn fraction		0.35
Gain		100
Fusion energy	(MJ)	750

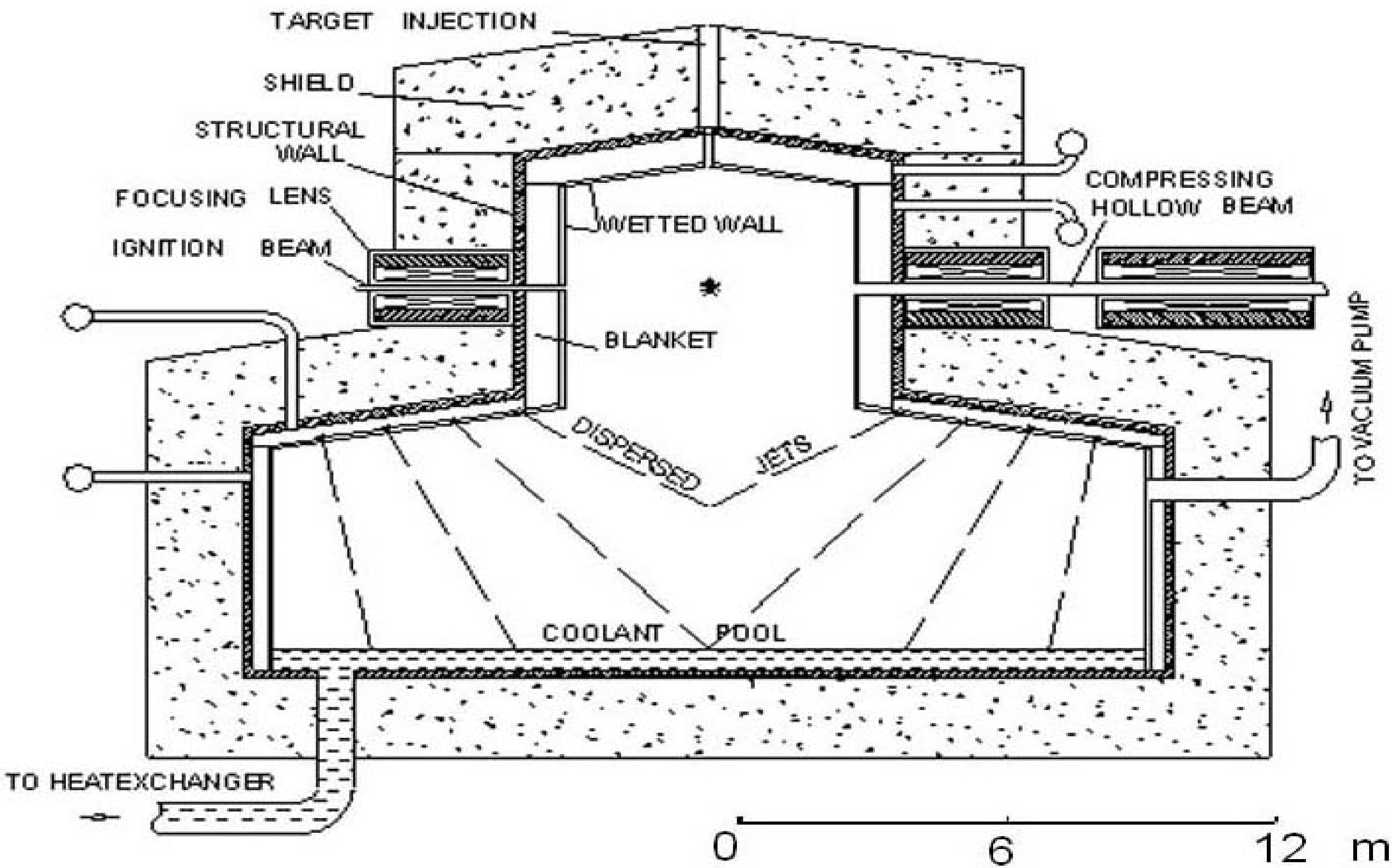
Energy partition

X-ray	(MJ)	17
Ion debris	(MJ)	187
Neutrons	(MJ)	546

Density distribution in compressed cylindrical target for FIHIF (t=30ns)



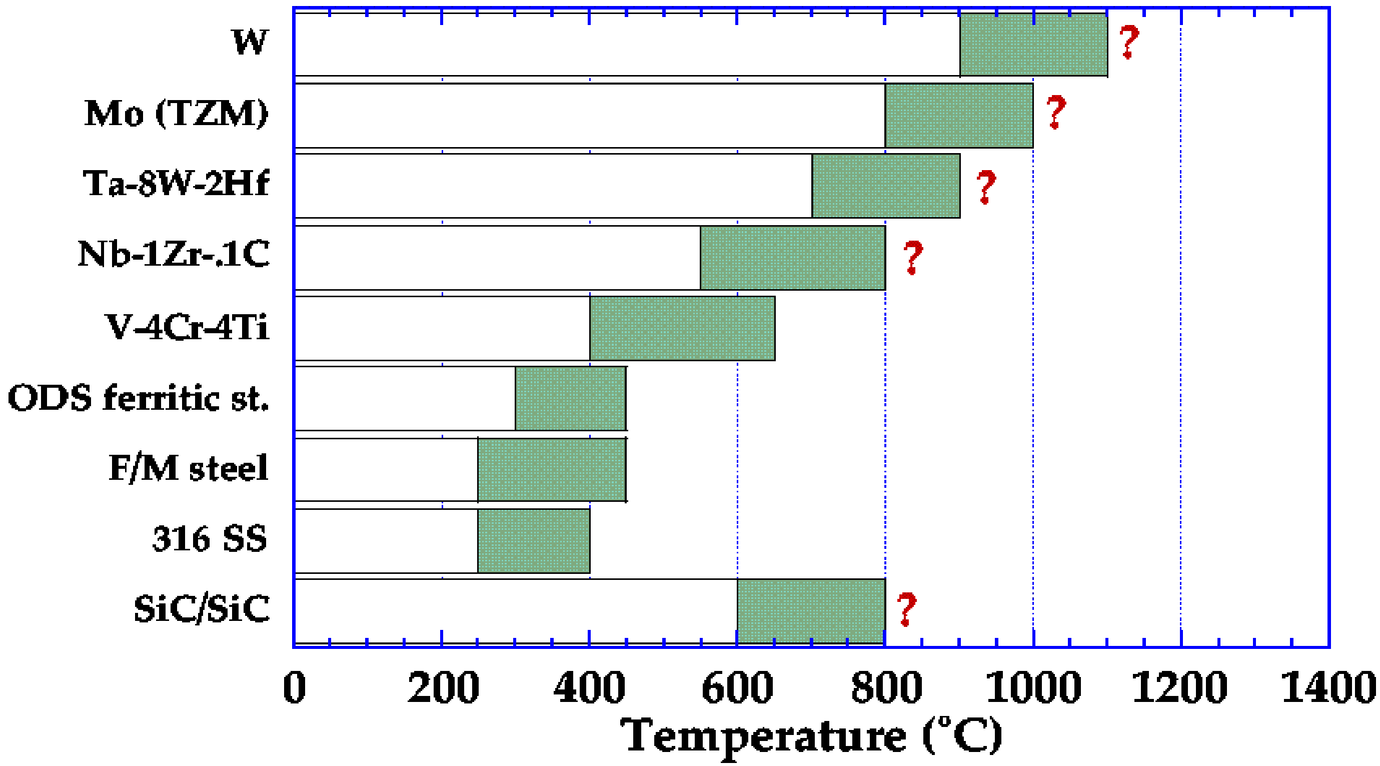
REACTOR CHAMBER FOR FIHIF POWER PLANT



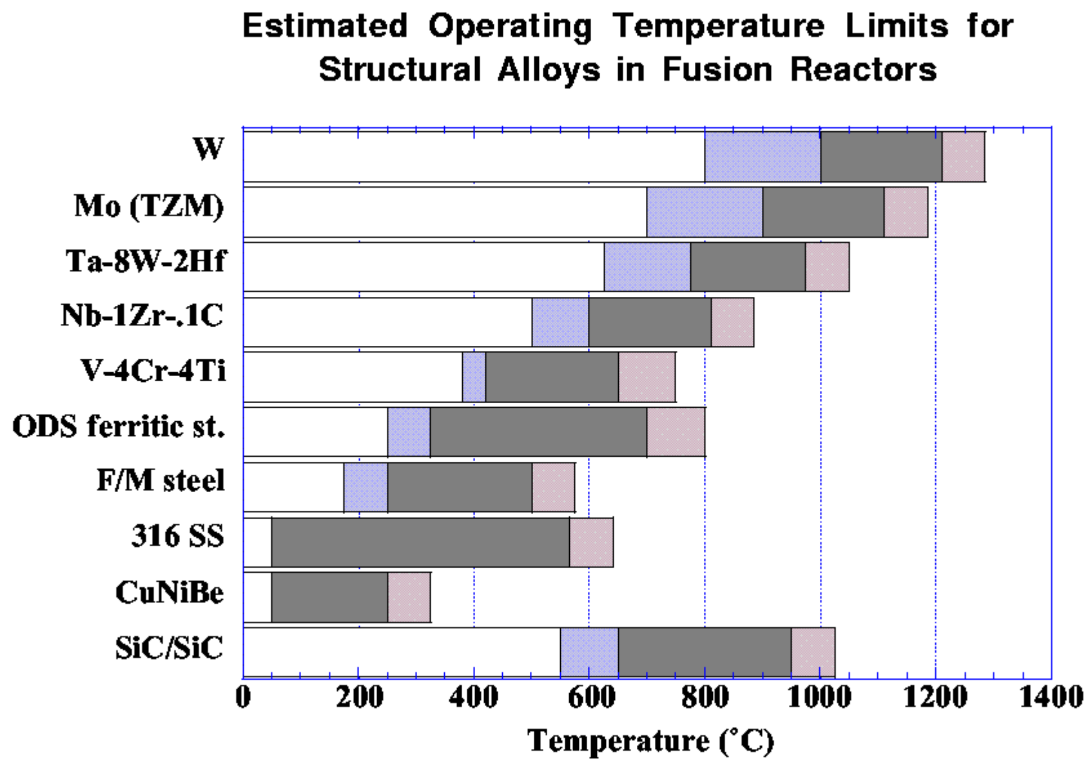
REACTOR CHAMBER CHARACTERISTICS

Fusion energy per shot	**(MJ)**	**750**
Repetition rate	**(Hz)**	**2**
Li/Pb atom density	**(cm^{-3})**	**10^{12}**
Coolant temperature	**(^{o}C)**	**550**
Explosion cavity diameter	**(m)**	**8**
Number of beam penetrations		**2**
First wall material		**SiC**
Coolant tubes material		**V-4Cr-4Ti**
Energy multiplication		**1.096**

Estimated Operating Temperature Limits for Structural Alloys in Fusion Reactors: Pb-17%Li Coolant



S.J. Zinkle
11th APEX Meeting
Argonne National Laboratory, May 10-12, 2000



- Lower temperature limit based on radiation hardening/ fracture toughness embrittlement (K_{1C}< ~30 MPa-m$^{1/2}$)—large uncertainty for W due to lack of data
- Upper temperature limit based on 150 MPa creep strength (1% in 1000 h); chemical compatibility considerations may cause further decreases in the max operating temp.

Summary of SiC/SiC Properties

Ultimate Tensile Strength (unirradiated)
σ_{UTS} ~ 220-240 MPa (20-1000˚C)

Proportional Limit Strength (Unirradiated)
σ_Y(MPa) ~70 MPa (20-1000˚C)

Elongation
e_{tot} , eu, RA are very low in unirradiated and irradiated conditions

Elastic constants
E_Y GPa) ~400 GPa 20- 1000˚C (Sylramic or Hi-Nicalon type S fibers, 10% matrix porosity)

G (GPa) =~165 GPa 20- 1000˚C

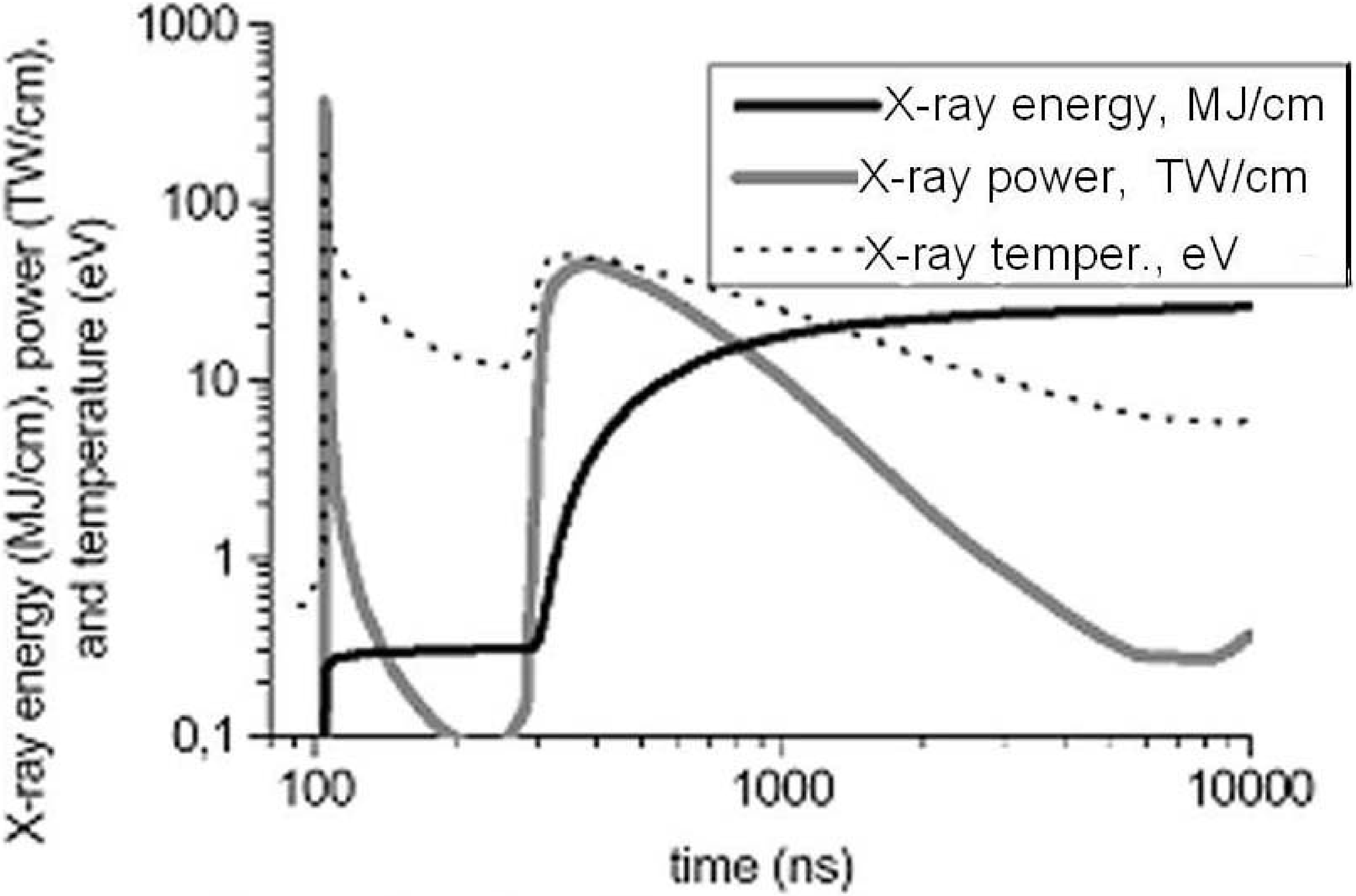
ν=0.16 20- 1000˚C

Thermophysical properties
α_{th} ~ 2.5 ppm/˚C (20˚C) to 4.5 ppm/˚C (1000˚C)

$C_P = 1110 + 0.15\,T - 425\,e^{-0.003T}$ J/kg-K (1000˚C)

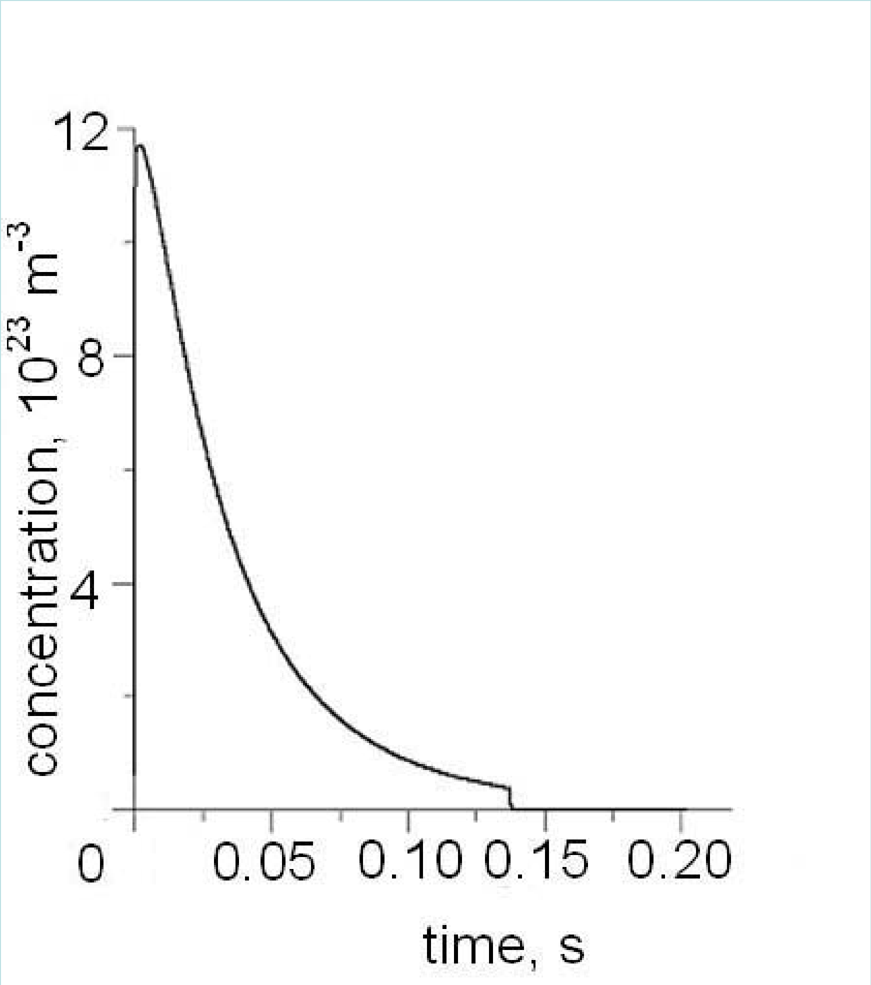
k_{th} = 10-15 W/m-K (400-1000˚C, after irradiation)

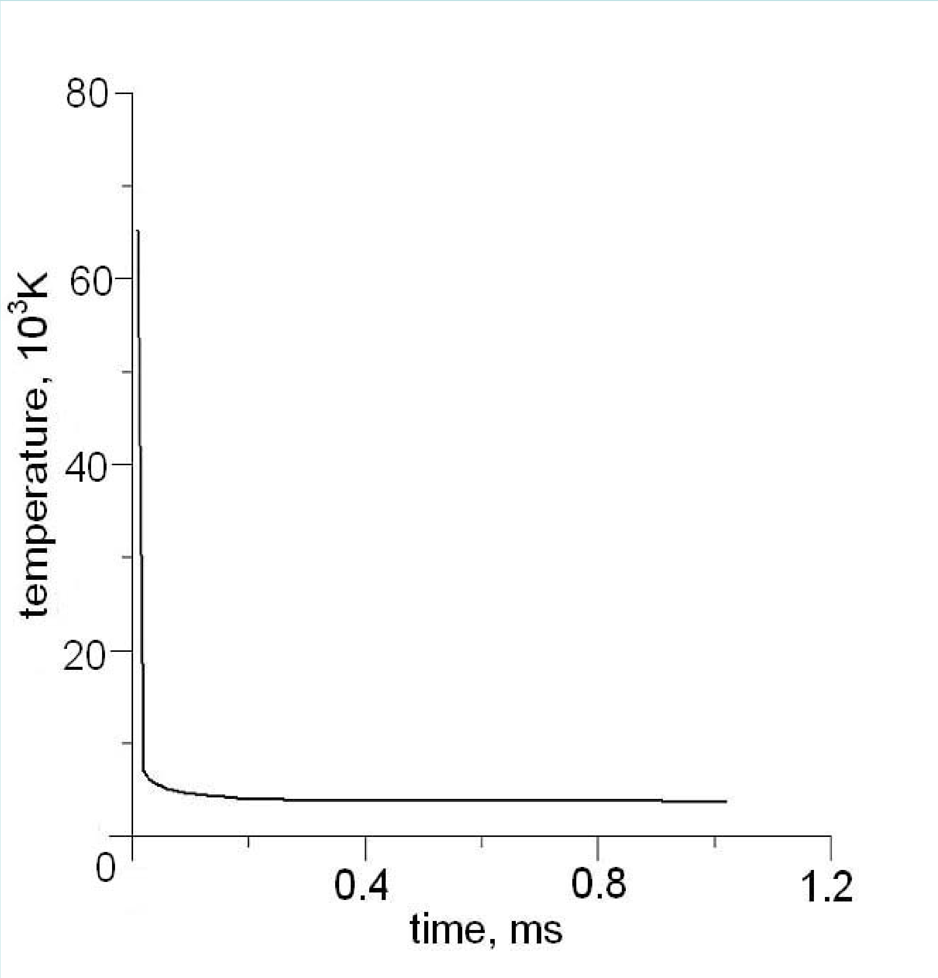
Recommended operating temperature limits (structural applications)
Tmin ~ 400˚C (due to rad.-induced decrease in thermal conductivity)
Tmax = 1000˚C? (due to cavity swelling)

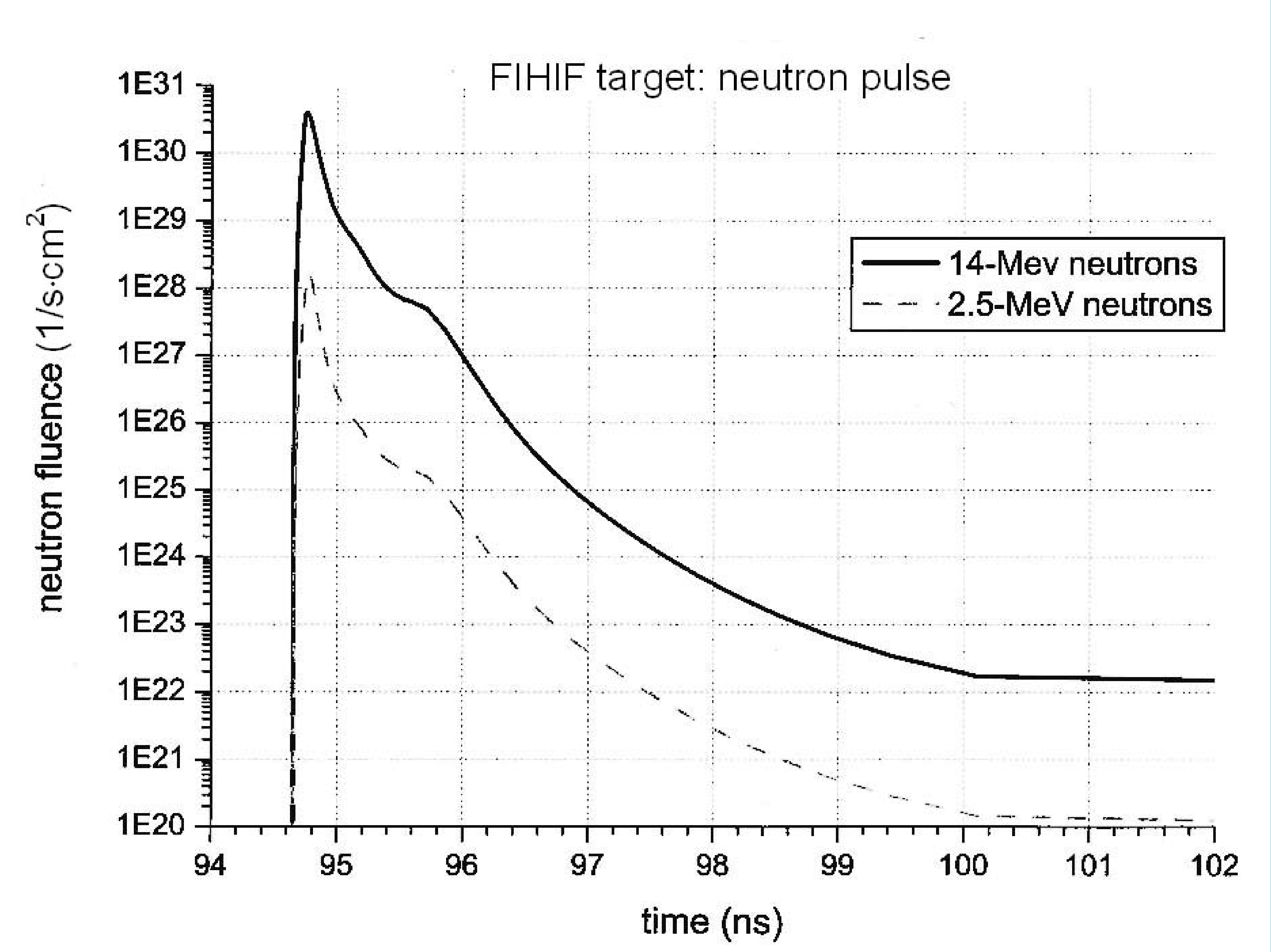


Temporal profiles of X-ray radiation characteristics for FIHIF cylindrical target

Evaporation-condensation dynamics





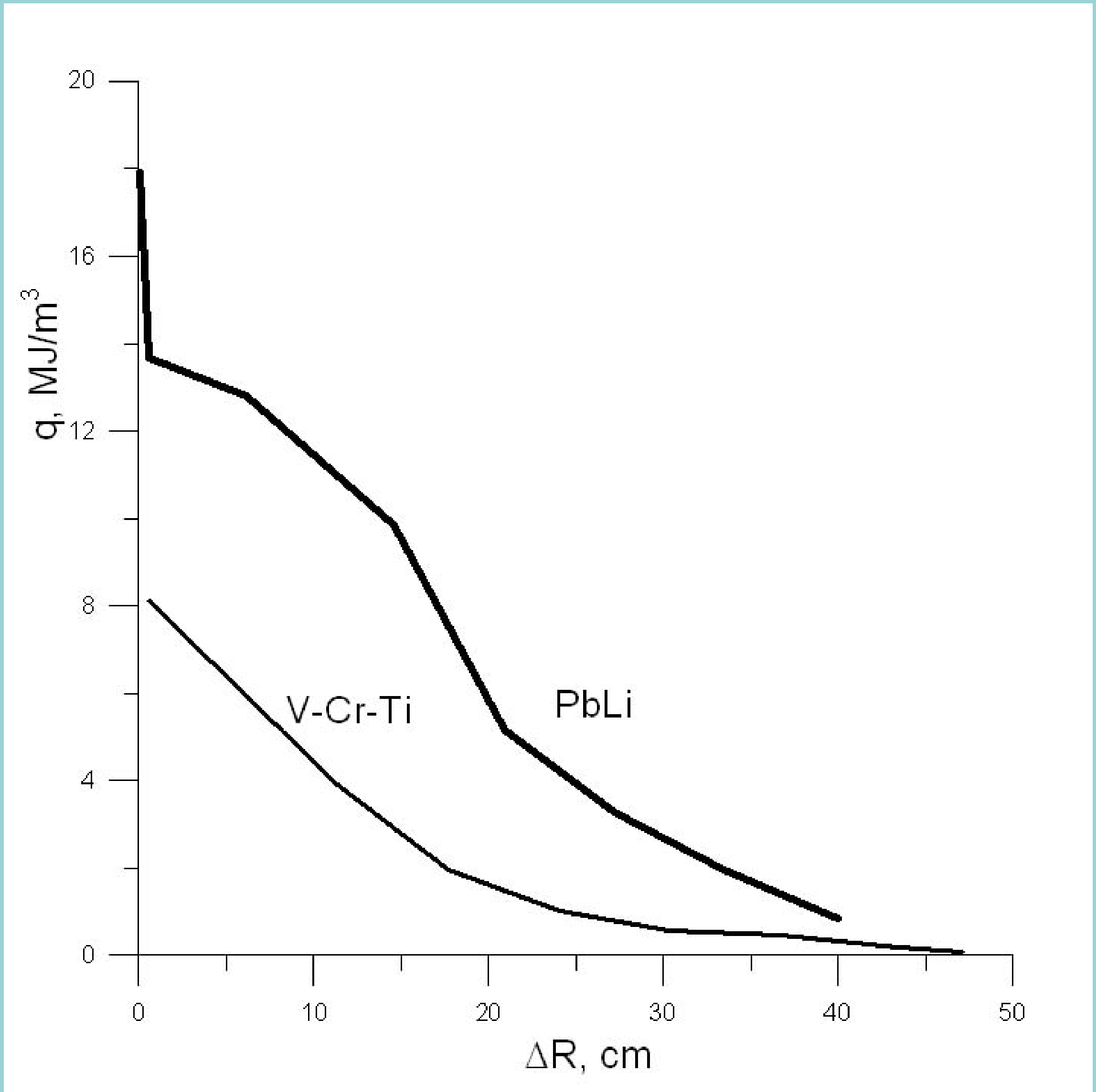


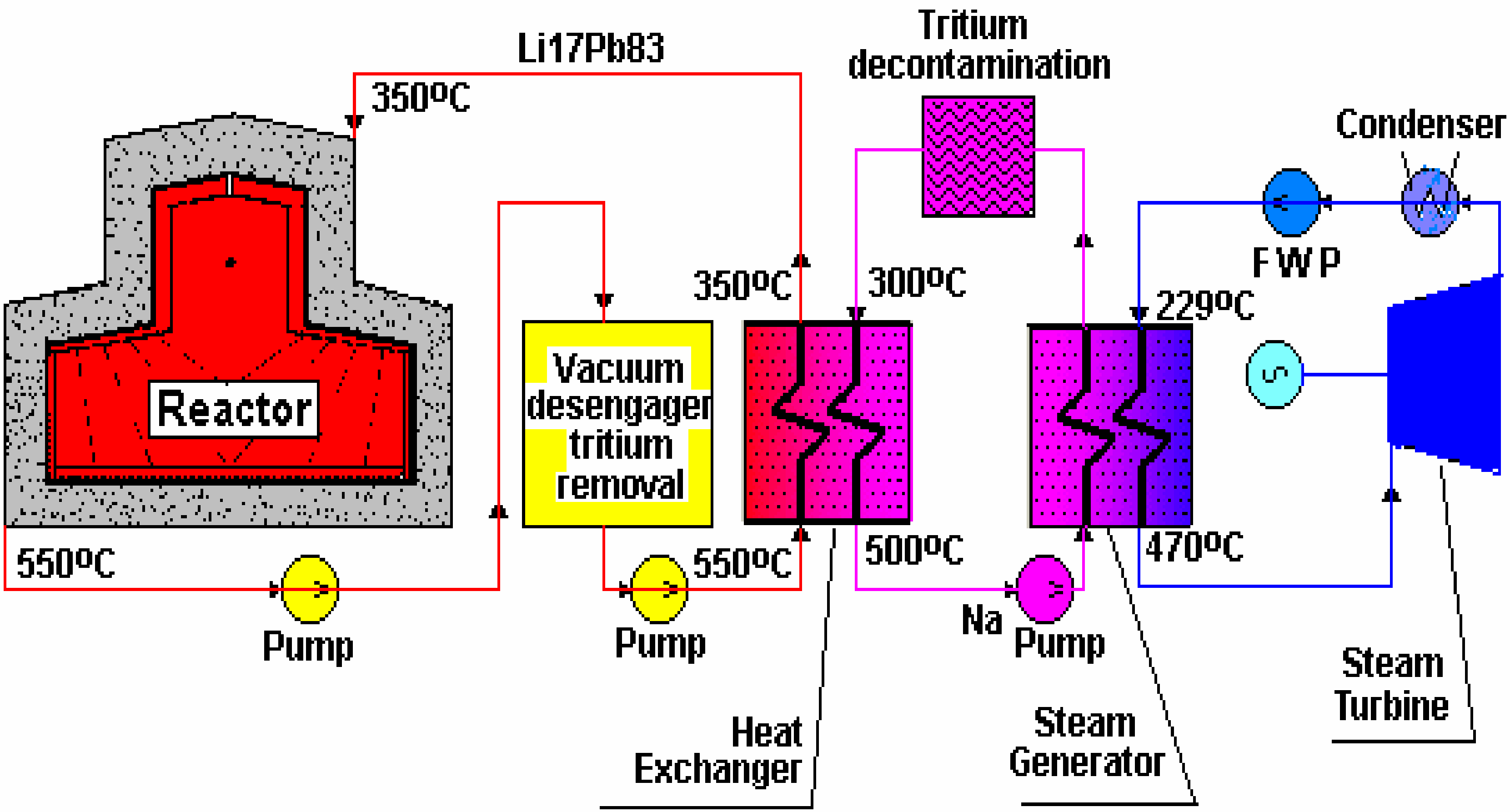
FIHIF target: neutron pulse
1E31
1E30
1E29
1E28
1E27
1E26
1E25
1E24
1E23
1E22
1E21
1E20
neutron fluence (1/s·cm²)
94
95
96
97
98
99
100
101
102
time (ns)
14-Mev neutrons
2.5-MeV neutrons

FIHIF Blanket Structure and Neutron Energy Deposition

Material of blanket zones	R, cm	ΔR, cm	ρ, g/cm^3	M, 10^3 kg	Q/V, MJ/m^3	Q, MJ
1. PbLi	400,0	400	10^{-9}	$3 \cdot 10^{-6}$	$5 \cdot 10^{-9}$	$1{,}6 \cdot 10^{-6}$
2. PbLi	400,1	0,1	9,3	1,86	17,92	3,58
3. SiC/ PbLi	401,1	1	5,7	11,51	13,68	27,65
4. PbLi	411,1	10	9,3	192,69	12,79	276,26
5. V/10Cr/5Ti	411,6	0,5	5,96	6,31	3,89	4,13
6. PbLi	417,6	6	9,3	120,62	9,85	127,84
7. V/10Cr/5Ti	417,9	0.3	5,96	3,87	1,96	1,27
8. PbLi	423,9	6	9,3	124,24	5,17	69,24
9. V/10Cr/5Ti	424,2	0,3	5,96	4,05	1,03	0,71
10. PbLi	430,2	6	9,3	127,96	3,29	45,46
11. V/10Cr/5Ti	430,5	0,3	5,96	4,17	0,56	0,40
12. PbLi	436,5	6	9,3	131,78	1,95	27,98
13. V/10Cr/5Ti	436,8	0,3	5,96	4,29	0,48	0,34
14. PbLi	443,0	6,2	9,3	140,15	0,85	13,33
15. V/10Cr/5Ti	444,0	1	5,96	14,72	0,17	0,44
16. HT-9	450,0	6	7,9	119,05	0,08	1,32
				Total: 1000		Total: 600

ENERGY DEPOSITION IN BLANKET MATERIALS





Thermal schematic of FIHIF power plant

ENERGY CONVERSION SYSTEM

Primary coolant loop $Li_{17}Pb_{83}$	
Max./min. temperature (°C)	550/350
Mass flow rate (ton/s)	13.1
Pump power (MW)	11.5
Intermediate coolant loop Na	
Max./min. temperature (°C)	500/300
Mass flow rate (ton/s)	6.40
Pump power (MW)	3.77
Steam cycle	
Steam parameters (MPa/°C/°C)	18/470/470
Net efficiency	0.417
Power plant parameters	
Net power (per 1 chamber) (MW)	670
Net efficiency	0.373

CONCLUSIONS

The concept of power plant for fast ignition HIF involves a number of new components and devices. High power heavy ion driver and cylindrical target look to have clear basic design. The massive target causes some redistribution of energy fluxes resulting from microexplosion. Altogether the long driver train and target positioning in flight are problems of concern.

The reactor chamber with wetted first wall has a minimum number of ports for beam injection. The composition of the reactor chamber of two sections makes easier the condensation problem and partly lessens pressure loading. The problems of coolant droplets and thermal stresses in blanket materials are of major concern in the reactor chamber.

The energy conversion system consisting of three loops is a convenient object for the plant efficiency optimization and thermal equipment development.