Target Design Effects in Chamber and Fusion Technology

(thinking in HiPER)

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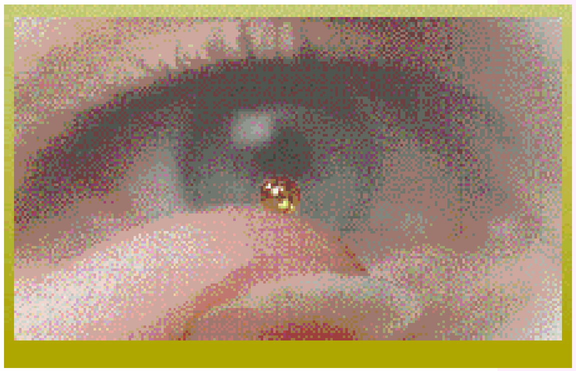


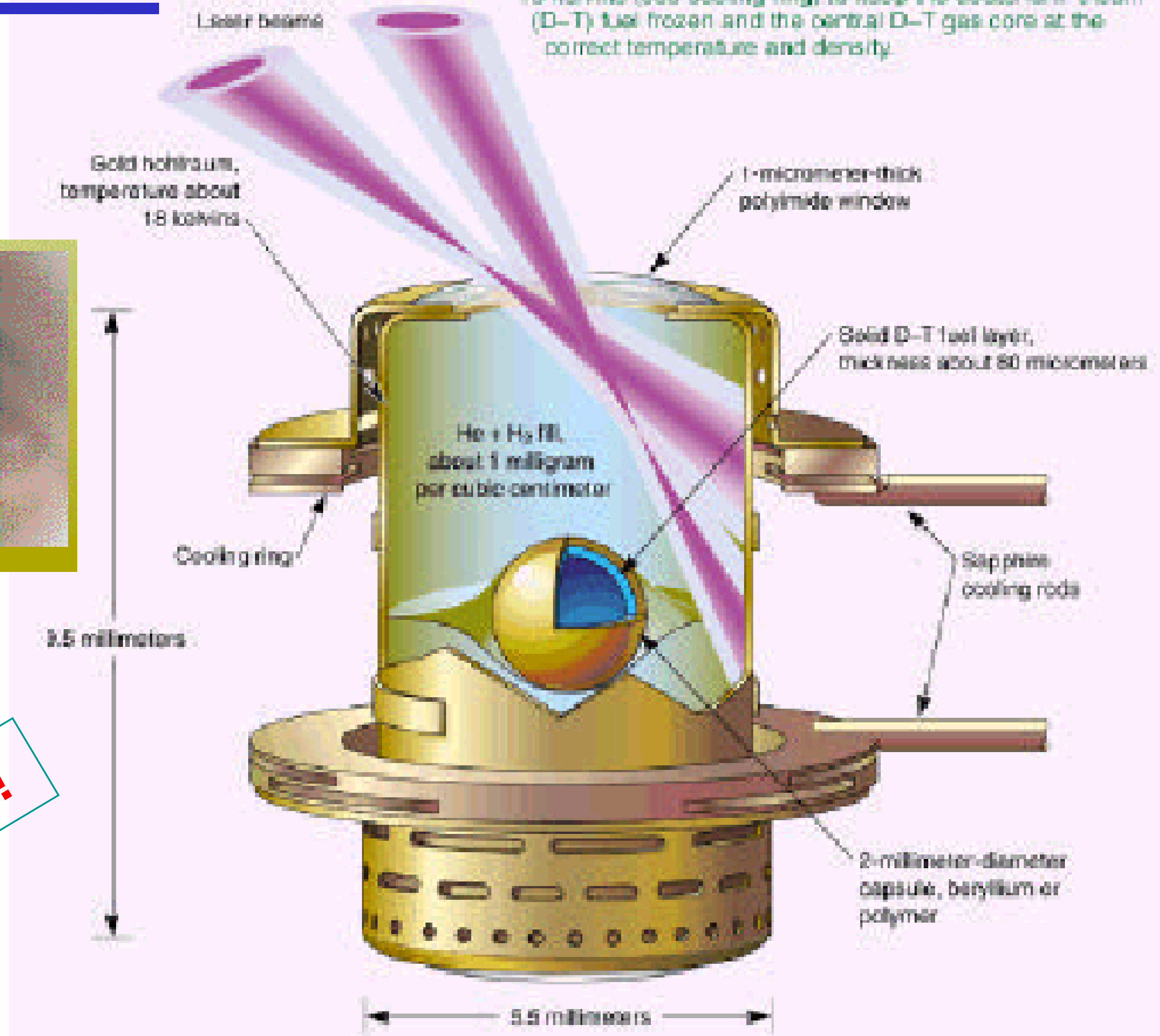
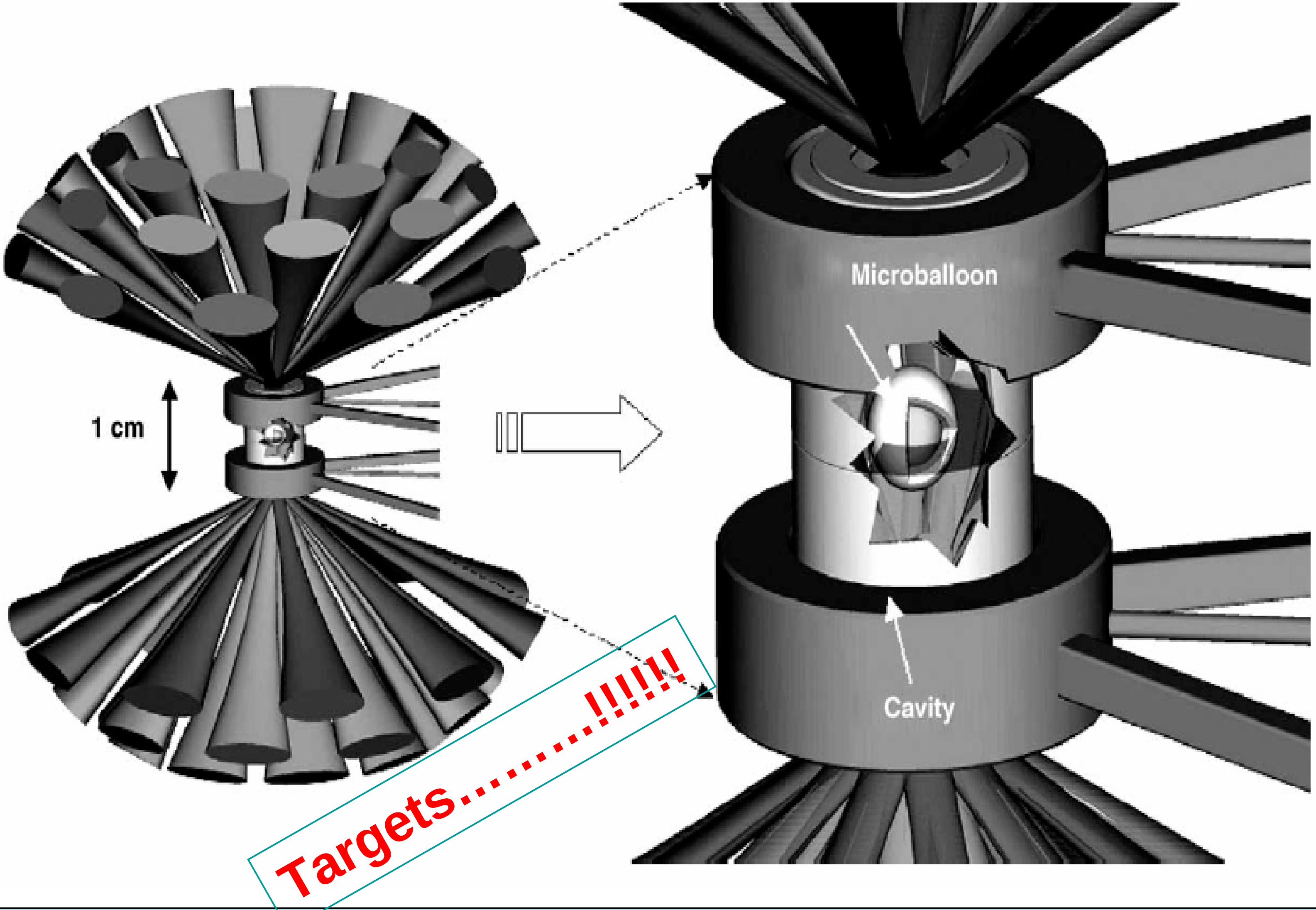


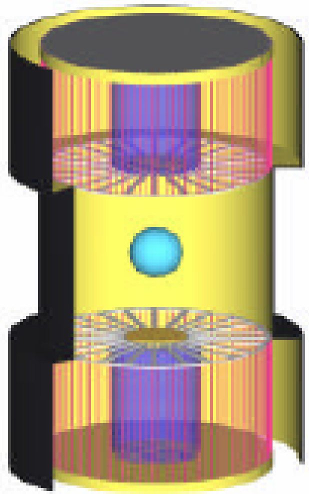
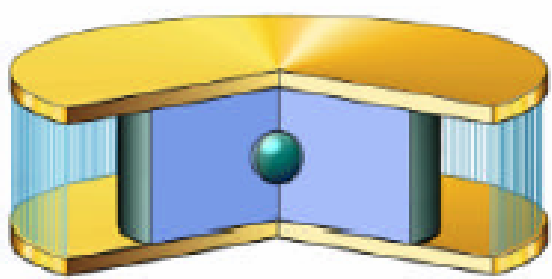
Figure 3. The hohlraum will be filled with hydrogen–helium gas (which will be contained inside polyimide windows) to minimize laser light scattering. The hohlraum will be maintained at 18 kelvins (see cooling ring) to keep the deuterium–tritium (D–T) fuel frozen and the central D–T gas core at the correct temperature and density.

Targets…….!!!!!!



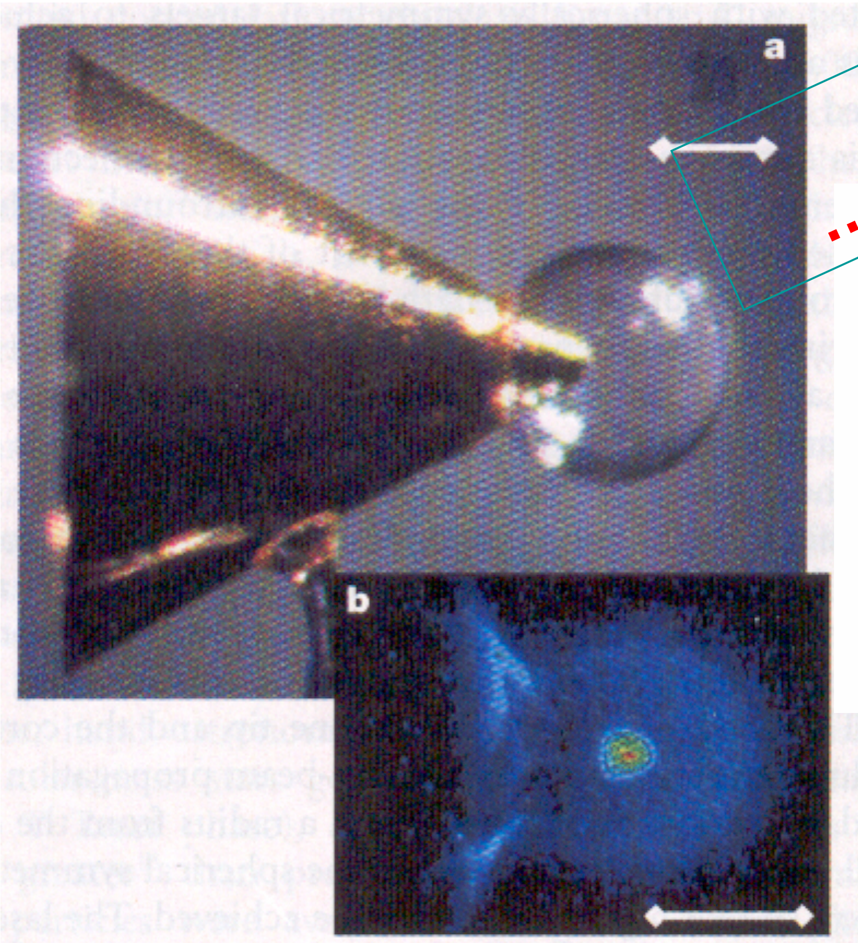
LaserMegaJoule (LMJ) / CEA-CESTA / Burdeos

Targets ....!!!!!!!!

	ICF – IFE Current / Driver / E_{abs} / Yield
Double-Pinch Hohlraum 	2 x 62 MA 16 MJ 1.3 – 2.6 MJ 400 – 1300 MJ
Dynamic Hohlraum 	54 – 95 MA 12 – 37 MJ 2.4 – 7.2 MJ 530 – 4400 MJ

Options for FAST IGNITION !!!!!!!!!!!!

TARGETS
……!!!!!!!!!!!!!!!!!!!!!!



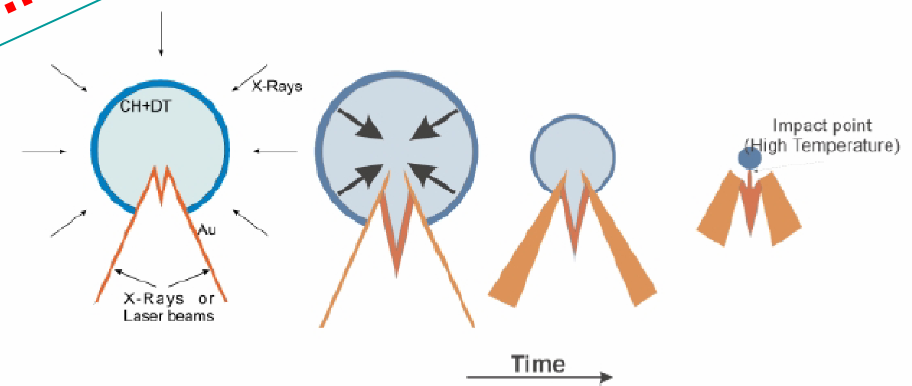
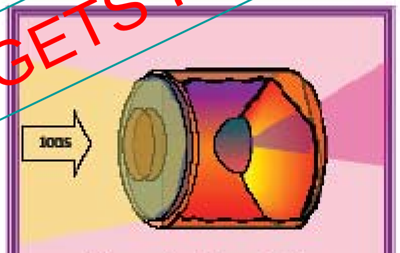
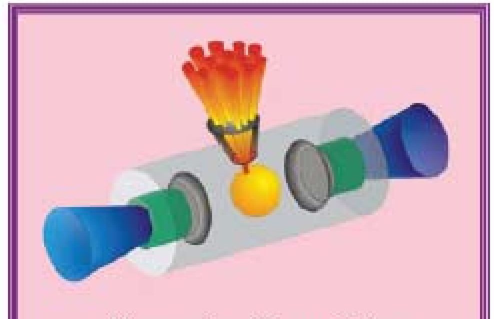


Fig. 1. Fast Ignition target driven by jet collision. The target is place inside a hohlraum and the payload used for jet production can be directly or indirectly illuminated. On the right, schematic view of the evolution of the proposed fast ignition target. A conical shaped target produces an adiabatic jet when illuminated by laser or X-rays from outside. This jet could bring enough energy to the compressed core to start ignition.

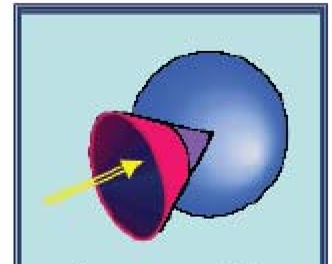
TARGETS ....!!!!!!!!!!!!



Heavy Ion Beam Drive



Heavy Ion Beam Drive

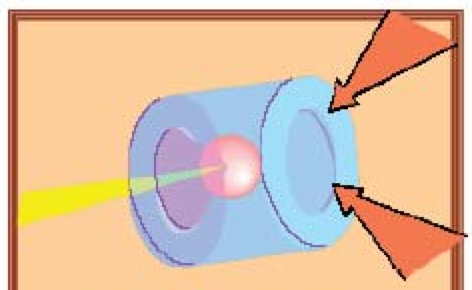


Direct Laser drive

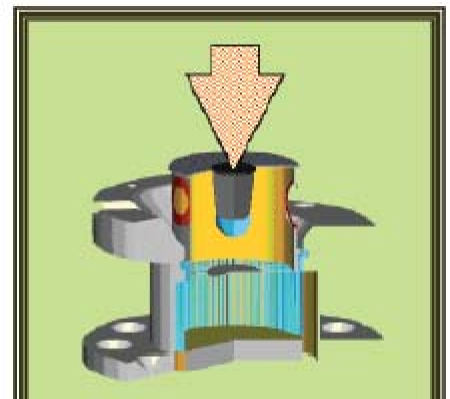
Innovative target designs are possible

BUT

Ignitor laser energy must be determined!

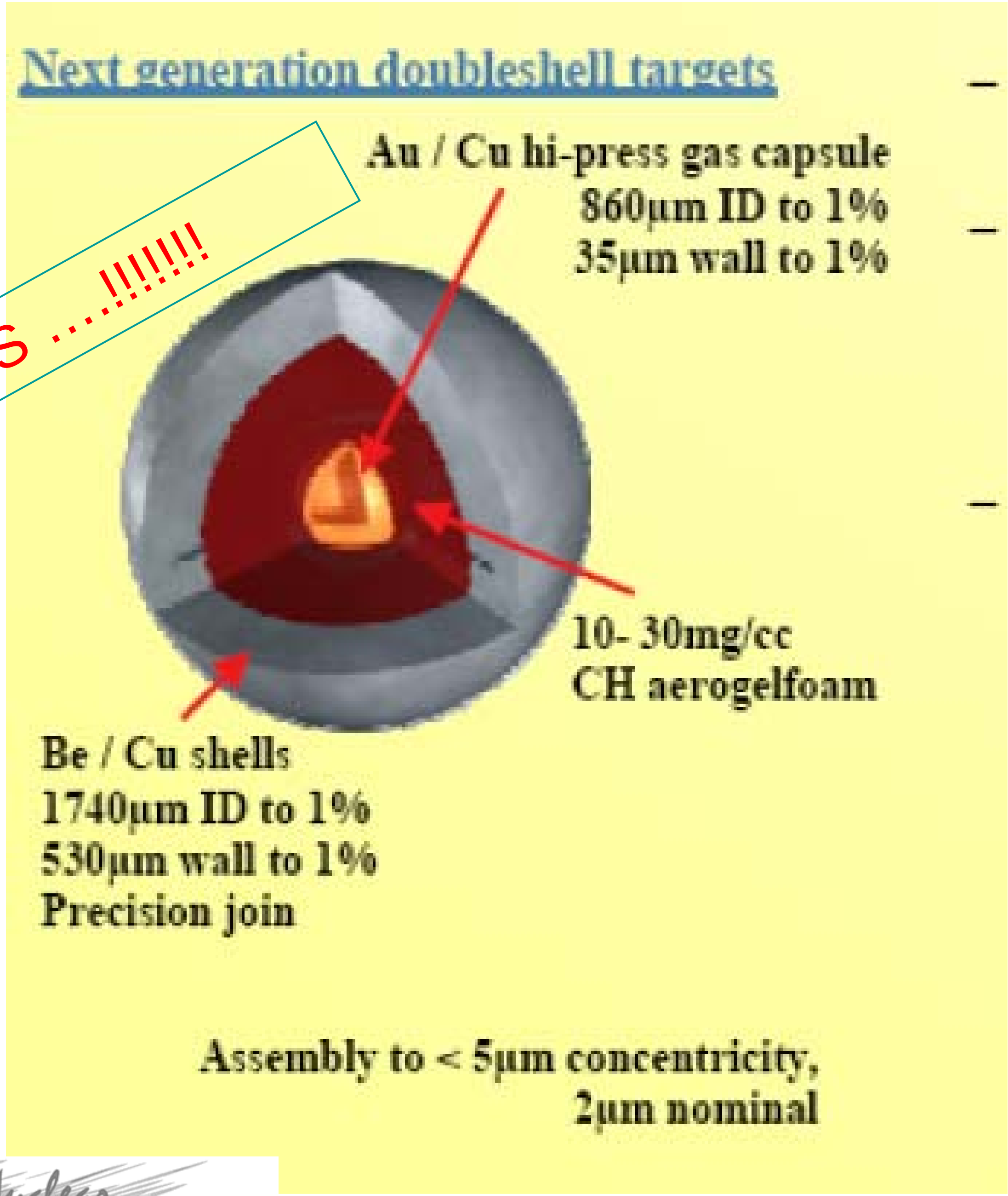


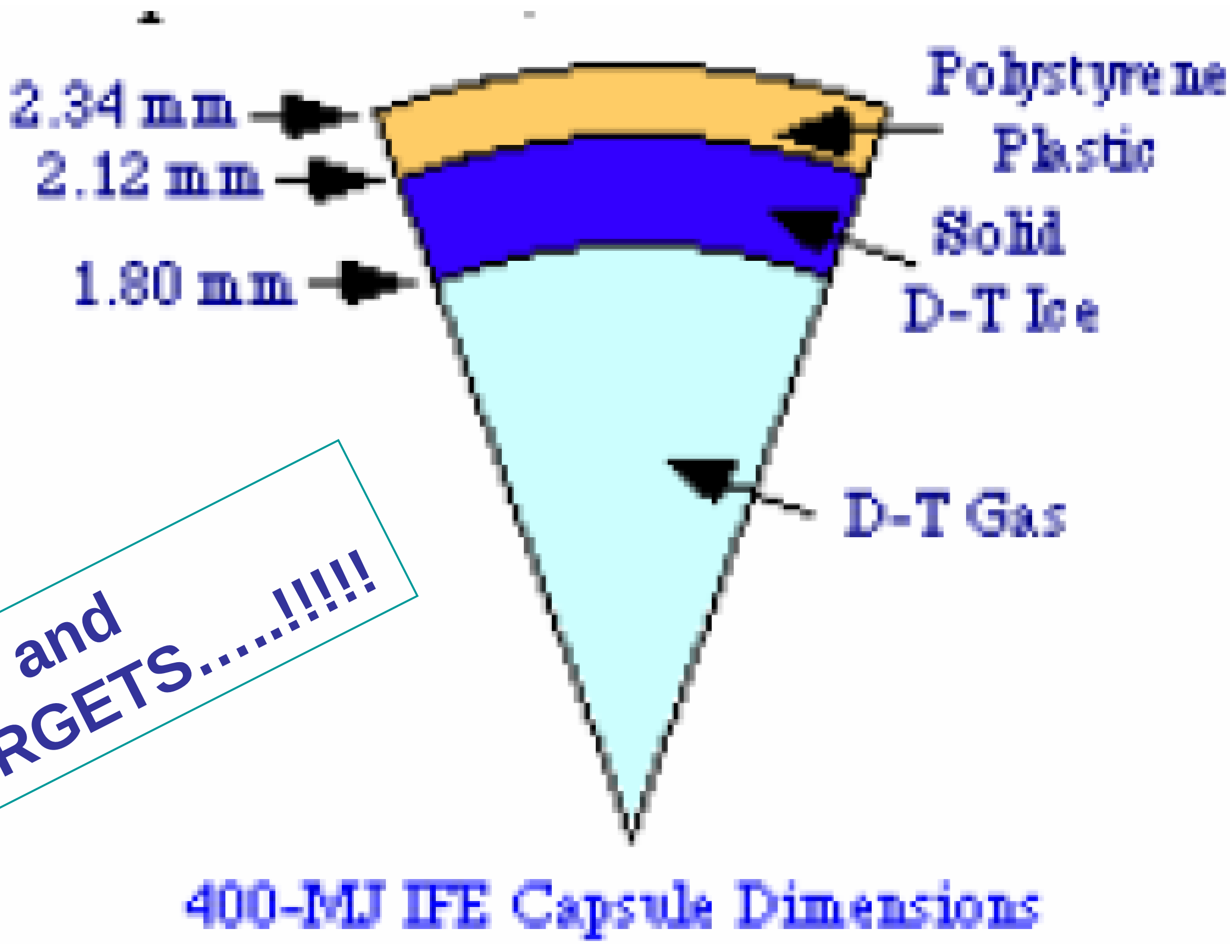
Indirect Laser drive



Z-pinch Drive

TARGETS ….!!!!!!!


Next generation doubleshell targets
Au / Cu hi-press gas capsule
860µm ID to 1%
35µm wall to 1%
10- 30mg/cc
CH aerogelfoam
Be / Cu shells
1740µm ID to 1%
530µm wall to 1%
Precision join
Assembly to < 5µm concentricity,
2µm nominal



2.34 mm
2.12 mm
1.80 mm
Polystyrene Plastic
Solid D-T Ice
D-T Gas
400-MJ IFE Capsule Dimensions

and …..TARGETS…..!!!!!

EMISSIONS FROM TARGETS !!!!!!!!!!!!!!!!!!!!!!!!

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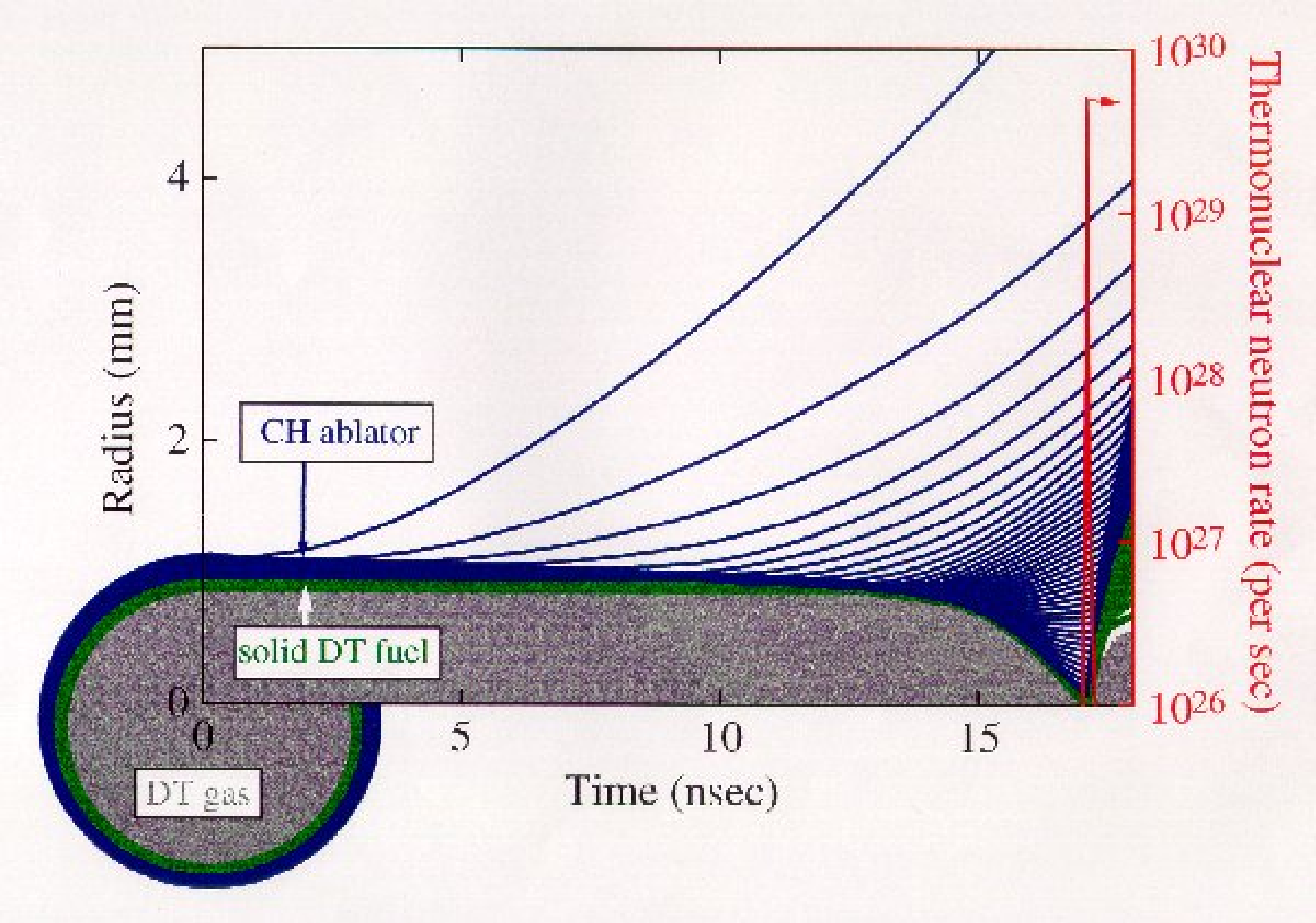
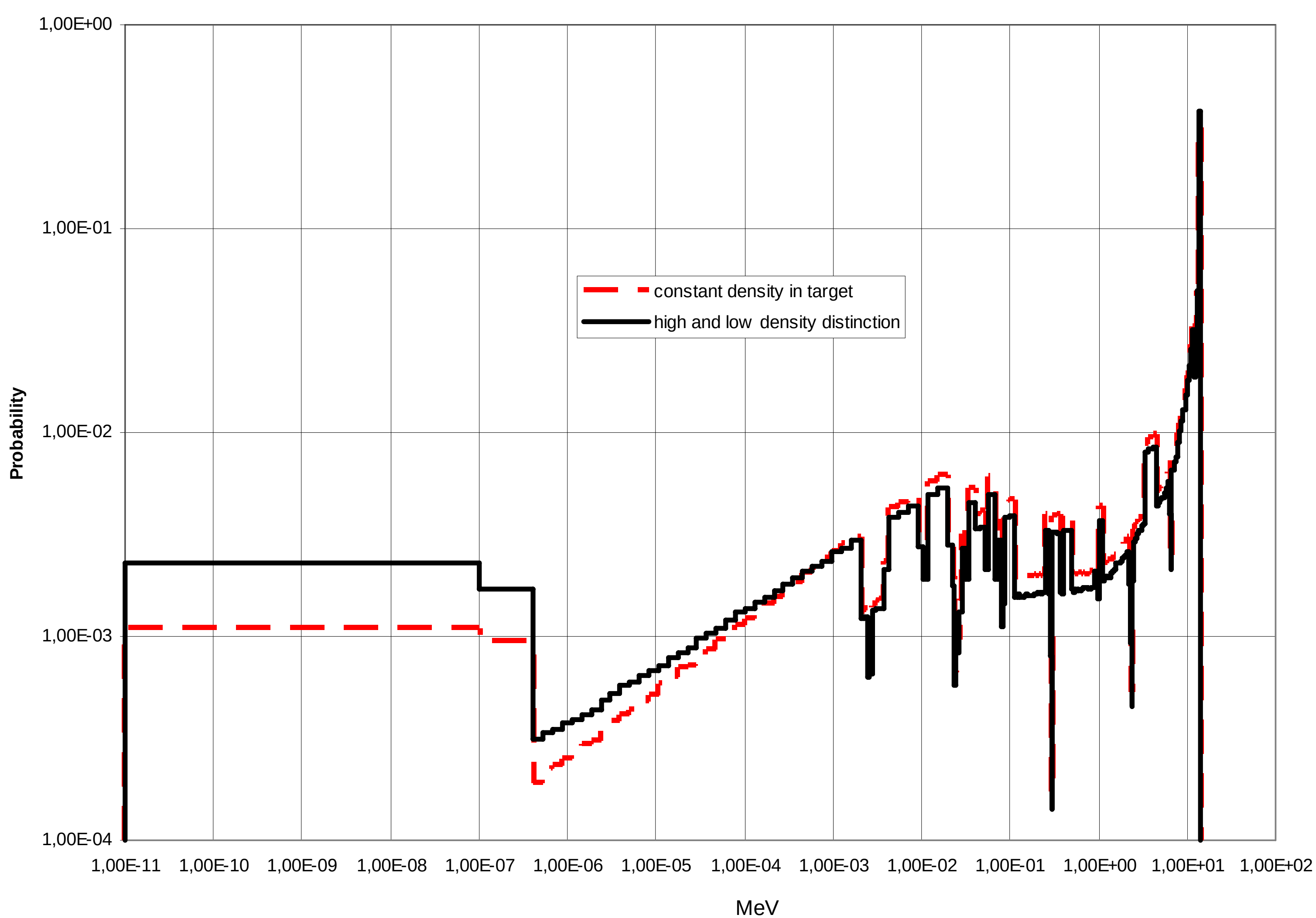
Type of particles
emerging from fusion in the target:

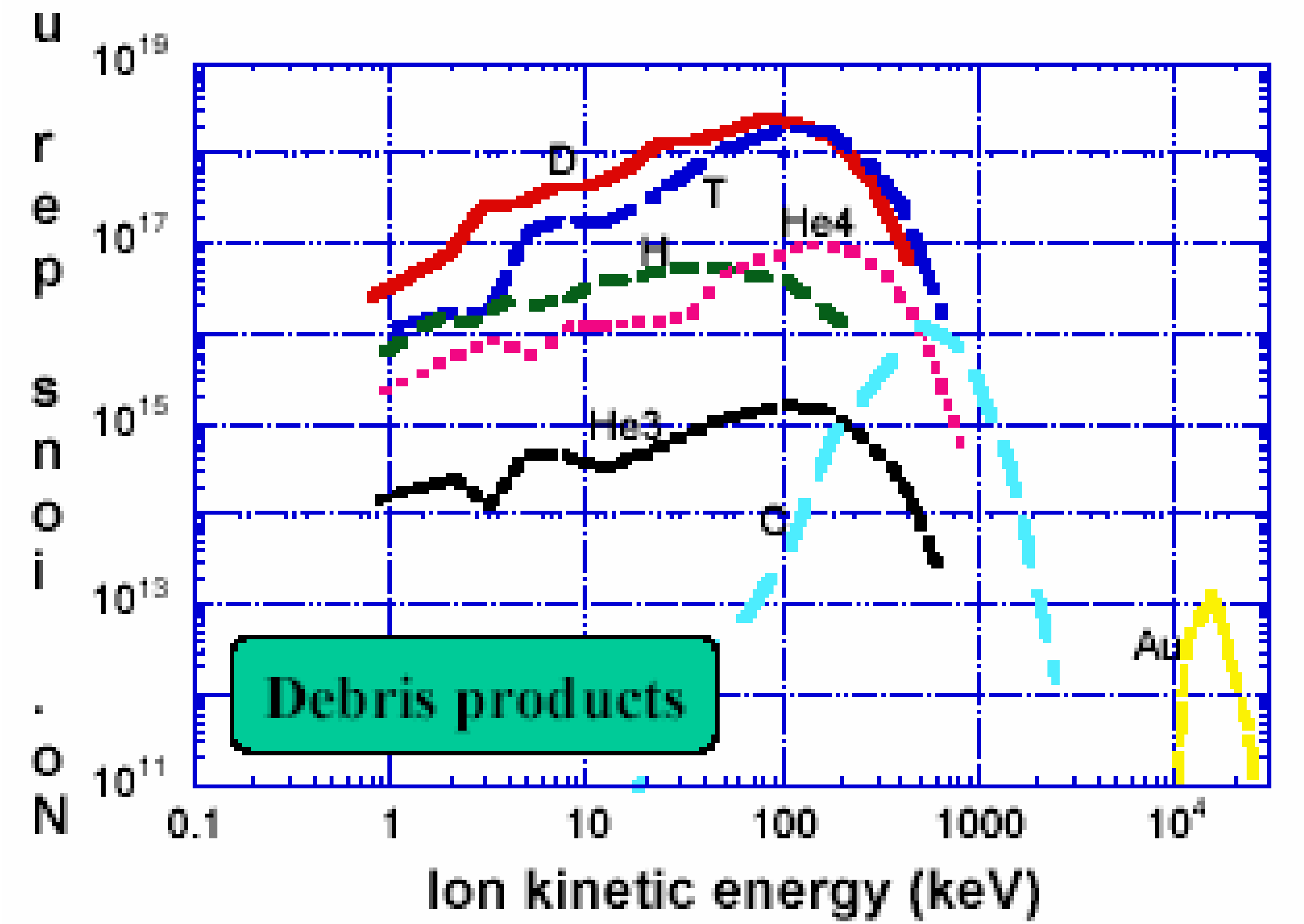
- Neutrons
- Alpha particles
- Charged Particles from fuel (D, T) no fusion
- Other charged particles from component of targets (cone, positioner of target…..)
- Debris, Shrapnel
- Gamma Radiation

Target Emissions

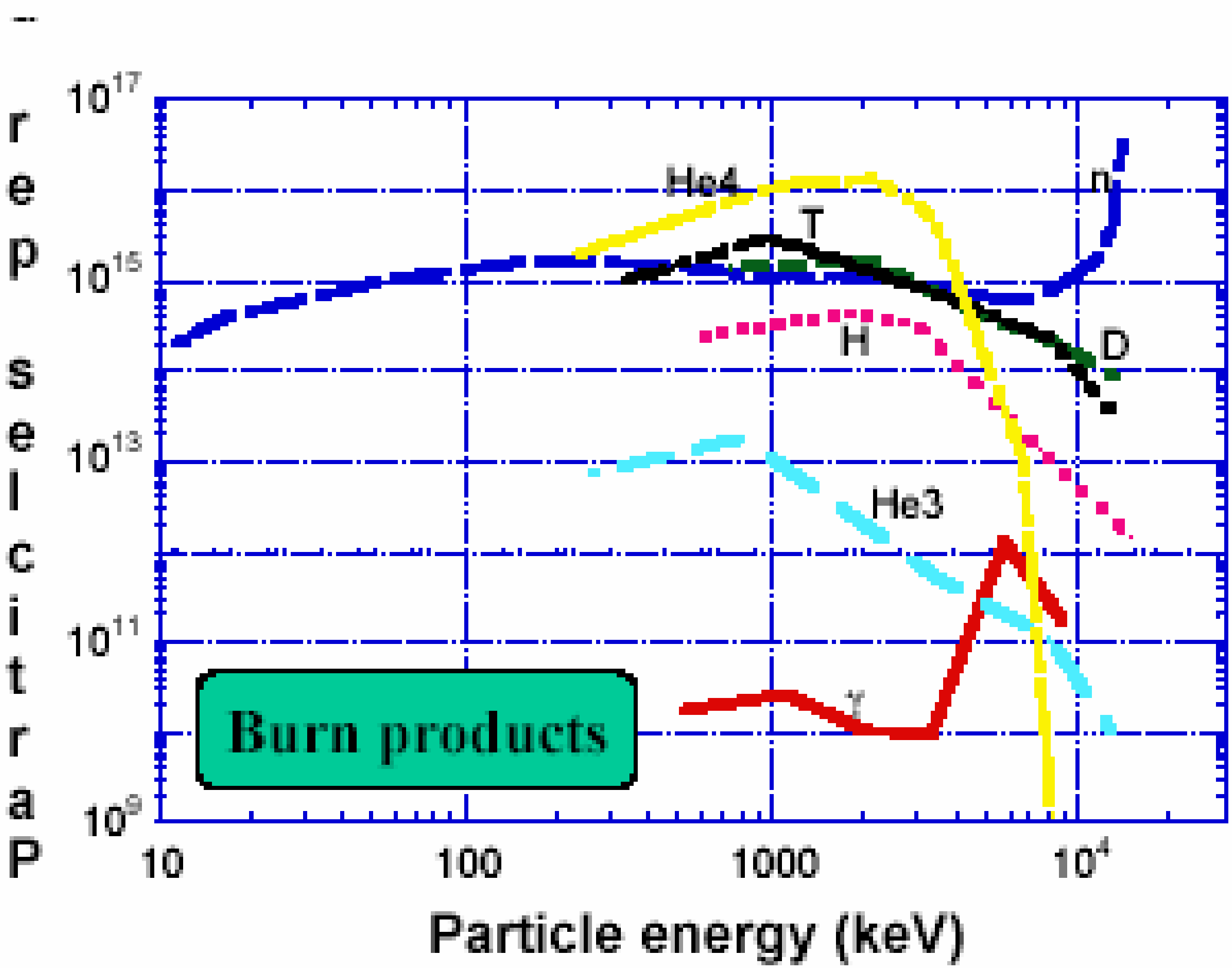




Of course this energy spectra will depend on final density and composition of TARGET



No. ions per
10^19
10^17
10^15
10^13
10^11
0.1
1
10
100
1000
10^4
Ion kinetic energy (keV)
D
T
He4
H
He3
C
Au
Debris products


Particle energy (keV)
Particles per
Burn products
He4
T
n
H
D
He3
γ
10^{17}
10^{15}
10^{13}
10^{11}
10^{9}
10
100
1000
10^{4}

Type of effects (different “lecture” if single shot IGNITION or REACTOR IFE Energy):

Heating

Erosion

Sputtering

Radiation Damage:

Bulk Structural Materials, Diagnosis, Optics

Activation

Tritium

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Consequences in design

This WILL INFLUENCE HiPER design

– Dimensions; basically separation from capsule central positioning (Radius)

– Material (type, thickness)

– Potential protection of some systems (Debris Shields for FOA or others)

– Operation of the system (manual, remote) depending of type of shot and their energies. That is related to the neutrons emerging from capsule (kilojoules …..Megajoules…..), and the activation of the materials.

– ***Programming of the number of shots*** and their energy gain for clear operation in licensing the Installation.

– A key aspect is the Activation generated because of Deposition of particles from capsule explosion in the Chamber that are afterwards Activated (very important).

Target	Yield (MJ)	Laser energy (MJ)	Debris energy (MJ)	X-ray energy (MJ)	BBT (eV)	Pulse 10–90% (ns)	Fluence (J cm^{-2})			
							5 meters 10°	5 meters 30°	5 meters 50°	5 meters 90°
Hohlraum closing LEH	0.10	1.8	0.75	1.08	—	—	0.57	0.51	0.41	0.12
				0.70	255	10.0	0.45	0.39	0.29	0.00
				0.23	52	61	0.07	0.07	0.07	0.07
				0.15	12	61	0.05	0.05	0.05	0.05
Hohlraum closing LEH	20.00	1.8	2.05	4.54	—	—	2.03	1.87	1.61	0.86
				1.84	400	6.3	1.17	1.01	0.75	0.00
				2.50	89	49	0.79	0.79	0.79	0.79
				0.20	18	49	0.06	0.06	0.06	0.06
Hohlraum open LEH	20.00	1.8	1.65	4.94	—	—	2.64	2.35	1.88	0.51
				3.35	320	13	2.13	1.85	1.37	0.00
				1.38	81	67	0.44	0.44	0.44	0.44
				0.21	15	67	0.07	0.07	0.07	0.07

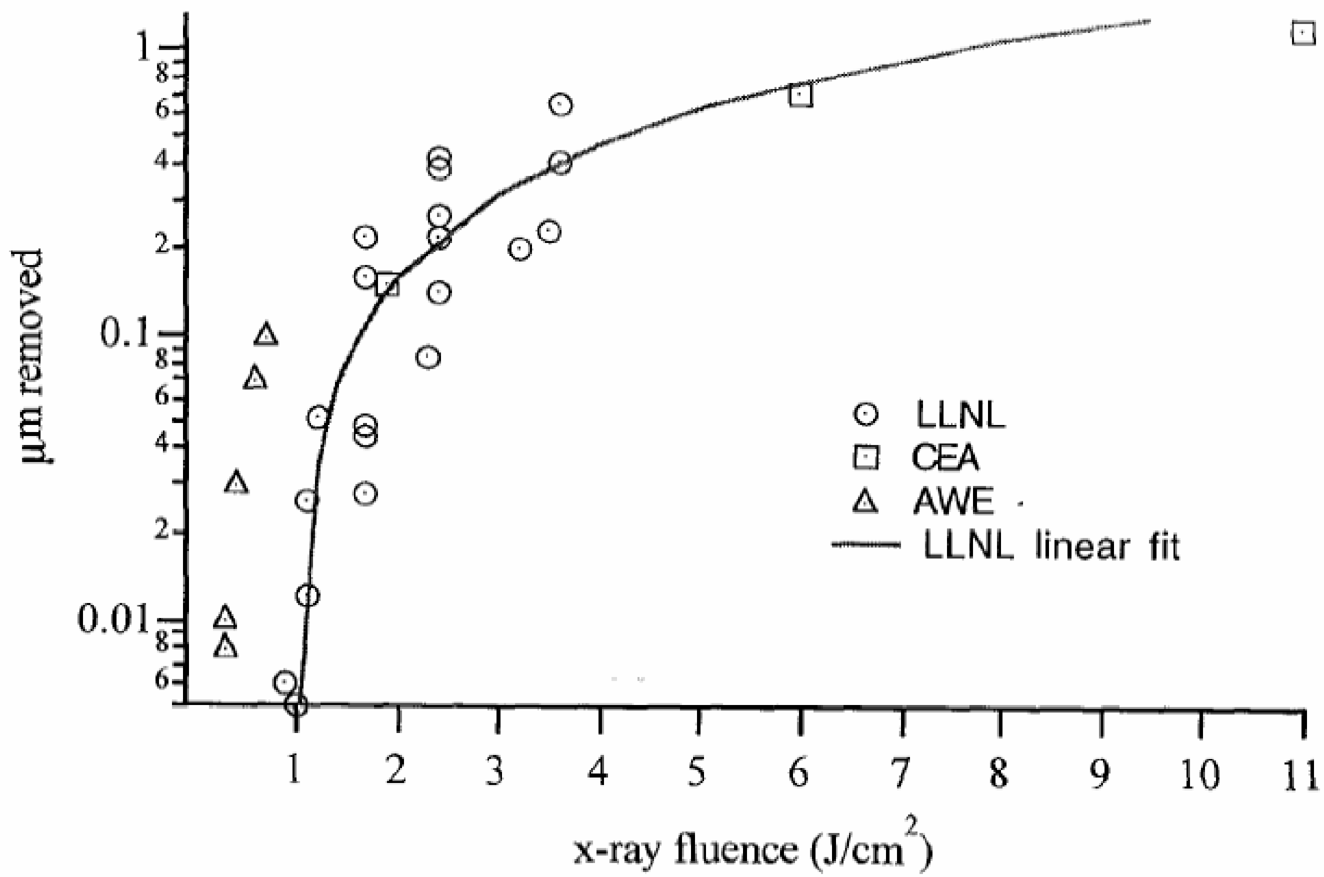
LEH, laser entrance holes.

Thanks to Anderson (LLNL)

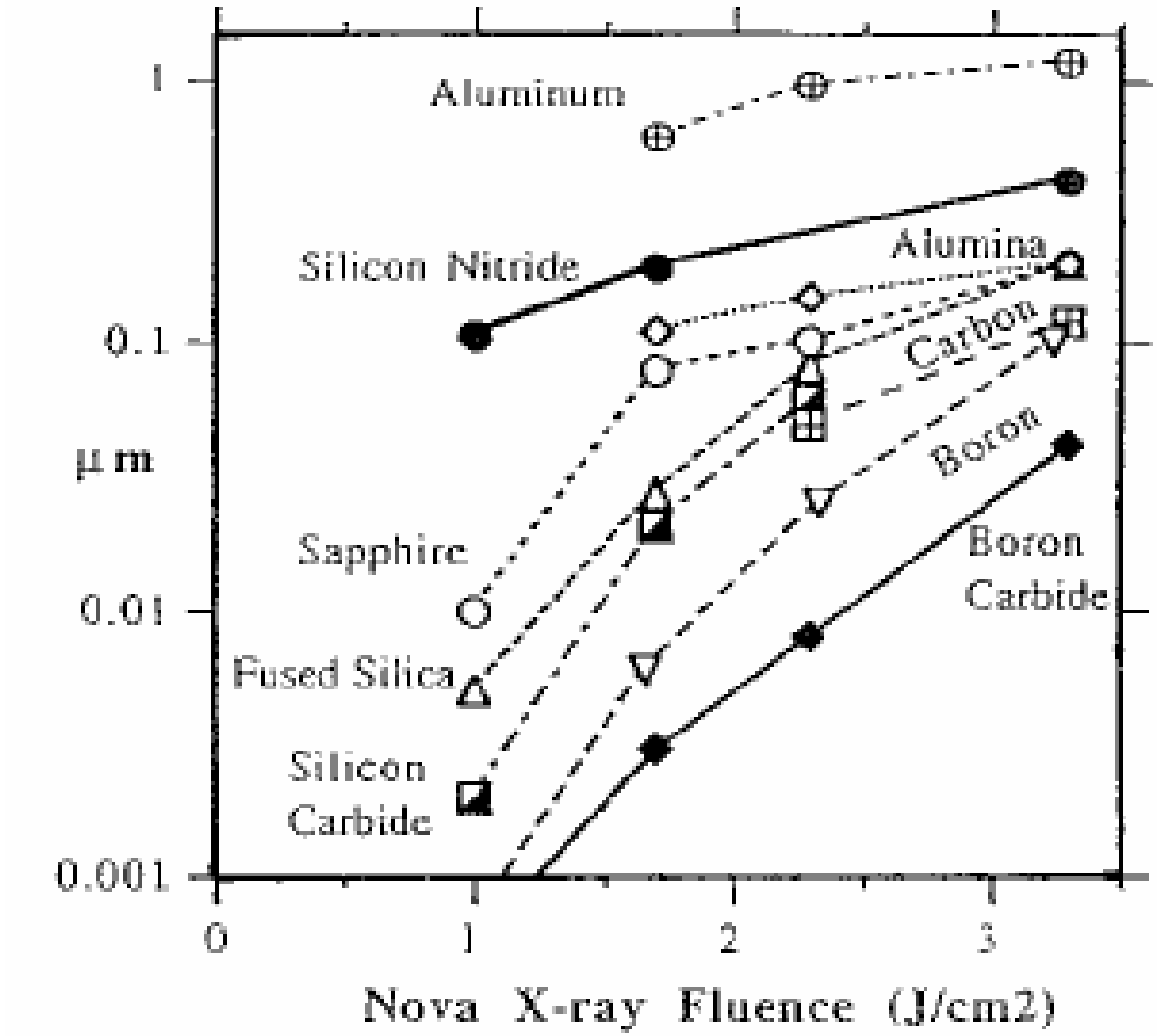
ICF direct and indirect drive emitted target energy balance comparison [14]

Thanks to Tobin, Karpenko, Reyes (LLNL)

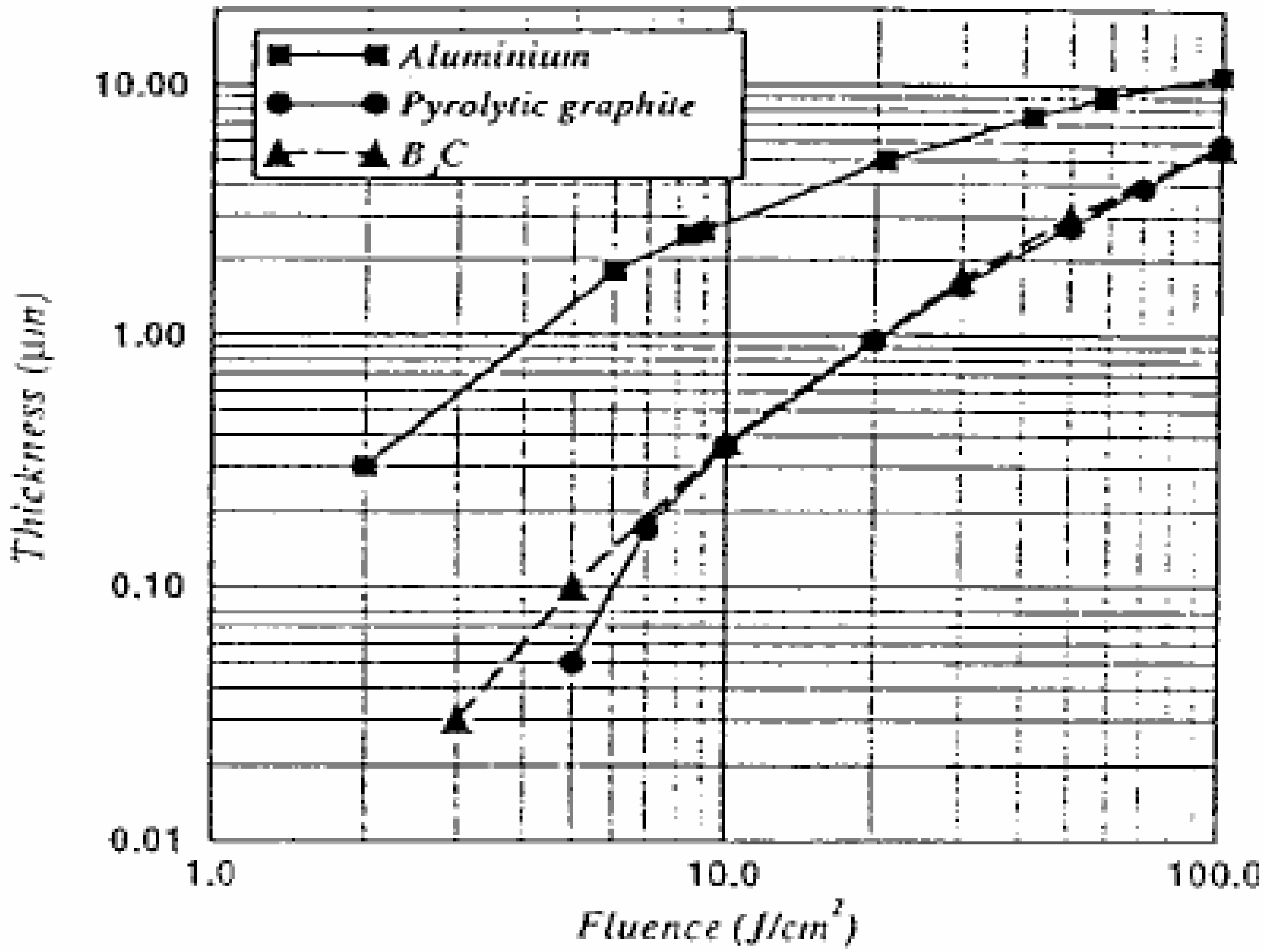
	Direct drive		Indirect drive	
Energy (MJ)	Pure DT	CH-coated	Just ignited	Large yield
Laser	1.26	1.27	1.31	1.33
Fusion yield	38.6	39.7	0.11	9.4
Neutron	32.4	33.1	0.08	7.1
X-rays	0.4	0.4	0.45	2.0
Debris	7.04	7.44	0.89	1.63
Total	39.8	41.0	1.42	10.73



For HiPER design we will need to clearly determine response of emissions from fast ignition (conical, non-conical) targets and perform a similar analysis to this presented here.



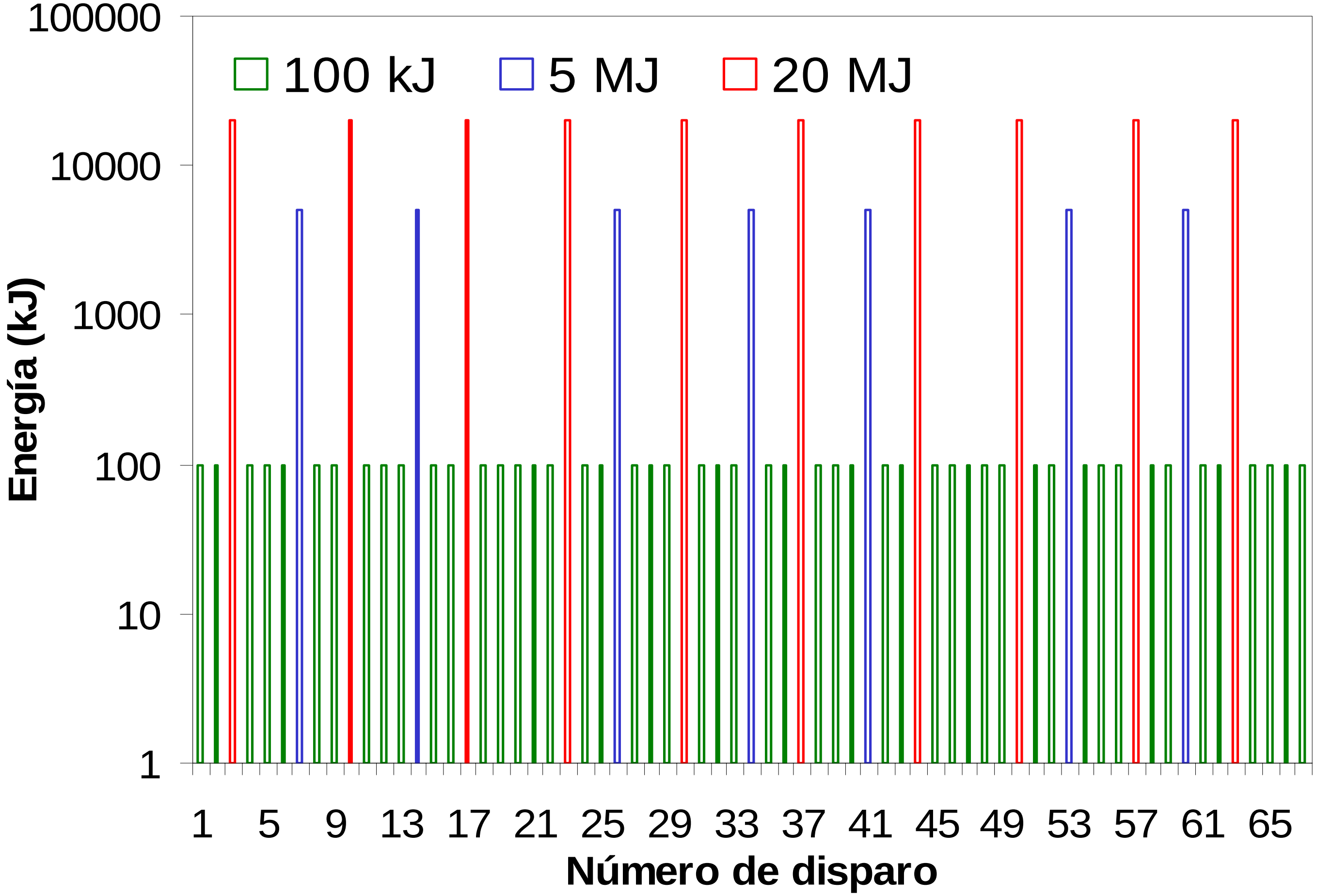
Summary of removal depths measured on Nova X-ray exposures. One to two ns pulses of 200–250 eV blackbody X-rays [Anderson, Burnham]



Vaporized thickness predictions for aluminium, B4C and pyrolitic carbone graphite versus X-ray fluence for a 350 eV blackbody temperature X-ray spectrum [Schirmann, Tobin]

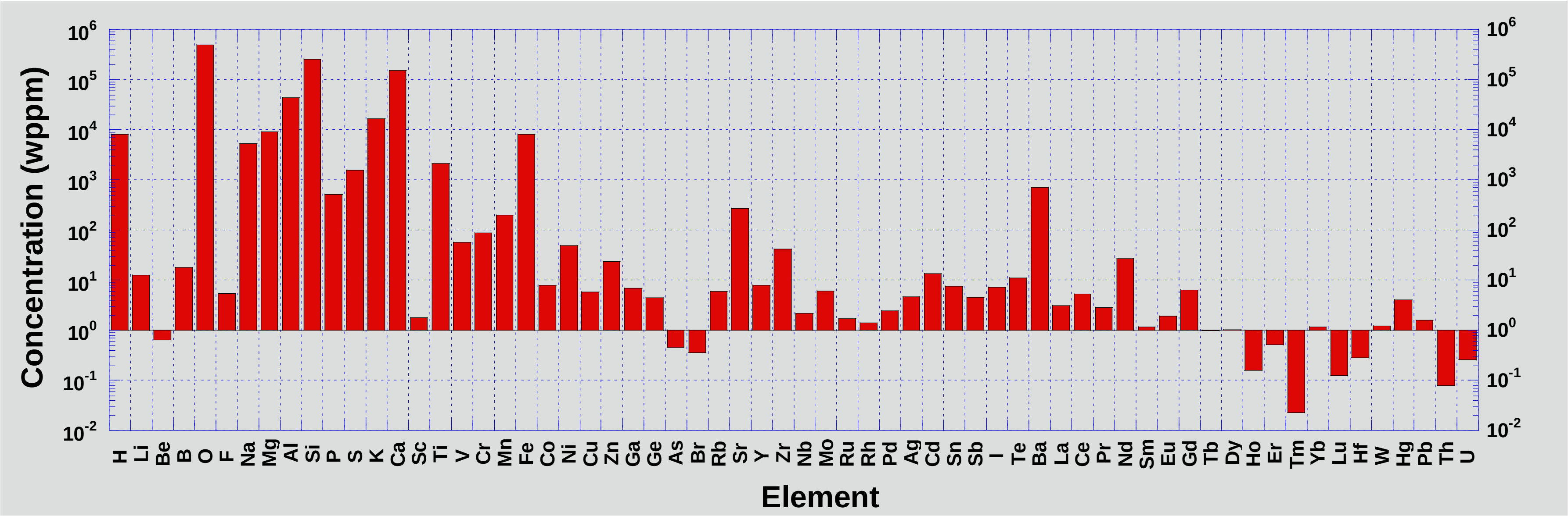
ACTIVATION: dependence of operation / Sequence of shots

NIF: tentative used during design

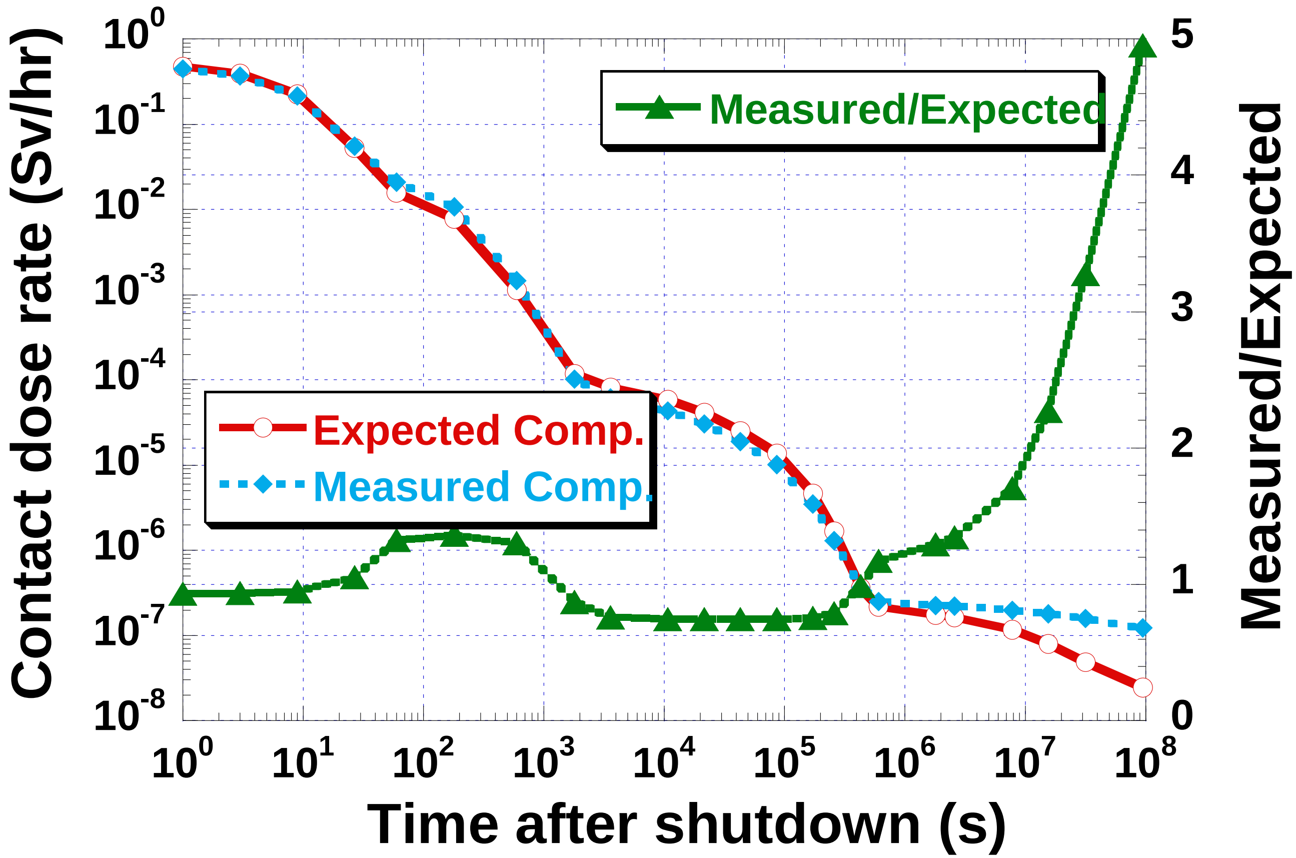


Some of these small concentrations make significant changes

^{60}Co and ^{152}Eu, which are builded-up from Cobalt impurities of no more than …….3 ppm, and Europium with contents of 3.7 ppm………….!!!!!!!!!!!!!!!!!



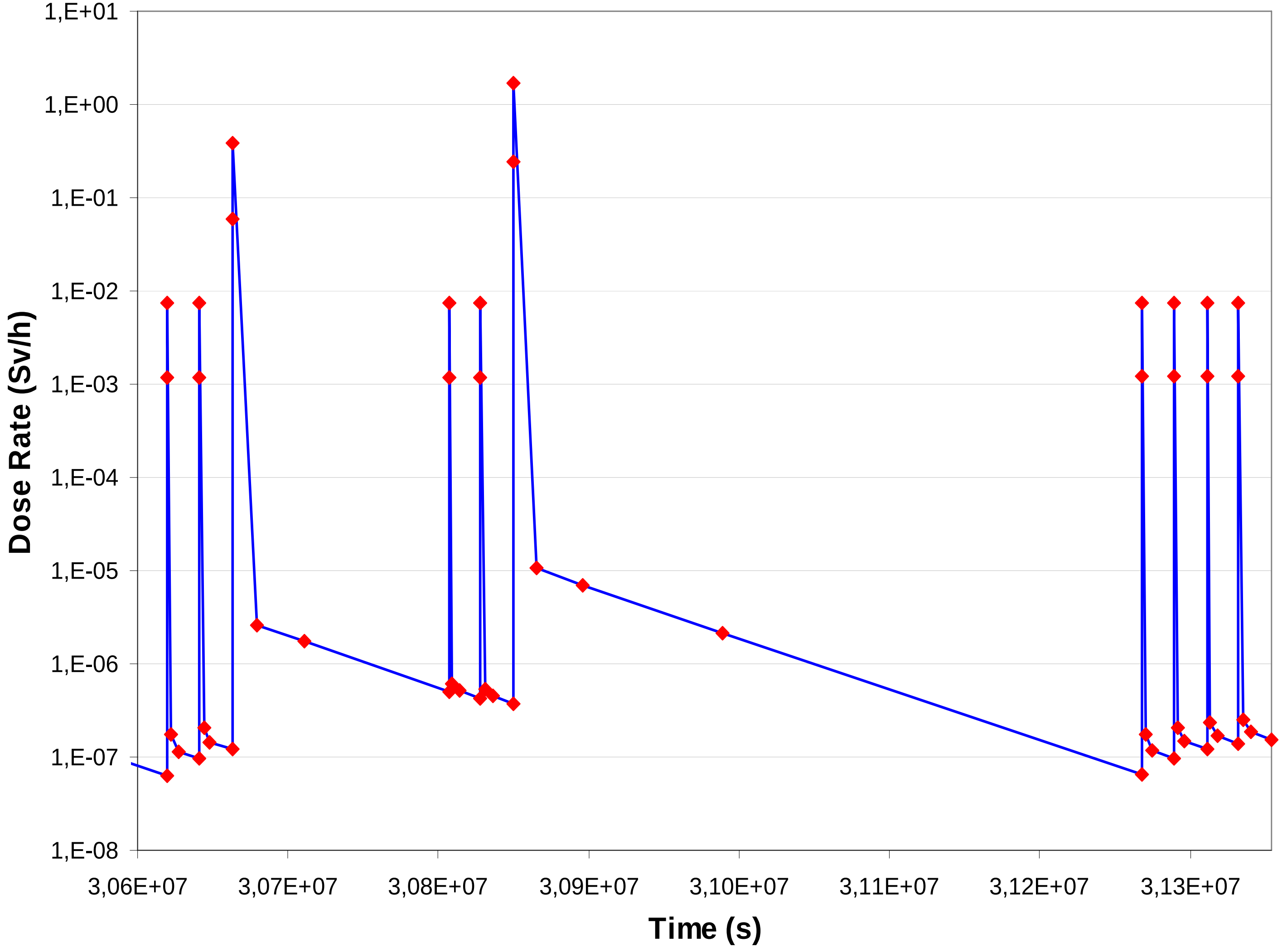
Elemental composition of a concrete simple from soil at elevation –7.1 m [Latkowski & Sanz 00b].



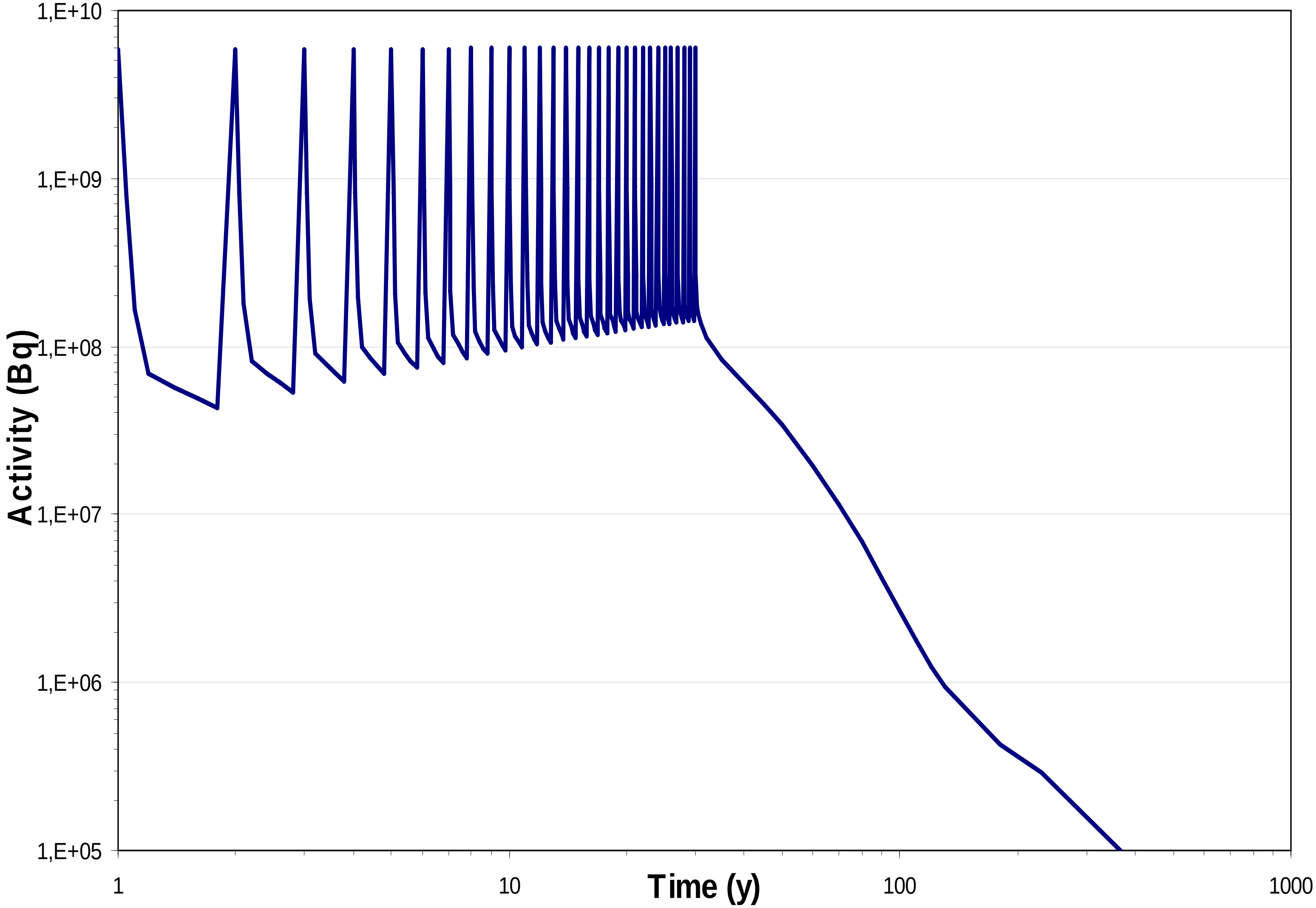
Comparison of the contact dose rate corresponding to the real measured composition and that expected from the original composition of the concrete. [Latkowski & Sanz 00b].

- ***The material that finally will be activated by the neutrons from one shot, and that activation is named PRIMARY ACTIVATION.***

- Afterward, that material is irradiated by the neutrons from next shots generating a new activation, or ***SECONDARY ACTIVATION***.



Contact dose rate in the internal part of the chamber during the last 10 shots of the yearly sequence of shots [Sanz, Instituto Fusion Nuclear].



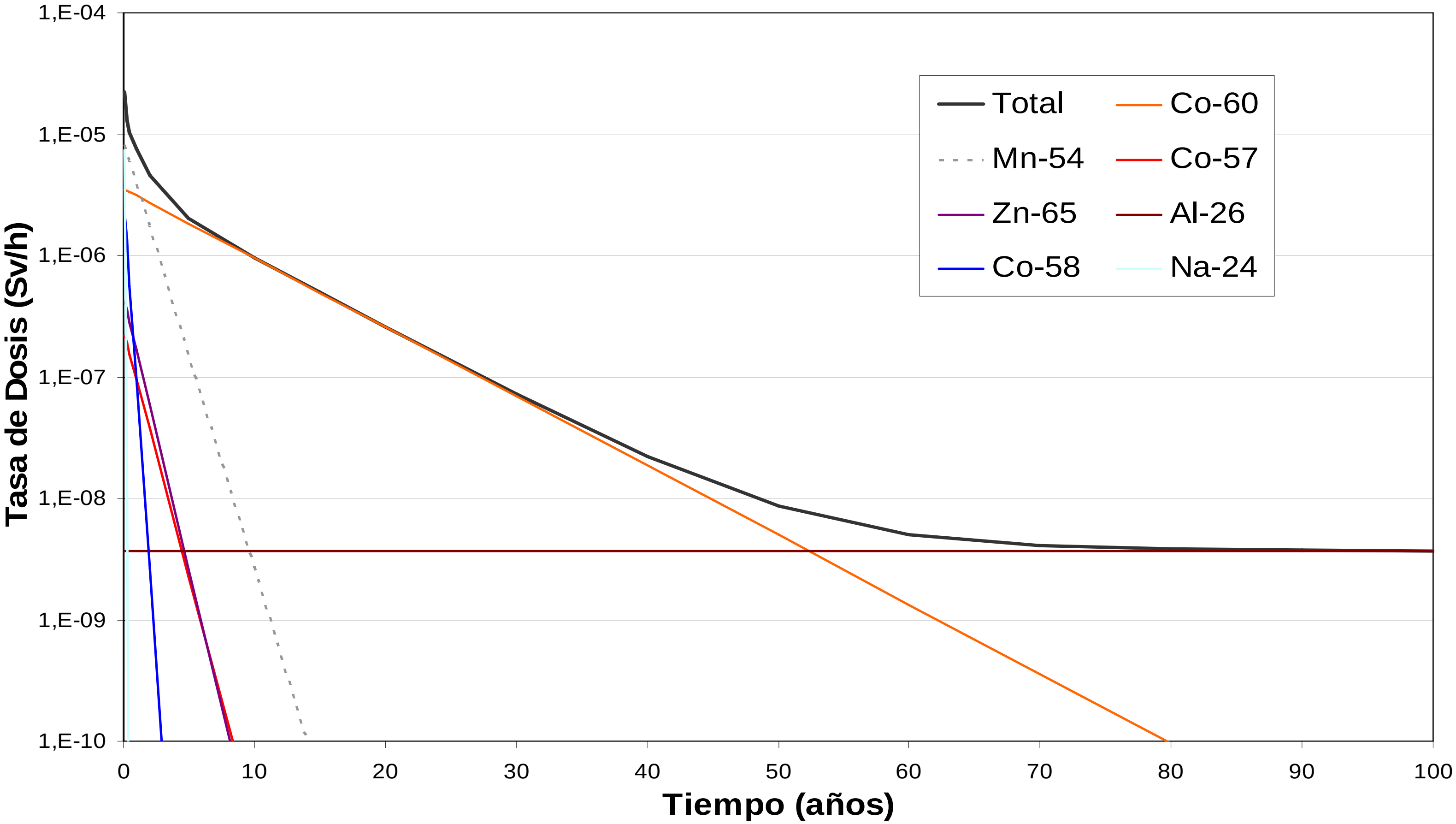
Temporal Evolution of the total dose rate and that corresponding to the most significant radionuclides after the last discharge of activated material in the Storage Facility [Sanz, Instituto Fusion Nuclear.

Neutron environment at NIF and time to access to activated areas, depending on yield per shot [3]

Yield (MJ)	Spectra (MeV)	Target positioner@20 cm (n cm^{-2})	First wall (n cm^{-2}) at 5 m	Dose rate limit (mrem h^{-1})	Time to dose rate (days)
2.8 kJ[a]	14	2E11	3.2E8	0.7	—
1.9 (100 kJ)	14	7E12	1.12E10	0.7	1.0
2.8 (1 MJ)	14	7E13	1.12E11	0.7	3.1
6.8 (5 MJ)	14	3.5E14	5.6E11	0.7	4.5
21.8 (20 MJ)	14	1.4E15	2.24E12	0.7	5.8
46.8 (45 MJ)	14	3.5E15	5.6E12	0.7	6.5

[a] Exploding pusher experiment.

Thanks to Tobin, Karpenko, Reyes, Sanz (LLNL/Instituto Fusion Nuclear)



Main Contibutors (Sanz, Instituto Fusion Nuclear

Power Plants: Reactors for Inertial Fusion Energy

Need to understand Fusion Technology….

I would say better ***Physics for Fusion Technology***

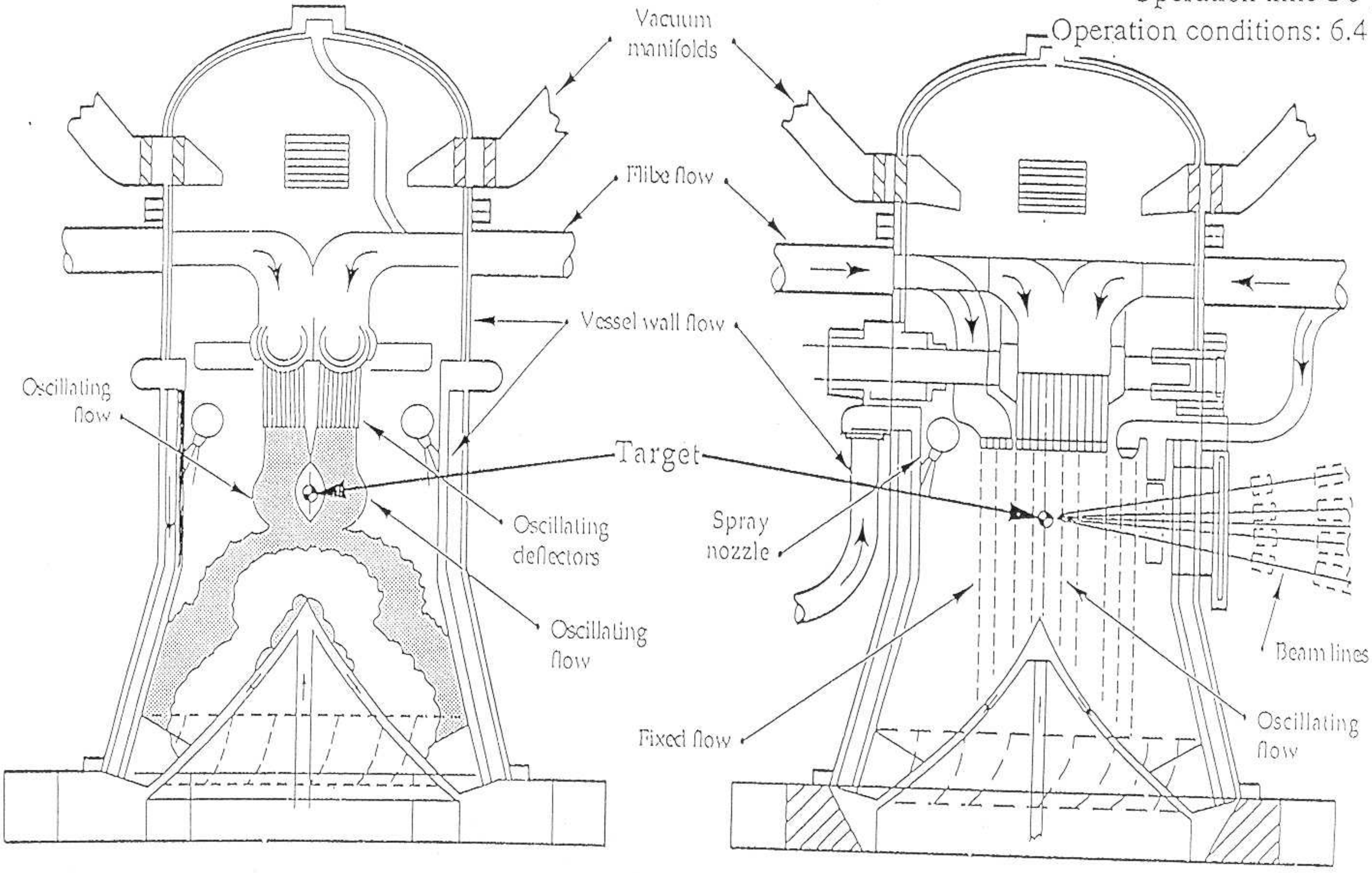
THAT REQUIRES specific Experiments and Predictive Multiscale Modeling Tools

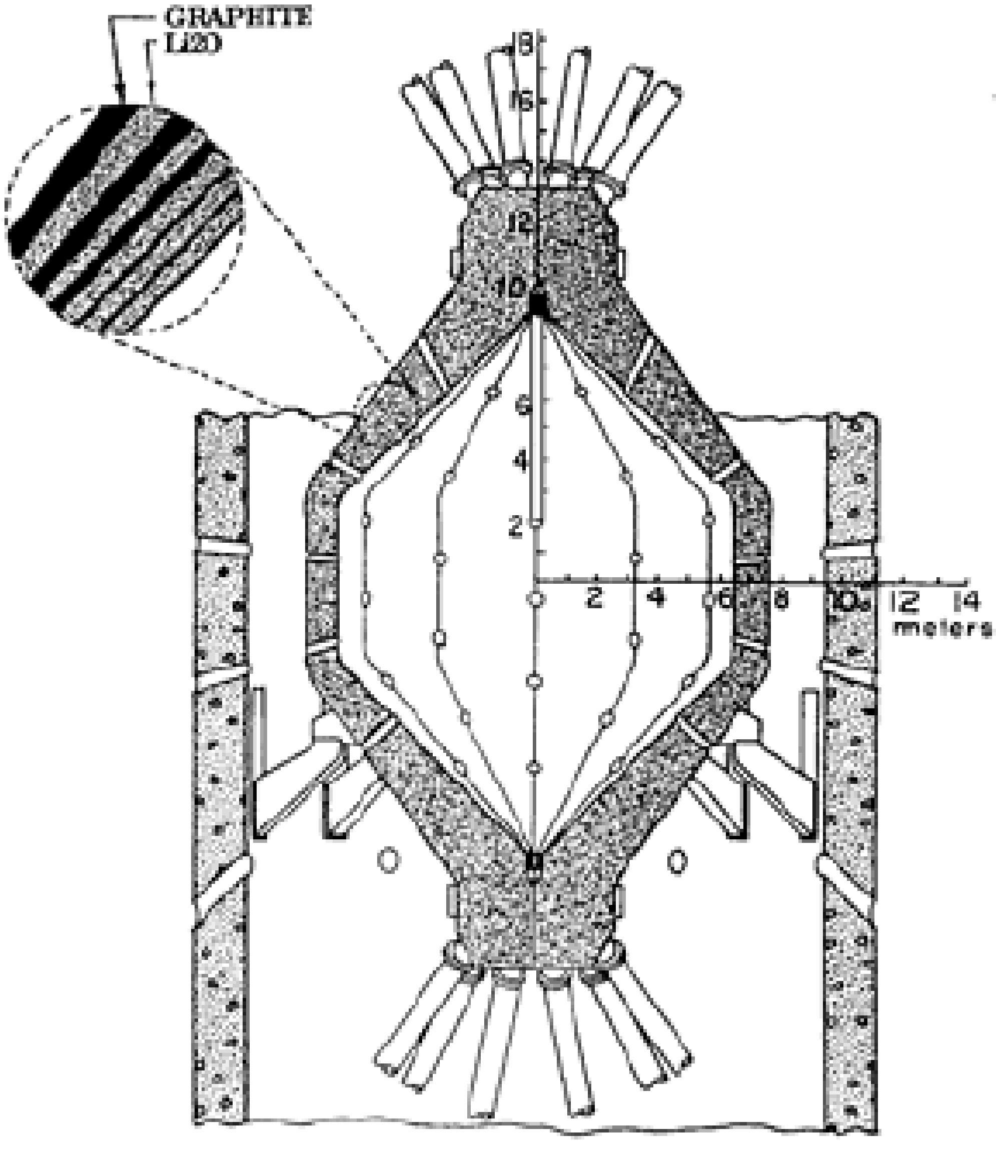
HiPER

HYLIFE-II reactor vessel

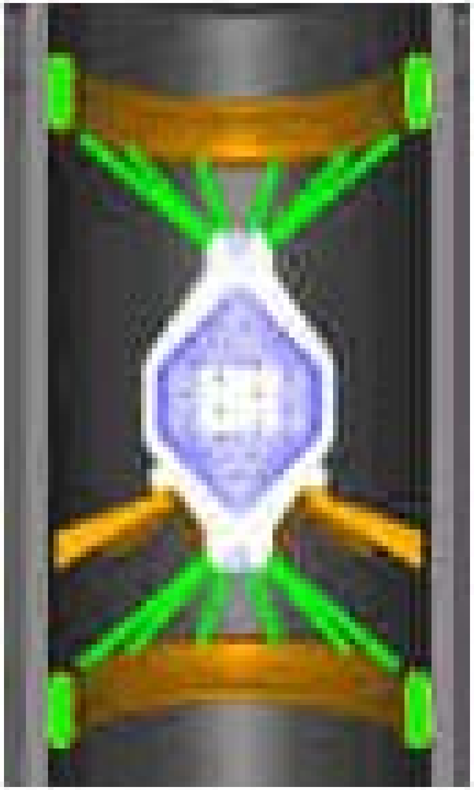
- Neutron Environment
  - $\phi = 1.29 \cdot 10^{15}$ n cm^{2}s^{-1}
  - $< E > = 0.38$ MeV
  - Operation time 30 yr

Operation conditions: 6.4 Hz, 350-MJ

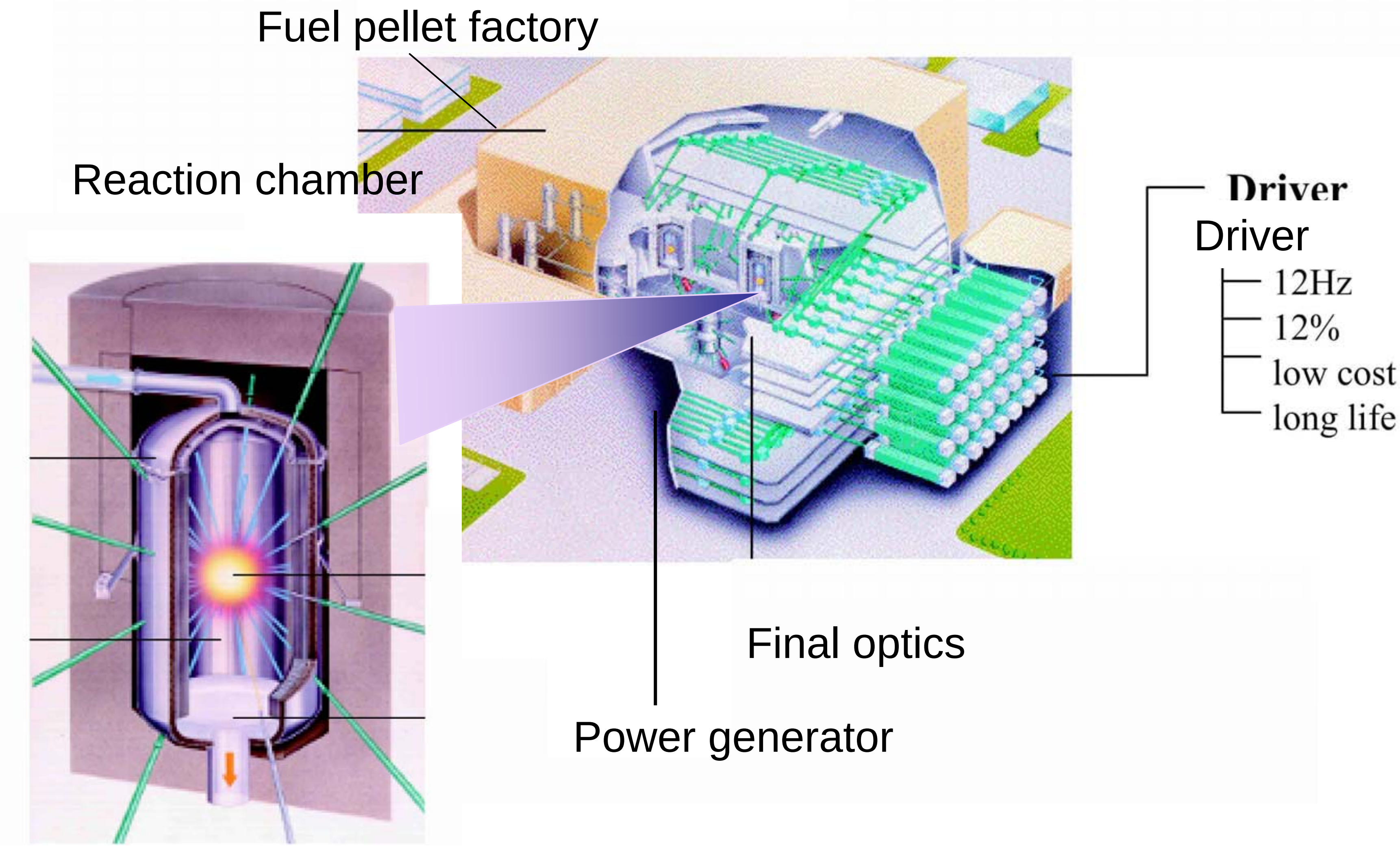




CROSS-SECTION OF SOMBRERO CHAMBER



KOYO Wetted wall reaction chamber



Wall interaction chamber

- Thick wall (flowing) PbLi -FLiBe
  – Formation of jet-simulation
  – Evaporation during shot- where does it go?

- Thin layer
  – Under load (vessel in a vessel in primary chamber)
  – Porous material development and testing
  – Debris + neutron (multi KJ test chamber @ Hz)

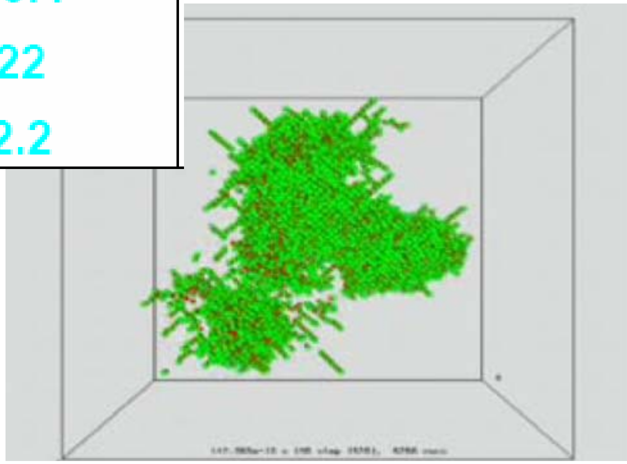
- Dry Wall - Sombrero
  – Test panel in primary chamber
  – Debris + neutron (multi KJ test chamber @ Hz)

- **At the end DAMAGE and ACTIVATION**

Irradiation parameter		ITER*	DEMO*
Total neutron flux	[n/(s cm^2)]	4×10^{14}	7.1×10^{14}
Hydrogen production	[appm/FPY]	445	780
Helium production	[appm/FPY]	114	198
Damage production	[dpa/FPY]	10	19
H/dpa ratio	[appm/dpa]	44.5	41
He/dpa ratio	[appm/dpa]	11.4	10.4
Nuclear heating	[W/cm^3]	10	22
Wall load	[MW/m^2]	1.0	2.2

Candidates:

- Vanadio
- SiC/SiC
- Aceros martensiticos "EUROFER"

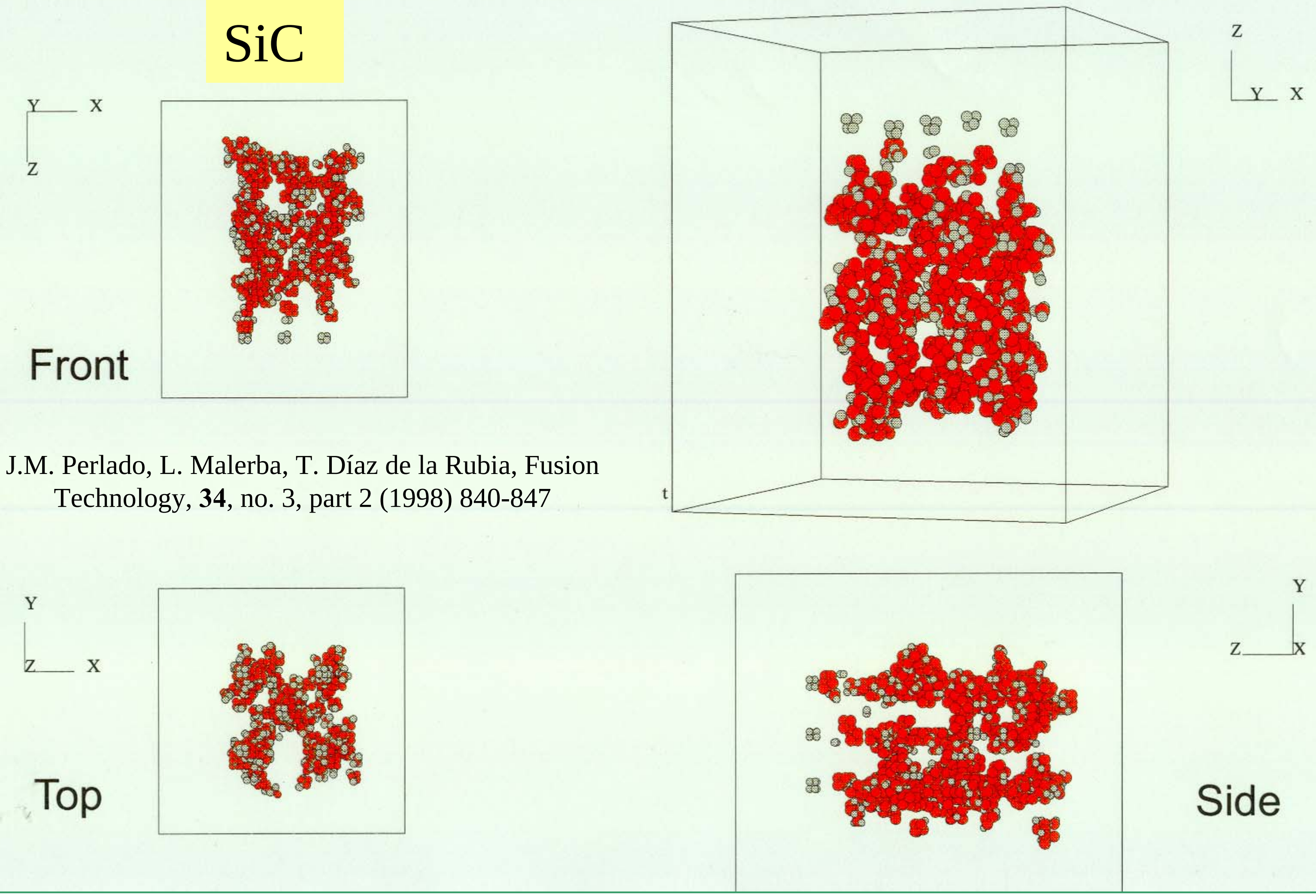


Molecular dynamics calculation of displacement damage due to neutron impact.

D a m a g e A c c u m u l a ti o n

Accumulation of 25 1 keV Si-recoils at 1300 K - Excited Atoms

SiC



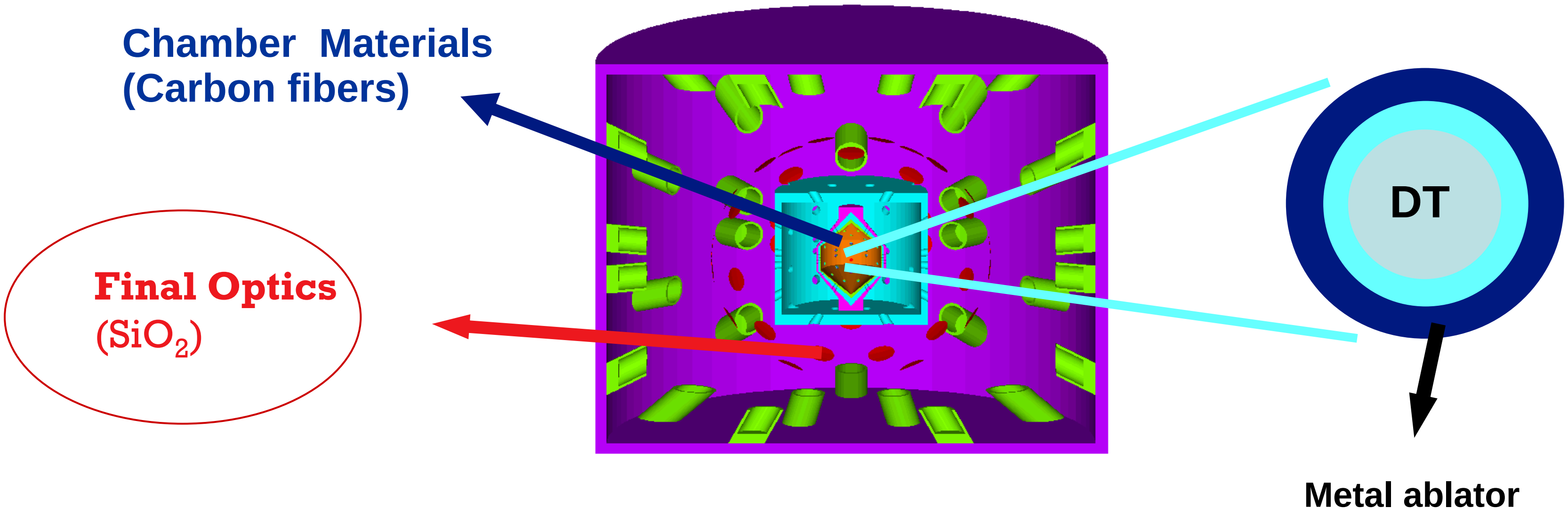
J.M. Perlado, L. Malerba, T. Díaz de la Rubia, Fusion Technology, **34**, no. 3, part 2 (1998) 840-847

MOLECULAR DYNAMICS: Identifying Primary Damage

Introduction: Motivations

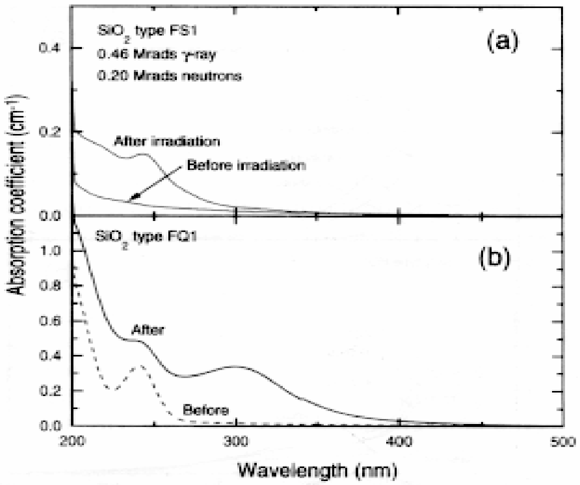
Laser or ions used to focus energy on a small DT target

A conceptual model: the SOMBRERO reactor



These lenses will be exposed to high energy neutrons (14 MeV) and ions.

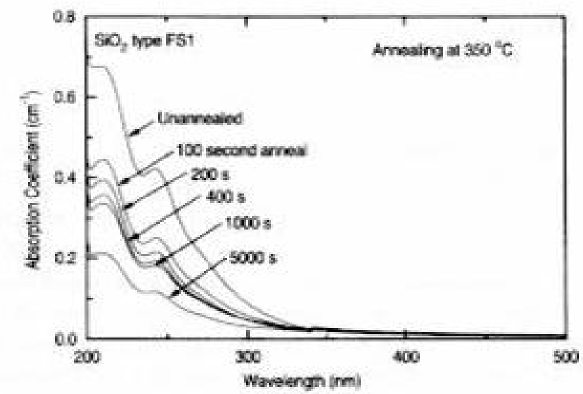
The radiation could affect the optical properties of the material



- Spectroscopic observations show increase in defect densities (NBOHC, ODC, E’) with MeV neutron irradiation
- ODCs gives rise to the $B_2\alpha$ band at 5 eV (248 nm)
- The ODC can be coverted to an E’ center by losing an electron. E’ absorption occurs at 5.8 eV (214 nm)

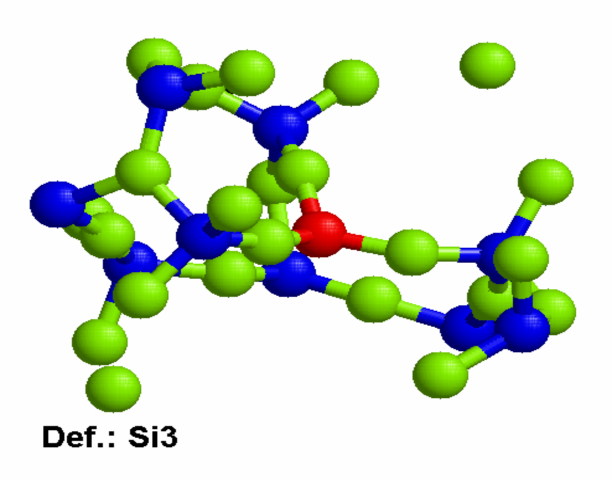
Induced optical absorption in silica glasses from neutron and gamma irradiation

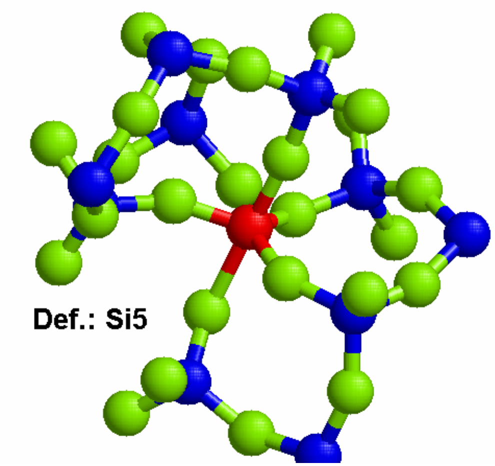
- These defect concentrations are shown to decrease with annealing, though the annealing mechanism is not well understood.
- There are some suggestions that cascade overlap can also contribute to reduced defect densities

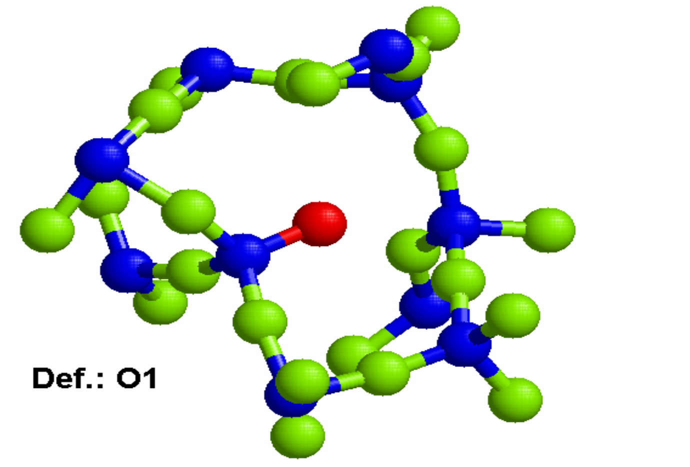


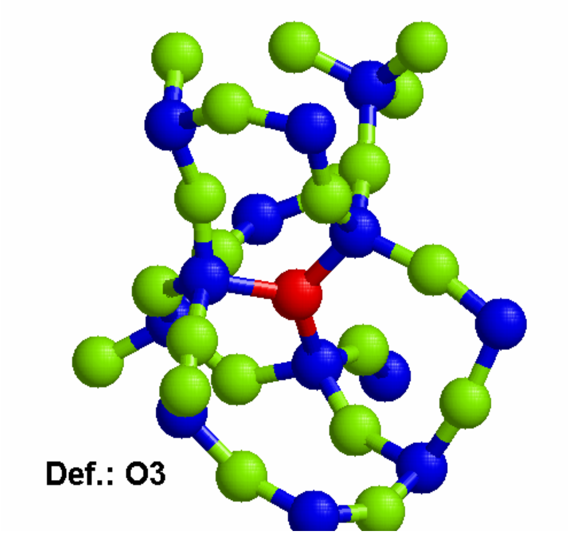
C.D.Mashall, J. A. Speth, S. A. Payne, Non-Crystalline Solids 3212

Characterization of defects (Si-O 2.15 Å)









STRATEGY FOR IRRADIATION

Installations for NEUTRON IRRADIATION are strongly needed: **(INTERNATIONAL FUSION MATERIALS IRRADIATION FACILITY, IFMIF)**,
but also of key importance are:

Small / Medium Scale irradiation facilities in Europe and elsewhere to start to understand basic mechanisms of damage and properly **design** future materials,
together with appropriate **atomic/microscopic/macroscopic diagnosis**.

USE OF HiPER as a pulsed NEUTRON SOURCE

MATERIALS

Ceramics (Windows/Optics): **SiO_2, Alumina, FCa**

First Wall: **Be, C, W, Ferritic Steels**

Structural: **Ferritic Steels (FeCr based), Vanadium Alloys, Composites based in SiC or C fibers.**

Nanocrystal material for high T / high P conditions in target design, and through Oxide Dispersion Strength in FeCr Ferritic Steels.

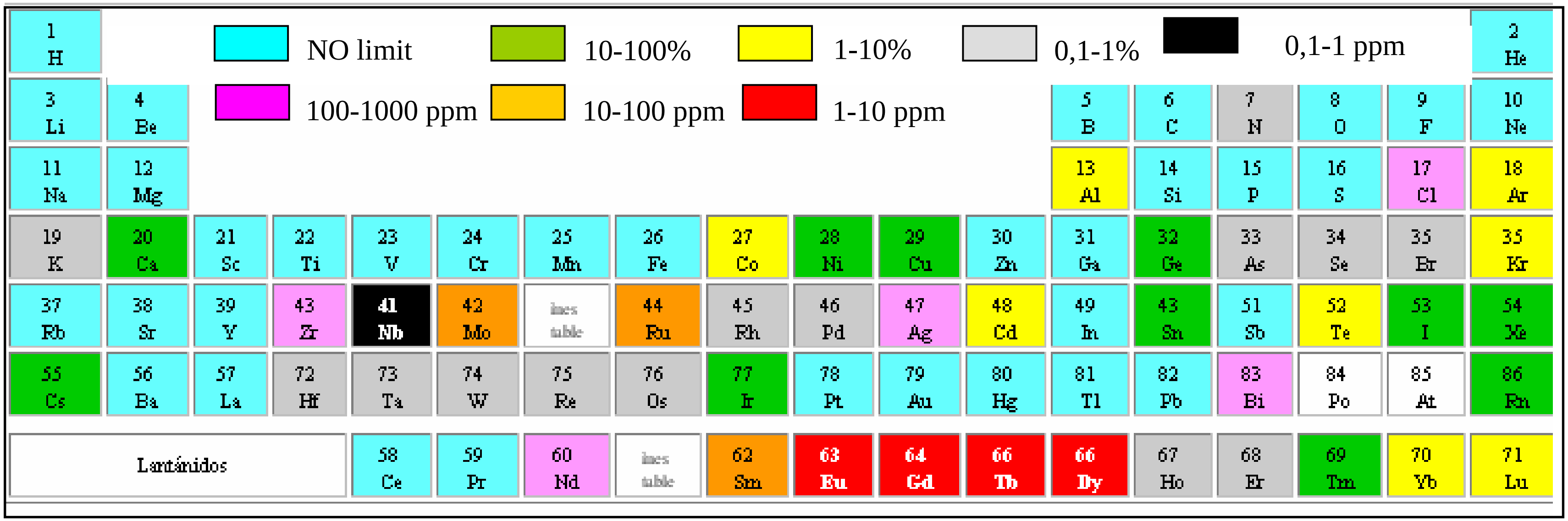
Selection of Low Activation elements

in HYLIFE-II irradiation conditions

Limits in the concentration (weight fraction) for all natural elements

	DOMINANTS NUCLIDES			LIMIT CONCENTRATION		
		RECYCLING			RECYCLING	
ELEMENT	SLB	REMOTE	HANDS-ON	SLB	REMOTE	HANDS-ON
NB	NB 94 (100.)	NB 94 (100.)	NB 94 (100.)	6,93E-07	1,91E-05	4,78E-08
TB	H0166M (100.)	H0166M (100.)	H0166M (100.)	4,82E-06	1,43E-04	3,67E-07
ZN	-	CO 60 (100.)	-	NL	7,59E-01	NL

Acceptability of pure elements under Shallow Land Burial Criteria (SLB)



- **Elements with good engineering properties but not acceptable from activation**
- **Elements as impurities restricted to very severe limits**

Simulating Neutron Source in IFE reactors

Monte Carlo codes have become an essential tool for transport analysis in fusion experiments design and validation.

Although complex geometry can be modeled, extensive effort is needed to generate the input card.

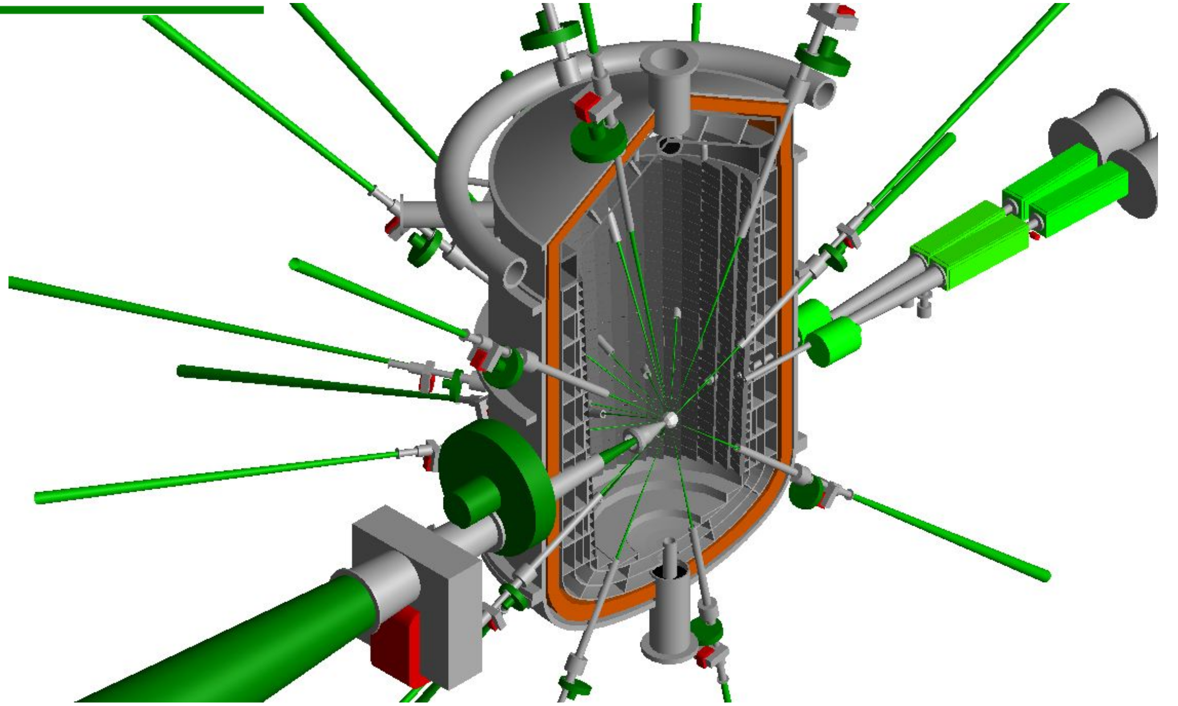
Realistic complex input geometries can be achieved with CAD-MCNP geometry conversion systems.

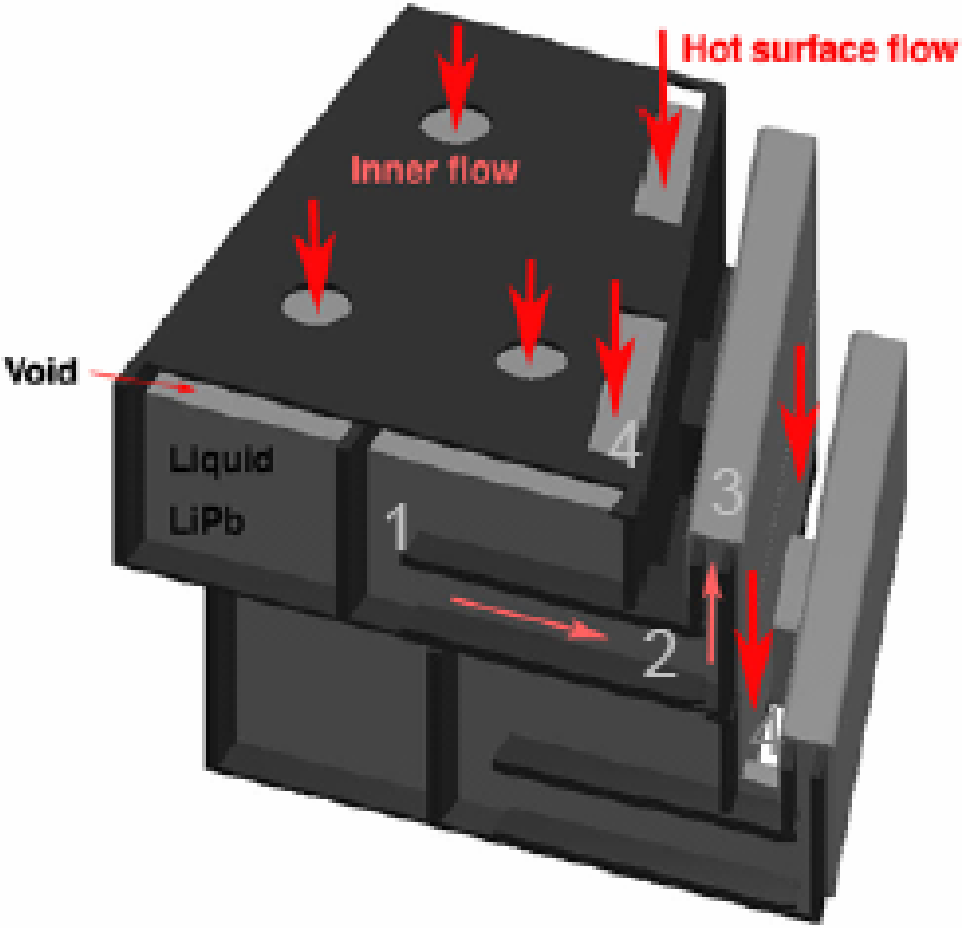
The geometry system design is first fully modeled with a CAD program, and subsequently processed through a MCNP-CAD interface in order to generate the MCNP geometry input file.

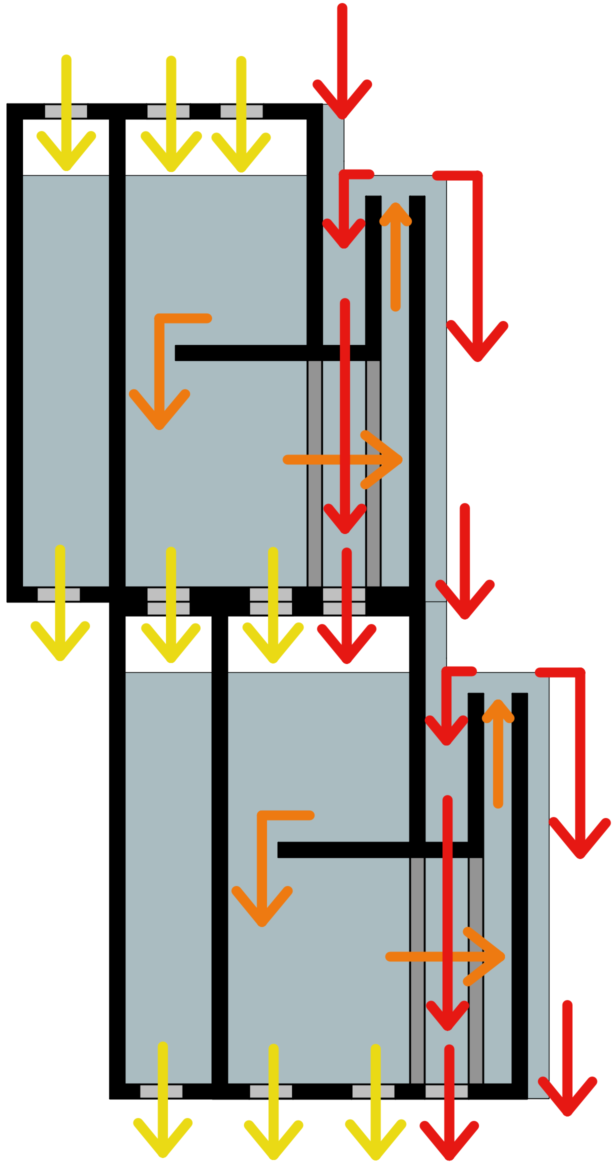
This methodology can be applied to determine neutronic calculations for inertial fusion experiments with complex geometries.

Neutronic calculations in KOYO-F blanket will be determined following this methodology, in order to evaluate material activation for the vessel.

Net output	1200 MWe (300 MWe x 4)
Laser Energy	1,1 MJ
Target gain	165
Fusion output per pulse	200 MJ
Pulse rep-rate in reactor	4 Hz
Blanket energy multiplication	1,2
Thermal output per reactor	916 MWth
Total output at plant	3664 MWth
Thermal to electricity efficiency	41,5% (LiPb at 500 ºC)
Total electric output of plant	1519 MWe
Laser efficiency	8%
Rep-rate of laser	16 Hz
Recirculating power of laser	240 MWe
Total plant efficiency	1200 MWe

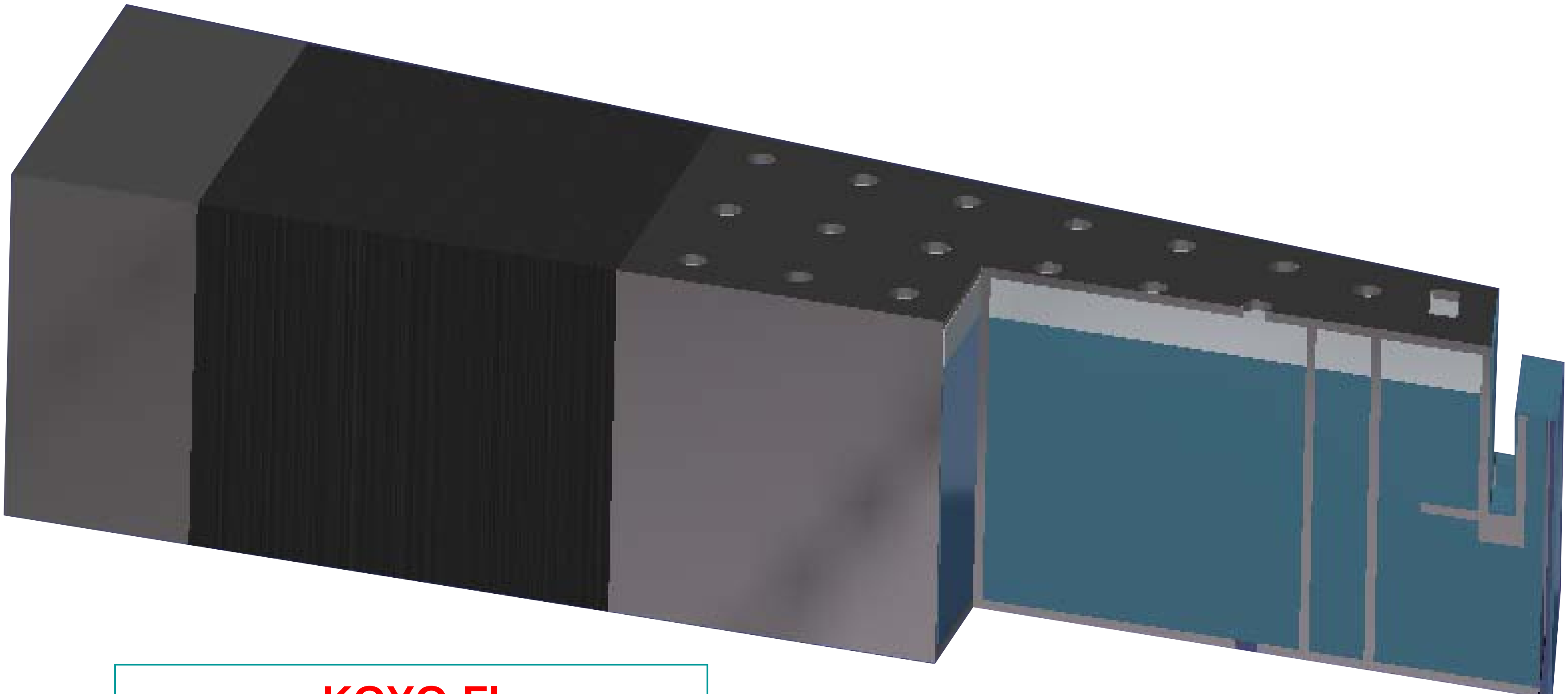



Hot surface flow
Inner flow
Void
Liquid
LiPb
1
2
3
4
4



CAD representation for full 3 dimensional description of the Reactor to study neutron / gamma transport by MonteCarlo Method:

Neutron Fluxes in each point of Facility and then responses such as heating, tririum Breedind, activayion and damage



KOYO-FI

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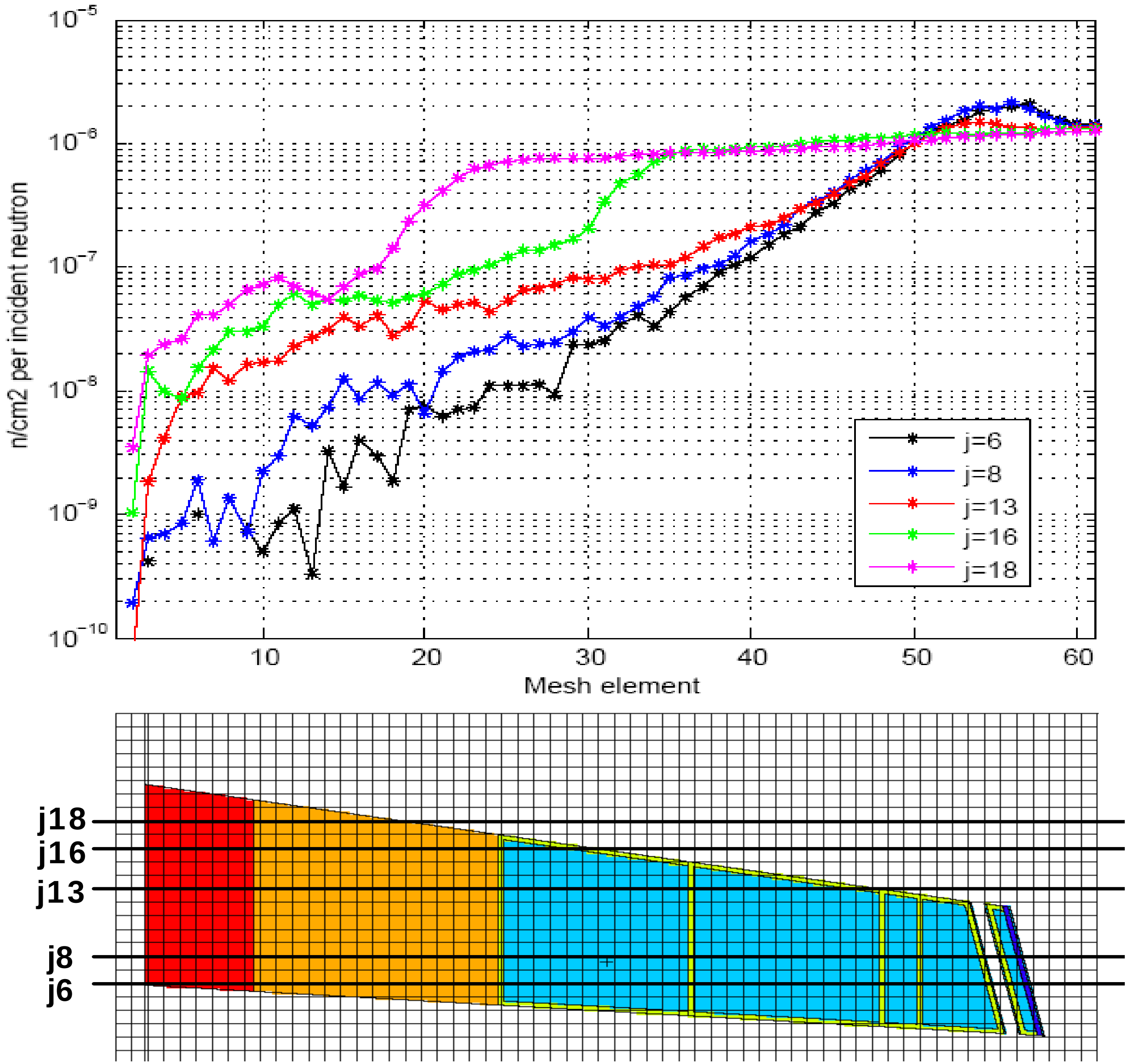
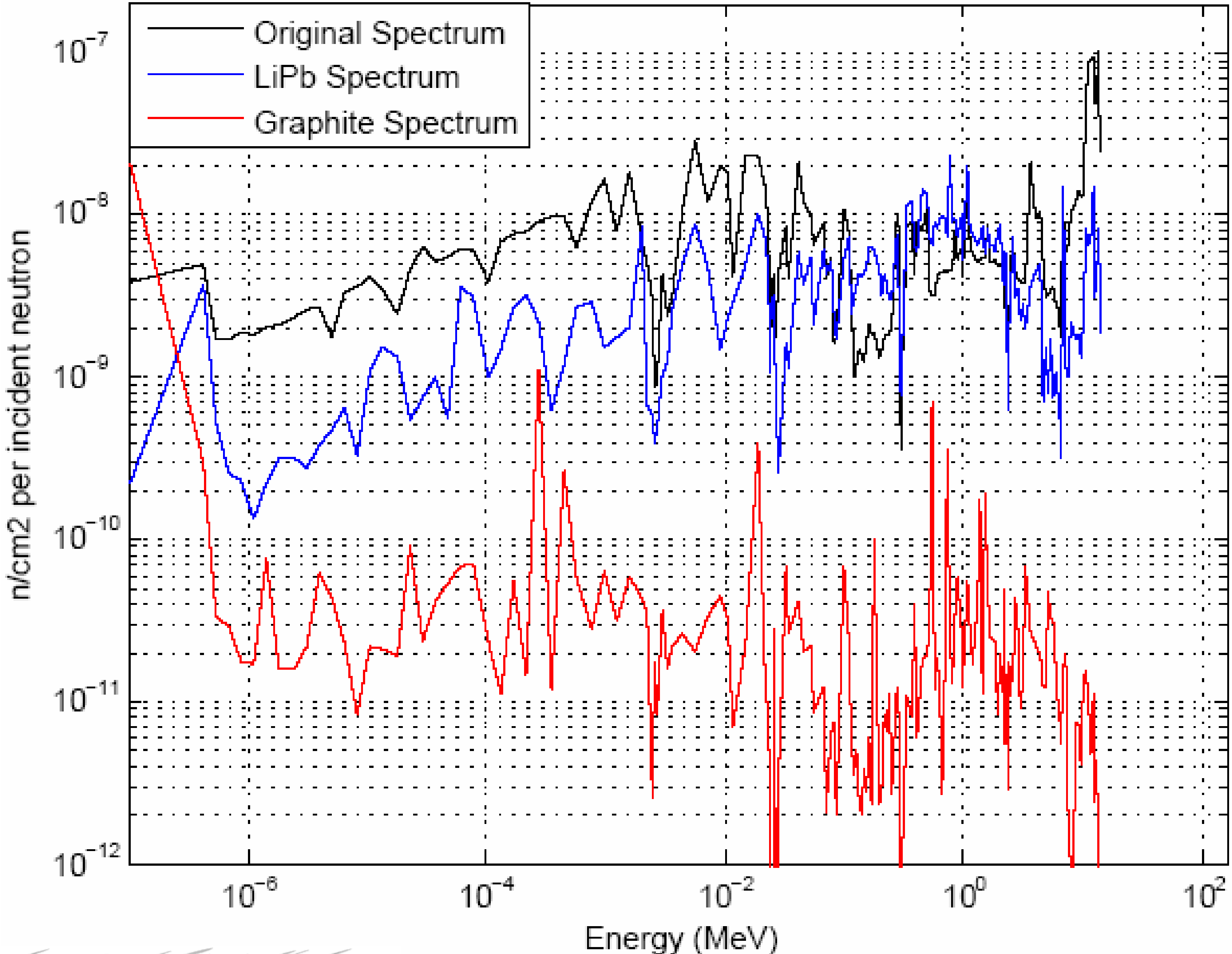


10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
n/cm2 per incident neutron
10
20
30
40
50
60
Mesh element
j=6
j=8
j=13
j=16
j=18
j18
j16
j13
j8
j6



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Vessel material activation has been analyzed –using ACAB with the EAF2005 data library- after 30 years at nominal operation.

Immediate total activity → 0,64 Ci/cm^3
After 1 year decay → 0,28 Ci/cm^3
For periods longer than 100 years → 5E-5 Ci/cm^3

Isotopes that most contribute to the total radioactivity:

During the first month → Fe55 (70%) and Cr51 (20%)
Until the 10th year → Fe55 (90%)
After 100 years → C14 (75%)

Activated material classification is not a problem for the vessel:
The activated 9Cr-1Mo martensitic steel meets both remote recycling (after 50 years) and hands on recycling criteria (after 100 years).

However, SLB is not possible since WDR is always >1.

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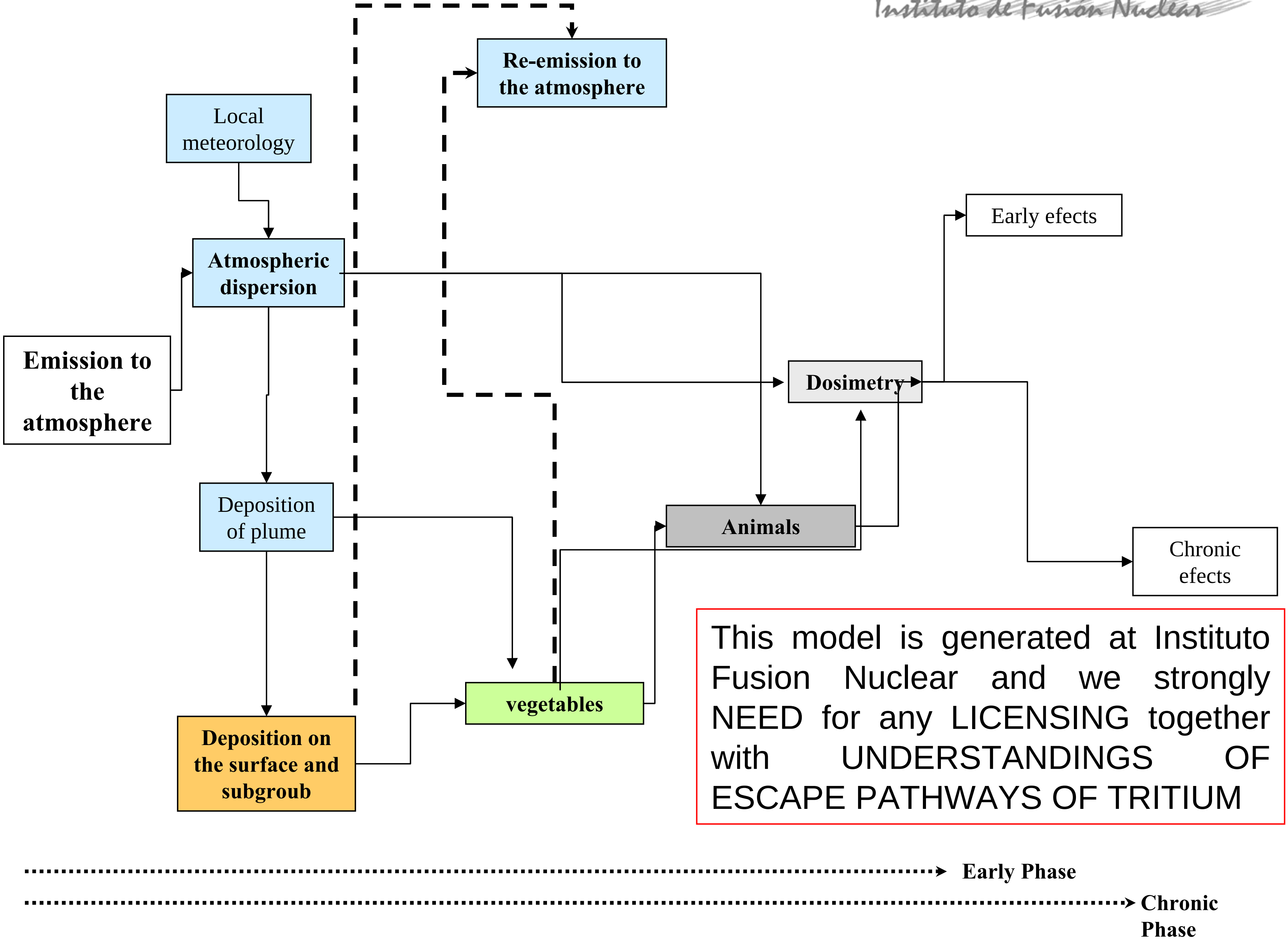
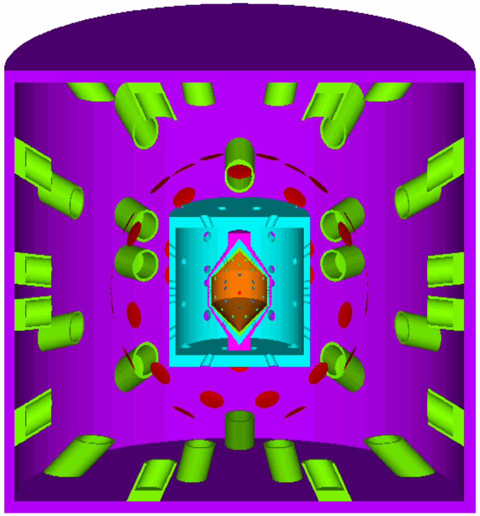


This model is generated at Instituto Fusion Nuclear and we strongly NEED for any LICENSING together with UNDERSTANDINGS OF ESCAPE PATHWAYS OF TRITIUM

Accident analysis for SOMBRERO potentially in HiPER

- Afterheat is low enough to allow rapid cooling of structures (T < 1000 ºC in less than 1 minute)
- Recent experiments on carbon oxidation indicate no oxidation at accident temperatures, more studies are under way
- Tritium retention in carbon structures is a critical issue that still needs to be addressed

- The activation products for Xe (cesium and iodine) are the main contributors to accident dose, possible solutions are:
  - removal of I and Cs by the chamber vacuum system
  - use of alternative gas such as Kr



SOMBRERO model for neutron transport

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