Initial Parameters for ARIES-IFE Laser/HIB Nuclear Analysis And FW Issues

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Web address:
http://fti.neep.wisc.edu/FTI/ARIES/SEP2000/param_lae.pdf

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PPPL

Power Plant Relevant Parameters Needed to Perform Nuclear Analysis for Dry Wall Concept

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- Parameters categorized according to nuclear subtasks:
  - General
  - Target and first wall neutronics
  - Shielding of FF optics/magnets and insulators
  - Activation of target and chamber

- List of parameters will be posted on UW web site:

  http://fti.neep.wisc.edu/FTI/ARIES/AUG2000/nuclear_lae.pdf

  List will be updated as design proceeds and changes will be marked in red

- Currently available laser and HIB target parameters do NOT lead to net electric power of 1000 MW_e

Initial List of Parameters

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General Parameters:

Driver	Laser (KrF, NRL)		HIB (LBNL)	
	Available	Power Plant Relevant*	Available	Power Plant Relevant
driver energy (MJ)	1.3	~2.4	1.5	~6
Target gain	124	~180	100	~70
Target fusion yield (MJ)	161	~430	150	~430
Rep rate (Hz)	5-7	~6.2	5-7	~6
Fusion power (MW)	~ 1000	≤ 2677#	~ 1000	≤ 2580
Thermal power (MW_{th})	?	≤ 2891#	?	≤ 2790
Thermal efficiency	?	47# - 60%	?	45 - 60%
Driver power (MW_e)	?	< 304#	?	?
Driver efficiency	> 7%	7.5#%	20%	20%
Net electric power (MW_e)	<< 1000	~1000	<< 1000	~1000
Plant lifetime	40 FPY		40 FPY	
Availability	> 80%		> 80%	

* from literature and personal communications
# SOMBRERO parameters for 3.4 MJ laser energy, 118 gain, and 400 MJ yield

Initial List of Parameters (cont.)

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Target Neutronics:	**Laser**	**HIB**
Average neutron source energy	< 14 MeV	TBD
Average gamma source energy	< 6 MeV	TBD
Neutrons per fusion	< 1.05	TBD
Gammas per fusion	< 0.003	TBD
Neutron and gamma source spectra @ burn	Figs 1&2	TBD

FW Neutronics:		
FW radius	6.5 m or TBD	3-6 m or TBD
Neutron wall loading*	3.5 MW/m^2 or TBD	4-16 MW/m^2 or TBD
Candidate FW materials	C/C, SiC/SiC, SiC/C, FS, V	
Max. FW thickness**:		
Non-metallic	1 cm	
Metallic	0.5 cm	
FW Lifetime criteria**	dpa, burnup, waste level, stresses, ...	
Blanket thickness#	1 m	
Concrete shield thickness	2 m	
Containment building thickness	2.5 m	

* for 400 MJ yield and 6 Hz

** Materials dependent

\# Consider one meter thick compatible breeding zone for n reflection.
Candidate breeders: LM and SB for both FS and composites; Li for V

Initial List of Parameters (cont.)

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Shielding of FF optics/magnets and insulators:

	Laser	HIB
Target diameter	1.95 mm	6 mm
# of beams	$\geq 60^*$	2
# of penetrations	≥ 60	4
Penetration diameter	20 cm @ 6.5 m FW	~5 cm @ 3 m FW
FW area occupied by penetrations	< 0.5%	< 0.01%
Final optic location from target	30 m	> 25 m
FFM location from target	50 m	> 50 m
Mirror's f #	50	?
Laser beam diameter @ final optic	~60 cm	?
Laser beam diameter @ FFM	~100 cm	?
final optic bend angle	$\geq$ 10 degrees	
Mirror dimensions	?	
Mirror composition	Al/H_2O (75/25) ?	
FFM coating material	MgF_2 or ZnS	
Damage limit to final optics	?	
Quadrupole magnets		HT S/C** ?
Magnet to target distance		~15 m
Magnet center from beam axis		30 cm
Fast n fluence limit to magnet		10^{19} n/cm^2
Fast n fluence limit to spinel insulator#		4×10^{22} n/cm^2

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* depends on heating limit to FF mirrors (5-8 J/cm^2)

** YBCO, GFF polyimide, CeO_2, SS, Ag, LN

\# Spinel insulator for chamber wall and adiabatic lens. Limit is for 3% swelling

Initial List of Parameters (cont.)

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Activation:	Laser	HIB
Target burn time	50 ps	50 ps
Candidate target coating/ hohlraum	300 Å of Au, W, Pb, Ta, or Ag	Au, Gd, Fe C, D, Al
Target constituents	D, T, CH	D, T, Be, Br
Target configuration	Fig. 3.a	Fig. 3.b
Candidate chamber gases	Xe, Kr, Ne, He, or Ar	Xe
Gas pressure @ RT	0.1 Torr ?	5 Torr

Yearly pulse sequence for scheduled maintenance:

Case I*: (mirrors annealed every year):

Irradiation period	> 9.5 months
Down time	< 2.5 months

Case II: (mirrors annealed every month):

# of irradiation periods	10
Duration of irradiation period	> 29 days
Down time between irradiation periods	2 days
Extended end-of-year down time	< 2 months

* reference case

Initial List of Parameters (cont.)

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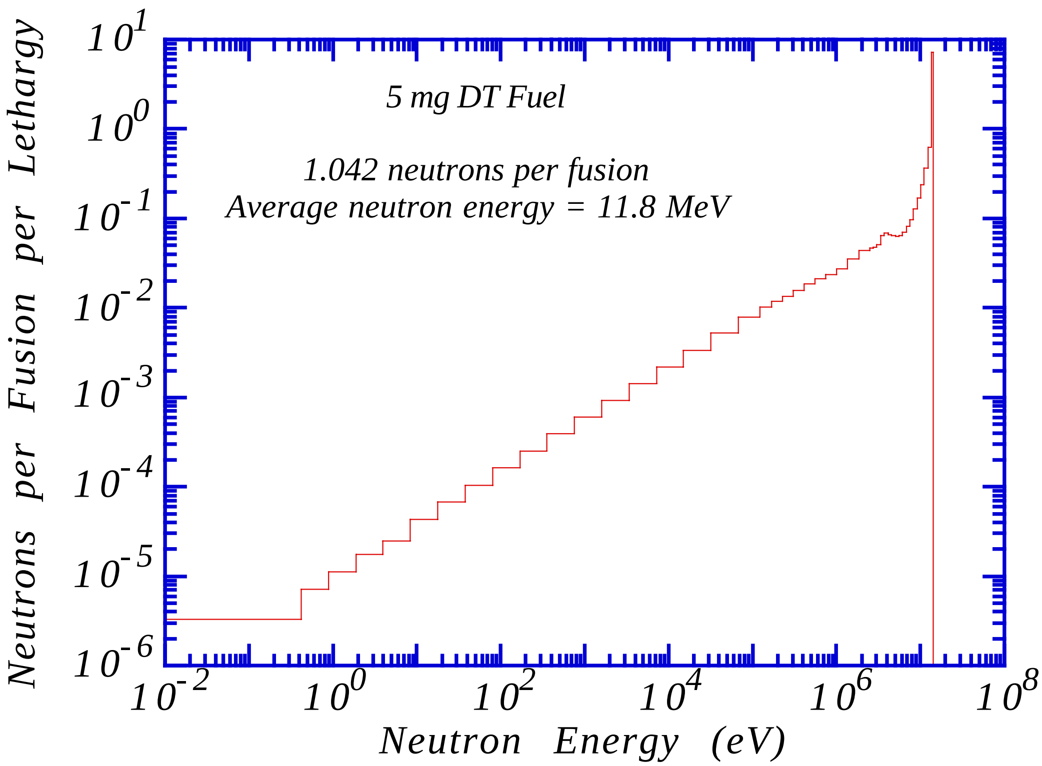

Fig. 1 Neutron source spectrum for LIBRA-SP* target

- Similar spectrum will be generated for Laser and HIB targets

* Light Ion Beam self-pinched design

Initial List of Parameters (cont.)

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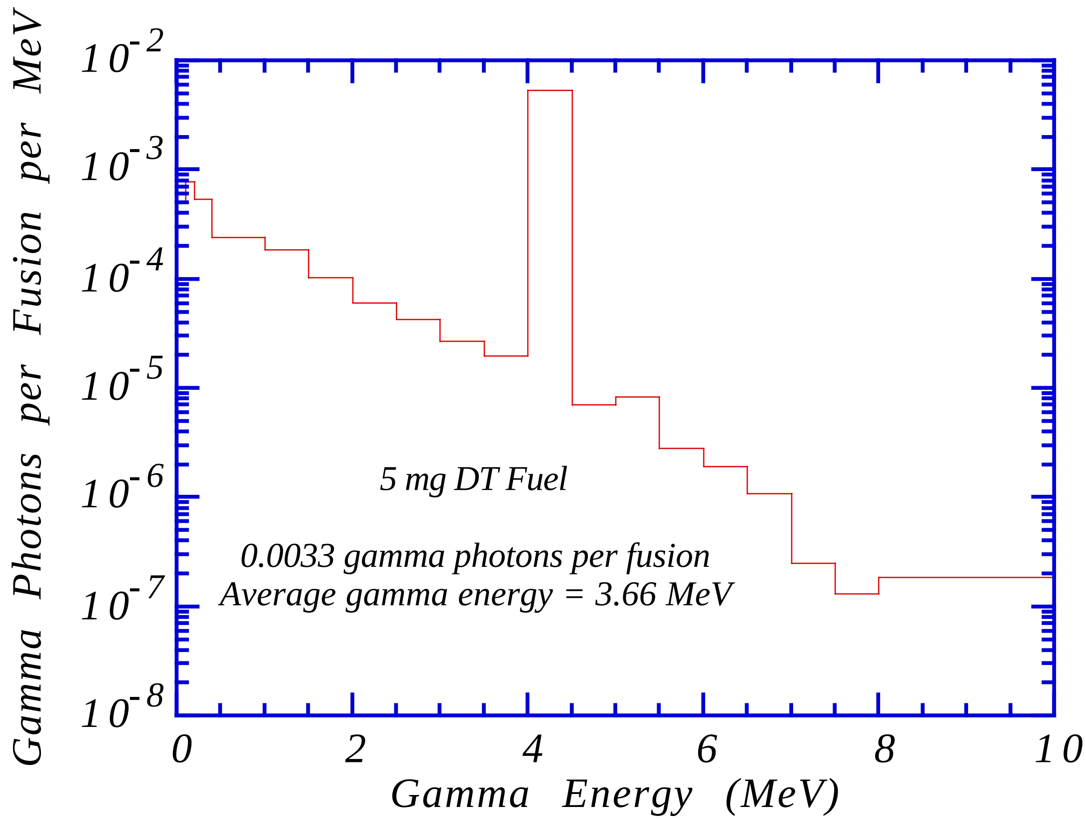

Fig. 2 Gamma source spectrum for LIBRA-SP* target

- Similar spectrum will be generated for Laser and HIB targets

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* Light Ion Beam self-pinched design

Initial List of Parameters (cont.)

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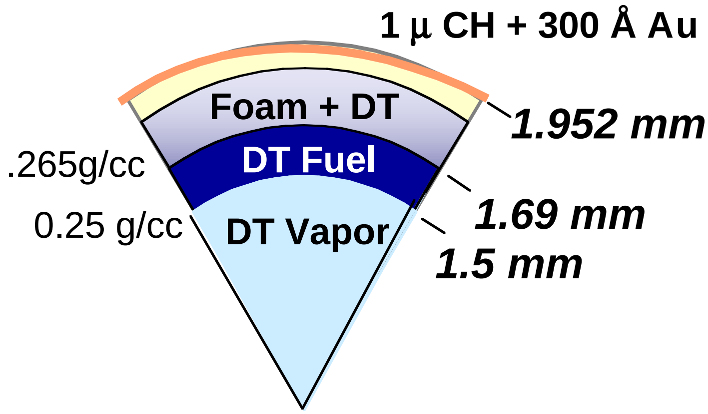

Fig. 3.a Schematic of NRL laser target configuration

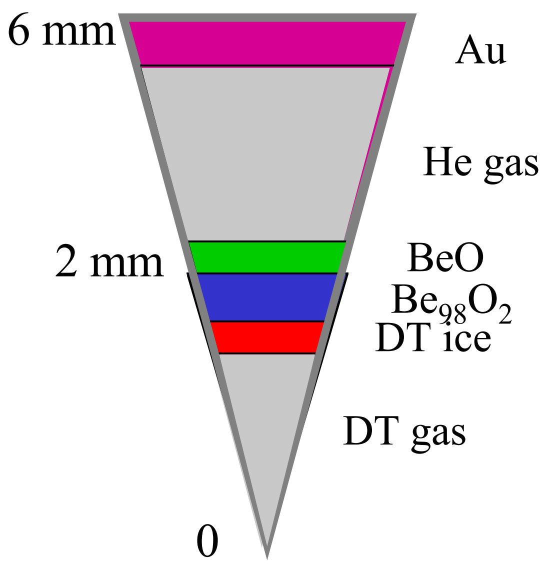

Fig. 3.b Schematic of HIB target and hohlraum configuration

Amount of High Z Material Used in Laser and HIB Targets Are Needed for Activation Analysis

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	Laser	HIB
Coating/hohlraum material	Au	Au (+10% Gd)
Target radius	1.95 mm	6 mm
Equivalent thickness of coating/ hohlraum	300 Å	75 µm
Rep Rate	~6 Hz	~6 Hz
# of targets per year	190 million	190 million
Volume of coating/hohlraum per year	280 cm^3	6.4 m^3
Mass of Au* per year	5 kg	120 tonnes (??? M$/y)
FW lifetime	4.8 FPY	4.8 FPY
FW radius	6.5 m	6.5 m
Thickness of Au condensed on FW after 4.8 FPY	2.5 µm	5.8 cm

* 18.9 g/cm^3

Gold Plated FW and Mirrors

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- Au will penetrate several microns into FW material
- Thin layer (1 mm) of Au could stick on FW @ T ~ 1100 ºC.
- If FW temperature considerably exceeds Au melting point (1064 ºC), most of Au will be collected at bottom of chamber and recycled
- Au will affect FW response and radiation-wall interaction. This issue should be investigated for both Laser and HIB drivers
- Impact of Au on FW material properties needs to be addressed
- Peak FW temperature will change as it depends on thermal conductivity of first few microns
- Au may impact other properties such as FW absorption for tritium
- Au will diffuse out of chamber through beam ducts and condense on mirrors, causing hot spots and laser beam defocusing
- After burn, Au gets activated by source neutrons and reactivated at FW by n's from subsequent shots for maximum time of 4.8 FPY(FW lifetime)
- If collected and recycled, Au will be irradiated for short period of time, depending on Au removal scheme

Several Factors Influence FW Location

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- These are:
  1. Surface heat flux
  2. Mechanical load
  3. Neutron wall loading and damage
  4. FW lifetime and cumulative radwaste
  5. Chamber, shield, and building volumes
  6. GIM/FF mirror location

- Impact of factors # 1, 3, 4, and 5 assessed for FW radii ranging between 3 and 12 m

- SOMBRERO engineering parameters used in sensitivity analysis with NRL target parameters scaled to 430 MJ yield and 6 Hz

- **Assumptions:**

  Surface heat flux
  - Heat load per shot from radiating gas, ions in wall, and x rays in wall
  - Results for 161 MJ yield multiplied by 2.7
  - 5 J/cm^2 per shot limit for no evaporation of C/C composites

  Damage and lifetime
  - 3.5 MW/m^2 @ R_{FW} = 6.5 m for 430 MJ yield and 6 Hz
  - 75 dpa limit for C/C composites
  - 15.6 dpa/FPY $\Rightarrow$ 4.8 FPY for R= 6.5 m
  - Neutron wall loading and damage scale as 1/r^2

  Geometry and volumes
  - Spherical chamber: 1 cm thick C/C FW, 1 m thick blanket with 30% C/C
  - Single FW/blanket unit (no blanket segmentation)
  - Cylindrical shield: 2 m thick, 60 m high
  - 2.5 m space between blanket and shield
  - Cylindrical containment building: 55 m radius, 2.5 m thick, 90 m high

Sensitivity of FW Radius to Neutron and Surface Loadings

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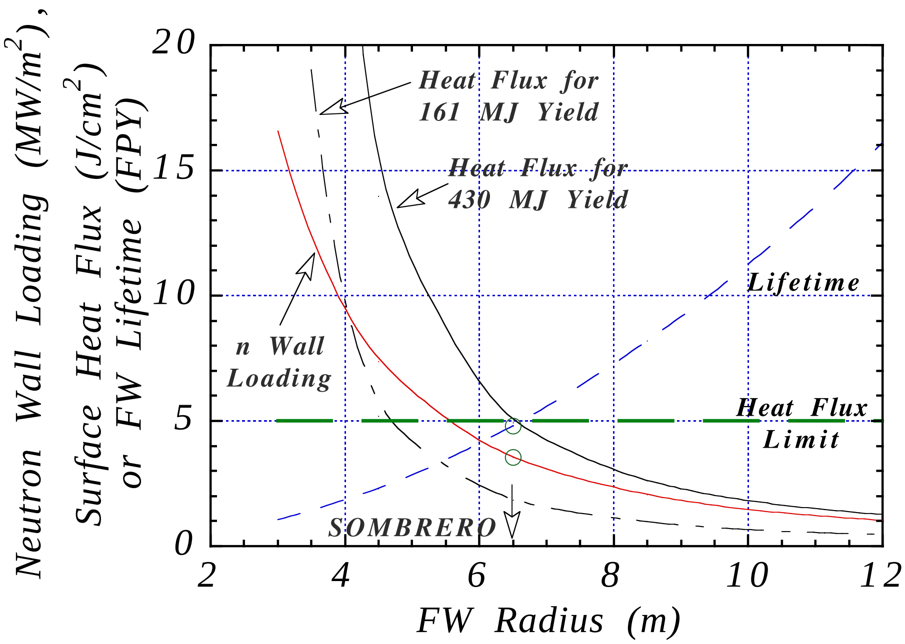

- To avoid evaporation of C/C composites, FW radius should be ≥ 4.5 m for 161 MJ yield and ≥ 6.5 m for 430 MJ yield

- Neutron wall loading will not exceed 7 MW/m^2

Surface heat flux limit will determine minimum FW radius

Cumulative Chamber Volume is not Strong Function of FW Location

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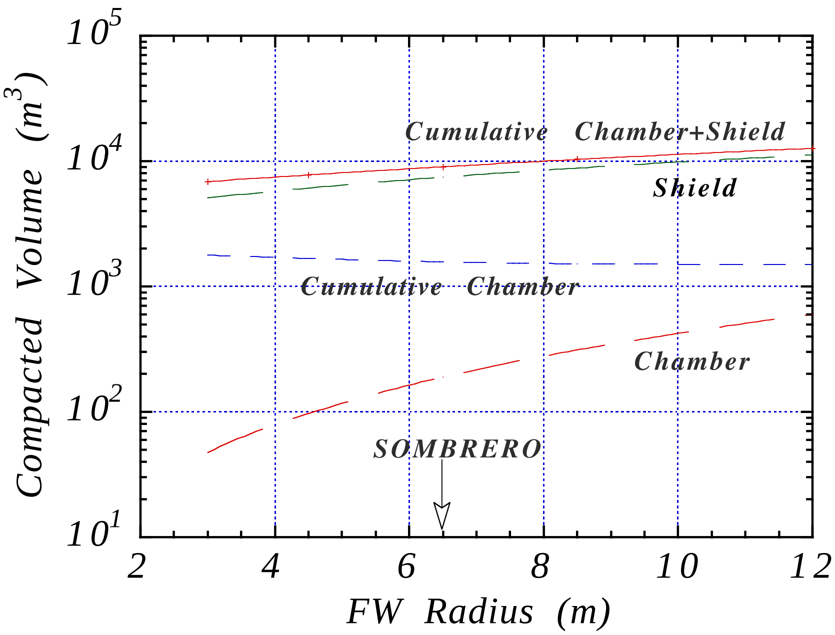

- Smaller FW location ⇒ higher FW damage
  ⇒ more frequent chamber replacement
  ⇒ higher cumulative chamber waste

- Cumulative chamber waste varies within 15-20%

- Shield volume is more sensitive to FW radius (factor of 2 change)

Containment Building Dominates Volume of Waste

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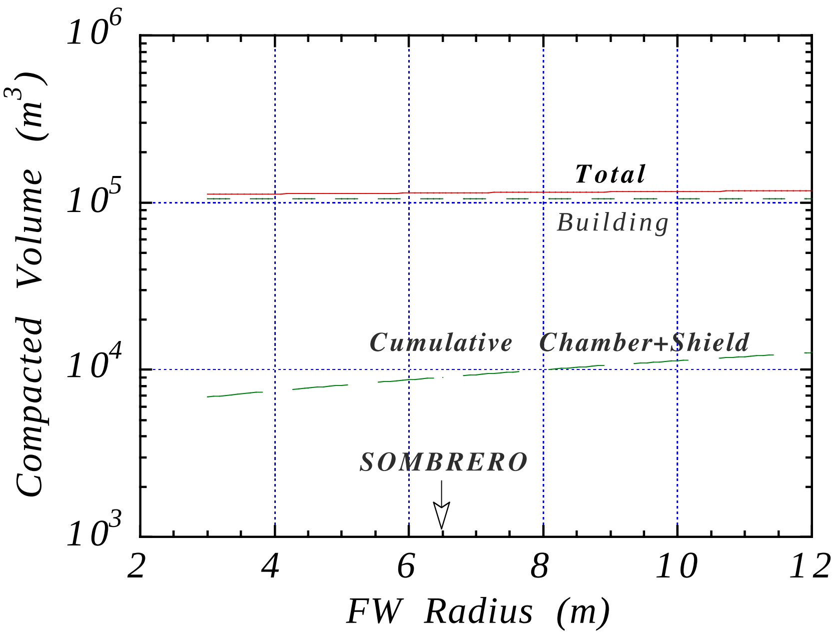

Total waste volume is not sensitive to FW radius (5% change)

Conclusions

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- A list of power plant relevant parameters developed for both laser and HIB drivers. Nuclear group needs feedback from ARIES-IFE physics and engineering groups before October 1.

- Sensitivity of FW radius to neutron wall loading, surface heat flux, and waste volume has been examined for laser driver. Similar analysis will be performed for HIB driver

- Cumulative chamber waste volume is not strong function of FW location

- To minimize shield volume, reduce FW radius as practically possible

- Containment building dominates volume of waste and is not sensitive to FW location

- Surface heat load will determine FW location. Capability of C/C composites to handle ~5 J/cm^2 per shot without evaporation calls for FW radius of 4.5-6.5 m, depending on fusion yield

- Neutron wall loading will not exceed 7 MW/m^2