GENERAL ATOMICS
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Heavy Ion Fusion Target Materials Selection and Removal of Tungsten Carbide from Flibe

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Los Alamos
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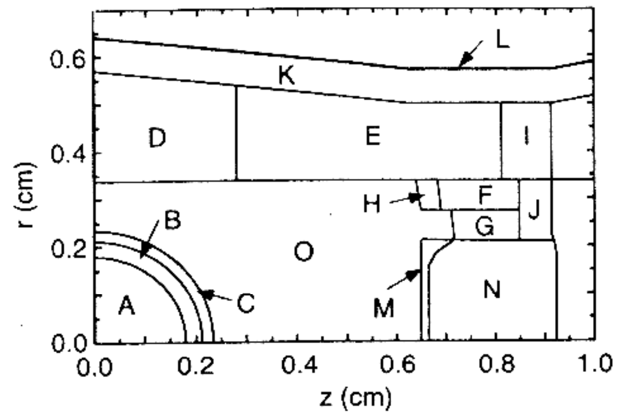
We set out to do a detailed evaluation of hohlraum materials for the heavy ion target. Final selection requires an overall systems view

Excellent e-mail exchanges took place discussing the relative merits of various hohlraum materials.

- Strong opinions
- Continuing disagreement
- Single use vs recycle
- Isotopic separation

-Fabricability
-Target energetics
-Materials separation
-Radioactive inventory and handling
-Materials compatibility
-Injectability

The heavy-ion driven target has a number of unique and challenging materials



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… This work significantly improved materials selection knowledge and awareness

Summary

- Task = Evaluate hohlraum materials from an overall systems viewpoint
- We now have a good range of options available
- All have distinct advantages/disadvantages

	Material \ Issues	Target gain	Manufacture	Separable from Flibe	Waste hazard
Ref.	Au/Gd	0% loss	Costly (Recycle)		Radiation
	Hg and Hg/X	0-13% loss	Toxicity	Easy (Hg)	Mixed waste (Hg)
Cost study	PbHf PbW	2% loss 4% loss	OK ($0.41) OK	Electrochemical (Hf)	Mixed (Pb)
LCVD Demo	W	12% loss	Great	Potential plating prob	Low level Radiation
	PbHfXe	0% loss	Higher cost		Mixed (Pb)

… Several viable target options exist …..

Seed particles can minimize WC plate out on surfaces

Proposal: **Add 0.5 μm W and WC particles to flibe at rate ~ 2 kg/day**
Elements diffuse to and plate on these particles
Remove particles in a slip stream

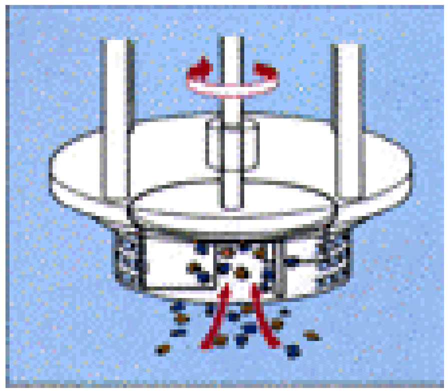
Assumptions and Calculations:

- **2,500,000 kg (1250 m^3) of Flibe in loop [Ref. 1]**
- **85 m^3/s Flibe flow rate**
- **30,000 m^2 plant surface area (heat exchangers etc.)**
- **55,000 kg/yr (3 m^3) W used in hohlraums**
- **Carbon in targets will result in CH_4 and WC**
- **Growth rate plant surfaces without removal = 100 micron/yr**
- **Vacuum disengager spray nozzle diameter = 400 microns [Ref. 2]**
- **Flibe jet screen openings = 1200 microns**

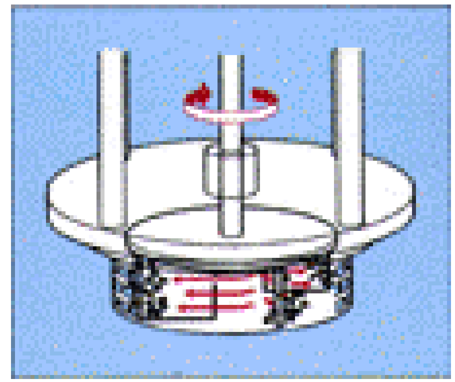
Require: Particle surface area >> plant surface area
3,000,000 m^2 gives 1 micron/year growth rate and allows 99% removal

Ref.
1. Moir, et. al., *Fusion Technology*, Vol. 25, (1994) 1-25
2. Dolan and Longhurst, *Fusion Technology*, Vol. 21 (1992) 1949-1954

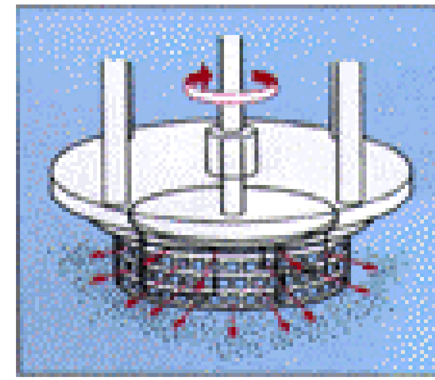
Seed particles are disbursed in Flibe with high sheer mixer



Powder and fluid drawn in



Powder and fluid thrown outward and milled with high speed blades



Mixture is ejected with high sheer

Silverson’s high sheer mixer operation

High concentration mixtures would be added to the bulk Flibe and further disbursed by turbulent mixing

Required particle volume fraction in Flibe to provide 100X surface area increase is ~0.1%

$N(D) = N(D_0) \exp\{-(D-D_0)/\lambda\}$
Required mass to provide surface area increases linearly with particle diameter

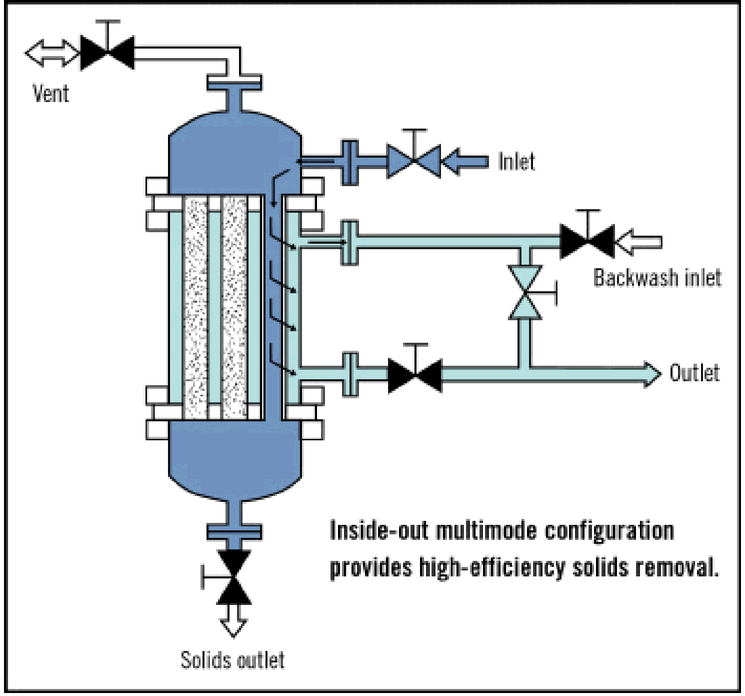
For typical values: D_0 =0.5 μm, λ= 1 μm, 1 μm/yr growth rate
- **D_{ave} = 1.5 μm**
- **Total particle volume = 1.5 m^3**
- **Average particle residence in Flibe = 6 Mo**
- **Purification flow rate = 4.8 l/min**

3 μm particles settle at only 8 mm/hr so should remain suspended

Short diffusion time will further reduce required number of particles
- **Just 0.7 s is needed to reduce atom concentration to 1/e for the typical values above**
- **Even with 5X fewer particles only 3 s is needed out of a typical 15 s loop recirc time**
- **Fewer particles increase purification flow rate for a given size distribution**

□Cross-flow sintered metal filters are recommended to remove particles

Figure 2. Inside-out Multimode Filter Configuration



Alternate separation methods:
Cyclone separator - better for larger particles (~20 μm)
Centrifuge

Conclusions

Viable target materials exist

- **PbW is good if mixed waste handling improves**
- **W is a leading material choice (but any single material has high wall losses)**

W and WC may be removed by seeding the Flibe with fine particles

- **Sufficient particles will minimize buildup on plant orifices to acceptable levels**
- **Seed particles may be incorporated with a high-sheer mixer**
- **Particles can be removed by filtering**

If droplet density and size are not excessive, in-chamber tracking should not be necessary for indirect-drive targets

Calculate maximum acceptable single droplet radius near edge of 3 m chamber To not exceed 0.3 mm change in axial position prediction

$$\Delta R = \frac{\Delta v}{v_0} R_c = \frac{m_d}{m_t} R_c \Longrightarrow m_d = \frac{\Delta R}{R_c} m_t = \frac{0.3\ \text{mm}}{3\ \text{m}} 2\ \text{g} = 0.2\ \text{mg}$$

Droplet radius is 0.29 mm (assuming 2 g/cc liquid density).

Further calculations show that chamber density is limited to about 1 g/m^3 for numerous smaller droplets.

1 g/m^3 could cause 0.3 mg/cm^2 accumulation on target passing through a 3 m radius chamber

$$\frac{\rho}{A} = \rho R_c = \left(1g/m^3\right)\left(3m\right) = 0.3mg/cm^2$$

This is roughly 1% of ion beam range for 3.5 GeV Pb ions so energy loss is acceptable (<1%) for HIF targets.
Scattering of beam by droplets in chamber may cause more losses.

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Schafer

Back up slides

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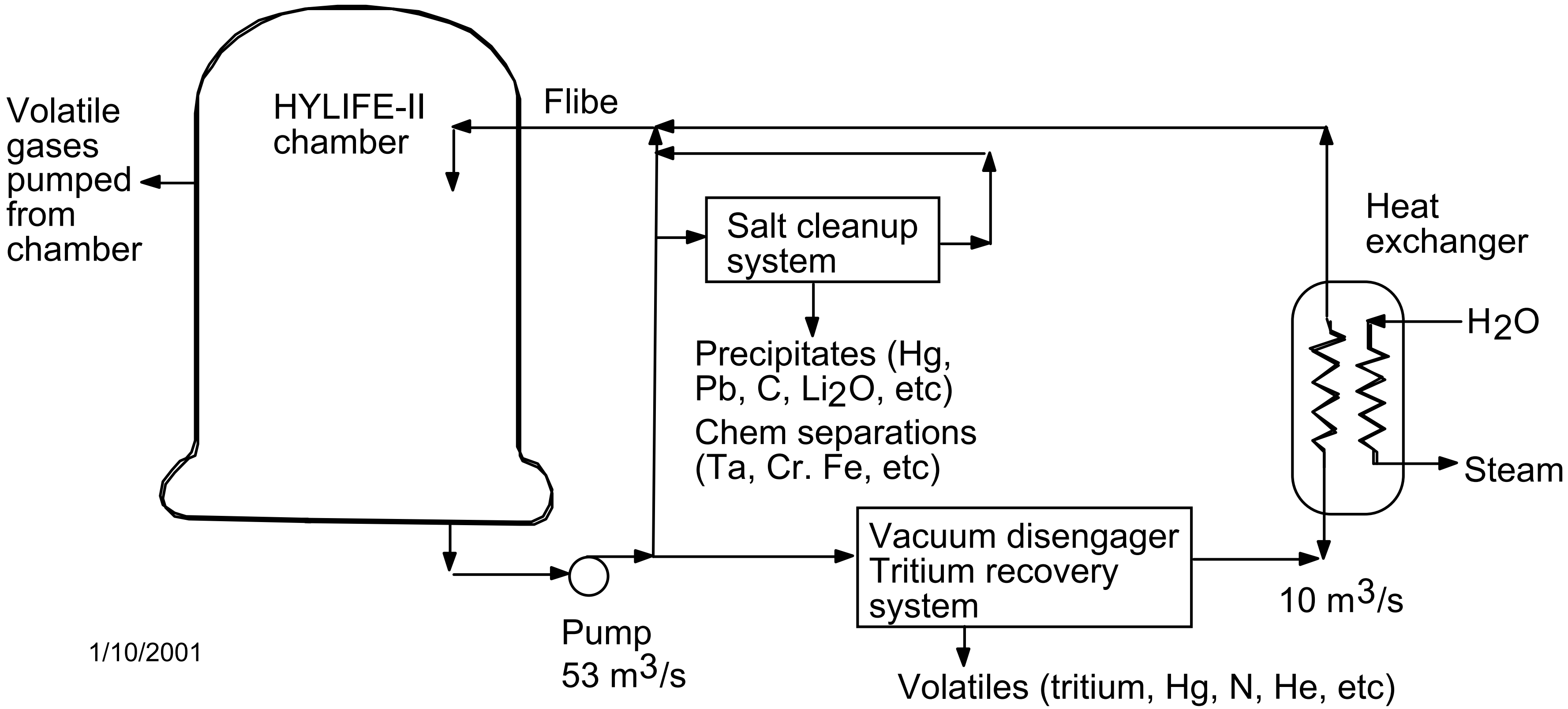
□Hohlraum wall materials selection affects the target energetics

Material	$E_{wall} / E_{wall\ AuGd}$
Au/ Gd (50 :50)	1.00
Au	1.25
Pb	1.28
Hg	1.26
Ta	1.25
W	1.25
Pb/ Ta (50:50)	1.08
Pb/ Ta (70:30)	1.06
Hg/ Xe (50:50)	1.18
Pb/ Ta/ Cs (50:20:30)	1.01
Pb/ Ta/ Cs (45:20:35)	1.01
Hg/ Ta/ Cs (45 :20:35)	1.03
Hg/ W/C s (45:20:35)	1.04
Pb/ Hf (70:30)	1.04
Pb/ Hf/ Xe (45:20:35)	1.00
Th/ Bi/ Ta/ Sm/ Cs	0.82
U/P b/ Ta/ Dy/ Nd	0.76

Uranium and thorium may be undesirable due to fission radioactivity

Ref: D. A. Callahan-Miller and M. Tabak, "Progress in target physics and design for heavy ion fusion," Physics of Plasmas 7 (2000) 2083-2091

□Volatile, centrifugal and chemical processes are used for impurity separation*



1/10/2001

*Ralph Moir, **Flibe coolant cleanup and processing in the HYLIFE-II inertial fusion energy power plant, UCRL-ID-143228 (2001)**

Recent materials selection evaluation*

We first eliminated elements that are

-Not naturally occurring or fissionable

-Too costly

-Inseparable from Flibe or

-Too radioactive for shallow land burial

The remaining elements were ranked (and some more eliminated) for

-Energetics

-Cost

-Chemical toxicity

-Ease of separation from Flibe

-Ease of fabrication and

-Radiological toxicity

***Review from spring meeting**

7 elements survived the above criteria

W, Yb, Nd, Pr, Ce, La (group A high Z) and Pb (group B very high Z)
Very high Z combined with high Z tends to give best energetics

Pb/W has low energy loss (1.08 times Au/Gd) but creates mixed waste

Ce > La > Nd > Pr > Yb have higher cost than W
and form stable fluorides soluble in Flibe which may be costly to separate

W is a leading candidate

Pros

-Low to moderate cost materials
-Solids at room temp
-Amenable to LCVD
-W separable by centrifugation (or settling/filtering)

Cons

-Higher wall energy loss (1.25 times Au/Gd)
-May settle in Flibe loop*
-Tungsten might clog spray nozzles*

***Recent study indicates this can be avoided**