Target Materials Selection and Constraints on Chamber Conditions

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On Liquid Wall Chamber Dynamics
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□Outline

-Background materials selection work

-Recent materials selection evaluation

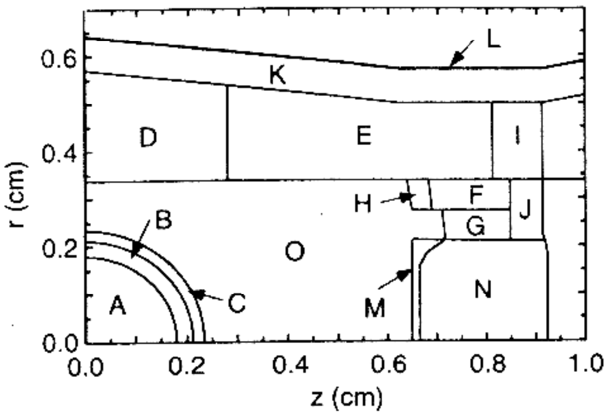
-Target constraints on chamber conditions

Final selection of materials requires an overall systems view

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

A:	DT	0.0003 g/cc
B:	DT	0.25 g/cc
C:	$Be_{0.995}Br$	1.845 g/cc
D:	Au	0.032 g/cc
E:	$CD_2Au_{0.03}$	0.011 g/cc
F:	Fe	0.064 g/cc
G:	Fe	0.083 g/cc
H:	$CD_2Au_{0.03}$	0.032 g/cc
I:	AuGd	0.1 g/cc
J:	AuGd	0.26 g/cc
K:	AuGd	0.099 g/cc
L:	AuGd	13.5 g/cc
M:	Al	0.055 g/cc
N:	AuGd "sandwich"	0.1/1.0/0.5
O:	D_2	0.001 g/cc

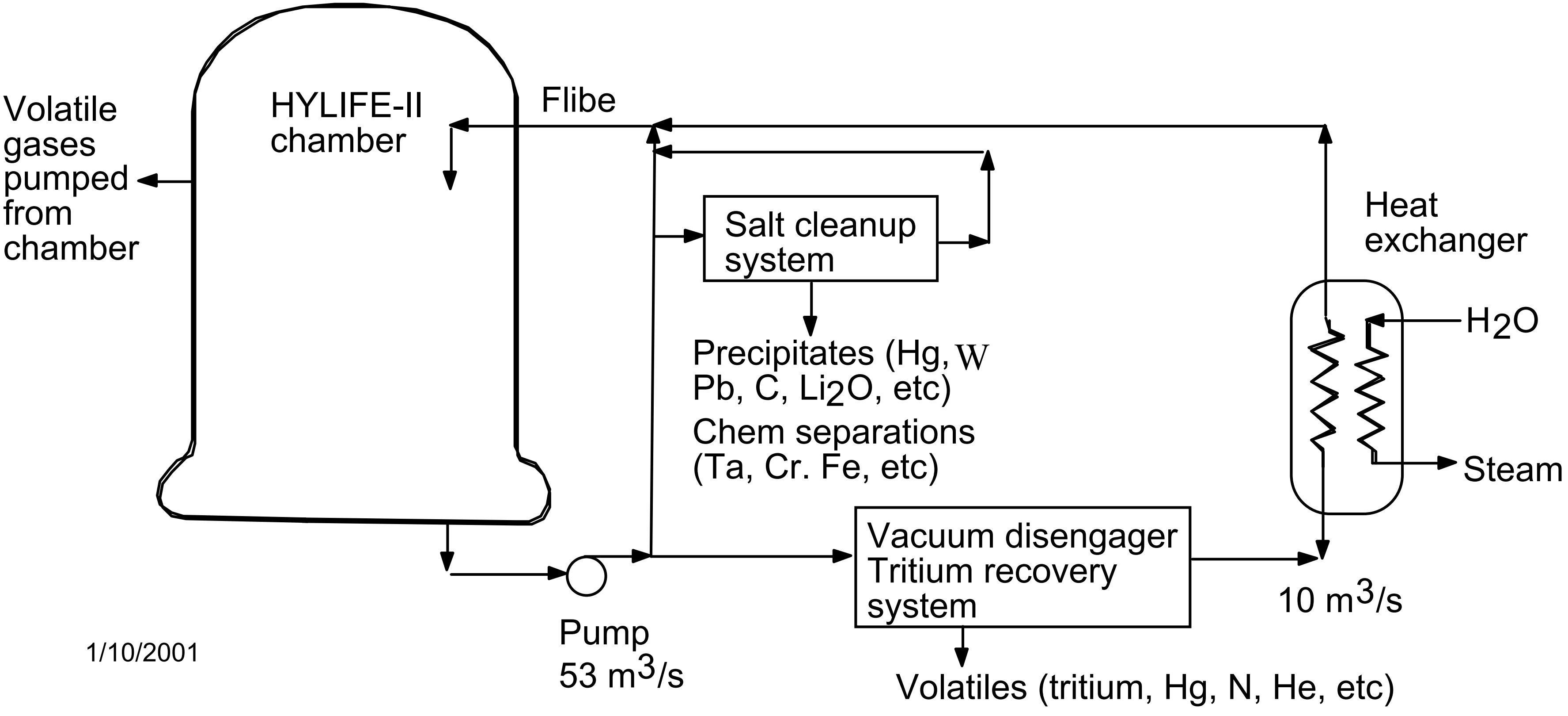
- Fabricability
- Target energetics
- Materials separation
- Radioactive inventory and handling
- Materials compatibility
- Injectability



***Nuclear Fusion* 39, 883**

… Simplification and material substitutions are needed to reduce complexity of the target

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



Volatile gases pumped from chamber

HYLIFE-II chamber

Flibe

Salt cleanup system

Precipitates (Hg, W Pb, C, Li_2O, etc)
Chem separations (Ta, Cr. Fe, etc)

Heat exchanger

H_2O

Steam

Vacuum disengager
Tritium recovery system

10 m^3/s

Pump
53 m^3/s

Volatiles (tritium, Hg, N, He, etc)

1/10/2001

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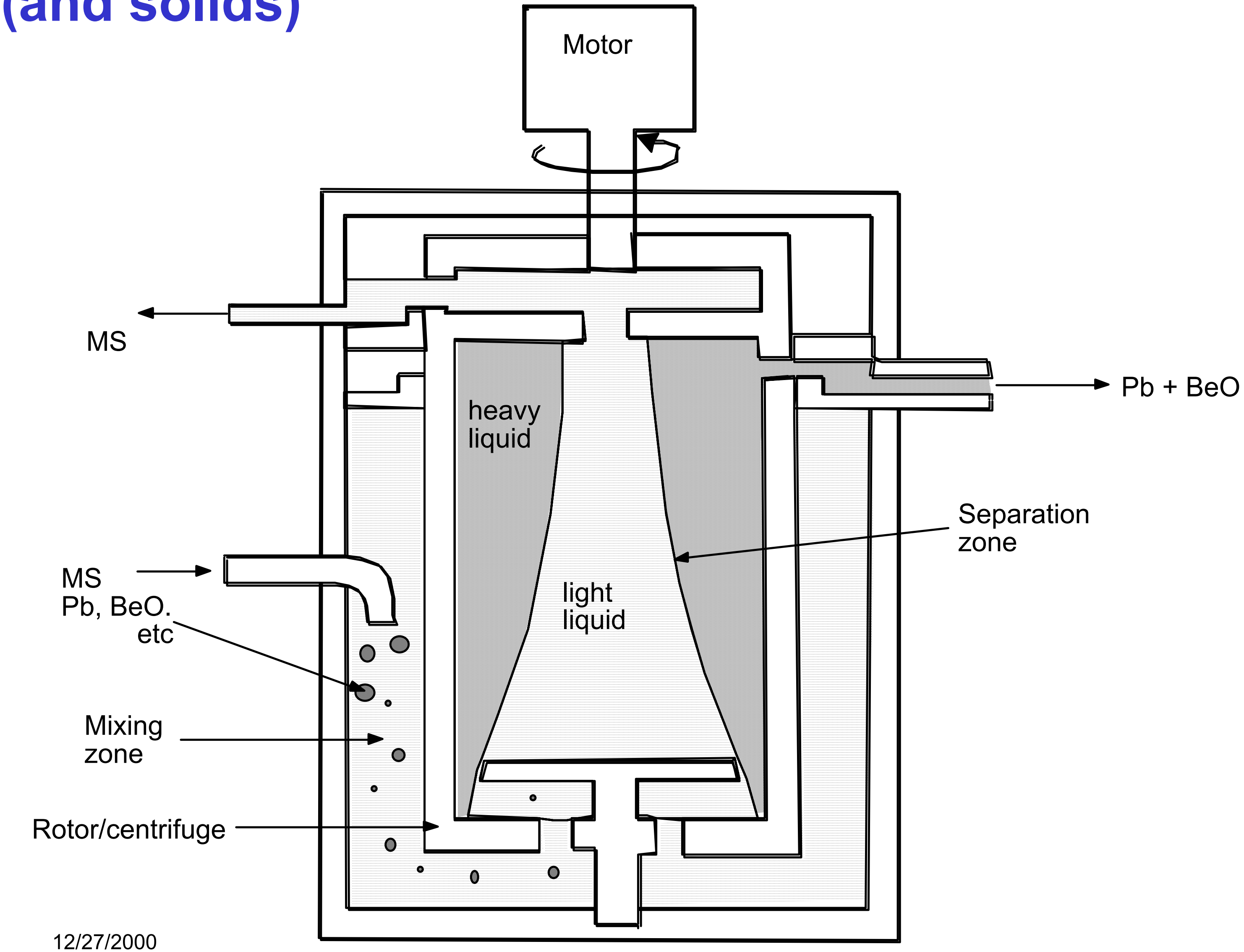
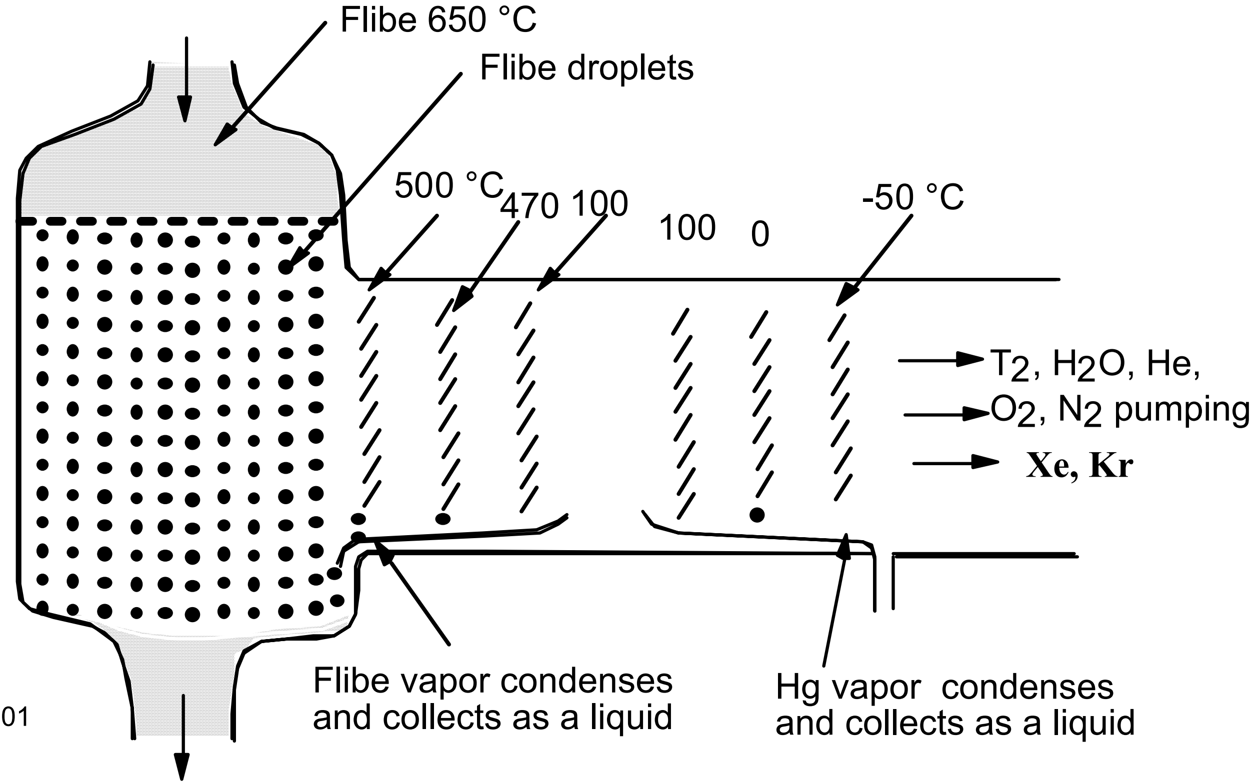
*Ralph Moir, **Flibe coolant cleanup and processing in the HYLIFE-II inertial fusion energy power plant, UCRL-ID-143228 (2001)**

A centrifuge will effectively remove insoluble liquids (and solids)



Flow rate
~ 1 l/s

Mercury, xenon, and krypton are volatile and easily removed from Flibe*



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Flow rate up to 10,000 l/s

This allows much lower impurity concentrations and lower separation costs

*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

□14 elements meet Moir’s screening of high Z materials and also meet shallow land burial radioactivity requirements

Z	Element	Separation methods
82	**Pb**	**Centrifuge**
81	**Tl**	**“**
80	**Hg**	**volatility, centrifuge**
74	**W**	**Centrifuge**
73	**Ta**	**TaF_5, volatility, electrochemical**
72	**Hf**	**HfF_4, electrochemical**
71	**Lu**	**LuF_3, Bi extraction**
70	**Yb**	**YbF_3, Bi extraction**
60	**Nd**	**NdF_3, Bi extraction**
59	**Pr**	**PrF_3, PrF_4, Bi extraction**
58	**Ce**	**CeF_3, Bi extraction**
57	**La**	**LaF_3 , Bi extraction**
55	**Cs**	**volatility, electrochemical, CsF**
54	**Xe**	**volatility**

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

Materials were ranked for energetics and material cost

Energetics	Ref. 2
Material	E(wall)/E(wall for Au-Gd)
Pb/Hf/Xe	1.00
Pb/Ta/Cs	1.01
Hg/Ta/Cs	1.03
Hg/W/Cs	1.04
Pb/Hf	1.04
Pb/Ta	1.06
Pb/W	1.08
Hg/Xe	1.18
Ta = W	1.25
Hg	1.26
Pb	1.28
Tl, Lu, Yb, Nd, Pr, Ce, La	Not Calculated

Cost	Ref. 3 Pure Au =4400 {Ref. 4 Bulk Au=1230)
Element	$/100g
Pb	1.50{0.13}
Hg	5{0.87}
W	11{1.50}
Tl	48
Ce	57
La	64
Nd	110
Ta	{22}
Hf = Xe = Pr	120
Yb	170
~~Cs~~	1110
~~Lu~~	6900

□Materials were ranked for chemical toxicity and ease of separation from Flibe

(RefÕs 5 & 6)	Chemical Toxicity
Xe	ÒEntirely harmlessÓ
Hf, Yb, Nd, Pr, Ce, La, Cs, Lu	ÒMetals OK, all compounds to be considered toxic, although danger is limitedÓ
W, Ta	ÒMetals normally OK, all compounds to beconsidered highly toxicÓ
Pb	ÒToxicity by inhalation>>ingestionÓ, Òtoxic compounds carcinogenic & teratogenicÓ
~~Tl~~	ÒElements and compounds are extremely toxic, teratogenic, and carcinogenicÓ
~~Hg~~	ÒToxicity by inhalation>>ingestionÓ, ÒDreadfull poison, all compounds extremely toxicÓ

Ref. 4	Ease of separation from Flibe
Xe > Hg> Cs	Volatility
Hg, Pb, W	Centrifugation
Lu, Yb, Nd, Pr, Ce, La	Bismuth extraction from fluorides
~~Hf~~	Electrochemical separation from flouride
~~Ta~~	Volatility + Electrochemical separation from fluoride

□Materials were ranked for ease of fabrication and radiological toxicity

(RefÕs 3&5)	Ease of Fabrication
W, Ta, Lu, Nd, La, Pr, Yb, Ce, Pb, Tl,	Solid at room temperature. W, Hf, and Pb are amenable to LCVD (Ref. 7)
Cs	Melts at 28□C
~~Hg~~	Liquid, melts at Š39□C
~~Xe~~	Gas, boils at Š108□C

(Ref. 6)	Radiological Toxicity
Pb, Hg, Yb, Pr, La	Meet 1-week hands-on, shallow burial WDR, and accident criteria
Tl, W, Ta, Hf, Lu, Nd, Ce, Cs, Xe	DonÕt meet 1-week hands-on, but meet shallow burial WDR, and accident criteria

References:

1. “Narrowing the choice of hohlraum materials”, Draft March 3, 2003, R. Petzoldt
2. “FY03 ARIES Target Materials Study”, August 20, 2002
3. “http://www.chemicool.com/elements/”
4. “Flibe coolant cleanup and processing in the HYLIFE-II inertial fusion energy power plant”, Draft UCRL-ID-143228, January 19, 2001, R. W. Moir
5. “http://www.webelements.com/webelements/elements/print/Hg/biol.html”
6. “Safety Implications of Hg and Pb as IFE Target Materials: Radiological vs. Chemical Toxicity”, September 24, 2001, S. Reyes
7. “Fabrication of Functionally-Graded Inertial Fusion Energy (IFE) Targets”, 5 February 2002, J. Maxwell et al.

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 the leading candidate

Pros

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

Cons

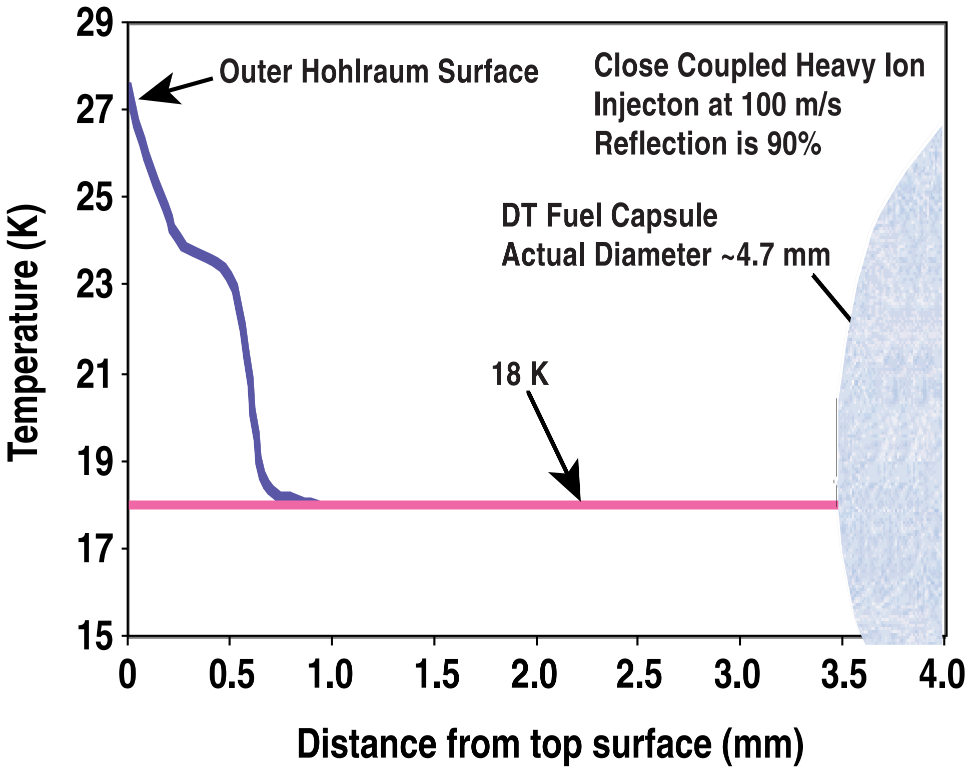
-Higher wall energy loss (1.25 times Au/Gd)
-May settle in Flibe loop
-Tungsten might clog spray nozzles*

***However, very small particles should not clog nozzles and larger particles can be filtered**

Target Constraints on Chamber Conditions

Previously reported at ARIES meetings
-Chamber temperature
-Liquid wall aerosol density

Heating of indirect drive targets during injection is small



Heating Profile:
300 K gas for 32 ms
No heat load for 30 ms
900 K chamber for 40 ms

...Indirect drive targets don’t constrain chamber temperature

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

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

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

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

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.

Backup slides

Use of plastic vs FLIBE outer shells

Using plastic rather than flibe for the target shell is a trade-off between recovery of much larger amounts of hydrocarbon material from the chamber, and the potentially lower cost of the targets. Dr Peterson points out that since we must have at least some plastic due to capsules and support membranes, this appears to be more of an optimization question than a viability question.

some of the advantages to plastic outer hohlraum shells would be:

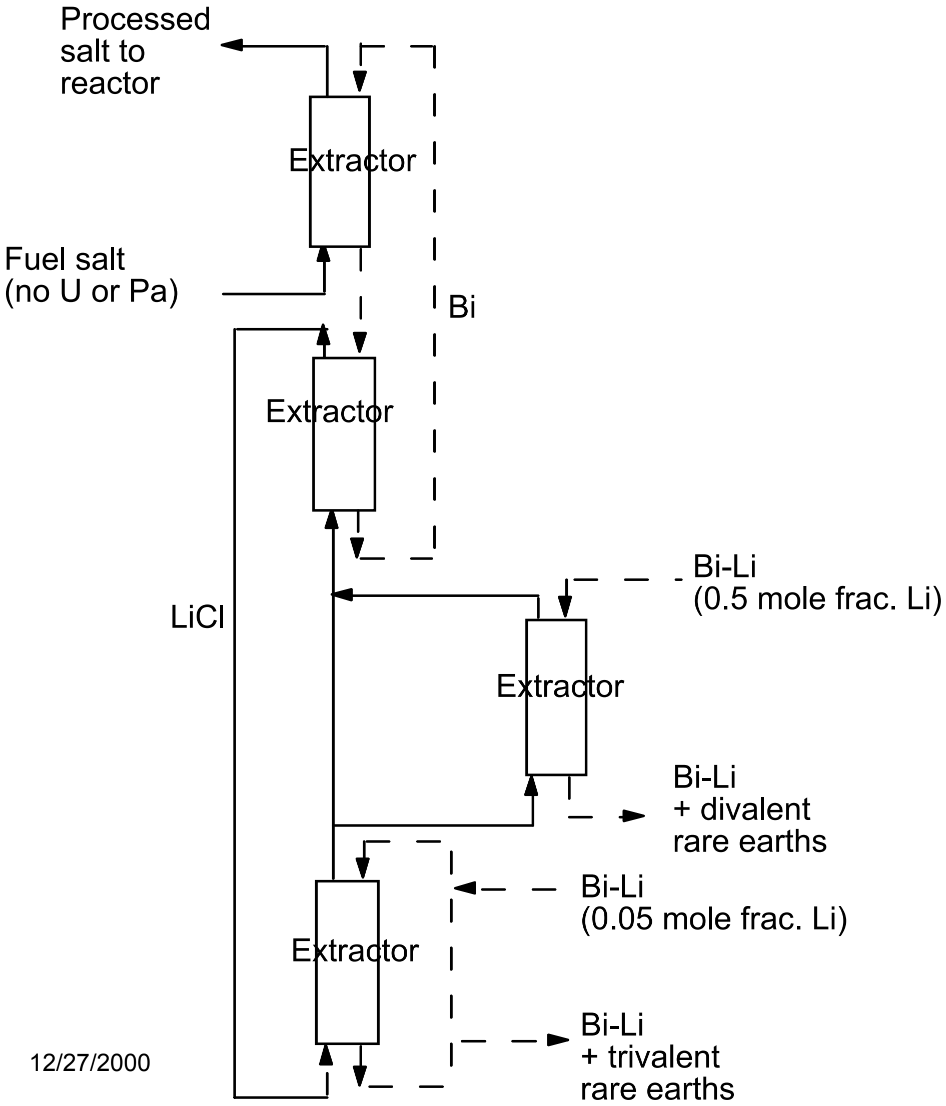
(1) elimination of radioactive handling in the hohlraum production process, and,
(2) ability to produce the hohlraums at a central large-scale facility (instead of at each reactor site) - thus improving the economies of scale and reducing costs significantly

the poly-CH_2 plastic shell would char to produce solid carbon particulates suspended in the FLIBE - these char particulates could potentially be controlled in 2 ways:

(a) filtration (they may be fairly fine and it may be tough to develop a sufficiently durable filtration media), or,
(b) gasification - the hydrogen-bearing reducing conditions in the reactor loop should favor (thermodynamically) the formation of light hydrocarbons such as CH_4, etc, which would separate easily as gases from the molten FLIBE
- the question is whether mass-transfer (getting the hydrogen to the carbon surface) or kinetics (is it hot enough?) will overly limit the gasification reaction rate - but the process is favored by both the high diffusivity of hydrogen and the high surface area of the carbon char - it may be that these factors coupled with long residence times can maintain reasonably low equilibrium concentrations of solid char in the FLIBE

what we would need therefore is some initial data from a simple lab-scale test - wherein some plastic shards (such as poly-propylene) are immersed in FLIBE at typical loop temperatures and varying hydrogen partial pressures to determine the evolution of C (presumably as gaseous hydrocarbons) from the FLIBE as a function of time - this could be done in a standard thermogravimetric analysis (TGA) set-up with a GC outlet gas analyzer

Lanthanide-Fluorides may be removed by a bismuth extraction process



Flow rate
~ 0.1 l/s

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

12/27/2000

Oxygen may be removed with HF or H_2 purge*

Oxygen in Flibe produces BeO
Solubility is 125 wppm
For 1000 g/day oxygen, 75 days accumulation is allowed
Small slipstream may be processed with H2 or HF purge

Flow rate ~ 0.1 l/s

It may be possible to remove carbon particulates with an H2 purge producing hydrocarbon gases (experiments needed)

***Dai Kai Sze - e-mail to Per Peterson, September 2002**

Order of magnitude cost estimates for cleanup processes

Process	Cost est.	Process rate, PR	Cost scaling	Inventory/concentration/holdup time
Volatility, Hg	$\$10^7$	100 *l*/s	$(PR)^{0.6}$	0.17 kg/7 wppm/3.3 hr
Centrifugation, Pb	$\$10^7$	1 *l*/s	$(PR)^{0.6}$	1740 kg/700 wppm/13.9 d
Reductive extraction, Gd	$\$2\times10^7$	0.1 *l*/s	$(PR)^{0.6}$	17,400 kg/7000 wppm/139 d
Volatility, Xe	$\$5\times10^6$	1000 *l*/s	$(PR)^{0.6}$	0.017 kg/0.7 wppm/20 min.

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