

Coolant Cleanup and Process Requirements

I. Sviatoslavsky and L. El-Guebaly

Fusion Technology Institute
University of Wisconsin - Madison

With input from R. Moir (LLNL)

ARIES Project Meeting
Princeton Plasma Physics Laboratory
Princeton, NJ

October 2-4, 2002



Acknowledgement

- This presentation relies heavily on the HYLIFE-II study documented in LLNL report:

Flibe Coolant Cleanup and Processing in HYLIFE-II
Inertial Fusion Energy Power Plant

R. Moir

UCRL-ID-143228, March 2001.

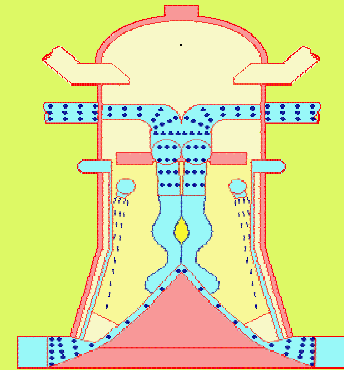
Coolant Cleanup Entails Several Procedures

- Target and hohlraum debris, transmutation and evaporated products must be removed from Flibe coolant/breeder.
- Cleanup of corrosion products from chamber structures and coolant piping.
- Removal of air leakage and possible moisture leakage from contact with heat exchanger.
- Recovery of tritium from coolant.



What Are the Most Likely Hohlraum Materials?

- **Selection criteria:**
 - Target performance
 - Fabricability
 - Activation and safety
 - **Separability from Flibe**
 - Costs of materials and separation process.
- **Au and Gd** are favorite target materials in present laboratory experiments, but cost considerations will probably preclude their use in power plants.
- **Moir** selected **Pb, W, Hg, and Xe** that can be easily separated from Flibe.
- **Moir** excluded many materials for one or more of following reasons:
 - React with Flibe forming corrosive fluorides
 - Have high T_m forming powder precipitates
 - Radioactive
 - Costly.



HYLIFE-II



Processes for Separation of Materials

- Filtration.
- Distillation/evaporation/volatility separation (**most attractive**).
- Centrifugal separation (**acceptable**).
- Reductive extraction/metal transfer (**least attractive**).



Filtration

- Flibe coolant may contain **non-soluble** particulate matter such as C from target or BeO slag.
- **Particles having same density as Flibe** must be filtered out. Heavier or lighter particles than Flibe (e.g., Pb and W) can be segregated in a centrifuge.
- Filter out constituents **to prevent plugging of nozzles**, specially **in vacuum disengager**, where nozzle orifices are ~ 0.2 mm in diameter.
- **Filters must be regularly replaced** when loaded and pressure drop across them exceeds some nominal value.



Distillation/Evaporation/Volatility Separation Process (most attractive)

- Tritium is recovered from Flibe by vacuum disengagement process where Flibe is sprayed in two series flow drop towers.
- Tritium diffuses from droplets along with other volatile materials.
- Using cooled baffles at different temperatures, volatile materials are condensed from effluent and drained.
- Flibe condenses at 470 °C, Hg at -50 °C, and Xe at -107 °C.

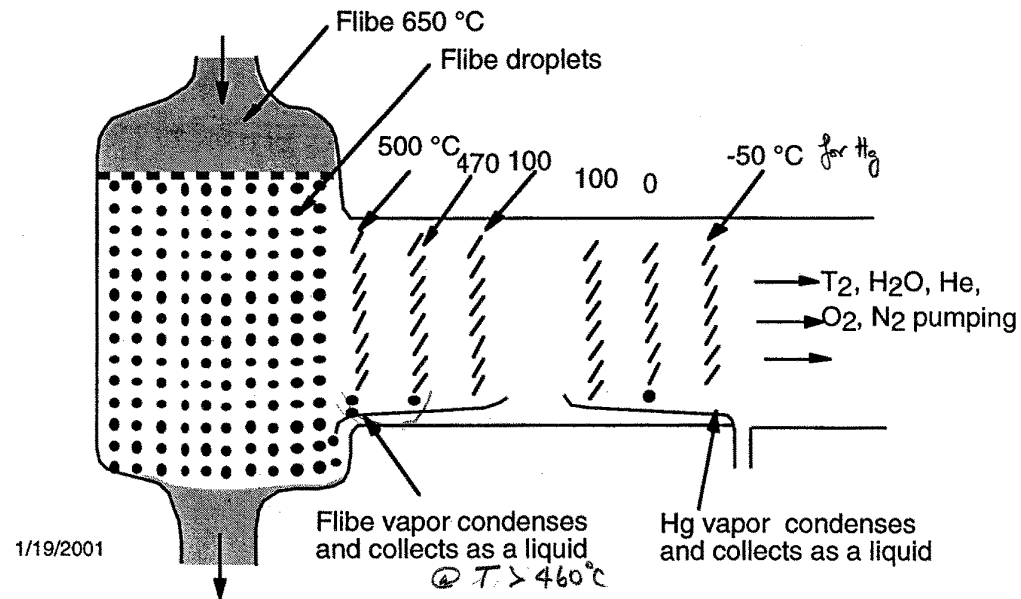


Fig. 3. Vacuum disengager modified to remove mercury vapor and other volatile materials from flibe.

Centrifugal Separation Process (acceptable)

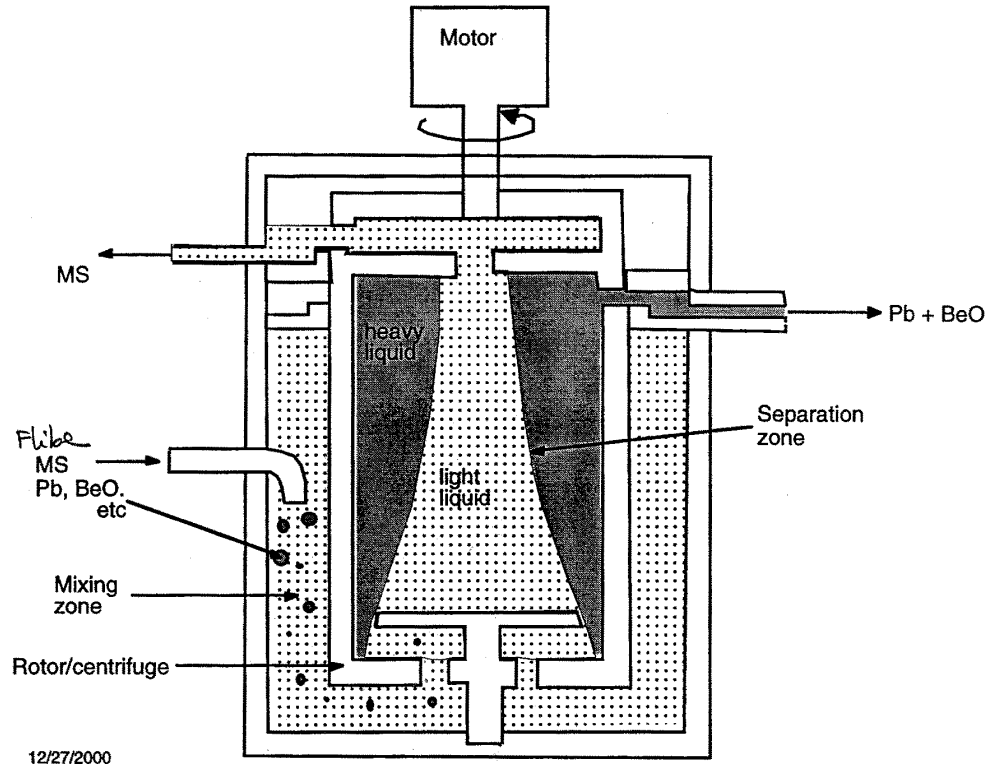


Fig. 4. Schematic illustration of a centrifugal separator design from a working ANL cadmium-chloride salt contactor (Chow et al, 1993).

Heavier or lighter particles than Flibe (e.g., Pb and W) can be segregated in a centrifuge.



Reductive Extraction/Metal Transfer Process (least attractive)

- Lanthanides (e.g., Gd) form stable fluorides that are soluble in Flibe and have low vapor pressure.
- Flibe is contacted with Bi in a continuous flow. Lanthanides preferentially transfer to Bi then are separated by centrifugation.

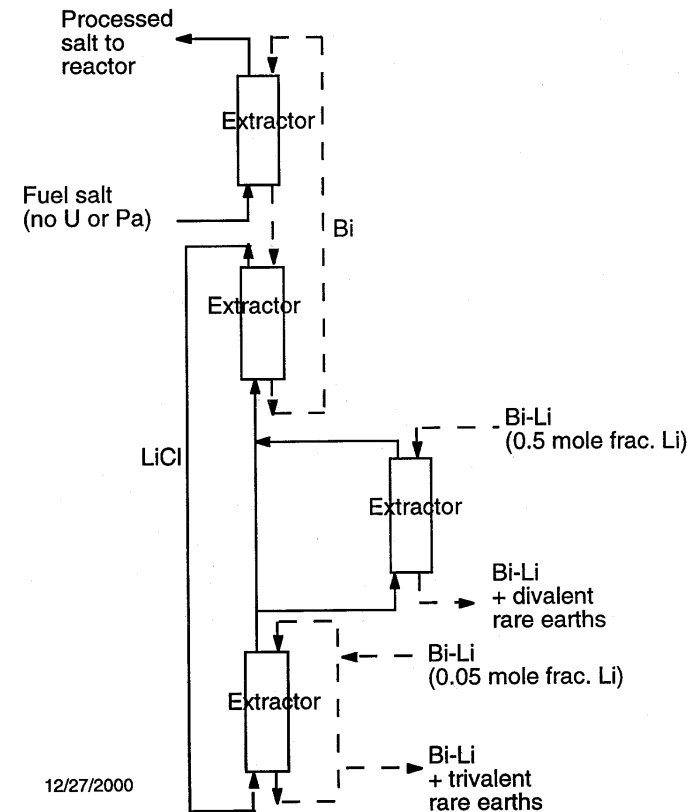


Fig. 5. Metal transfer process for removal of rare earths from single-fluid MSBR fuel salt (Fig. 11.5 from Haubenreich and Briggs, 1972).

Separation Rates and Equipment Costs

- Hg and Xe are easiest and cheapest to separate. Added cost of providing cooled chevron plates for condensing Hg and Xe in the vacuum disengager would be small.
- Since all circulating Flibe inventory (10,000 l/s in HYLIFE-II) goes through vacuum disengager for T₂ recovery, Hg and Xe will also be separated.
- Series of progressively cooler plates will condense Flibe at 470 °C, Hg at -50 °C and Xe at -107 °C.
- R. Moir estimated cost of **vacuum disengager** T₂ system at 60 M\$ and added cost of **volatile separator** < 10 M\$ at process rate of 100-1000 l/s.
- Separation of Pb (or W) will have to be done by **centrifugal process** at low rate of 1 l/s and cost ~10 M\$.
- **Reductive extraction** of Gd costs ~20 M\$ at very low rate of 0.1 l/s.



Corrosion Product Separation

- The most likely structural material used in an IFE chamber will be **Ferritic Steel**.
- There is **no direct data on the corrosion of ferritic steel with Flibe**, (S. Zinkle, ORNL). However, because corrosion is controlled by Fe and Cr, **rates would be similar to 304 or 316 SS**.
- Main constituents of **304-SS** are: Fe 70.578%, Cr 17.7%, Ni 9.3% and Mn 1.17%. Main constituents of the low activation **ODS-M-F82H FS** are: Fe 87.9%, Cr 8.7%, W 2%, V 0.29%, Mn 0.5%, and Ta 0.08%.
- Fe and Cr dominates in FS and therefore, using corrosion data of 304SS is justified.
- Flow loop experiments have estimated a **corrosion rate of 2 $\mu\text{m}/\text{y}$ for 304-SS** (Keiser, DeVan, and Lawrence, ORNL, 1979) .
- Assuming total contact area between Flibe and FS is **$\sim 5000 \text{ m}^2$** , total dissolution rate will be **80 kg/y**, of which 88% is Fe, 9% Cr, 2%W, 0.3% V, 0.5% Mn, and 0.08% Ta, with smaller amount of impurities.
- All these metals can be **removed by reacting with Be contactor**.
Assuming Be is soluble in Flibe, metals transfer to Be and then are removed by **centrifugation at rate of 1 l/s**.



Removal of Air and Moisture Leakage

- **Air leakage** into Flibe coolant would be **very unlikely**, since Flibe will always be at higher pressure. However, **moisture** can leak into coolant from the interaction with power cycle.
- **O₂** from air and **moisture** leaks will react chemically with Flibe in endothermic and exothermic reactions, forming BeO and **corrosive HF**.
- It may also be possible to **remove moisture** in vacuum disengager. H₂O is **volatile** and is removed as vapor in getter bed.
- To keep **O₂** and **moisture** low in Flibe, continuous **hydro-fluorination** process, called scrubbing, is done **off-line** with 10%HF and 90%H₂ in Ni containers because HF corrodes Fe-Cr containers.
- Continuously **remove corrosive HF** by reaction with Be. Solubility of Be in Flibe must be experimentally determined.
- Allowable build-up of HF and BeO dictates size of hydro-fluorination system, thus setting a limit on water leak rate in power cycle.



Summary and Conclusions

- **Flibe cleanup involves** removal of target debris, transmutation and corrosion products, tritium, and air and moisture leakages into coolant.
- Depending on materials used in target and hohlraum, **processes can be multifold**, including filtration, vacuum disengager distillation facility, centrifugation, and reductive extraction with metal transfer.
- **Pb, W, Hg, and Xe hohlraum materials are insoluble in Flibe, do not form fluorides, and are easiest, cheapest to separate from Flibe**
- **Tritium recovery from Flibe requires large vacuum disengager system capable of handling ~10,000 l/s of liquid. At this rate, recovery of Hg and Xe is more than adequate.**
- **Centrifugal system with rate of 1 l/s will be adequate to separate heavy metals such as Pb and W.**
- **Total cost of all systems described above is ~100 M\$.**



Importance of Results and What Needs to be Done

- Cleanup process is important to feasibility of thick liquid wall concept.
- Cleanup processes must be further investigated to determine their practicality.
- Experiments are needed to validate processes outlined in this presentation. In particular, experimental determination of solubility of Be in Flibe must be established. This is important as it determines feasibility of extracting corrosion metal products and corrosive HF from Flibe, with benefits to ARIES and APEX projects.
- Compatibility of Flibe with ODS-FS and experimental corrosion data are needed.
- Continue effort to establish whether Pb, Hg, Xe and W (or others?) are best materials to use in hohlraum from standpoint of economics, environmental, and extraction considerations.

