Transmutation and Production Rates of Elements in Flibe and Flinabe with Impact on Chemistry Control

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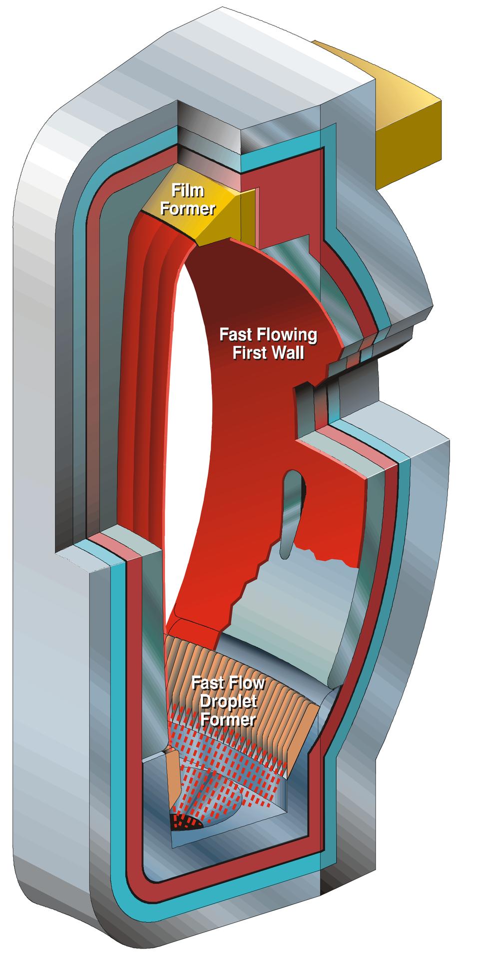
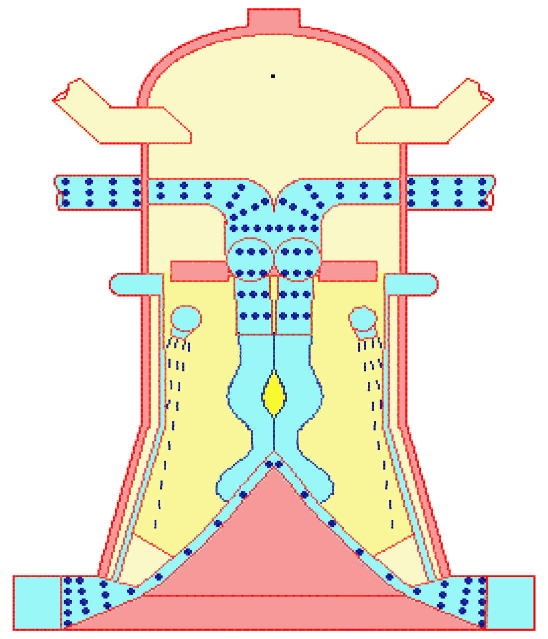
Molten Salt Considered as Breeder/Coolant in Fusion Systems

CLiFF - Convective Liquid Flow First Wall





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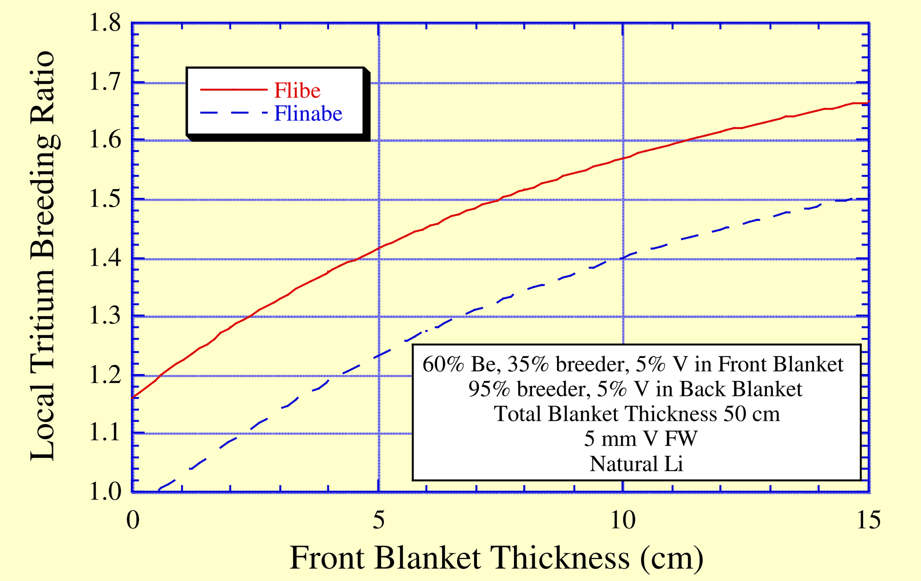
Features of Molten Salts

- Low viscosity Flibe with 2:1 LiF and BeF_2 has attractive features:
  - Low activation
  - Low tritium retention
  - Small density change on melting
  - Low chemical reactivity with air and water
  - Low electrical conductivity (reduced MHD problems)
  - Good neutron attenuation properties
- However, it has high melting point (459°C), low thermal conductivity, and large tritium permeation

- Flinabe with 1:1:1 of LiF, BeF_2 and NaF has additional attractive features:
  - Low melting temperature (~240°C) resulting in larger temperature window
  - Low vapor pressure reducing plasma contamination from liquid walls
- However, it has lower breeding potential and more Be multiplier is required



Major Concern with Molten Salts

- Transmutation of constituent elements leads to production of highly corrosive free fluorine
- In addition, the less corrosive TF is produced as a result of combination of freed F and bred tritium
- TF is compatible with some structural materials, but free F is not compatible with any structural material
- Controlling the activities of free F and TF essential for the Flibe and Flinabe to be considered as a viable breeder/coolant candidate

Calculation Models

Flibe Blanket (60 cm Thick)	*Flinabe Blanket (60 cm Thick)*
6 cm front multiplier zone	12 cm front multiplier zone
60% Be	60% Be
35% Flibe	35% Flinabe
5% NCF steel	5% NCF steel
Rest of blanket	Rest of blanket
95% Flibe	95% Flinabe
5% NCF steel	5% NCF steel

- Most recent FENDL-2 cross section data used
- Natural Li used in both molten salts

Evaluated all possible neutron reactions with constituent elements

Be

^{9}Be (n,2n) 2 ^{4}He
^{9}Be (n,t) ^{7}Li
^{9}Be (n,α) ^{6}He ($T_{1/2}$ = 807 ms) → ^{6}Li
^{9}Be (n,γ) ^{10}Be

^{6}Li

^{6}Li (n,α) ^{3}H
^{6}Li (n,2nα) ^{1}H
^{6}Li (n,n'd) ^{4}He
^{6}Li (n,p) ^{6}He ($T_{1/2}$ = 807 ms) → ^{6}Li
^{6}Li (n,γ) ^{7}Li

^{7}Li

^{7}Li (n,n'α) ^{3}H
^{7}Li (n,2nα) ^{2}H
^{7}Li (n,γ) ^{8}Li ($T_{1/2}$ = 0.84 ms) → ^{8}Be → 2 ^{4}He
^{7}Li (n,d) ^{6}He ($T_{1/2}$ = 807 ms) → ^{6}Li
^{7}Li (n,2n) ^{6}Li

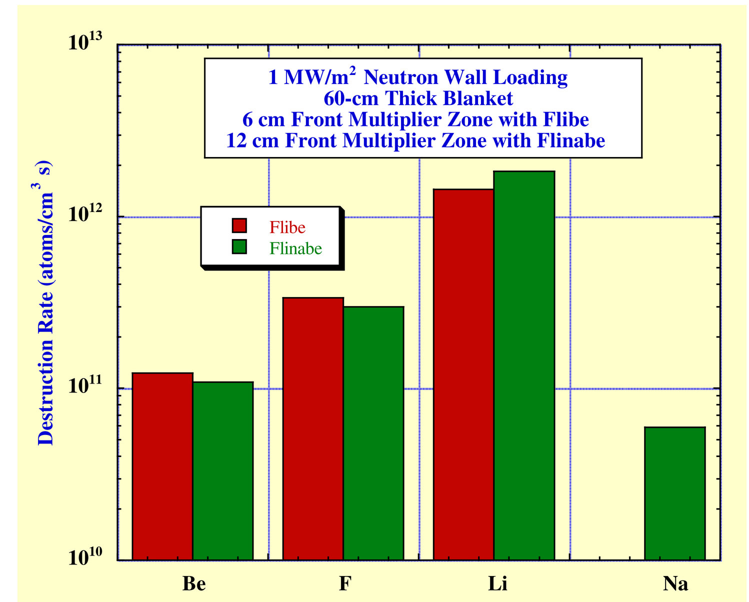
F

^{19}F (n,p) ^{19}O ($T_{1/2}$ = 26.9 s) → ^{19}F
^{19}F (n,d) ^{18}O
^{19}F (n,t) ^{17}O
^{19}F (n,α) ^{16}N ($T_{1/2}$ = 7.13 s) → ^{16}O
^{19}F (n,n'p) ^{18}O
^{19}F (n,n'α) ^{15}N
^{19}F (n,2n) ^{18}F ($T_{1/2}$ = 1.83 h) → ^{18}O
^{19}F (n,γ) ^{20}F ($T_{1/2}$ = 11 s) → ^{20}Ne

Na

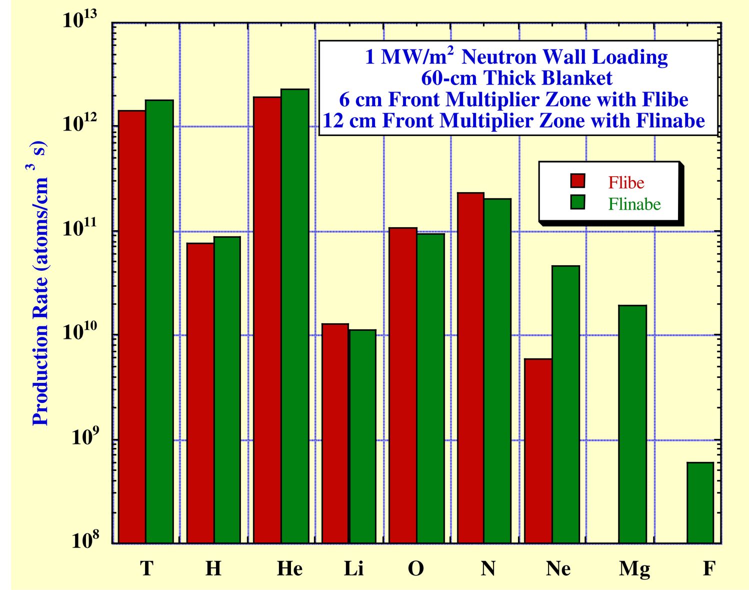
^{23}Na (n,p) ^{23}N ($T_{1/2}$ = 37.6 s) → ^{23}Na
^{23}Na (n,α) ^{20}F ($T_{1/2}$ = 11.4 s) → ^{20}Ne
^{23}Na (n,n'p) ^{22}Ne
^{23}Na (n,n'α) ^{19}F
^{23}Na (n,2n) ^{22}Na ($T_{1/2}$ = 2.6 y) → ^{22}Ne
^{23}Na (n,γ) ^{24}Na ($T_{1/2}$ = 15 h) → ^{24}Mg

Destruction rates of constituent elements



- Destruction rate of F is about three times destruction rate of Be
- Destruction rates for Be and F in Flinabe are about 12% lower than in Flibe while Li destruction rate in Flinabe is about 27% higher due to softer neutron spectrum resulting from using twice as much Be

Elemental production rates



- In addition to T and He, a large amount of O and N is produced
- O and N produced at ~7% and 14% of rate of tritium breeding
- Na in Flinabe results in production of additional modest amounts of Mg and Ne
- Production of O and N in Flinabe is ~13% lower than in Flibe
- A factor of 8 more Ne is produced in Flinabe
- These results should be taken into account when assessing compatibility with structural materials in fusion radiation environment

Atomic Balance

	Atoms/cm^3 s	
	Flibe	Flinabe
Free T	1.42×10^{12}	1.82×10^{12}
Free Li from F transmutation	1.70×10^{11}	7.45×10^{10}
Free Li as transmutation product of Be	1.26×10^{10}	1.12×10^{10}
Total free Li	1.83×10^{11}	8.57×10^{10}
Free Be from F transmutation	8.50×10^{10}	7.45×10^{10}
Free Na from F transmutation	--	7.45×10^{10}
Free F from Li transmutation	1.43×10^{12}	1.82×10^{12}
Free F from Be transmutation	2.46×10^{11}	2.18×10^{11}
Free F from Na transmutation	--	5.93×10^{10}
Free F as transmutation product of Na	--	5.93×10^{8}
Total free F available	1.68×10^{12}	2.10×10^{12}
F combined with Li to form LiF	1.83×10^{11}	8.57×10^{10}
F combined with Be to form BeF_2	1.70×10^{11}	1.49×10^{11}
F combined with Na to form NaF	--	7.45×10^{10}
F left combining with T to form TF	1.33×10^{12}	1.79×10^{12}
Free T left	7.00×10^{11}	3.00×10^{10}

- Results indicate that at least from mass balance considerations there will be no free F left provided that kinetics of combination reactions is fast enough
- In case of Flibe more than 95% of T bred in the blanket will be in the form of TF
- In the Flinabe blanket more than 98% of T bred will be in the form of TF
- These are very encouraging results since free F is very corrosive
- We only have to worry about chemistry control of the less corrosive TF

Impact of Li Enrichment

- Enriching the Li in ^{6}Li enhances tritium breeding with TBR maximizing at 40-50% ^{6}Li
- Impact of Li enrichment on atomic balance of transmutation products assessed by performing calculations for a Flibe blanket with 40% ^{6}Li and a reduced multiplier zone of 4 cm thickness
- Lithium enrichment has only a minor impact on mass balance with the conclusion regarding free F and TF being the same

Chemistry Control

- Chemistry control process is to control activities of the TF and free F
- A possible method is to use Be to reduce both TF and F_2 to BeF_2 and T_2
- From a thermodynamics point of view the chemical reaction will proceed $Be + 2TF \rightarrow BeF_2 + T_2$
- The equilibrium TF concentration in the Flibe will be about 10^{-12} mole fraction
- At this very low concentration Flibe will not react with any structural material
- It is important that kinetics of this reaction can be demonstrated so that proper chemistry condition can be reproduced in the experiment
- This along with calculated transmutation rates define experimental parameters to study thermodynamics and kinetics in the experiment being set up at INEEL

Summary and Conclusions

- Controlling activities of free F and TF is essential for Flibe and Flinabe to be considered as viable breeder/coolant candidates
- At least from mass balance considerations no free F will be left provided that the recombination reactions are fast enough
- More than 95% of tritium bred will be in the form of TF
- O and N are produced at about 7% and 14% of tritium breeding
- Be can be used to reduce both TF and F_2 to BeF_2 and T_2.
- Transmutation rates and thermodynamics define the chemistry conditions of Flibe and Flinabe under neutron irradiation that need to be reproduced in the experimental setup to study the thermodynamics and kinetics of the REDOX reaction
- After the REDOX condition is established, material corrosion experiments can be carried out to assess the compatibility between the molten salt, with proper chemistry control, and different structural materials