First Wall Temperature Window, Flibe Chemistry and Tritium Recovery

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First Wall Temperature Design Window

- The maximum allowable temperature of the coolant of CLIFF is determined by the allowable evaporate rate.

- The minimum temperature of the coolant of CLIFF is determined by the melting temperature of the coolant.

- This temperature difference needs to be sufficient to cover the following temperature differences

  a. The inlet coolant temperature needs to be higher than the melting temperature for the engineering design of the heat transport system.
  b. The coolant exit temperature needs to be higher than the coolant inlet temperature for heat transport.
  c. The surface temperature needs to be higher than the bulk coolant temperature for heat transfer.

- The size of the temperature window (Tmax-Tmin) determines the flexibility of the design of the design of the system.

The Allowable CLIFF Temperature

- The allowable CLIFF temperature was presented at the PMI part of the meeting.
- This allowable temperature depends on the materials properties, such as vapor pressure, and also on the recycling rate of the diverter.
- Since hydrogen isotopes have very low solubility in flibe, it is reasonable to assume that a flibe CLIFF has a high hydrogen recycle.
- With the material properties of flibe, and a high recycle divertor, the allowable flibe temperature is 400C.
- This temperature limit put severe limitation on the design flexibility of flibe CLIFF.
- The allowable temperature is higher if we have a low recycling divertor.

Minimum Coolant inlet Temperature

- Conventional design consideration requires the minimum coolant temperature to be 50C higher than the coolant melting temperature.
- This temperature difference is required so that the coolant will not freeze in the primary heat exchanger.
- If a steam cycle is going to be used as the power conversion system, and an intermediate loop will be used in between the primary coolant and the steam, the bulk temperature of the flibe will be about 50C higher than the surface temperature of flibe.
- Also, we will need thermal inertia to prevent freezing in the IHX in case of a plasma shut down.

Heat Transport Temperature Difference

- The coolant exit temperature has to be higher than the coolant inlet temperature to remove the thermal energy.
- The coolant flow rate is inversely proportional to the heat transport DT.
- The size of the primary heat transport system is directly proportional to the coolant flow rate.
- For the ARIES-RS design the cost of the primary heat transport system is 260 M$ with a heat transport temperature difference of 230C, while the total direct cost is 2200 M$.
- The best cost estimate of each system is proportional to the power of 0.6 of the capacity.
- To keep the cost of the primary heat transport system to within 20% of the total direct cost, the heat transport DT has to be kept between 50 to 100C.

Heat Transfer Temperature Difference

- A temperature difference of (Ts-Tbulk) is required for heat transfer.
- This temperature difference depends on the surface heat flux, the coolant material properties, as well as the degree of turbulence in the coolant.
- For the flibe CLIFF design, with a surface heat flux of 2MW/m2, the heat transfer DT is calculated to be 70C.
- If the low melting temperature flibe is used, the required heat transfer DT is much higher, due to the high viscosity, and its impact on turbulence.
- The increase of the temperature window, caused by the lower melting temperature, is more than offset by the increase of the heat transfer DT.

Conclusion on Flibe CLIFF Temperature

- To design an acceptable heat transfer system, the maximum flibe surface temperature will exceed 630C.
- It is not clear this temperature is acceptable to the plasma.
- Many different proposals to increase the acceptable surface temperature from plasma side have been considered and evaluated.
- Using the low melting temperature flibe has also been evaluated. The conclusion is that the effect of the low melting temperature will be more than off set by the effect of high viscosity.

Flibe Chemistry

- Flibe chemistry control is essential for corrosion control.
- The key element to be controlled is free fluorine.
- Free fluorine can be released by the transmutation of Be.
- Fluorine is very active chemically, and will react with any structural material.
- Recent discovery of the high transmutation rate of F may eliminate this problem.

Flibe Transmutation

- There are three elements in the flibe, Li, Be and F.
- Li will be transmuted into tritium to form the fusion fuel.
- Be will be transmuted into He to release free F.
- F will also be transmuted to release free Be.
- Since the chemical form is BeF_2, the transmutation of F has to be more than double of that of Be, to eliminate all free Fluorine.

Transmutation Calculation Results

The results are all normalized to 1MW/m2.

The rate of transmutation is in 10” atoms/cc-s.

	Front	Average
Tritium production	23.8	7.1
Free F from Li transmutation	27.0	7.4
Free F from Be transmutation	16.3	2.4
Free Li from F transmutation	13.6	1.7
Free Be from F transmutation	6.8	0.9
Free F left after forming LiF and TF	5.9	1.0
Extra Be left after the formation of BeF2	3.9	0.4

Conclusion: There is sufficient free Be to combine with free fluorine.

Comments On the Transmutation Results

- Base on mass balance and thermodynamics, there will be no free F in the flibe blanket due to the transmutation.
- It is not clear that if the reaction kinetics will be fast enough to combine Be and F to from BeF_2.
- If there is no free F, we still have to worry about TF.
- TF is compatible to some of the structural materials, such as W, Mo and maybe Ni.
- In comparison, free F will react with all the structural materials.
- By elimination of free F, the material compatibility issues become less severe.
- Calculations based on other blanket concepts, such as one with additional 5 cm of Be, show similar transmutation ratio.

Conclusions

- A new chemical control process for flibe has been identified.
- This process can control free F based on transmutation rate of Be.
- Since the transmutation rate of F is almost three times as high as the transmutation rate of Be, there will be sufficient Be to react with F to form BeF2.
- This process is nature occurring and no outside control is required.
- Methods to control TF still have to be developed.

Tritium Recovery

- If we have a low recycling diverter, tritium will be absorbed in the diverter and blanket coolants.
- The tritium throughput in the coolant maybe many times higher than the breeding rate.
- Questions were asked both at Snowmass, and within the APEX team, if the tritium recovery system can be designed.
- Since a lithium-cooled diverter will form low recycling diverter, it is assumed that we are dealing with a lithium system.

Work Statement

- A tritium recovery process will be selected.
- Tritium throughput to the coolant will be defined as a function of plasma burn fraction and the diverter recycling ratio.
- A blanket tritium recovery system will be developed.
- The tritium inventory, system cost, and power requirement will be calculated as a function of the tritium throughput.
- The throughput and the isotopic composition of the tritium stream will be defined.
- This information will be transferred to LANL (Willms) to design the ISS.

Tritium System Parameters

- It is assumed that all the tritium will be deposited on the diverter coolant.
- The tritium throughput will be from 500g/FPD (100% recycle), to 59Kg/FPD (1% burn fraction, 0% recycle.)
- Diverter power is assumed to be 300 MW.
- Diverter coolant volume is estimated to be 25 m3.
- Allowable tritium inventory in the diverter coolant is assumed to be 200g.
- Allowable tritium concentration in the diverter coolant is 20 appm.

Tritium Recovery Process Selection

- Tritium (hydrogen) can be recovered from lithium, Nak and sodium by the cold trap process
- Cold trap of tritium from lithium can control tritium concentration in lithium to the saturation limit.
- The saturation tritium concentration at the cold trap temperature of 200C is 440 appm.
- To reduce tritium concentration to the 20 appm limit, hydrogen isotopes will be added to reduce the total hydrogen concentration to the saturation limit, while the tritium concentration will be reduced to the design goal of 20 appm.
- The effects of hydrogen addition to the cold trap process have been demonstrated for both NaK and sodium
- The attractive feature of the cold trap process is that the only impurity added is the hydrogen isotope.

The Parameters of the Cold Trap Process

Tritium throughput, Kg/FPD	0.5	5	50
Tritium concentration, appm	20	20	20
Tritium inventory, Kg	0.2	0.2	0.2
Tritium recovery efficient, %	66	66	66
Lithium process rate, Kg/s	0.45	4.5	45
Lithium process rate fraction*, %	0.03	0.3	3
Hydrogen addition, Kg/FPD	12.5	125	1250
Power required for LiH decomposition, MW	0.16	1.6	16
Power lost in the regenerator, MW	0.01	0.1	1.0
Additional tritium inventory, g	0.06	0.6	6.0

- The lithium flow rate for tritium recovery/coolant flow rate

Tritium Recovery Process Steps

- Lithium will exit from the power plant with 420 appm of H, and 20 appm of T.
- A side stream of the lithium will be directed to the tritium recovery system.
- Protium will be added so that the protium concentration will increase form 420 appm to 1500 appm.
- The lithium stream will be cooled down to 200C, and the total hydrogen isotope concentration will be reduced to 440 appm, with the rest precipitate out.
- A meshless cold trap, which was developed for breeder program, will separate Li(H+T) from lithium by gravitational force.
- Li(H+T) will be heated up to 600C to decompose to form Li and (H+T).
- A 200C cold trap will remove lithium form the tritium stream.
- A Pa diffuser will be used for hydrogen clean up.
- The product from the Pa diffuser, with the H/T ratio defined above, will be fed to the ISS.

Comments of the Cold Trap Process

- The cold trap process is a very clean process, with no impurities added to the lithium stream.
- The cold trap process has been demonstrated in different systems. There is high confidence that it will work as designed.
- The total power requirements, as well as tritium inventory, is acceptable even with a very high tritium throughput.
- The key step to limit the tritium inventory, while the tritium throughput is so large, is that the lithium flow rate to the tritium recovery system is rather small.
- The flexibility of increase the lithium flow rate to the tritium recovery system is a key step to allow a high tritium throughput, while maintain low tritium inventory.
- Work on the tritium inventory and power requirement for the ISS is to be done.