A Helium Cooled Li_2O Straight Tube Blanket Design for Cylindrical Geometry

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ABSTRACT

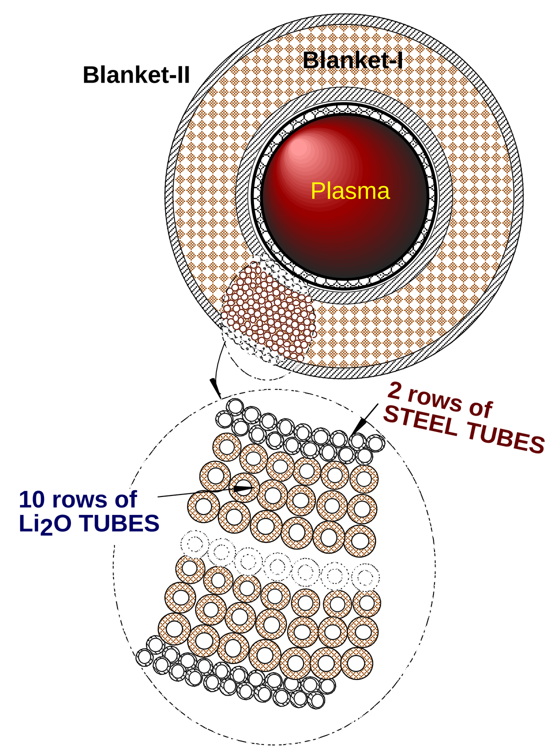
- A tritium-breeding blanket design is investigated for a D-T Field-Reversed Configuration (FRC) scoping study.
- The thrust of our initial effort on the blanket has been to seek solutions as close to present-day technology as possible, and we have therefore focused on steel structure with helium coolant.
- The simple FRC cylindrical geometry has allowed us reasonable success due to the low FRC magnetic field and relatively easy maintenance.
- In this design the breeder is Li2O tubes.
- The design is modular with 10 modules each 2.5 m long.
- The inner radius of the first wall is 2.0 m and the FW/blanket/shield thickness is about 2 m.
- The surface heat flux will be radiation dominated, fairly uniform, and relatively low, because most of the charged particles follow the magnetic flux tubes to the end walls.
- The neutron wall loading is 5 MW/m2. In this design the surface heat flux equals 0.19 MW/m2.
- The maximum Li2O tube temperature is 1003°C. The helium exit temperature from the heat exchanger is about 800°C which allows a thermal efficiency of about 52%.
- The local tritium breeding ratio (TBR) equals 1.1 and is sufficient because in the FRC geometry the plasma has nearly full coverage.
- The helium pumping power is 1 MW.
- The coolant routing is optimized to limit the steel maximum temperature to 635°C. The same concept would be applicable to a spherical torus and spheromak.

FRC GENERAL FEATURES

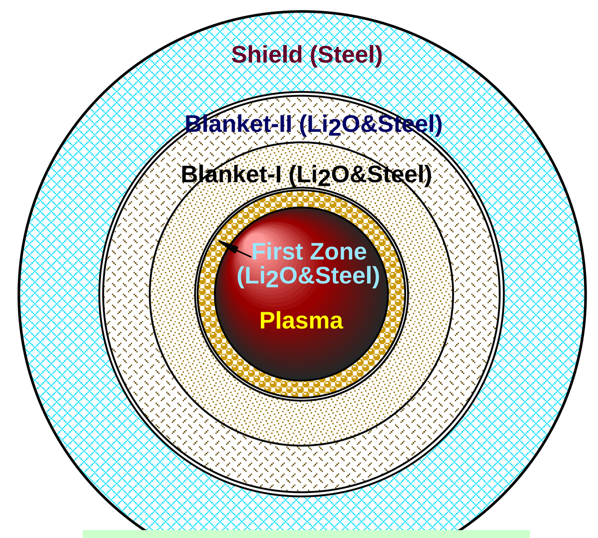
- The FRC design is modular with a length/module of 2.5 m.
- The total number of modules is 10.
- The solid breeder is Li_2O in the shape of tubes of 90% theoretical density.
- The cylindrical geometry of the FRC blanket (unlike the tokamak blanket) allows straight Li_2O tubes to be used.
- The coolant and the purge gas is helium at an average pressure of 18 MPa.
- In the first zone a single size Li_2O tube is used.
- The blanket consists of two zones, blanket-I and blanket-II, separated by two rows of steel tubes.
- The size of the Li_2O tubes in different zones is determined mainly by the temperature limits on the Li_2O solid breeder.
- The recommended maximum allowable temperature of the Li_2O solid breeder is 1000°C for sintering and the minimum allowable temperature is 400°C for tritium retention.
- The steady state nuclear heating in the different zones is calculated with an average neutron wall loading of 5 MW/m².
- The surface heat flux is 0.19 MW/m².
- The local tritium breeding ratio (TBR) equals 1.1 and is sufficient because in the FRC geometry the plasma has full coverage.

FRC GENERAL PARAMETERS

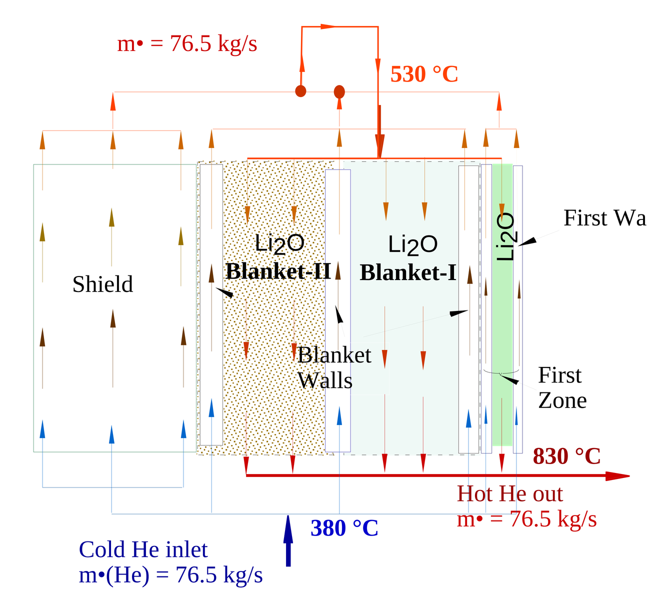
Module	
Length (m)	2.50
Number of modules	10
First zone	
1- First Wall (steel)	
Radius from the center of the plasma (m)	2.0
Outer tube diameter (mm)	15
Thickness of steel tube (mm)	2.5
Surface heating (MW/m²)	0.2
Heating in solid steel (W/cm³)	38.43
2- First Li_2O zone	
Number of rows	3
Width (m)	0.1575
Percentage of Li_2O (without steel)	30%
Percentage of He (without steel)	70%
Outer tube diameter (mm)	31.5
Average heating (Li_2O +He) (W/cm³)	13.04
Average heating in solid Li_2O (W/cm³)	33.12
3- Second Wall (steel)	
Outer tube diameter (mm)	15
Thickness of steel tube (mm)	2.5
Heating in solid steel (W/cm³)	24.88
Blanket-I & Blanket-II	
Percentage of steel	8.3%
Percentage of Li_2O (without steel)	40%
Percentage of He (without steel)	60%
a- Blanket-I	
1- Wall-I (steel)	
Number of rows	2
Outer tube diameter (mm)	50
Thickness of steel tube (mm)	14.1
Heating in solid steel (W/cm³)	15.8
2- First Li_2O zone	
Thickness (m) 0.535	
Average heating (Li_2O +He) (W/cm³)	2.3
Average heating in solid Li_2O (W/cm³)	5.75
3- Wall-II (steel)	
Number of rows	2
Outer tube diameter (mm)	50
Thickness of steel tube (mm)	14.1
Heating in solid steel (W/cm³)	1.0
b- Blanket-II	
1- First Li_2O zone	
Thickness (m)	0.535
Average heating (Li_2O +He) (W/cm³)	0.13
Average heating in solid Li_2O (W/cm³)	0.325
2- Wall-II (steel)	
Number of rows	2
Outer tube diameter (mm)	50
Thickness of steel tube (mm)	14.1
Heating in solid steel (W/cm³)	0.07
Shield	
Thickness (m)	0.60
Percentage of steel	90%
Percentage of He	10%
Average heating (W/cm³)	0.028



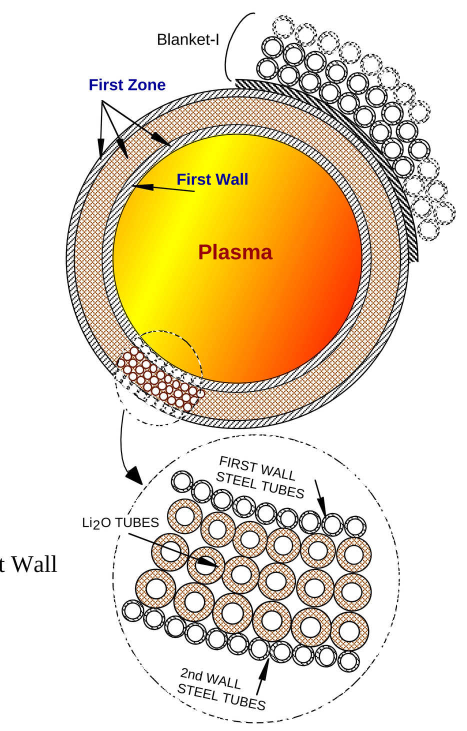
BLANKET-I OF THE FRC



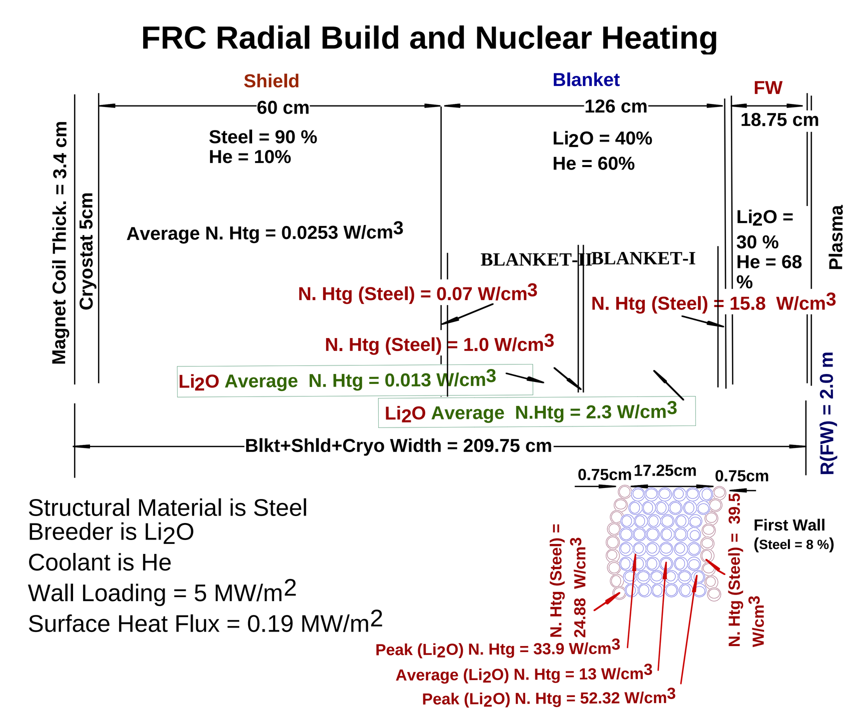
Concentric Arrangement

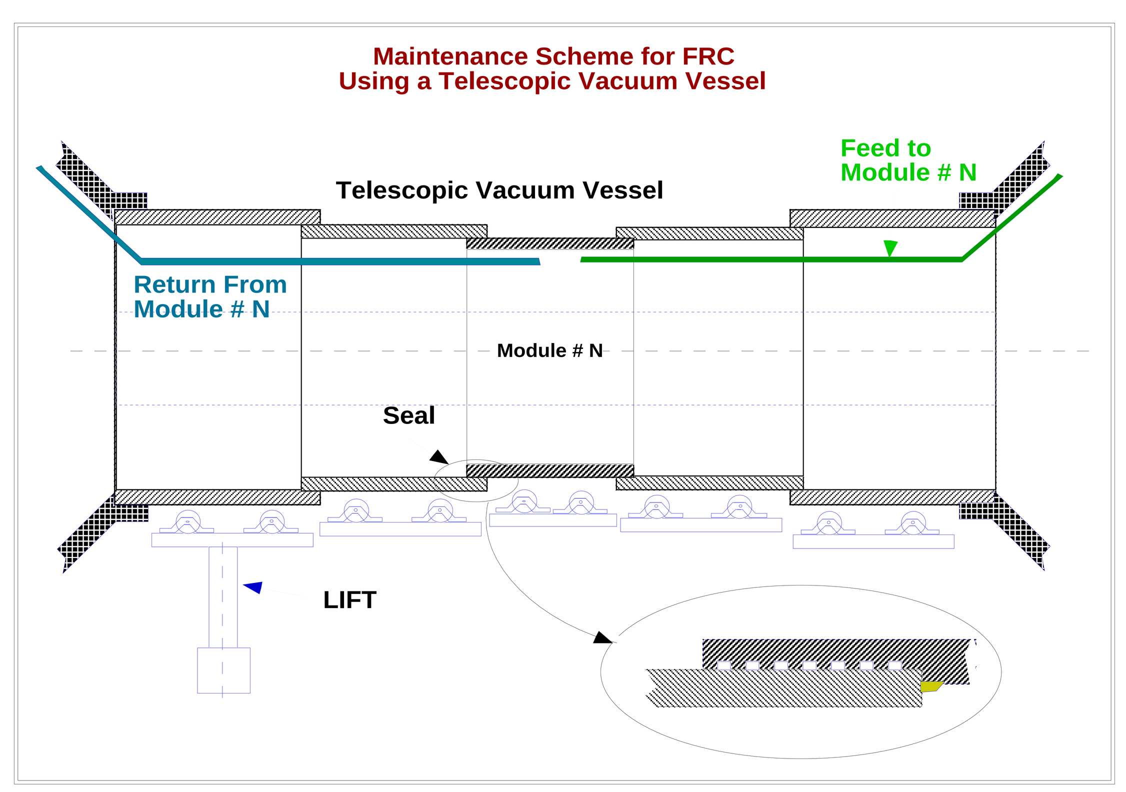


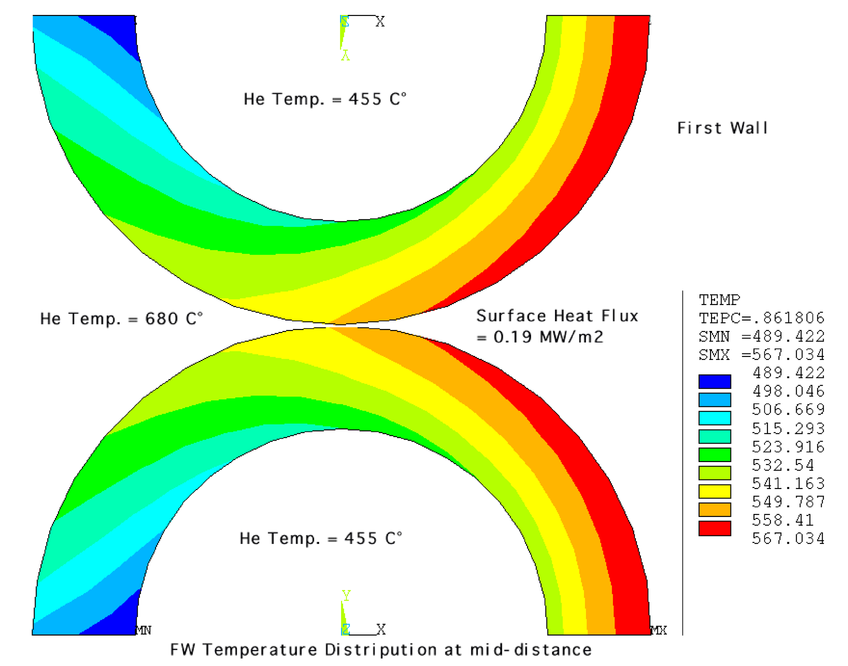
COOLANT ROUTING



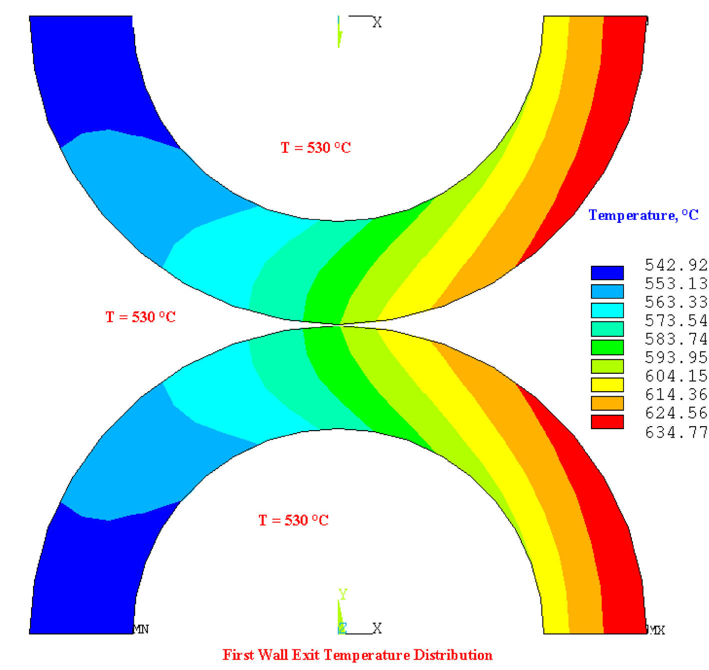
FIRST ZONE, BLANKET & SHIELD OF THE FRC



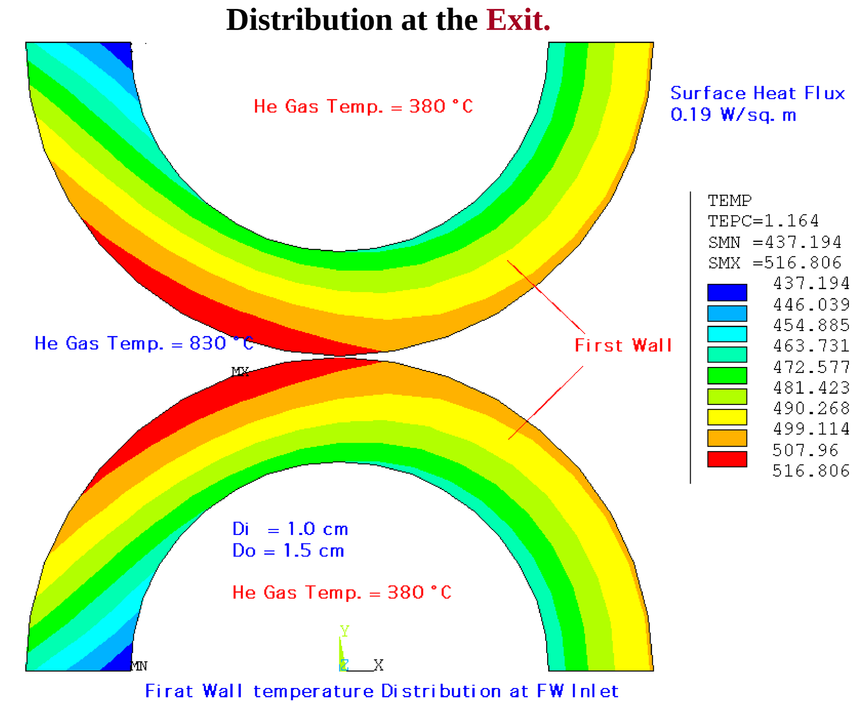




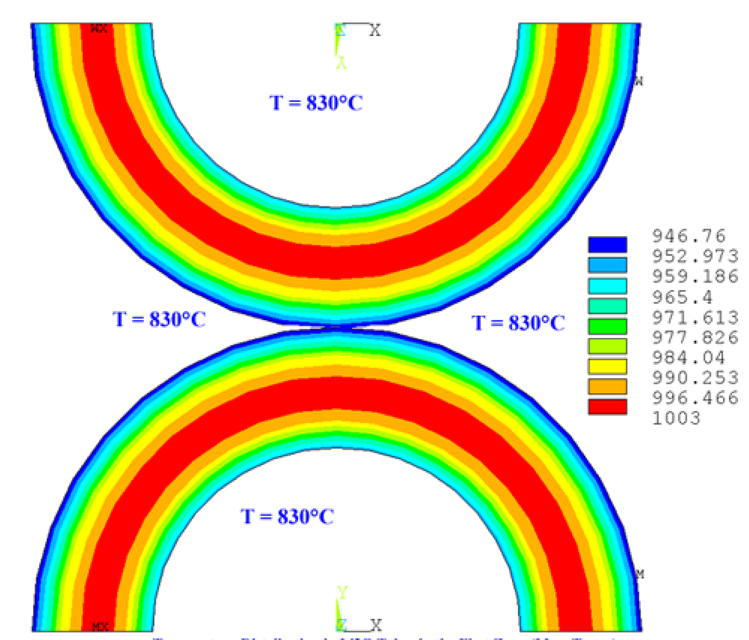
First Wall Temperature Distribution at the **Mid-Point.**



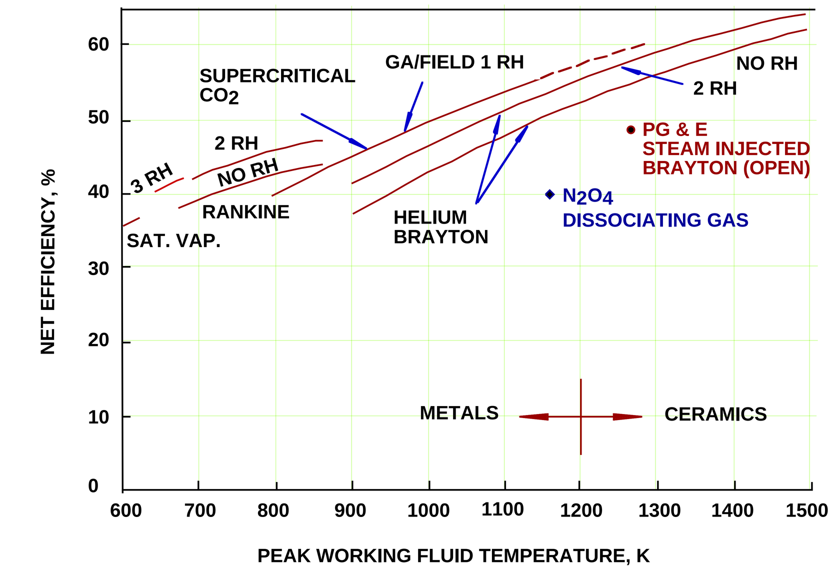
First Wall Temperature Distribution at the **Exit.**



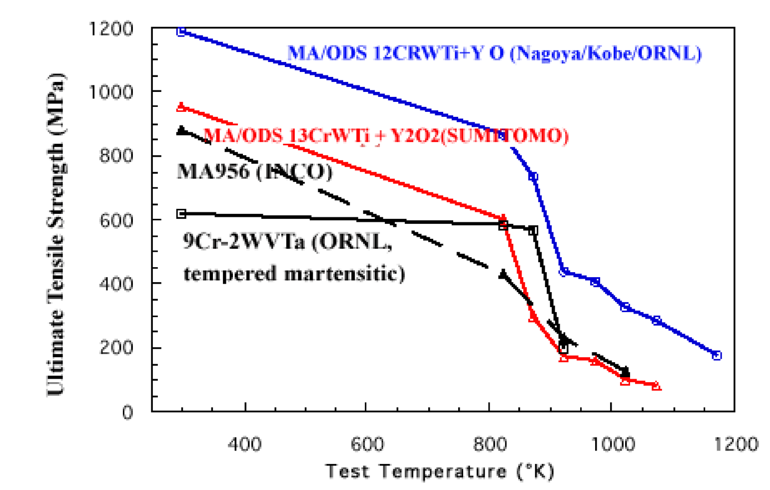
First Wall Temperature Distribution at the **Inlet.**



TEMPERATURE DISTRIBUTION IN FIRST ZONE Li_2O



NET EFFICIENCIES (FROM GA)



The steady state thermal load per module, helium coolant mass flow, and helium coolant average velocity

Zone	Total heating (MW)	He mass flow rate (kg / s)	He velocity (m / s)
First zone			
First wall (steel)	15.7	20.17	26.4
First Li_2O zone 67.55	48.38	3.44	
Second wall (steel)	6.14	7.89	9.22
Blanket-I			
Wall-I (steel tubes)	34.7	44.57	18.06
Li_2O	48.76	31.32	0.68
Wall-II (steel tubes)	2.2	2.82	1.14
Blanket-II			
Li_2O	3.41	2.19	0.039
Wall-III (steel)	0.15	0.2	0.078
Shield			
Bulk (steel)	0.64	0.83	0.0046
Total	180	76.5	

SUMMARY AND CONCLUSIONS

- The relative ease of maintenance and the use of steel structure with reasonable thermal efficiency (52%) are assumptions that make it a credible and attractive design.
- The resulting compact FRC fusion core of the reference case conceptual design possesses a high ratio of electric power to fusion core mass, indicating that it would certainly have favorable economics.
- The cylindrical geometry and low magnetic field allow removal of single modules containing the first wall, blanket, shield and magnet.
- The same concept would be applicable to a spherical Torus and spheromak.