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FLIBE/He/FS/Be CONCEPT

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8.10.1.2 Flibe/He/FS/Be Concept

The following section discusses a number of special issues for the Flibe design. The salt tubes immersed in the bed of beryllium balls must be spaced so the balls can flow into or out of the tube region with no bridging resulting in flow stoppage. We have conducted flow tests which show that if the balls are no larger in diameter than one-half of the free space between tube walls, free flow will occur. Since some balls may crack or swell and develop imperfections of shape, we prefer that the ball diameter not exceed one-third of that free space. The pebble size is picked to be large enough to avoid excessive pumping power but small enough to freely flow between the tubes during pebble changeout and during periodic pebbles movement to allow for pebble swelling. The nominal values we have chosen are given in Table 8.10-2.

Table 8.10-2
NOMINAL PEBBLE/PIPE PARAMETERS

Pipe outside diameter	1.7 cm
Pipe spacing	4.7 cm
Pipe wall thickness	0.5 mm
Pebble diameter	1.0 cm

The tubes are held in place by clips attaching them to perforated grid spacers not shown in the figure.

The tube diameter is large enough so that freeze-up will not occur and small enough so that the centerline temperature will stay well below the boiling point (1300°C at one atmosphere). These limits are discussed in the thermal hydraulic section. The tube spacing is selected based on nucleonics. Too large a spacing will give parasitic loss of neutrons in the beryllium and too small a spacing will displace beryllium and reduce fast neutron multiplication. The tube wall thickness is selected to reduce parasitic absorption in the steel and yet be thick enough to avoid buckling caused by the helium pressure being higher than the salt pressure. Normally, the salt pressure is one atmosphere below the helium pressure, but abnormally the salt may be depressurized to one atmosphere in which case the tubes will not buckle.

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Beryllium and Flibe Requirements

The salt volume is 9% of the blanket. The steel tube walls are 1% by volume and the structural fraction is 5% steel in the beryllium zone. The beryllium pebbles take up 53% and the Helium occupies 32%. In the reflector zone, the beryllium is replaced by SiC which occupies 75% of the volume. The beryllium zone is 20 cm thick and the SiC zone is 37 cm thick, except on the inside of the Tokamak where it is only 4 cm thick.

The beryllium zone volume is 0.2 m^3 per m^2 of first wall area in a Tokamak and 0.23 m^3 for the tandem mirror (larger due to the small first wall radius). The volume of the 37 cm thick SiC region is 0.59 m^3 in the mirror and 0.37 m^3 (assuming the same coverage on the inside as the outside) in the Tokamak. Taking 53% of the volume being beryllium and a full theoretical density of 1.84 g/cm^3 we get 0.20 tonnes/m^2 for a Tokamak and 0.22 tonnes/m^2 for a mirror. The salt volume is 0.033 m^3 per m^2 in a Tokamak and 0.053 m^3 in a mirror. For 3000 MW fusion and 5 MW/m^2 neutron, there are 480 m^2 of wall area. The salt volume in the blanket for a Tokamak is 16 m^3 and in a mirror is 25 m^3 . The mass of beryllium is 96 tonnes in a Tokamak and 110 tonnes in a mirror. There are approximately 100 million pebbles of 1 cm diameter.

Tube Failure Rate

Breeder tube failure rate is a concern for this concept. With so many tubes, the question comes up of the failure rate. For the case of a tube nominal spacing of 4.7 cm on a triangular array, there would be 80,000 tubes in the blanket each having an average length of 11 m. If we can tolerate one failure per five years, then the failure rate per tube per hour of operation must be less than 4×10^{-10} . The helium pressure outside the tube is about 1 atmosphere higher than the pressure of the molten salt in the tube. Small cracks, at welds, for example, would result in leakage of helium into the salt and does not constitute a failure. Too large a crack would result in too large a helium leak rate and force a shut down and module change but have little overall consequence. An offset tube break could lead to molten salt contamination of the helium coolant loop. This would require shut down and a clean up procedure to follow. Analysis should be carried out to determine what size of crack is tolerable and then if an acceptable failure rate ($< 4 \times 10^{-10}$ per tube per hr) can be achieved.

Alternate Module End Design

An alternative module end design to that shown in Fig. 8.10-1 is presented here. The idea is to allow the end modules of one sector to support the end modules of the adjacent sector as shown in Fig. 8.10-6. The viewer is looking in the poloidal direction in a tokamak or the azimuthal direction in a tandem mirror. The direction of the lobes is shown here to be poloidal (azimuthal) but could be oriented toroidally (axially) and the idea is equally applicable. Consideration must be given to tolerance accumulation which can cause overstress of module sidewalls. Also, unintentional "cold welding" of walls in contact could occur. This would prevent disassembly without damaging the module end-wall in contact with a neighboring sector. Both of these unpleasant effects can be overcome by a simple expedient. An aluminum oxide plate (or several smaller pads) can be mounted on the end walls of modules in adjacent sectors. The aluminum oxide pad thickness can be selected just before final assembly to compensate for tolerance build-up in the manufactured condition. Alternatively, a pressurized cushion could be used in conjunction with the aluminum oxide plate to take up the tolerance. The ceramic pads will not weld inside the vacuum. Pad spacing and area must be controlled to minimize any local wall bending stresses in an unsupported area. The space occupied by these thin ceramic pads can be small so that valuable breeding volume is conserved and parasitic neutron capture minimized. Clearly, further work is needed on design of the module end support.

Figure 8.10-6
Alternate module end design.