The Li2O Particle Blanket Concept and Power Conversion/Configuration and Maintenance

The APPLE Concept
(Advanced Plasma-facing Particulate Lithium-Oxide Evaluation)

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May 6-8, 1998

APEX Project Meeting

UCLA, Los Angeles, California

Radiation Damage

- The effect of radiation damage to 14 MeV neutrons is a key uncertainty because there is no intense 14 MeV neutron source.
- To develop 14 MeV neutron source and obtaining damage information is expensive and time consuming.
- For the APPLE concept, the damage is cause by lower energy neutrons. Fission irradiation results are much more applicable.

First Wall Reliability

- The conventional fusion first wall is very thin (~ 3 mm), and backed by high pressure coolant (~ 10 MPa), and subject to high radiation damage.
- To assure the first wall has minimum number of failures over many years of operation will be difficult.
- A first wall failure may require the change of the entire blanket module, which will be costly and time consuming.
- The first wall of APPLE is not a pressure boundary.
- Therefore, a first wall leak does not impact the operation of the plasma.
- The only role of the first SiC structure is to restrict Li_2O flow.

Tritium Breeding

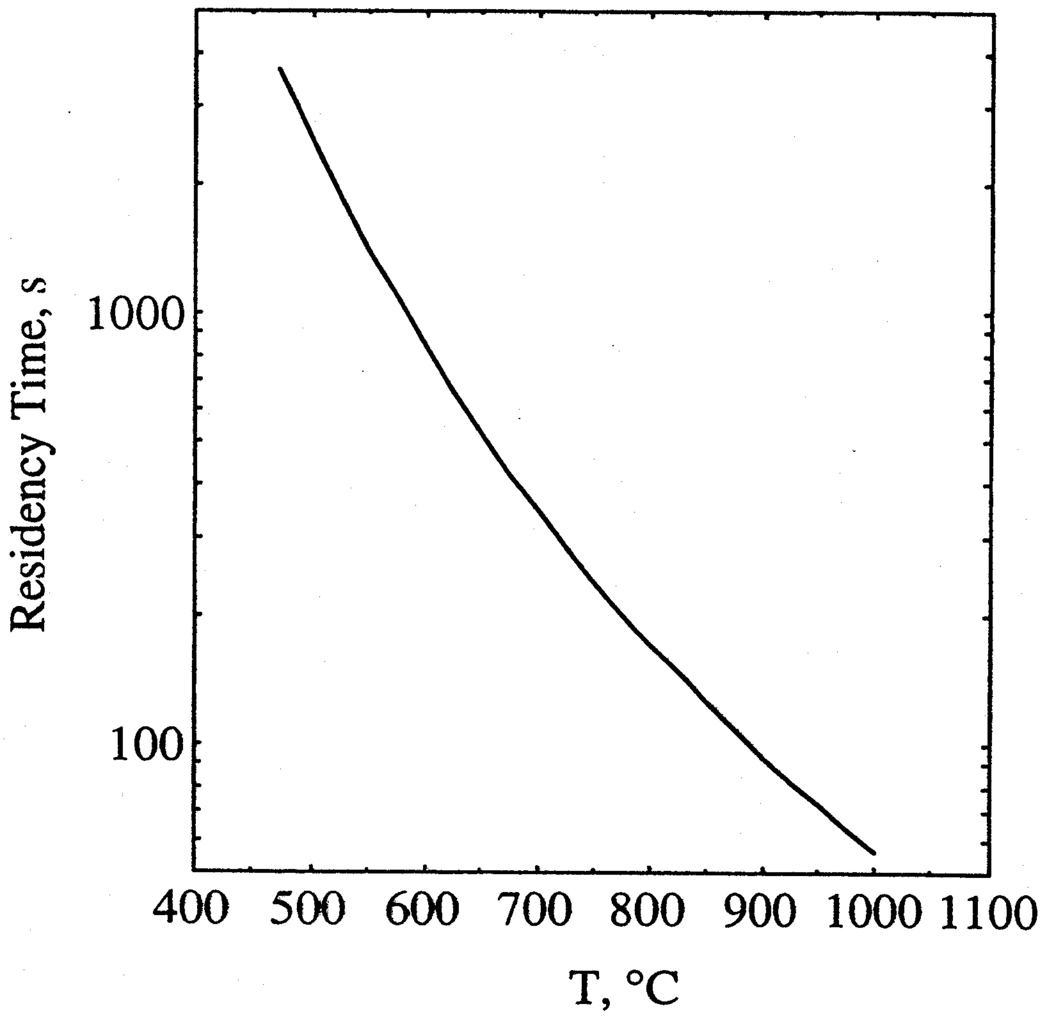
- A tritium breeding ratio of 1.15 has been calculated without Be and no Li enrichment.

- The removal of Be from the blanket enhances the safety characteristics of the power plant, and also simplifies the design.

- Also, removal of Be eliminates the concern of Be resource.

Tritium Recovery

- The tritium residence time in the Li20 is on the order of 100 s.
- With a tritium produced will diffuse out of particulates in the form of DTO.
- The tritiated water released outside of the reactor will be confined within the coolant channel and eventually reach an equilibrium state.
- The tritiated water released within the reactor will be back diffused to the plasma.
- With 500 g of tritium recovered per day, there my be 2.5 Kg of oxygen released to the plasma



Predicted residency time for 1-mm Li2O pebbles in vacuum with 25 μm grain size, 93% density and 0.12 m_2/g specific surface area

High Heat Flux Issues

- Since the coolant is facing the plasma directly, the heat transfer capability on the first wall and divertor is excellent.

- For the first wall, the residence time for the free drop Li_2O is about 2 s, a surface heating rate of 2 MW/m^2 can be handled.

- For the divertor surface, because of the much shorter residence time of the Li_2O, a surface heating rate of > 10 MW/m2 can be handled.

Sputtering Issue

- Since the Li20 Surface is a renewable surface, sputtering concern to the material is small.
- For 100 ev tritium ion, the sputtering ratio is estimated to be 0.03 atoms/ion, which is similar to Be.
- Self-sputtering characteristics of Li20 is also similar to that of Be.
- It is not expected that either sputtering or self-sputtering will be critical issues for the flowing Li20.

Disruption

- For ITER design, disruption has been a key factor.
- For a conventional fusion blanket, the first wall is a few mm thick, and the blanket has only a few percent in structural material.
- APPLE breeding zone is electrically non-conducting.
- The shield has over 90% structure, and is very robust against disruption.

Heat Transfer Concerns

- There were some concerns on the heat transfer on the APPLE concept.

- There are three different heat transfer regimes, i.e.,

  - First wall: To remove high first wall heat flux, the Li2O will drop at a high velocity to reduce the residence time of Li2O facing the high heat flux.

  - Blanket: Within the blanket, the heat is deposited inside the particulates. There is no heat transfer problem. The velocity of the Li2O has to be restricted to improve heat transport.

  - Heat exchanger: The heat transfer from particulates to a solid wall within high vacuum is an issue.

First Wall Evaporation Rate

- The vapor pressure over Li2O at 1000°C is 10^{-5} torr.
- For a surface area of 1000 m^2, the total evaporation rate of Li2O is 86 Kg/FPD.
- Another 2.5 Kg/d of oxygen may be released together with the back diffusion of tritium.
- A barrier reduction factor of ~100 will be required to reduce the impurity influx into plasma.
- This is termed as within the "moderate confidence" regime by Mattas.

Why APPLE

- Of all the free surface blanket concepts, APPLE is the only concept with low vapor pressure.

- If high evaporation rate from the first wall can be accepted, there are many free surface blanket concepts candidates.

- However, if only low evaporation rate can be accepted, APPLE is the only possible candidate for the free surface blanket.

Thermal Conversion

- The maximum Li_2O temperature is 1000C, while the average Li_2O exit temperature is 800C.

- The heat is transferred to a He stream at 700C.

- At this temperature, a He-cycle becomes feasible with an efficiency of close to 50%.

- Advanced steam cycle can also be considered with similar efficiency.

Heat Exchanger Design

- The effective of heat transfer from particulates to a solid wall is questionable, especially within a high vacuum.

- However, at a high temperature, radiation heat transfer can be effective.

- Heat transfer can also be improved by an increase

  Effective area and

  Heat transfer DT because of

  Q = UADT

- A finned coolant tube will be used for the heat exchanger.

Heat Exchanger Calculations

- The radiation heat transfer coefficient is 250 w/m^2-C, assuming the particulates are at 800°C and the emmisivity is 0.8.
- The outside of the coolant tube will have fins of 1 mm thick and 1 cm high.
- The fin heat transfer effectiveness is 0.66, partially due to the poor radiation heat transfer to the fin.
- If the fins are 3 mm apart, the effective heat transfer coefficient will increase by a factor of 3.3.

Heat Exchanger Calculations

(Cont.d)

- The overall heat transfer coefficient from the particulates through the fins to the coolant wall is now 825 w/m^2-C.

- If the heat transfer DT is 100°C, and the thermal power is 2500 MW, the heat exchanger surface area is 30,000 m^2, which is very reasonable.

- Contact conductance will further improve heat transfer.

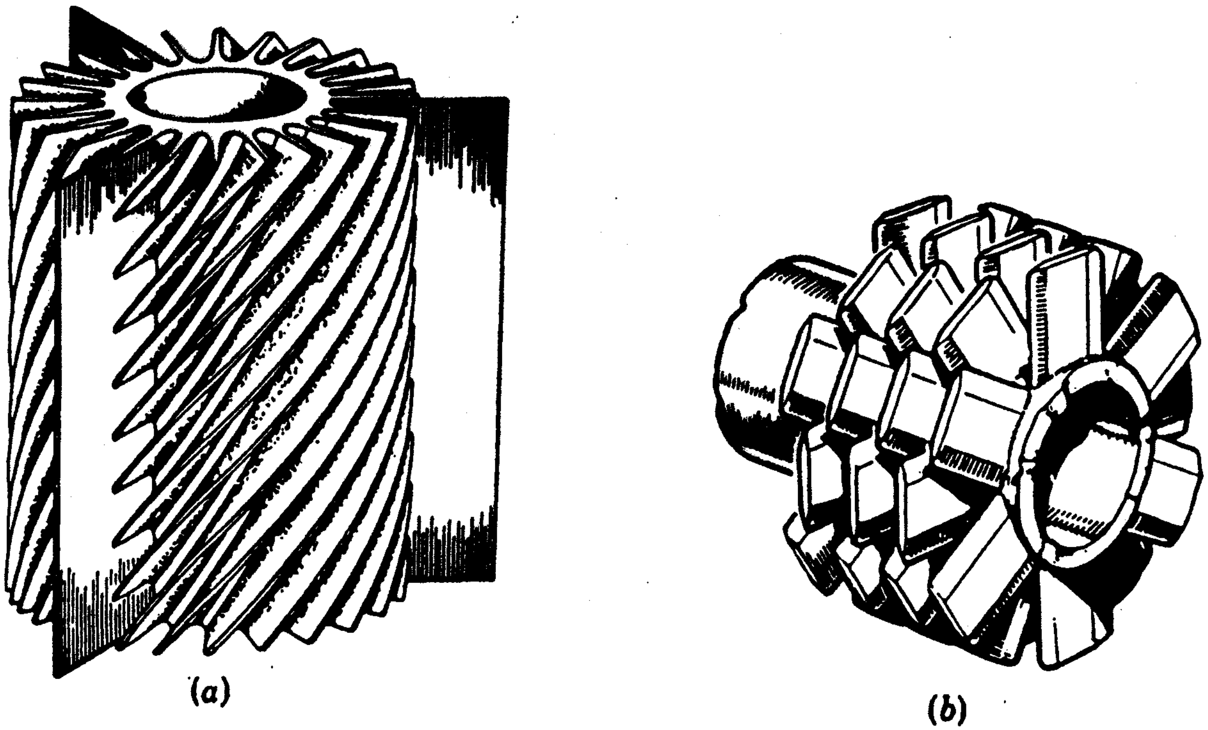


Fig. 16-11. Finning used in Hinkley Point power plant. (*a*) "Polyzonal" fuel-element cladding; (*b*) steam-generator tubing.

Safety

- The APPLE concept selects SiC and Li_20 as the materials.
- There is minimum activation and afterheat.
- The Li_20 will be at a high temperature. Therefore, tritium inventory will be low.
- The shield can be life time component, and qualify for level C waste disposal.
- There is no foreseeable major safety and environment concerns.

Key Issues

- Flow baffle cooling and replacement
- Penetration design
- Stabilizing shell location and design
- Flow control
- Particle erosion and attrition
- HX design
- Tritium containment

Unique Feature of APPLE

- Very low pressure system.
- No MHD effects. (No need to develop insulating coating)
- Radiation damage only to renewable materials.

International Collaboration

- This concept was discussed with Y. Seki.
- After discuss with the JAERI design team, Seki has shown interest on the concept.
- Possible collaboration under US-Japan collaboration in reactor design study maybe proposed.
- Further discussion will be held between Sze and Seki during the IAEA meeting.

Other Advantages

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a. Verly low activation and after heat

b. No first wall reliability issue

c. Life time structural material

d. Near surface burial

e. Breeding with no Be

f. High performance

Reasons to Evaluate APPLE Concept

The APPLE blanket concept has the potential to eliminate or alleviate most of these problems.

a. Blanket replacement

b. Radiation damage

c. First wall reliability

d. Breeding

f. High heat flux issues

g. Erosion

h. Disruption

i. Efficient thermal conversion

j. Safety

Capabilities of Advanced Technologies for Attractive Fusion Energy Systems

Quantitative Goals	Basic goal	Grand Challenge	APPLE
Average Neutron wall loading, MW/m2	2-3	5-10	5-10
Peak heat flux capability,MW/m2	5-7	50	10-15
First wall life time, (MW-y/m2)	10	20	
First SiC			Undefined Life time
First structure			
Average cost of core material ($/kg)	100	50	25*

* This is the average for Li_2O and 316 SS in the shield.

What Is Interest About Apple Concept

- The most critical issues associated with fusion reactor blankets and diverters are caused by the interaction with neutrons
- There are also critical issues associated with MHD effects, and plasma (alpha particles, disruption) effects
- The APPLE concept reduces the severity of most of those issues
- Instead, a new list of key issues are introduced, which are mostly of a mechanical and configurational nature.

APPLE Description

- To enhance the first wall/divertor heat transfer capability, the coolant will be exposed directly to the plasma.

- Li_2O is selected as the coolant/breeder because of
  - Low vapor pressure($<10^{-5}$ Torr at 1000°C)
  - Good breeding potential without Be
  - Very low activation and after heat
  - Good high temperature stability

- The first wall regime will be a free flow of Li_2O particulate to enhance heat transfer

- The blanket baffles will be constructed by SiC, which will restrict the Li_2O flow rate to increase the packing density.

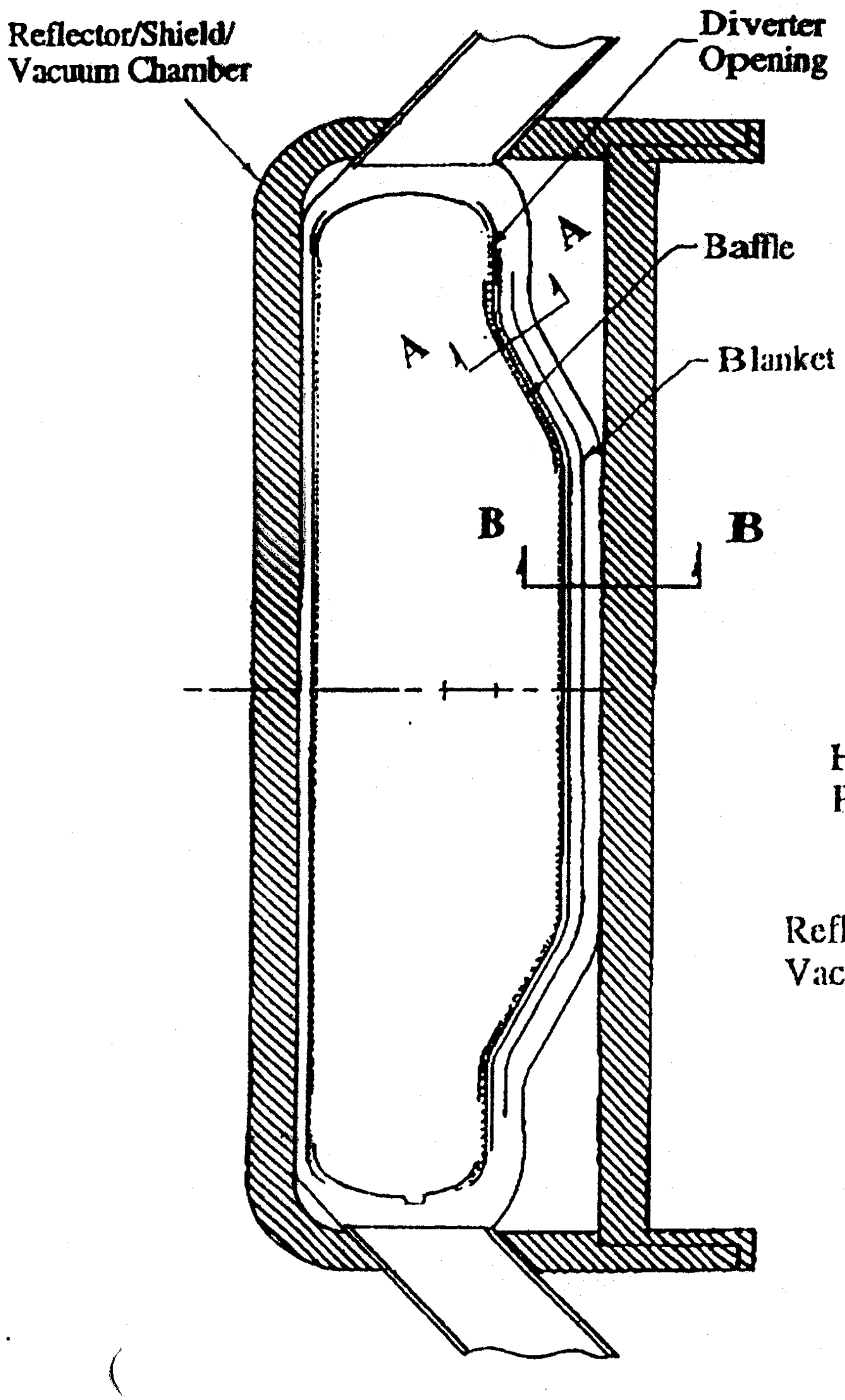
- The SiC layer will not be a heat transfer boundary so that low thermal conductivity is not a critical issue.

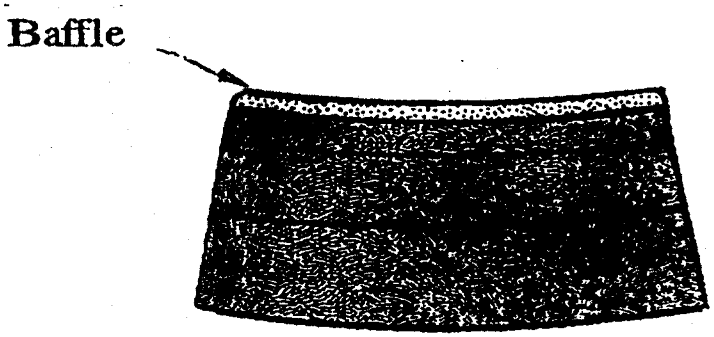
APPLE Description (cont'd)

- The Li_2O will be collected at the bottom of the blanket, and exit from the blanket by gravitational force.
- A mechanical conveyer will move the Li_2O particulate to the top of a heat exchanger.
- The Li_2O will drop down from the HX by gravitational force, and transfer heat to a secondary He loop.
- The Li_2O will be moved up again by another mechanical conveyer to the top of the blanket, and be fed into the blanket.
- Tritium produced in the Li_2O is expected to diffuse back to the plasma with very low tritium inventory.
- The He from the HX will enter a He turbine for efficient power conversion.

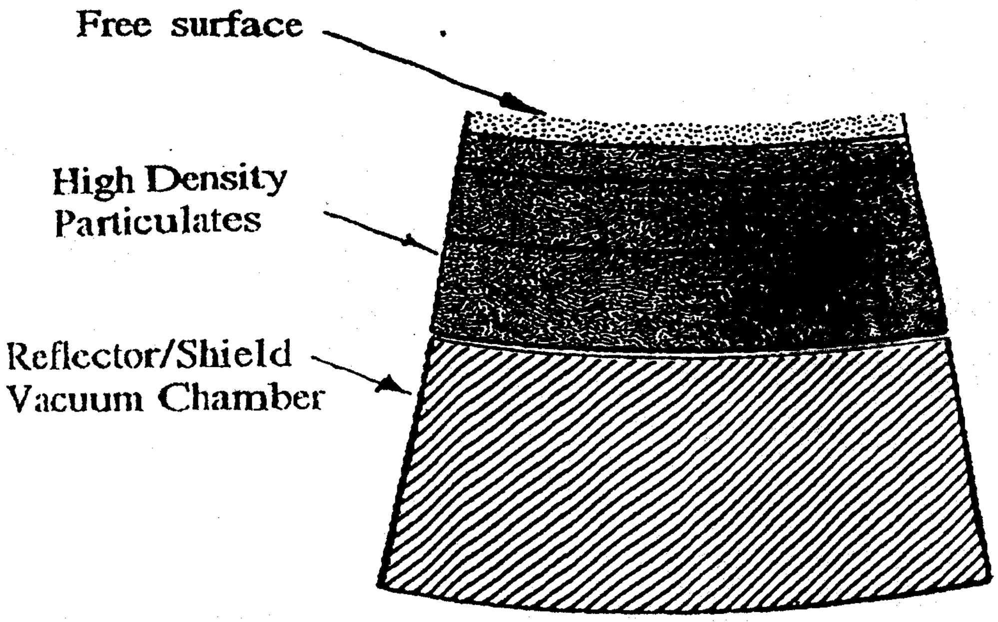
APPLE Configuration with Blanket/Shield Cross Sections

University of
Wisconsin



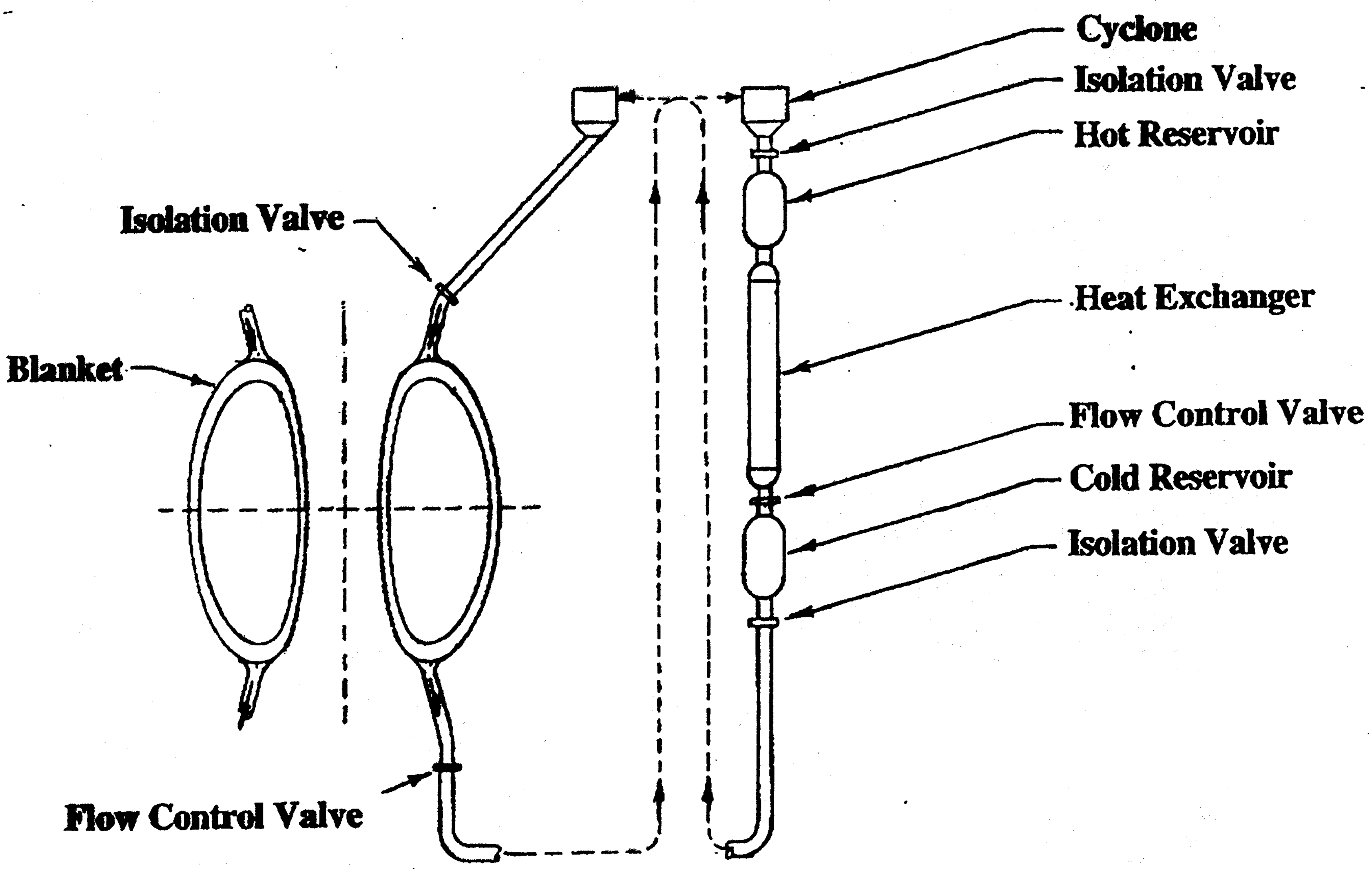


Cross Section A A



Cross Section B B

Flow Diagram for the APPLE Particulate Routing



Cyclone
Isolation Valve
Hot Reservoir
Isolation Valve
Heat Exchanger
Blanket
Flow Control Valve
Cold Reservoir
Isolation Valve
Flow Control Valve

Blanket Replacement

- The permanent structure is behind the L_2O breeding regime.
- The radiation damage is reduce by two orders of magnitude.
- With a reasonable breeding zone thickness, the permanent structure can survive the life time of the power plant.
- The SiC baffles in the breeding zone are non-structural and have long life time and made for easy replacement.