Blankets and Fuel Cycle

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FUSION power program

TECHNOLOGY DEVELOPMENT

Function of the Blanket

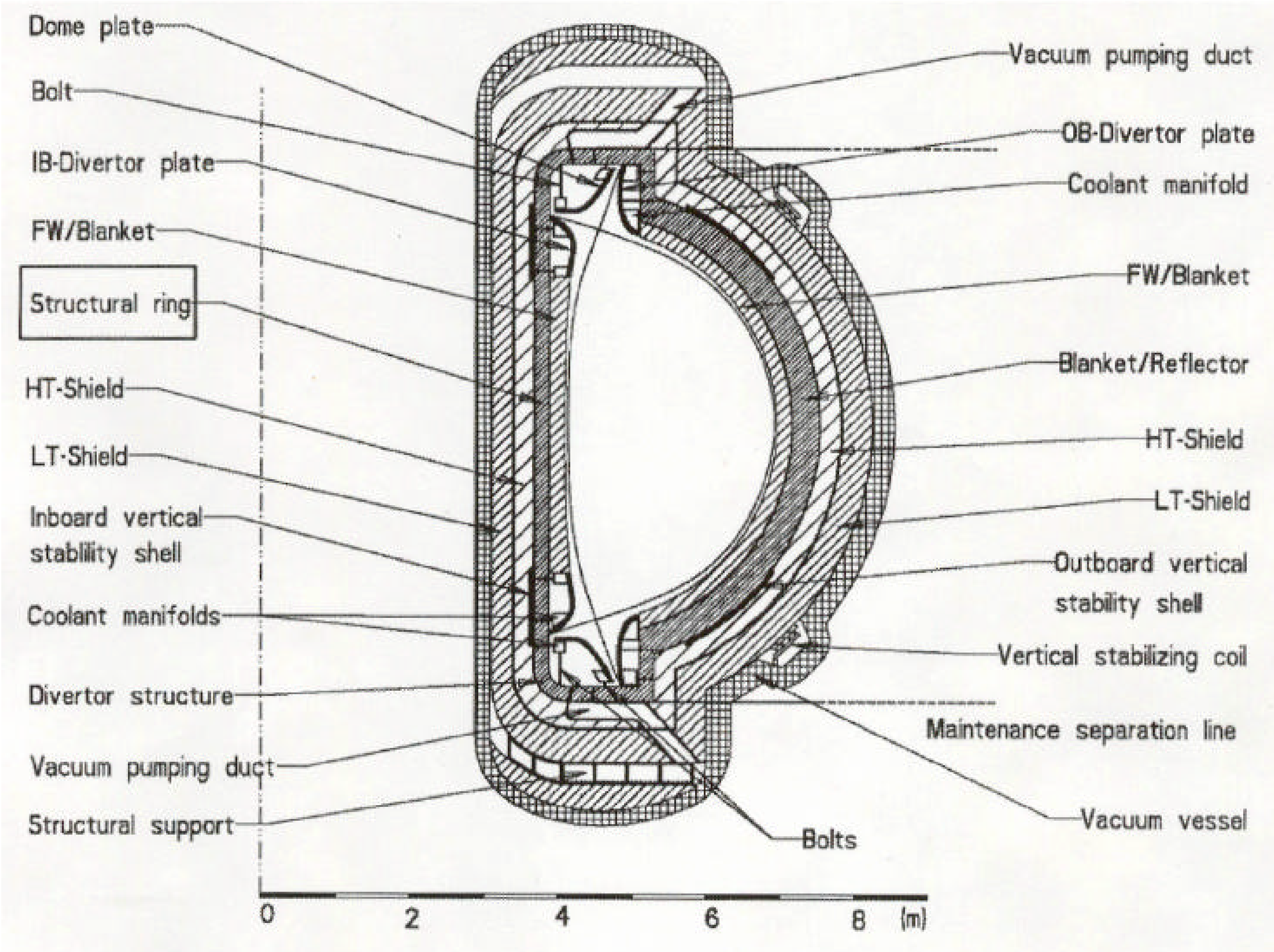
- Blanket is the region within which fusion energy is converted into thermal energy.
- Blanket is also the region within which the fusion fuel, tritium, is produced.
- Blanket is used to provide shielding and neutron moderation.

Issues Associated with the Blanket

- Since fusion energy is converted into thermal energy, the blanket temperature must be high to provide adequate thermal conversion efficiency.
- Since fusion fuel has to be produced in the blanket, the tritium breeding ratio has to be larger than 1.
- Since the blanket is subject the most intensive radiation damage, the blanket has to be replaced frequently.
- Since the blanket is subjected to the highest irradiation, it has be the highest activation and after heat. This dominates the safety issues.

- Since the first wall separates the blanket from the plasma, the reliability of the first wall is a key concern.

- Since the first wall is the first structural layer around the plasma, it suffers the most damage caused by plasma disruptions.


Dome plate
Bolt
IB-Divertor plate
FW/Blanket
Structural ring
HT-Shield
LT-Shield
Inboard vertical stability shell
Coolant manifolds
Divertor structure
Vacuum pumping duct
Structural support
Vacuum pumping duct
OB-Divertor plate
Coolant manifold
FW/Blanket
Blanket/Reflector
HT-Shield
LT-Shield
Outboard vertical stability shell
Vertical stabilizing coil
Maintenance separation line
Vacuum vessel
Bolts
0
2
4
6
8
(m)

Tritium Breeding Materials

- The only possible tritium breeding materials are lithium compounds.
- ^{3}He is another possible breeding materials, but it is scarce on earth.
- Some of the breeding materials are

Liquid metals	Li, PbLi, SnLi
Molten salts	Flibe
Solid Breeders	Li_2O, Li_4SiO_4, $LiAlO_2$ and Li_2ZrO_3

Coolants

- High pressure Helium
- Water
- Breeding materials (liquid and salt)

Structural Material

- Ferritic Steel
- Vanadium Alloys
- SiC/SiC Composites
- Refractory Metals

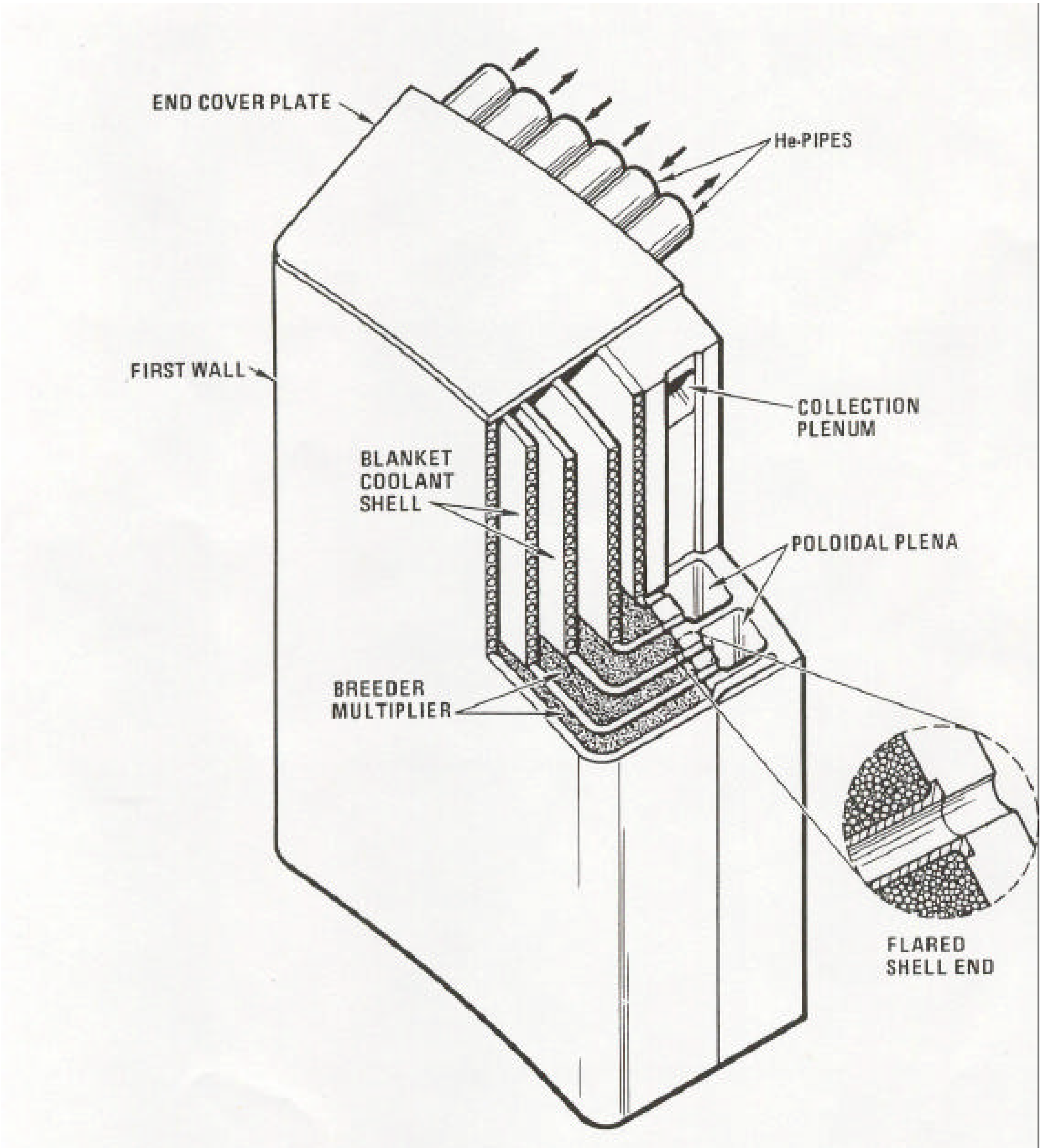
Blanket Type

There are two categories of blanket:

- Self-cooled: The tritium breeding material is used also as the coolant.
- Separate- cooled: A different coolant is used for heat removal.

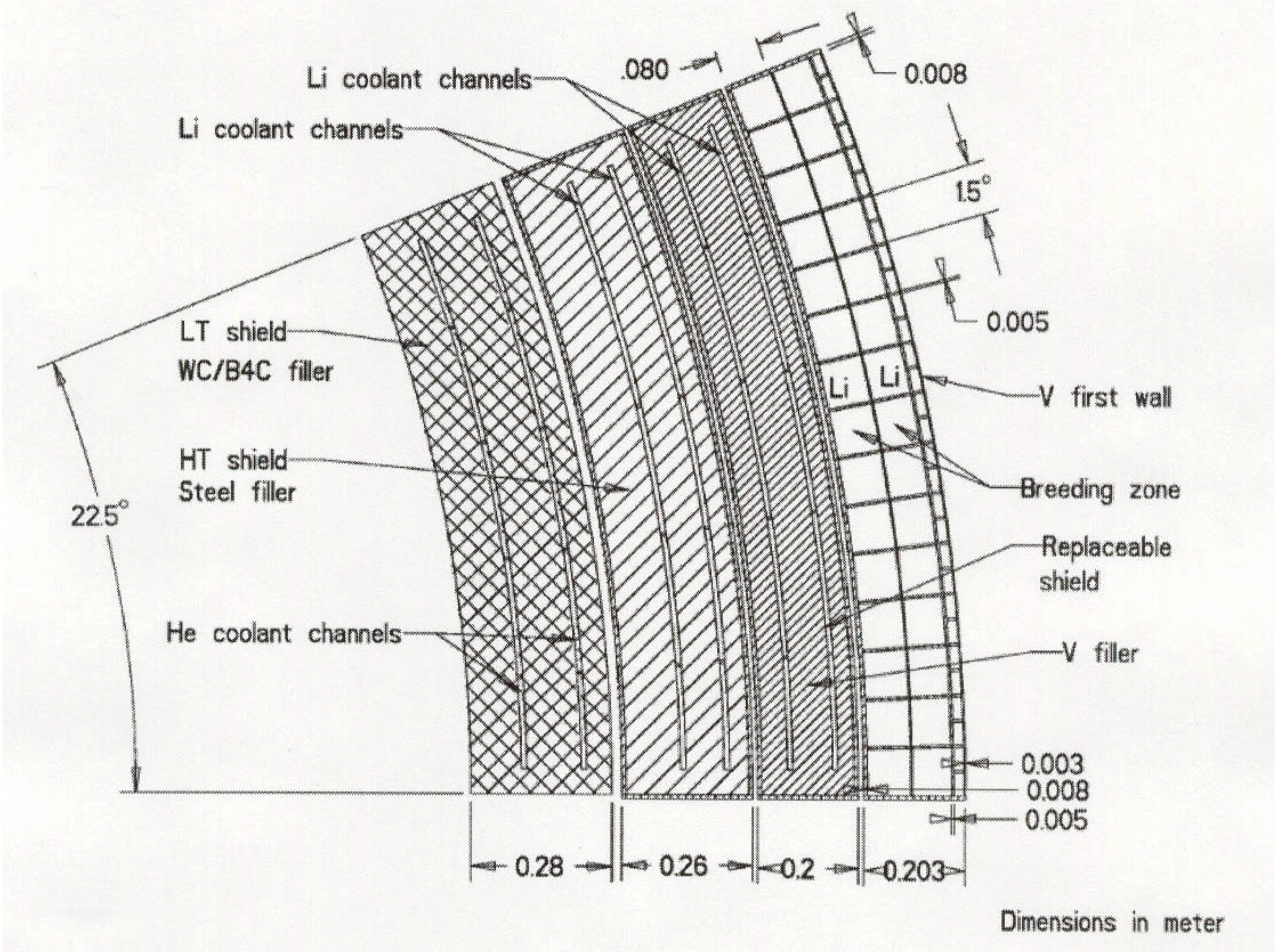
Separate-cooled Blankets

- A separate coolant, most likely high pressure He, is used for the coolant.
- The breeding material is most likely one of the solid breeders.
- To achieve sufficient tritium breeding, Be is added for neutron multiplication.
- Either FS or SiC can be used for the structural material.
- A He-purge gas is used for tritium recovery.

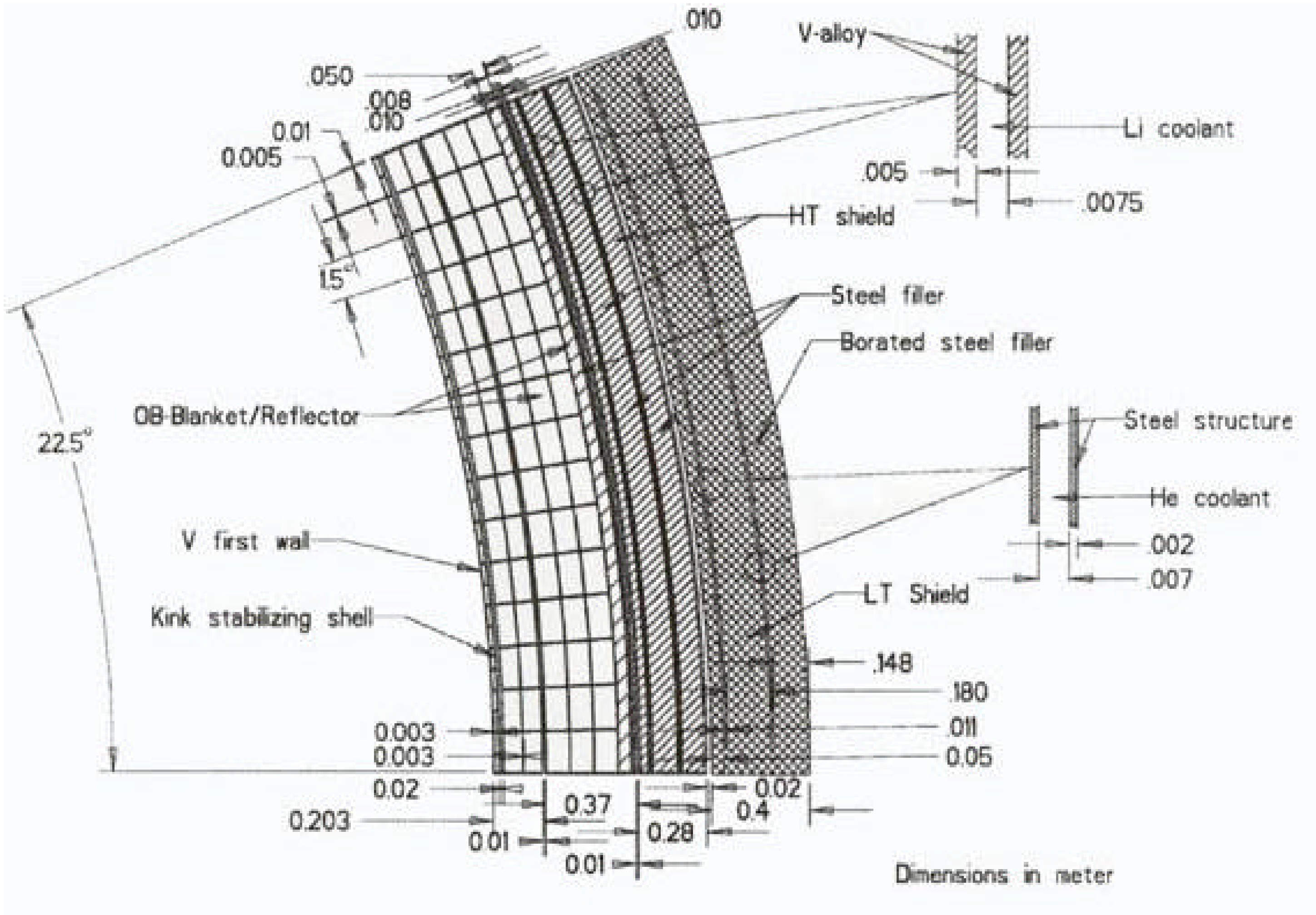

END COVER PLATE
He-PIPES
FIRST WALL
COLLECTION
PLENUM
BLANKET
COOLANT
SHELL
POLOIDAL PLENA
BREEDER
MULTIPLIER
FLARED
SHELL END

Self-cooled Blankets

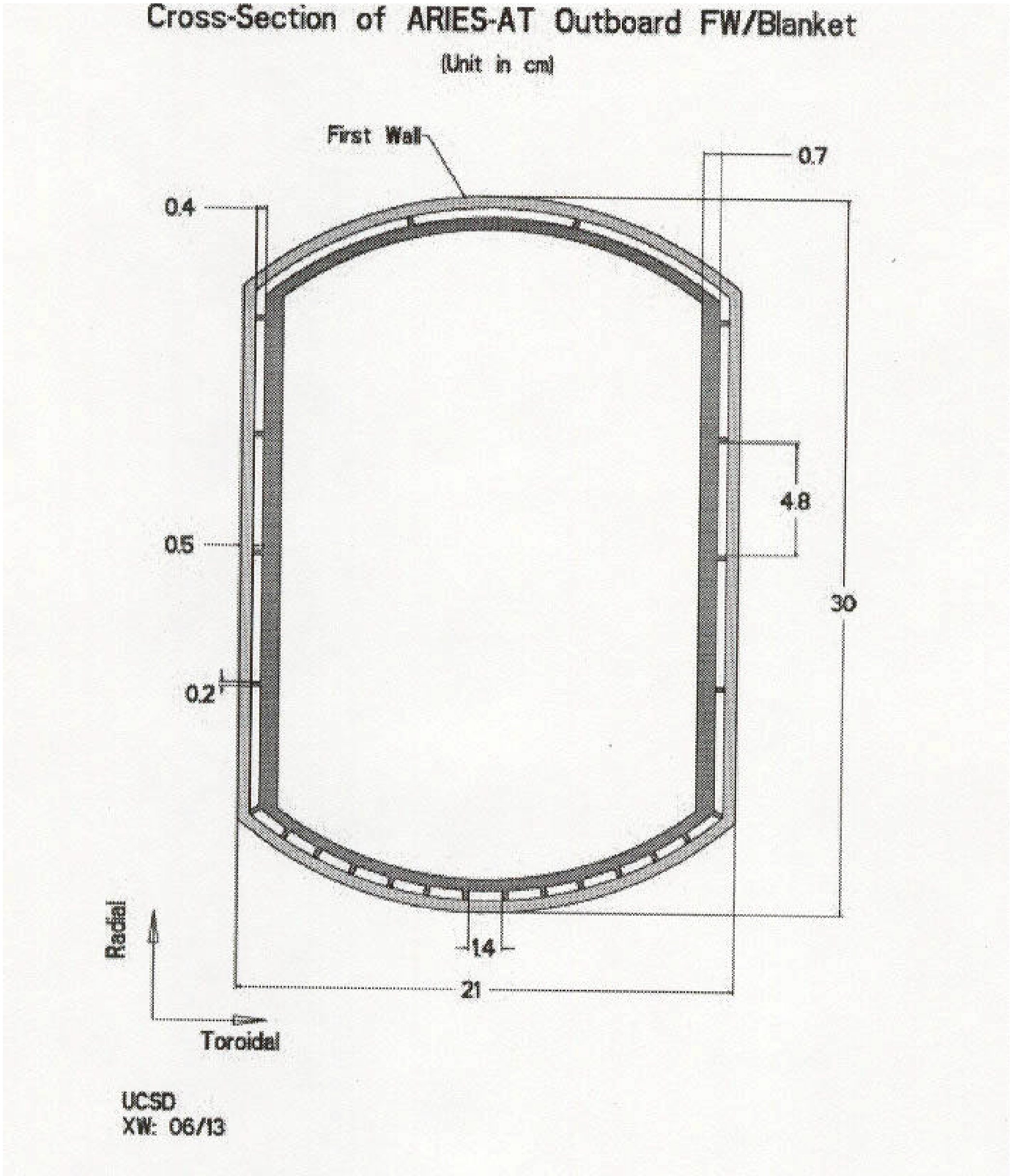
- The breeding material is used for coolant.
- The breeding material usually is one of the liquid breeders.
- Be is required to improve tritium breeding for Flibe and LiSn blankets, but is not required for the Li and LiPb blankets.
- Ferritic steel, Vanadium, SiC and refractory alloys can all be used for structural materials.
- A side stream of the coolant is processed for tritium recovery.



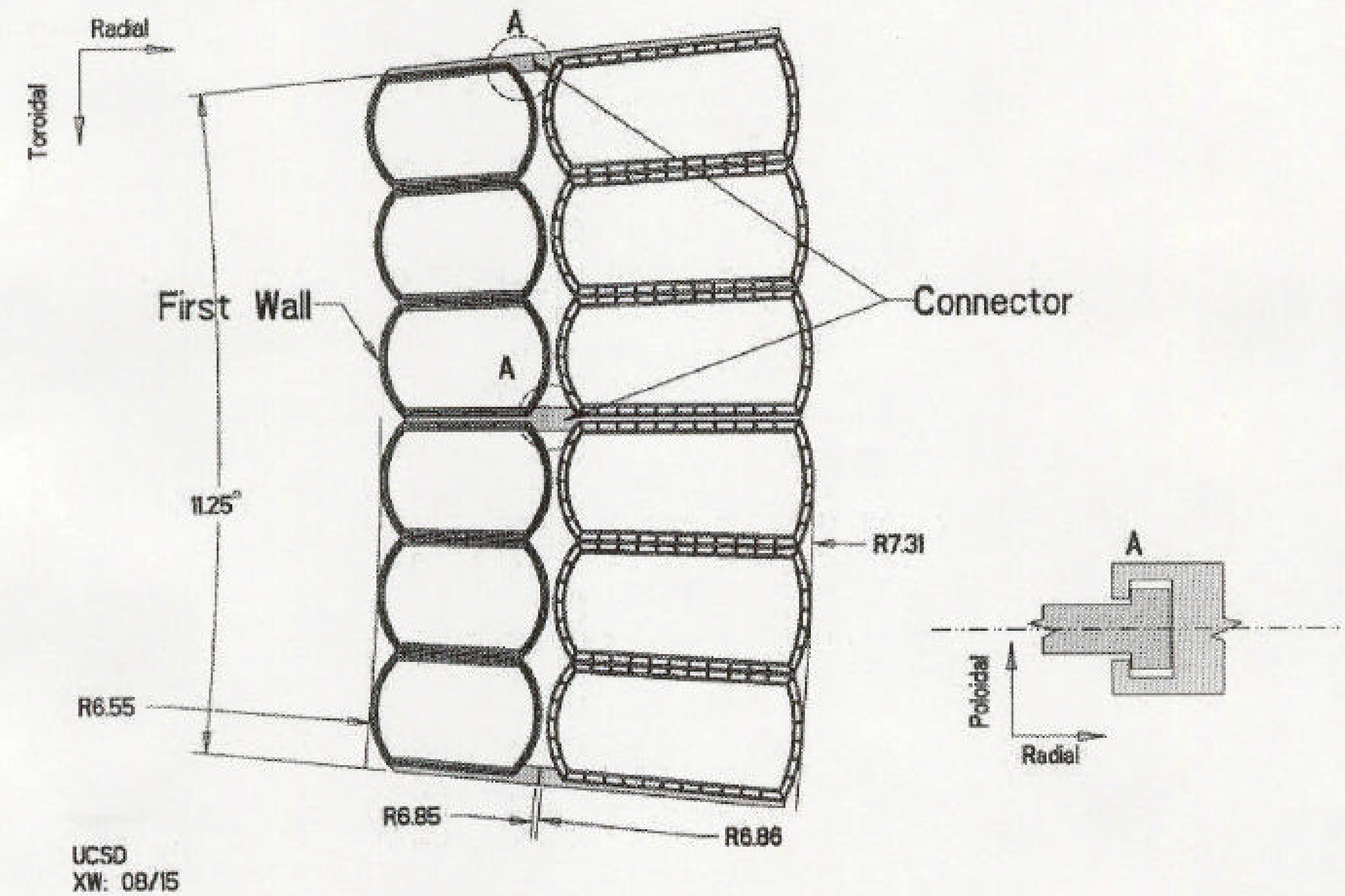
Li coolant channels
.080
0.008
Li coolant channels
1.5°
0.005
LT shield
WC/B4C filler
Li
Li
V first wall
HT shield
Steel filler
Breeding zone
22.5°
Replaceable
shield
He coolant channels
V filler
0.003
0.008
0.005
0.28
0.26
0.2
0.203
Dimensions in meter



.010
V-alloy
.050
.008
.010
0.01
0.005
Li coolant
.005
.0075
HT shield
1.5°
Steel filler
Borated steel filler
OB-Blanket/Reflector
Steel structure
22.5°
He coolant
V first wall
.002
.007
LT Shield
Kink stabilizing shell
.148
.180
.011
0.05
0.003
0.003
0.02
0.02
0.37
0.4
0.203
0.28
0.01
0.01
Dimensions in meter


Cross-Section of ARIES-AT Outboard FW/Blanket
(Unit in cm)
First Wall
0.7
0.4
4.8
0.5
30
0.2
1.4
21
Radial
Toroidal
UCSD
XW: 06/13

Cross-Section of ARIES-AT Outboard FW/Blanket (One Segment)



Typical separate-cooled blanket

Coolant – High pressure He at 10 to 20 MPa

Breeding Material – Li_2O with Be

Structural Material – SiC Composite

Tritium Recovery – He purge at 0.1 MPa

Coolant Temperature – 400-700C

Neutron wall loading limit – 3 MW/m^2

Typical self-cooled Blanket

- Breeder/Coolant - Lithium
- Structural material – V_4Cr_4Ti
- MHD Coating – CaO or AIN
- Tritium Recovery – Molten salt recovery or Cold Trap
- Coolant temperature – 330 - 610C
- Allowable surface heat flux > 1.0 MW/m^2

Key Issues on Blankets

- First wall /blanket life time and replacement.
- First wall/blanket reliability.
- Tritium breeding/recovery and containment.
- MHD related issues.
- Activation, afterheat and waste disposal.
- Structural material, breeding material, coolant and neutron multiplier interactions.
- Plasma stability requirements.

Fuel Cycle

- The fuel cycle of a D-T power plant has the following missions:
  - Assure sufficient fuel supply.
  - Produce enough extra fuel for the starting of the next power plant.
  - Processing fuel to sufficient purity for fueling of the plasma.
  - Contain the fuel to limit the release rate to between 1 to 10 Ci/d.

Fuel Supply

- The only potential tritium supply is from CANDU reactors.
- It is not certain the tritium from CANDU will be available for fusion power.
- Therefore, the tritium fuel has to be produced in the blanket, for both feeding the plasma, and to provide for the starting of the next power plant.
- To alleviate the issues on tritium breeding, the tritium inventory in a power plant needs to be kept on the order of few kg's.
- The real tritium breeding ratio required is about 1.01

Tritium breeding

- Most fusion power plant blankets can achieve breeding ratios > 1.01
- Some of the breeding material, in particular most solid breeders, will need neutron multiplier to increase the tritium breeding.
  - Be is the best neutron multiplier, with Pb as a distant second.
  - However, the addition of Be will cause other problems, such as safety concerns

Fuel Processing

- Fuel processing system needs to control impurities in the fuel, and also control of the isotopic ratio required by the plasma fueling.
- Tritium System Test Assembly (TSTA) has demonstrated the purification and isotope separation of D-T fuel on a scale only a factor of few from a D-T power plant.
  - The tritium isotope separation is based on cryogenic distillation, and has obtained both D and T exceeded 99% purity.
- Computer codes have been developed to simulate the operation fo the cryogenic distillation system.
- The fuel processing system may be the most well developed area in the fuel cycle.

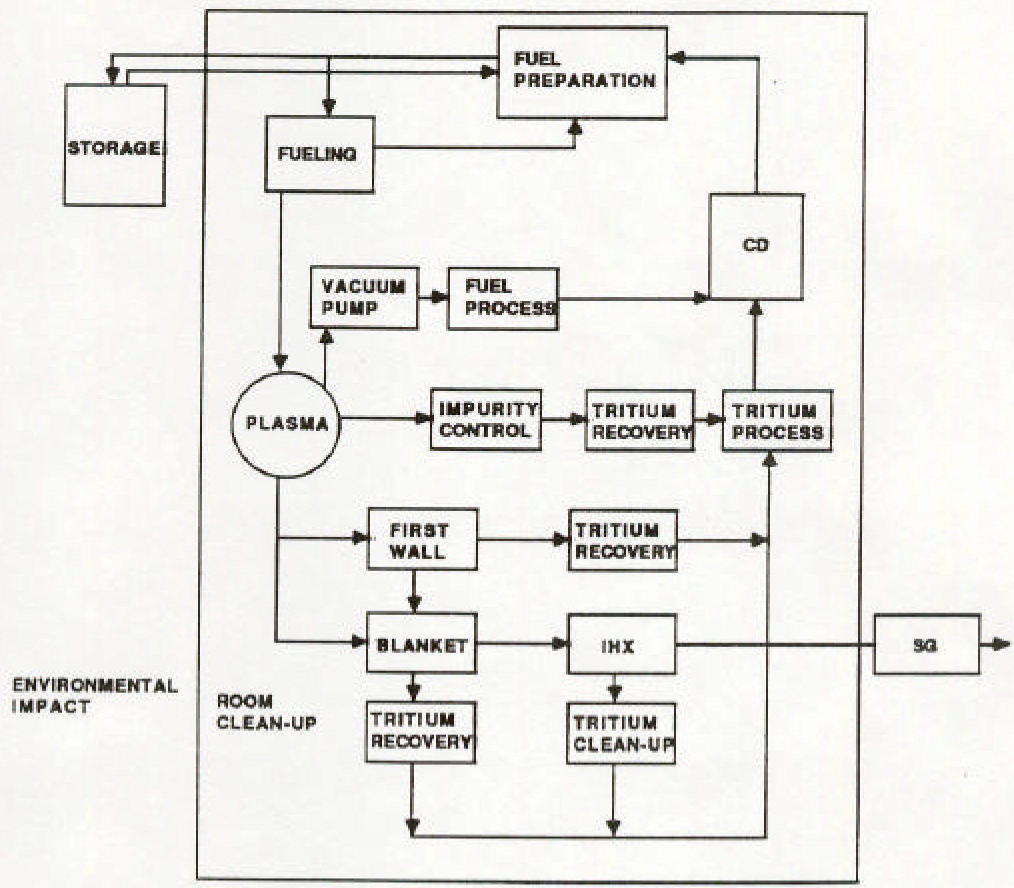


Figure 12.3-1. Flowchart of the TITAN-I tritium system.

Tritium Containment

- Tritium has to be contained to reduce the leakage rate within allowable safety limits
- The allowable leakage rate is between 1 to 10 Ci per full power day (FPD).
- The primary heat exchanger is the area has the most problem on tritium leakage, because of

Large Surface Area	~10,000 m^2
High Temperature	> 500C
Thin wall	~1 mm thick

Possible Methods to Reduce Tritium Leakage

Develop tritium permeation barrier

Not effective

Using double-walled heat exchanger

Not effective

Processing of the secondary coolant

Very costly

Tritium containment is a key issue

Summary

- The blanket and fuel cycle dominate the power generation and fuel supply of fusion power plant.
- The first wall and blanket are also the regions receiving the highest radiation damage.
- The key issues for the blanket and first wall are
    1. Reliability related
    2. Radiation damage related, and
    3. MHD related.
- Those issues have to be resolved
    - facilities are needed in order to build a data base.

Fuel cycle test facilities

- Most issues on fuel cycle do not depend on radiation damage and MHD.
- The development of the fuel cycle technology can be done by conventional R/D facilities.
- Tritium containment is a serious issue which needs much R/D

Main Parameters of Li/V Blanket

• Average neutron wall load	4.0 MW/m^2
• Maximum neutron wall load	5.6 MW/m^2
• Average surface heat flux	0.5 MW/m^2
• Max. design heat flux	1.0 MW/m^2
• Blanket life time	2.5 FPY
• Li inlet temperature	330C
• Li outlet temperature	610C
• Steam cycle efficiency	46%