Assessment of the Activation, Decay Heat, and Waste Disposal of a Dual Coolant Lithium Lead Test Blanket Module for ITER

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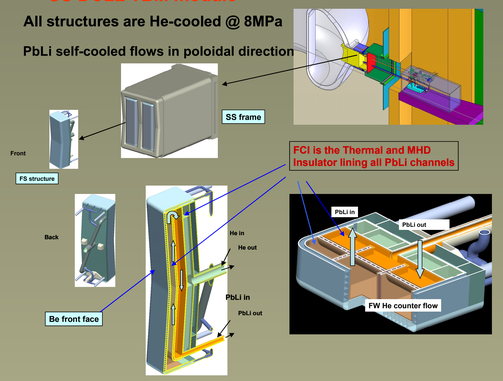
US DCLL TBM module

All structures are He-cooled @ 8MPa

PbLi self-cooled flows in poloidal direction



Relative location of the test module in the test port, transporter location and module cross-section sketch.

Radial Build of the HCLL TBM (90% Li-6) in the 1-D toroidal Model

Zone	Inner Radius (cm)		thickness (cm)	steel %	SiC%	LiPb%	helium%	Beryllium%	H2O %
1	0	Central Clenoid/maget arc	200						
2	200	Vacuum Vessel	100						
3	300	ITER blanket Shield	53						
4	353	ITER Cu FW	2						
5	355	Be-Tile	1						
6	356	Scrap-off Layer	10						
7	365	Plasma	475						
8	840	Scrap-off Layer	9.2						
9	849.8	Beryllium layer	0.2					100	
10	850	First Wall	0.4	100					
11	850.4	FW cooling Channel	2	17			83		
12	852.4	Second Wall	0.4	100					
13	852.8	SiC-insert	0.5	8.1	80		11.9		
14	853.3	Breedeing Channel 1	7	8.1	4.3	75.5	12.1		
15	860.3	SiC-insert	0.5	8.1	73.9	6.1	11.9		
16	860.8	Divider Plate	1.5	54.8	0.4	6.1	38.7		
17	862.3	SiC-insert	0.5	8.5	73.3	6.1	12.1		
18	862.8	Breeding channel 2	11	8.5	4.7	74.7	12.1		
19	873.8	SiC-insert	0.5	8.5	78.4	1	12.1		
20	874.3	Back plate	17	62.8	0.2	1	36		
21	891.3	Manifold	30.7	5	0.2	1	93.8		
22	922	Shield	128	75					25

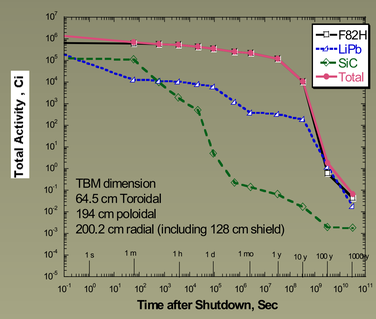
Calculation Procedures

- **The 1-D discrete ordinates code, ANISN, was used to calculate the neutron flux in the 1-D toroidal model with a multigroup cross-section library based on FENDL-2 data.**
- **The activation code, DKR-PULSAR, to calculate the radioactivity and decay heat levels at shutdown and at 11 post-irradiation times up to 1000 years.**
- **The activation/decay data library of FENDL-2 was used in the calculation.**
- **The impurities (wppm) considered for F82H structure are as follows: Co59 33.916, Nb93 3.99, Mo 69.806, Pd 0.1796, Ag 0.1596, Cd 0.0499, Eu 0.0499, Dy 0.0499, Ho165 0.0499, Er 0.0499, Os 0.01995, Ir 0.0499, and Bi209 0.0499. For Pb-17Li, they are: Na23 1.839, K 1.226, Ca 1.839, Cu 2.044, Ag 10.22, Sb 3.066, Bi209 40.88. And for SiC, they are: Sc45 0.0016, Cr 0.518, and Fe 3.626.**

Assumptions/data used in the calculation

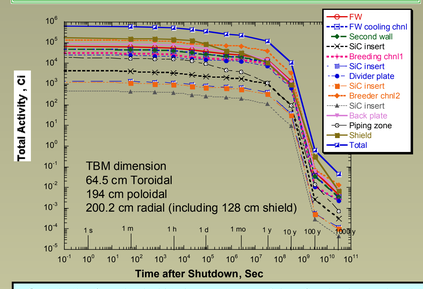
- **Average NWL at TBM= 0.78 MW/m2**
- **TBM has the dimension of 62 cm toroidal x 200 cm poloidal x 100 cm radial (including 69.5 back shield)**
- **Average NWL in ITER =0.57 MW/m2**
- ***A pulse is composed of 400 s on and 1800 sec off***
- ***Number of pulses to reach a fluence of 0.3 MWa/m2 at average NWL=0.57 MW/m2 is 41494 pulse***
- **Structure (F82H) and SiC inserts are irradiated during a pulse and allowed to decay during the 1800 dwell time. This is repeated 41494 times.**
- ***For LiPb breeder in addition to the above irradiation scenario, within each pulse it is irradiated for 36 sec and un-irradiated for 20 sec (see next view graph)***

Total activity generated in the test blanket module and contribution from each material



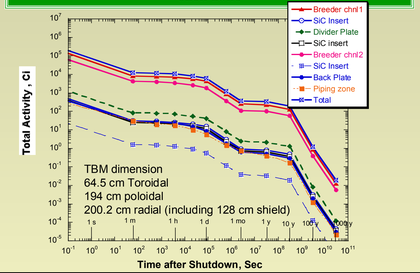
- **Shutdown activity ~2.4 MCi but drops in few seconds to~1MCi due to decay of Pb-207m**
- **Total activities is mainly due to structure F82H**
- **Activity in LiPb is 2-3 orders lower than in F82H**
- **Activity in SiC insert is 2-6 orders of magnitude lower than in F82H**

Total activity in the F82H structure and contribution from each zone



- **Contribution from the shield is dominant up to ~ 1 day after shutdown. when the contribution from the structure in the back breeder channel starts to be the largest.**
- **The activation in the back plate is also large.**
- **The activation inventories in the 1st and 2nd wall are comparable but they are less than those attainable in the shield, the back breeder channel, and the back plate.**
- **This illustrates the importance of accounting for the activation in zones other that the FW when assessing the total radioactive inventory in the TBM (blanket in general).**

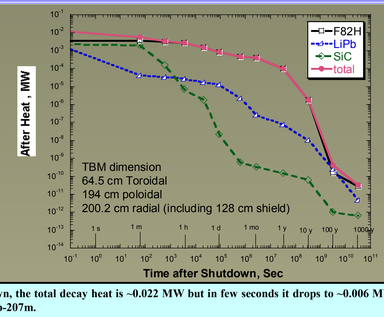
Total activity in the Pb-17Li breeder and contribution from each zone



- **The LiPb activity inventory includes the activation from the tritium that is generated in the TBM.**
- **The inventory is dominated from contribution from the front and back breeder channels.**
- **Activation levels of ~ 2-3 orders of magnitude lower are attainable in the back plate, the divider plate, and the piping zone.**

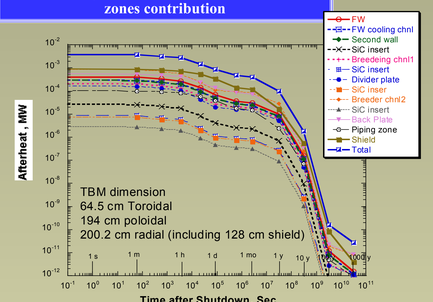
Radioactive inventory in the SiC insert stays at a level of 0.1 MCi for ~ 1 m, then it drops to a level of ~8 Ci after 1 day and to ~0.08 Ci after 1 year and is due mainly to the Fe impurity. At a 100 y, the inventory is extremely low (~0.002 Ci).

Total after heat generated in the test blanket module and contribution from each material



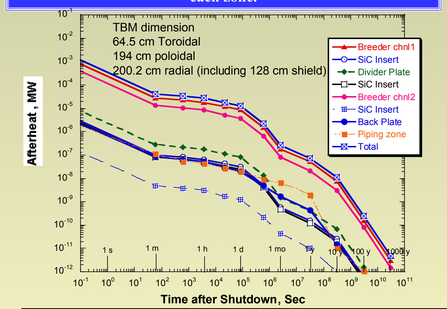
- **At shutdown, the total decay heat is ~0.022 MW but in few seconds it drops to ~0.006 MW due to the decay of Pb-207m.**
- **From a fraction of an hour up to ~100 years after shutdown, the total decay heat is attributed to the contribution from the structure.**
- **The decay heat generated in the Pb-17Li breeder is ~2-3 orders of magnitude lower for all times after few minutes following shutdown**
- **the attainable level in the SiC insert is 2-6 orders of magnitude lower than the level in the structure.**

Total decay heat in the F82H structure and zones contribution



The decay heat generated in the FW is not the major contributor to the total decay heat, as is the case for the total activation inventory. Contribution from the structure in the shield, the back breeder channel, and the back plate is dominant.

Total after heat in the Pb-17Li breeder and contribution from each zone.



- **The decay heat generated in the front and back breeder channels are the largest.**
- **The decay heat generated in the divider plate zone is about two orders of magnitude lower than the values in these channels.**

The total decay heat generated in the SiC inserts is larger than the decay heat generated in the Pb-17Li breeder for few minutes after shutdown.

It drops sharply thereafter and reaches very low values (~ 8x10-11 MW after 10 y). These values are insignificant and imposed no safety concerns.

Waste Disposal Rating

- **The waste disposal rating (WDR) depends on the level of the long-term activation.**

For the F82H structure: Nb-94 (T1/2=2.03x10^4 y), Mn-53 (T1/2=3.7x10^6 y), Ni-59 (T1/2=7.5x10^4 y), and Nb-91(T1/2=6.8x10^2 y)
For Pb-17Li breeder: Pb-205 isotope (T1/2=1.52x10^7 y)
For SiC insert: C-14 (T1/2=5730 y), Be-10 (T1/2=1.51x10^6 y)

- **The WDR was evaluated according to the Nuclear Regulatory Commission (NRC) 10FR61and Fetter waste disposal concentration limits.**
- **The limits given are based on the assumption that all solid components are crushed before being disposed (no voids).**

The WDR values according to the conservative limits of Fetter are:

For F82H structure: 1.3x10^{-2}
For Pb-17Li breeder: 8.7x10^{-3}
For SiC insert are: 2.1x10^{-4},

- **The WDR values are much lower than unity and therefore these materials are qualified for shallow land burial according to the Class C limits.**

Summary

Activation:

- ***The total radioactive inventory in the DCLL TBM at shutdown is relatively small (2.44 MCi) and drops rapidly within a minute to reach a level of ~0.7 MCi* due to the decay of the Pb-207m isotope. It stays at that level for ~ 1 hr and drops slowly thereafter. *The level is ~0.1 MCi after 1 year and is ~0.01 MCi after 10 years.***
- **The inventory is almost entirely due to the activation of the F82H structure**
- ***The activation in the structure is not dominated by the FW*, rather by structure in in the back breeder channel, the back plate, and the shield.**
- **Few minutes after shutdown, the activation level in the Pb-17Li breeder is ~2 orders of magnitude lower than the level in the structure, even with the inclusion of the activation of the tritium bred while the activation in the SiC insert is ~2-6 orders of magnitude lower.**

Decay Heat:

- ***At shutdown, the total decay heat is as low as ~0.022 MW*. After the decay of the Pb-207m isotope, *the total decay heat is attributed mainly to the structure*. The total decay heat after 1 hour, 1 day, 1 year, 10 years, and 100 years are 3.5x10-3 MW, 1x10-3 MW, 1x10-4 MW, 2x10-6, and 7x10-10 MW, respectively.**
- ***These are extremely low values and impose no safety concerns.***
- **The decay heat generated in the FW is not the major contributor to the total decay heat.**
- **The decay heat generated in the Pb-17Li breeder is ~2-3 orders of magnitude lower for all times after few minutes following shutdown while the attainable level in the SiC insert is 2-6 orders of magnitude lower.**

Waste Disposal Rating:

- **The WDR values for F82H structure, the Pb-17Li breeder, and the SiC insert according to the conservative Fetter limits are 1.3x10-2, 8.7x10-3, and 2.1x10-4, respectively.**
- ***They are thus much lower than unity and therefore these materials are qualified for shallow land burial according to the Class C limits.***