Radiation Damage Parameters in SiC/SiC Composites

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Objectives

- Determine damage parameters for SiC/SiC composite structure in candidate FW/blankets
  - LiPb/SiC (considered in ARIES-AT, TAURO and APEX)
  - Flibe/Be/SiC (considered in APEX)
  - Li_2O/Be/He/SiC (considered in ARIES-IV and DREAM)
- Rates of dpa, He production, H production, and % burnup calculated for both sublattices of SiC fiber/matrix and interface material

Background

- Lifetime of SiC/SiC composites in fusion radiation environment is a major critical issue
- Radiation effects in fiber, matrix, and interface components represent important input for lifetime assessment
- Relative values of damage parameters are different for the constituents of the composite
- Bonding for SiC involves collective bond sharing among several adjacent atoms and displacement energies are dependent on bonding
- Radiation damage parameters calculated for both C and Si sublattices
- Used recommended displacement energies for SiC, namely 20 and 40 eV for the C and Si sublattices, respectively
- Breeder and/or coolant such as $Pb_{83}Li_{17}$, Flibe and Li_2O affect radiation damage parameters by impacting neutron spectrum

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Calculation Model

- Used ARIES-AT configuration
  - 5.2 m Major radius
  - FW location at midplane: 6.55 m OB, 3.85 m IB
- The model includes 5 mm thick SiC/SiC structural FW followed by blanket (80 cm OB, 40 cm IB) made of
  - 86% LiPb and 14% SiC/SiC
  - 6 cm front zone (60% Be, 35% Flibe, 5% SiC/SiC) back zone (86% Flibe, 14% SiC/SiC)
  - 6 cm front zone (60% Be, 33% He, 7% SiC/SiC) back zone (50% Li_2O, 15% SiC/SiC, 35% He)
- Natural Li used except for LiPb where 90% Li-6 is used
- 1-D toroidal cylindrical model
- Peak neutron wall loading 10 MW/m^2 OB, 6.5 MW/m^2 IB

Damage Parameters at Front of OB FW ($10\ MW/m^2$) for LiPb/SiC FW/Blanket

	C Sublattice	Si Sublattice
dpa/FPY	163	147
He appm/FPY	26,460	6,680
H appm/FPY	5	12,155
% Burnup/FPY	0.93%	1.88%

Damage Parameters at Front of IB FW ($6.5\ MW/m^2$) for LiPb/SiC FW/Blanket

	C Sublattice	Si Sublattice
dpa/FPY	170	137
He appm/FPY	19,300	4,900
H appm/FPY	4	8,936
% Burnup/FPY	0.68%	1.38%

- Highest damage parameters for SiC/SiC composite structure occur in OB FW at chamber midplane

Observations on Damage Parameters

- Higher atomic displacement damage rates occur in the C sublattice
- He production in C is about a factor of 4 larger than in Si and is dominated by the (n,n´3α) reaction
- Significant H production occurs in Si with negligible amount in C
- Burnup of Si is about twice that of C

Interface Material between Fiber and Matrix

- Leading interface material candidates are:
  - Graphite for near-term applications
  - Multilayer or porous SiC for longer-range applications
- Damage parameters for the SiC interface material are identical to those for the SiC fiber/matrix
- Damage parameters for the graphite interface material are same as those for the C sublattice of SiC except for dpa which will be 33% lower due to the higher (30 eV) displacement energy

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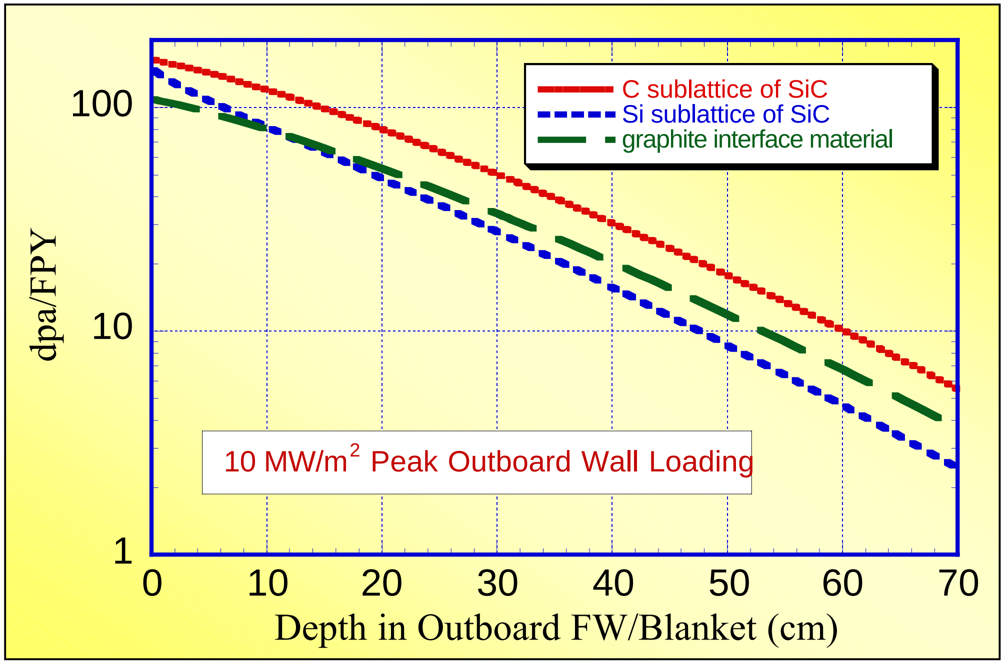
Radial Variation of Atomic Displacement in LiPb/SiC Blanket



- dpa rate in C sublattice is larger than in Si sublattice of the SiC fiber/matrix. Difference increases as one moves deeper in blanket
- dpa rate in graphite interface material is 33% lower than in C sublattice of SiC

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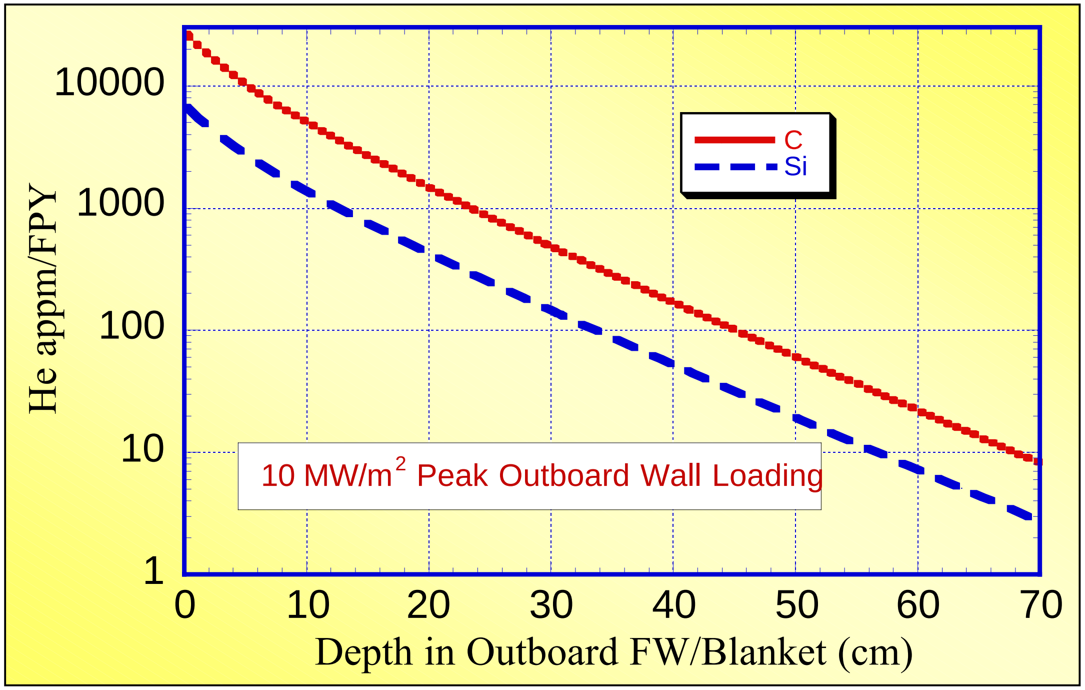
Radial Variation of Helium Production in LiPb/SiC Blanket



- He production rate in C sublattice of SiC fiber/matrix and graphite interface material is about a factor of 4 higher than in Si sublattice of SiC fiber/matrix
- Average He production rate in graphite interface is 60% higher than average He production rate in SiC fiber/matrix
- He production rates drop by an order of magnitude in ~20 cm of LiPb/SiC blanket

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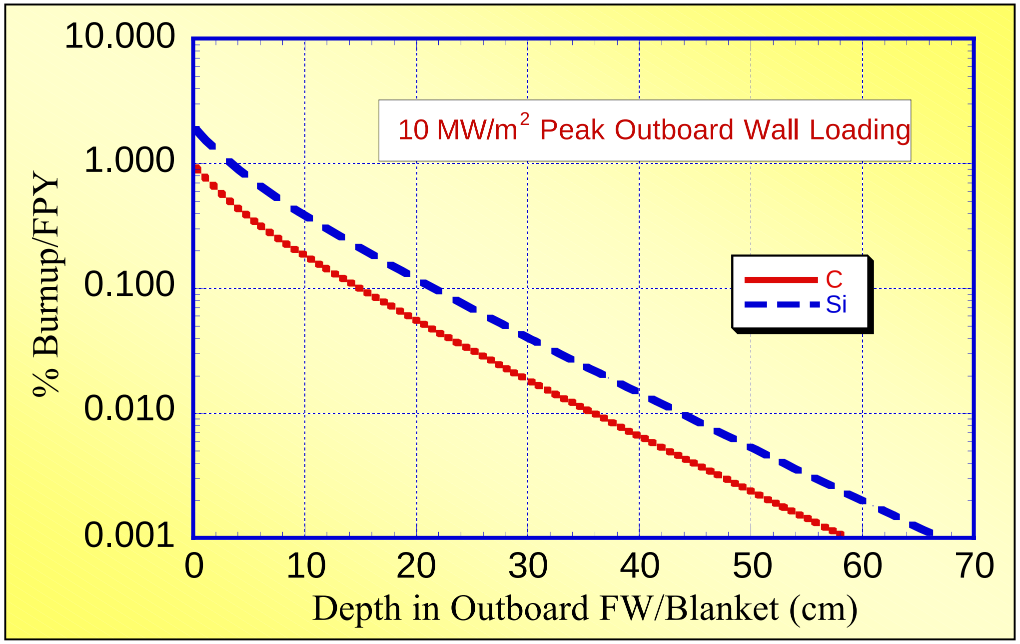
Radial Variation of Burnup for LiPb/SiC Blanket



- Burnup rate of Si sublattice is twice that for C sublattice of SiC fiber/matrix and graphite interface material
- Burnup rates drop by an order of magnitude in ~20 cm of LiPb/SiC blanket

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Comments on SiC Burnup

- Burnup of Si sublattice is about a factor of 2 more than that for C sublattice
- The burnup is equivalent to introducing impurities in the sublattices of the SiC
- Property degradation depends on the kind of impurities introduced
- The transmutation products include Al, Mg, Li, and Be
- The nonstoichiometric burnup of Si and C is expected to be worse than stoichiometric burnups and could be an important issue for SiC

Peak Damage Parameters in Si and C Sublattices at Midplane for the Flibe/Be/SiC FW/Blanket

	C Sublattice		Si Sublattice	
	OB	IB	OB	IB
dpa/FPY	89	86	109	94
He appm/FPY	27,140	19,755	7,316	4,444
H appm/FPY	5	4	13,226	9, 832
% Burnup/FPY	0.99%	0.73%	2.05%	1.53%

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Peak Damage Parameters in Si and C Sublattices at Midplane for the Li_2O/Be/He/SiC FW/Blanket

	C Sublattice		Si Sublattice	
	OB	IB	OB	IB
dpa/FPY	93	91	112	97
He appm/FPY	27,140	19,755	7,316	4,444
H appm/FPY	5	4	13,226	9, 832
% Burnup/FPY	0.99%	0.73%	2.05%	1.53%

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Impact of Blanket Concept on SiC/SiC Damage Parameters

- Peak dpa rates in Flibe/Be/SiC FW/Blanket are lower by 25-45% than in LiPb/SiC FW/blanket due to the factor of 1.75 larger fast neutron flux (E>0.1 MeV) at the FW when Pb is in the blanket
- Gas production and burnup rates in Flibe/Be/SiC FW/Blanket are higher by 3-10% than in LiPb/SiC FW/blanket. These rates produced from high energy reactions with threshold energies above 3 MeV are lower for the LiPb blanket due to competition from (n,2n) reactions in Pb. The (n,2n) cross section at 14 MeV for Pb is 2.14 b compared to only 0.52 b for Be

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Impact of Blanket Concept on SiC/SiC Damage Parameters (Continued)

- Peak dpa rates in Li_2O/Be/He/SiC FW/blanket are slightly higher than in Flibe/Be/SiC FW/blanket by 3-6% due to less absorption in front blanket zone (with 33% He gas) leading to ~5% larger fast neutron flux at FW
- Gas production and burnup rates are identical in Li_2O/Be/He/SiC and Flibe/Be/SiC blankets since both blankets use similar amount of Be that knocks down neutron energies below threshold energies for gas production reactions

Impact of Blanket Concept on Radial Variation of SiC/SiC Damage Parameters

	1/10 fold distance (cm)		
	LiPb/SiC FW/Blanket	Flibe/Be/SiC FW/Blanket	Li_2O/Be/He/SiC FW/Blanket
Atomic Displacement	40	30	45
Gas Production & Transmutation	20	25	35

- Radial drop of damage parameters is slowest in Li_2O blanket since about a third of blanket volume is occupied by He gas
- dpa has fastest drop in Flibe blanket while gas production and burnup rates drop faster in LiPb blanket.

Observations on Effect of Blanket Concept

- If dpa is lifetime driver for SiC/SiC structure, lifetime is significantly longer in Flibe/Be/SiC or Li_2O/Be/He/SiC blankets than in LiPb/SiC blanket operating at same neutron wall loading
- If gas production or burnup determine lifetime, lifetime will be slightly longer in a LiPb/SiC blanket
- A thicker Li_2O/Be/He/SiC blanket required to provide adequate shielding for the permanent components behind it (shield, vacuum vessel, and magnet)

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Summary and Conclusions

- Higher atomic displacement damage rates occur in C sublattice
- He production in C is about a factor of 4 larger than in Si
- Large H production occurs in Si with negligible amount in C
- Burnup of Si is about twice that of C. This is expected to be worse than stoichiometric burnups and could be an important issue for SiC
- FW dpa rate is smallest with faster radial drop in Flibe/Be/SiC FW/blanket
- FW gas production and transmutation rates are smallest with faster radial drop in LiPb/SiC FW/blanket
- Impact of damage parameters on SiC/SiC composite properties and lifetime needs to be assessed