Neutronics Issues and Radiation Damage Parameters in SiC/SiC Composite Structure

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With input from Steve Zinkle (ORNL) and
ARIES-AT input from Laila El-Guebaly (UW)

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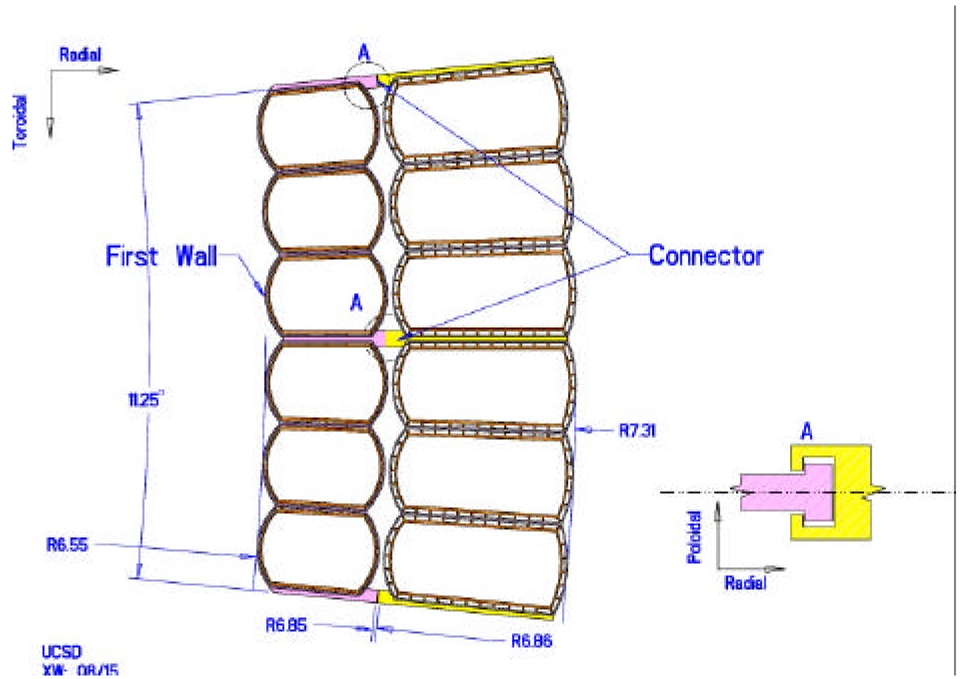
Objectives

- Determine required blanket radial build
- Assess potential for achieving tritium self-sufficiency
- Evaluate nuclear heating profiles in SiC/SiC and LiPb
- Determined damage parameters profiles for SiC/SiC composite structure in LiPb-SiC FW/blanket with peak neutron wall loading of 10 MW/m^2
- Rates of dpa, He production, H production, and % burnup calculated for both sublattices of SiC fiber/matrix and graphite interface material

Calculation Model

- Used ARIES-AT configuration
  - 5.2 m Major radius
  - FW location at midplane: 6.55 m OB, 3.85 m IB
- FW consists of:
  - 1 mm CVD SiC sacrificial layer
  - 4 mm SiC/SiC structural wall
  - 4 mm cooling layer (94% LiPb, 6% SiC/SiC)
  - 5 mm SiC/SiC structural wall
- Blanket composition is 86% LiPb and 14% SiC/SiC
- Lithium enriched to 90% ^6Li
- 1-D toroidal cylindrical model
- Peak OB neutron wall loading 10 MW/m^2
- Peak IB neutron wall loading 6.5 MW/m^2

ARIES-AT Outboard FW and Blanket Segment



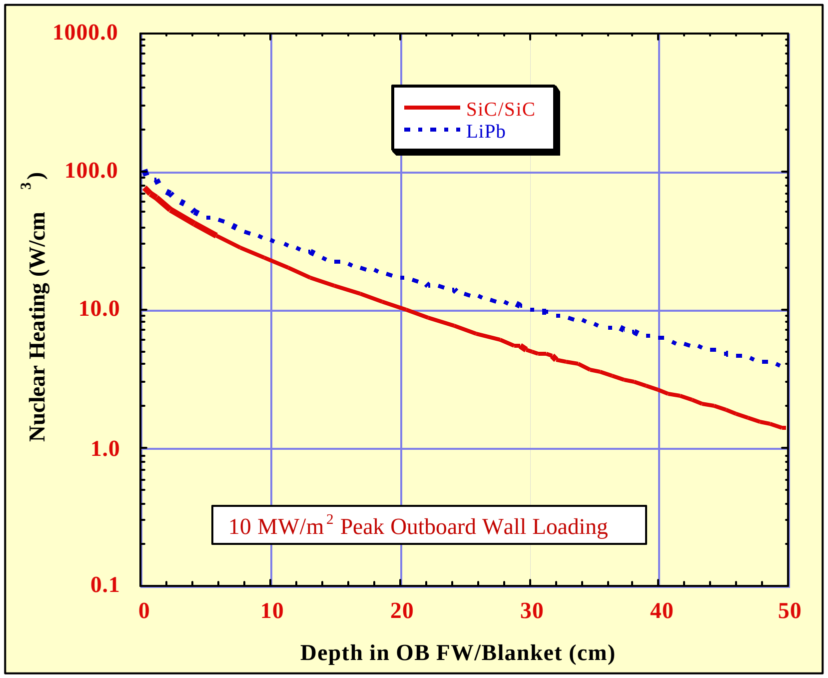
Blanket Segmentation Depends on Lifetime Criteria and Peak Neutron Wall Loading

- Blanket is segmented to reduce radwaste stream and lower replacement cost
- In ARIES-AT a replaceable blanket is used in both IB (35 cm) and OB (30 cm) regions. It is followed by 45-cm-thick permanent blanket in OB and shield in IB
- Front blanket channels should be sized to ensure that back blanket/shield zones are lifetime components
- For the same lifetime criteria, front blanket thickness should be ~7 cm thicker in APEX with twice neutron wall loading
- In APEX, front blanket channels are 37 cm OB and 42 cm IB

Tritium Self-Sufficiency is Achievable

- ✍Local 1-D TBR in ARIES-AT is 1.292 (0.353 IB, 0.939 OB)
- ✍With 7 cm thicker blanket in APEX local 1-D TBR in is 1.344 (0.387 IB, 0.957 OB)
- ✍3-D neutronics calculations for ARIES-AT (with stabilizing shells and no breeding in divertor region) showed that an overall tritium breeding ratio > 1.1 is achievable
- ✍Based on ARIES-AT results, tritium self-sufficiency is not a concern for the SiC/LiPb blanket concept

Radial Variation of Nuclear Heating



- Nuclear heating in LiPb is ~35% larger than in SiC/SiC at FW. The difference increases as one moves deeper in the blanket
- Nuclear heating in SiC/SiC drops by an order of magnitude in ~30 cm of LiPb/SiC blanket

SiC/SiC Damage Parameters

- SiC/SiC damage parameters updated based on comments from Steve Zinkle to provide necessary information for lifetime assessment
- Damage parameters (dpa, He production, H production, burnup) reported separately for the C and Si sublattices
- Recommended displacement energies for C and Si sublattices in SiC are 20 and 40 eV, respectively

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

	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 ($6.5\ MW/m^2$)

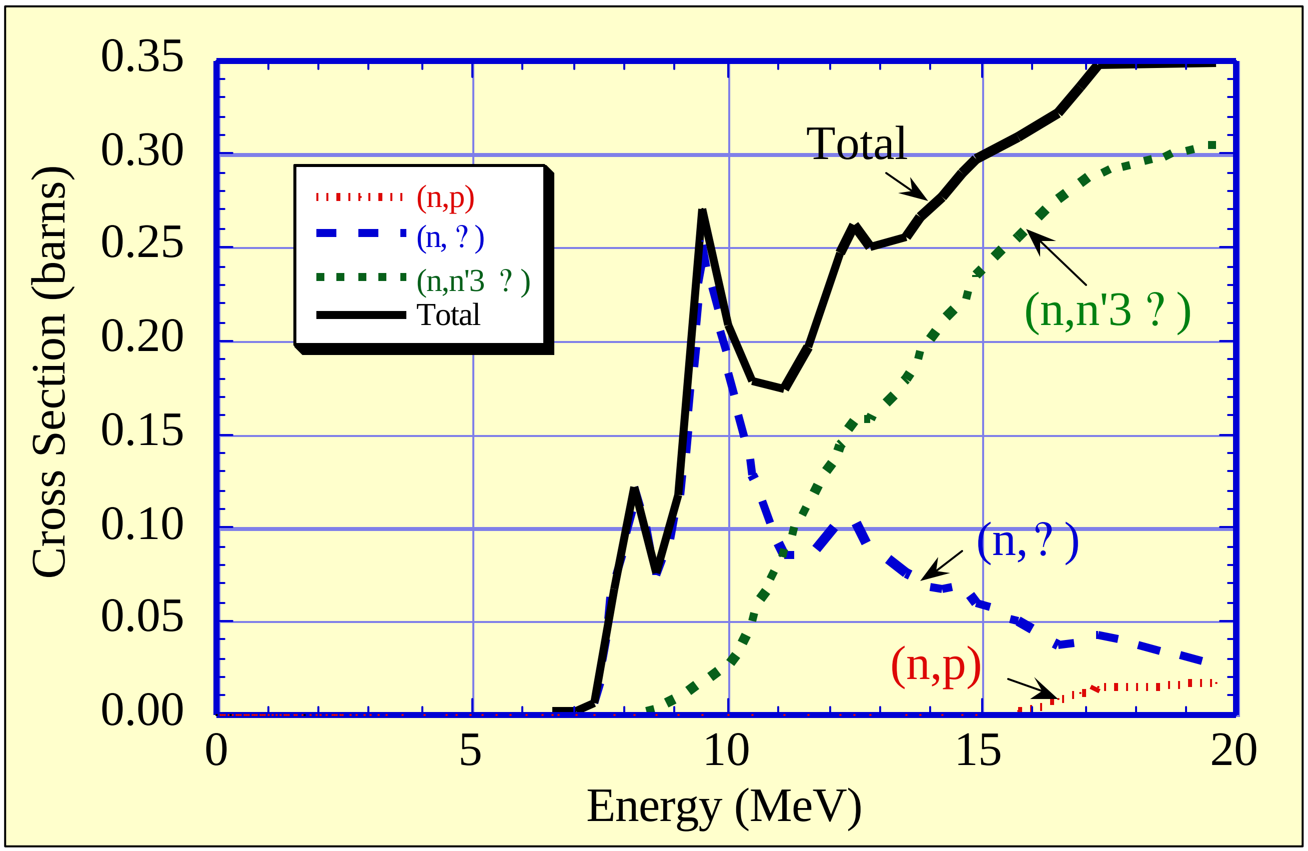
	C Sublattice	Si Sublattice
dpa/FPY	170	137
He appm/FPY	19,300	4,900
H appm/FPY	4	8,936
% Burnup/FPY	0.68%	1.38%

- 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´3?) reaction
- ✍ Significant H production occurs in Si with negligible amount in C
- ✍ Burnup of Si is about twice that of C

Carbon Burnup Cross Section



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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

1-D Neutronics Yield Conservative Peak FW Damage Parameters

	Exact 3-D	Approximate 1-D
Source shape	**Finite height**	**Infinite height**
Neutron source distribution	**Peaked at midplane**	**Vertically uniform**
Angular distribution of source neutrons incident on OB FW	**Mostly perpendicular**	**Less perpendicular**

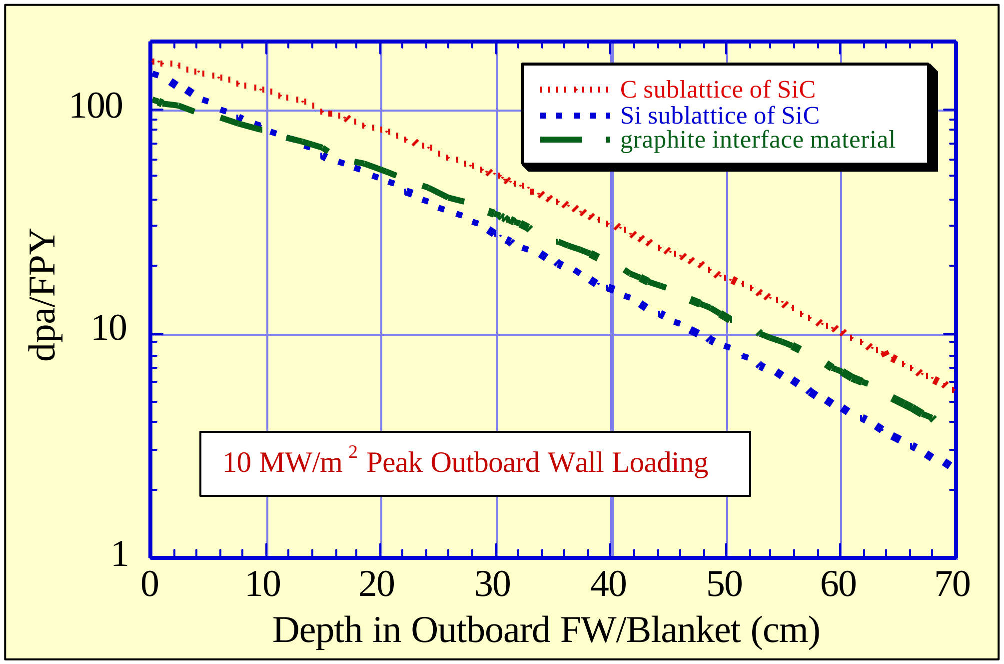
1-D ?? Higher front damage and larger radial damage gradient

Reflection from chamber components	**Exact**	**No divertor**
Vertical variation of neutron wall loading	**Nonuniform**	**Uniform**

1-D ?? More reflection from parts off midplane ?? Higher damage at midplane

- 3-D results were compared to 1-D results for ARIES-ST and ARIES-AT
- 1-D calculations overestimated peak damage parameters at FW by up to a factor of 1.6 depending on the aspect ratio

Radial Variation of Atomic Displacement



- 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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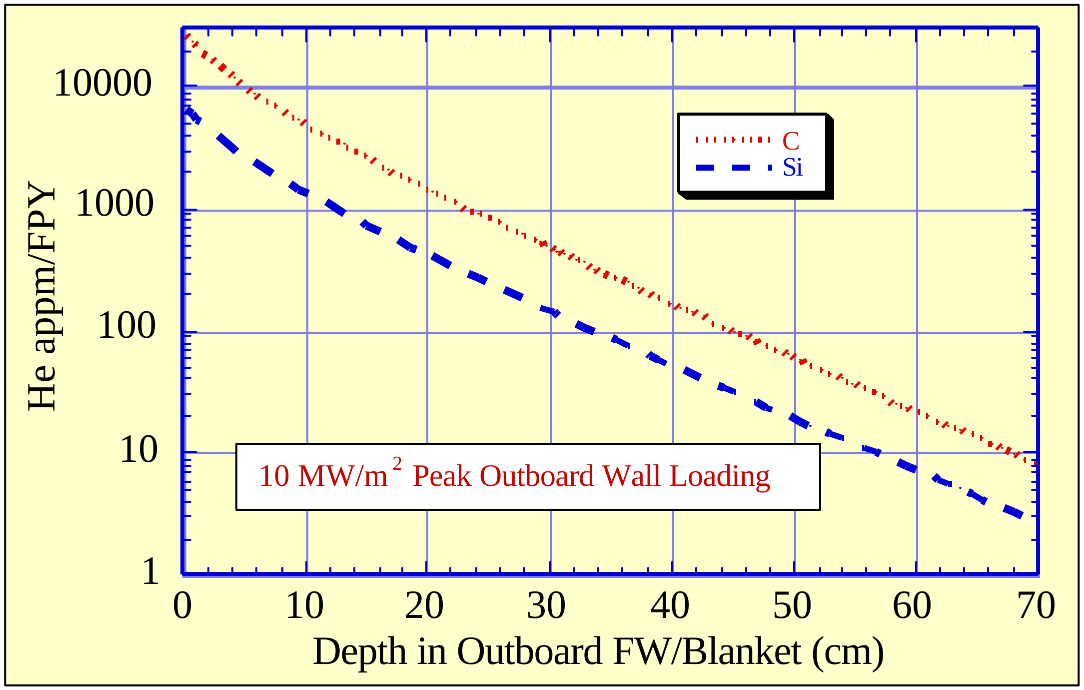
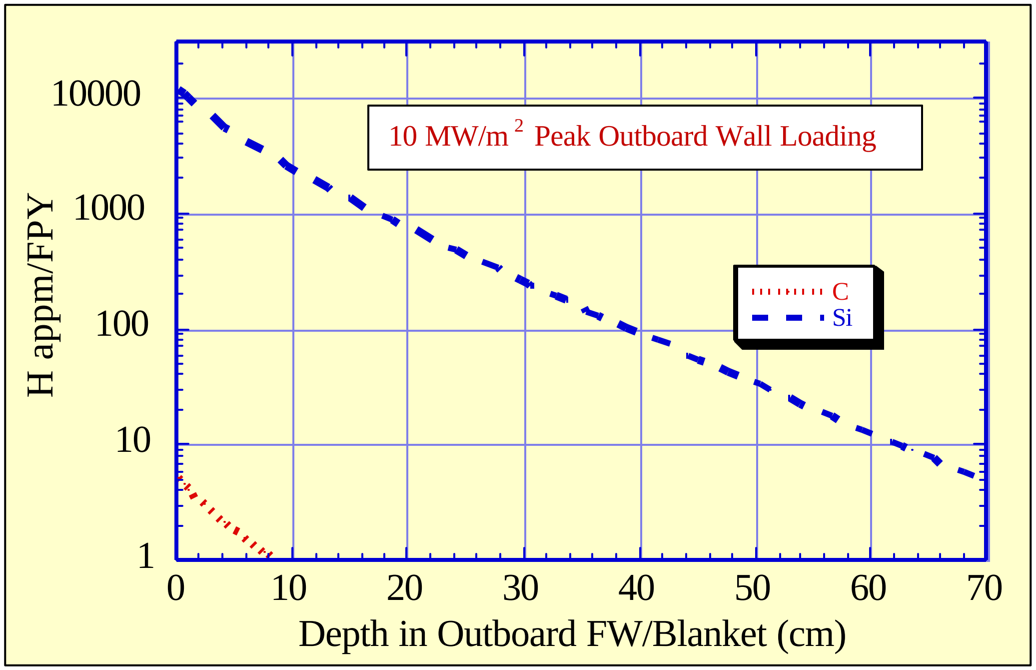
Radial Variation of Helium Production



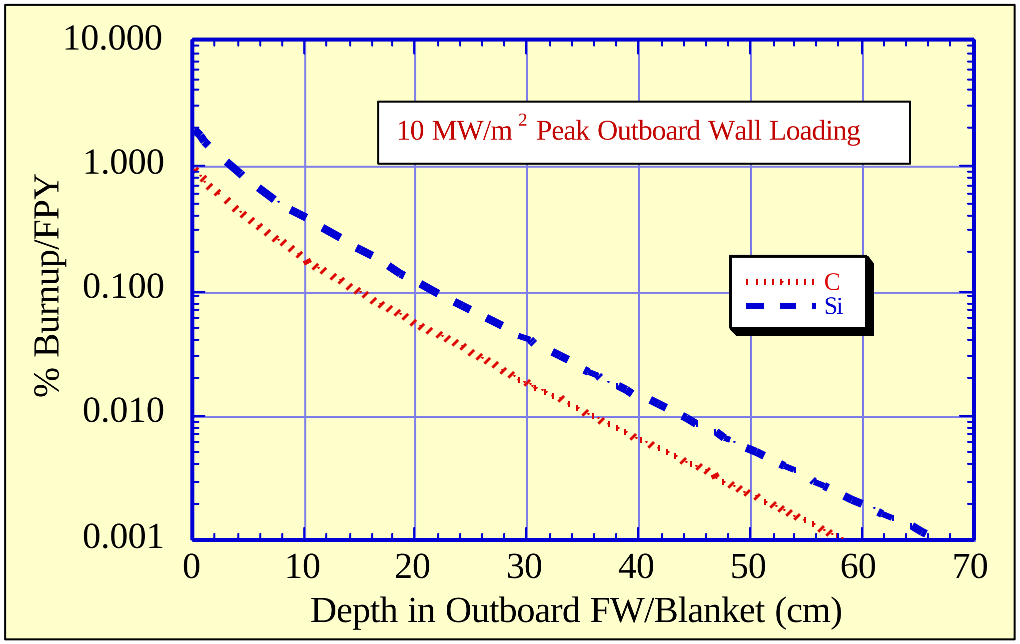
- He production rate in C sublattice of SiC fiber/matrix and graphite interface material is about a factor of 4 higher than in Si sublattice of SiC fiber/matrix
- Average He production rate in graphite interface is 60% higher than average He production rate in SiC fiber/matrix
- He production rates drop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

Radial Variation of Hydrogen Production



- H production rate in graphite interface material and C sublattice of SiC fiber/matrix is more than three orders of magnitude lower than in Si sublatticeof SiC fiber/matrix

Radial Variation of Burnup



- 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

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

Summary and Conclusions

- Front blanket thickness should be ~7 cm thicker than in ARIES-AT
- Tritium self-sufficiency is achievable with LiPb/SiC blanket
- 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
- Impact of damage parameters on SiC/SiC composite properties and lifetime needs to be assessed