The Low Tritium Inventory Argument for the Use of High-Z Materials

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PFC Material Choices

PFC materials generally fall into three different categories:

Liquid metals - Li, Sn, and Ga

Low Z materials - Be and C

High Z materials - Mo and W

Tritium Retention in Liquid Metals

While tritium retention values for Sn and Ga have not been measured for fusion applications, indications are that the retention levels will be negligible (low solubilities).

Li retains almost every hydrogen atom that it encounters. Inventory will be controlled by processes external to the torus.

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Tritium Retention in Be

Due to a hydrogen solubility in beryllium effectively equal to zero, tritium inventory in beryllium due to plasma exposure will be negligible.

The codeposition of beryllium, oxygen, and tritium can produce tritium inventories in the 100’s of grams.

Tritium can also be bred in the beryllium due to nuclear reactions induced by neutrons. For long term use in high power fusion devices, this process can also produce inventories of 100’s of grams.

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Tritium Retention in Carbon

Tritium inventory in graphite that has been exposed to moderate neutron damage can reach levels of 100's of grams.

Tritium inventory due to codeposition is almost certain to reach kilogram levels if not removed.

Carbon is the poster child of tritium problems.

Tritium Retention in Tungsten

Tungsten has a relatively low solubility for hydrogen, a relatively high diffusivity, moderate to low trapping, and an extremely high recombination rate coefficient.

The recombination rate coefficient determines how rapidly hydrogen isotope atoms can recombine back to molecules after reaching the surface of the metal ($J=K_rC^2$). Rapid recombination almost guarantees low retention (inventory).

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Tungsten Inventory Calculations

Hydrogen diffusivity was determined by Frauenfelder:
$D = 4.1 \times 10^{-7} \exp(-0.39 \text{ eV}/kT) \text{ m}^2/\text{s}$

Hydrogen recombination rate coefficient ~ infinity
(same boundary condition as C=0)

If annealed after machining, tungsten trapping levels for hydrogen should be ~ 100 appm

Trap energy = 1.4 eV

Thickness = 2 mm

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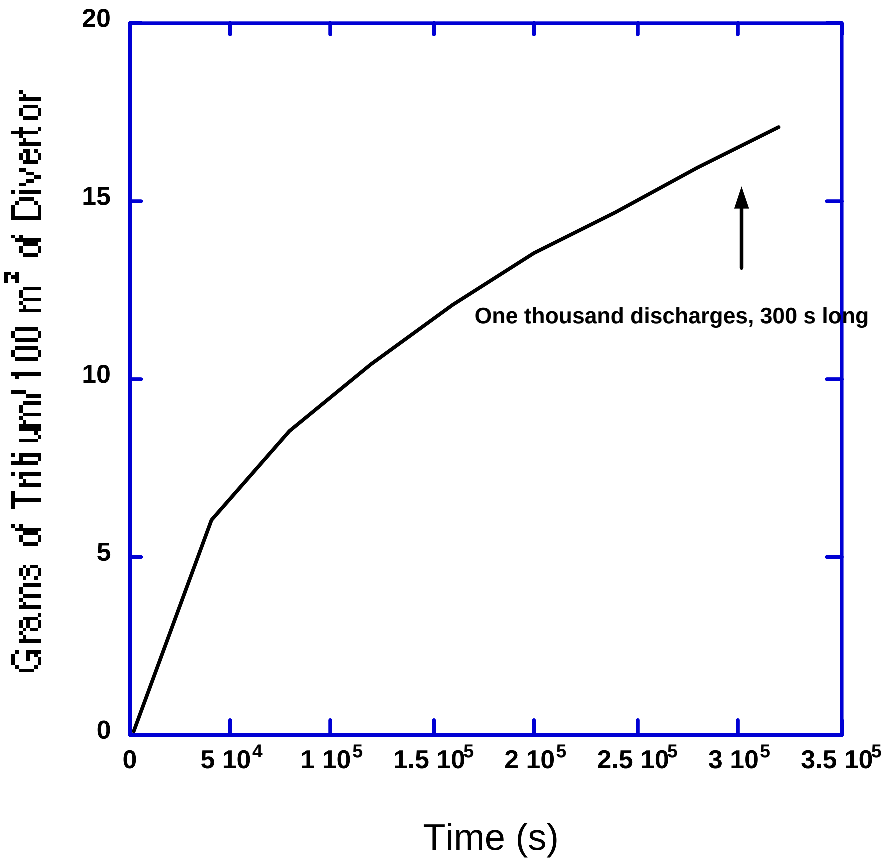
Tungsten Inventory Calculations



Calculations are based on a tungsten divertor at 700 K with 100 eV triton flux of 10^{22} T/m^2.

Trap density set at conservatively high value of 1000 appm.

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Tritium Retention in Molybdenum

Molybdenum also has a relatively low solubility for hydrogen, a relatively high diffusivity, moderate to low trapping, and an extremely high recombination rate coefficient.

I am in the process of writing a mini-review of hydrogen in molybdenum. My conclusion so far is that the diffusivity of hydrogen in tungsten and molybdenum differ by less than 15%. The trap energy is the same as tungsten (1.4 eV). The trap density appears to be almost the same. In fact, they are so similar, that there is no reason to repeat the calculation. They are the same!

Codeposition of tritium with tungsten and molybdenum

Mayer [M.Mayer et al., J. Nucl. Mater. 230 (1996) 67] showed rather convincingly that tungsten and hydrogen isotopes do not codeposit.

Miyamoto [Miyamoto et al., J. Nucl. Mater. 307-311 (2002) 710] showed that hydrogen isotopes will codeposit with molybdenum and oxygen, but only on an iron substrate at high temperatures. They actually formed Fe_2MoO_4. I am not convinced that just molybdenum and oxygen will codeposit with hydrogen any more than tungsten will. Experiments are needed.

Summary

Tritium retention in tungsten and molybdenum is almost identical.

Tritium retention in either material at 700 K is calculated to be less than 15 grams/100m^2, even with moderately high trapping. This inventory is less than that expected for either beryllium or carbon.

Tritium inventory will not be a problem if a high-Z tokamak is developed.