

**HYDROGEN UPTAKE IN VANADIUM FIRST WALL STRUCTURES - E. P. Simonen  
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**OBJECTIVE**

To evaluate hydrogen isotope concentrations in layered vanadium structures.

**SUMMARY**

Evaluation of hydrogen sources and transport are needed to assess the mechanical integrity of V structures. Two sources include implantation and transmutation. The proposed coatings for the DEMO and ITER first wall strongly influence retention of hydrogen isotopes. Upper limit calculations of hydrogen inventory were based on recycling to the plasma and an impermeable coolant-side coating. Hydrogen isotope concentrations in V approaching 1,000 appm may be achieved.

**TECHNICAL PROGRESS**

Background

Vanadium is being considered as a first wall structural material due to its many advantages including low activation and potential for resistance to high temperature and high dose irradiation. A critical issue for the use of V is its compatibility with hydrogen. Hydrogen is known to affect the mechanical behavior of refractory metals such as V. Two key sources of hydrogen are from plasma implantation fluxes and from transmutations. Because of incompatibility of V with the plasma and MHD compatibility with the Li coolant, coatings have been proposed for use on both the plasma surface and the coolant surface. Be is proposed on the plasma side to minimize problems associated with sputtered surface atoms. An insulating coating is proposed on the coolant side to minimize MHD pumping losses in the liquid Li coolant. These coatings affect the inventory of hydrogen during first wall exposure.

In this study, the permeation model DIFFUSE<sup>1</sup> has been used to evaluate the potential build up of hydrogen in V as a function of temperature and irradiation fluence.<sup>2</sup> DEMO and ITER relevant conditions are examined and effects of boundary condition assumptions are described.

Hydrogen Uptake Considerations

A schematic of the multilayer first wall structure assumed in the present analysis is shown in Figure 1. A 1 mm Be layer is assumed on the plasma side and an impermeable barrier is assumed on the coolant side. The Be and V diffusivities and solubilities are assumed as given in the DIFFUSE code.<sup>1,3</sup> The down-stream insulating barrier is accounted for by assuming a zero flux boundary condition across the barrier. A temperature gradient of 200°C was used in the calculations such that the plasma interface was 200°C higher than the coolant interface.

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## SCHEMATIC OF MULTILAYER STRUCTURE

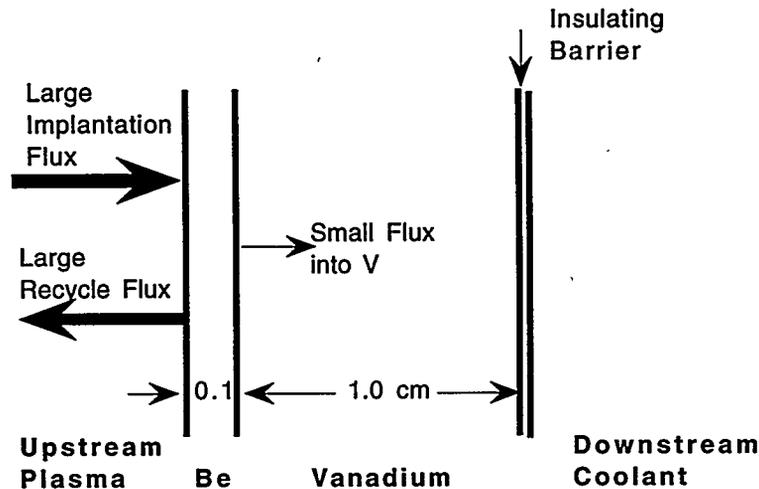


Figure 1. A schematic of hydrogen isotope uptake by implantation. Most of the implanted hydrogen is recycled to the plasma because of the shallow depth of implantation. Transmutation produced hydrogen isotopes (not shown) are generated throughout the structure based on local elemental compositions, neutron spectra, and cross-section for nuclear reactions.

The implanted tritium concentration profile was calculated from the TRIM code<sup>4</sup> and an energy of 100 eV for implantation into Be. An implantation flux of  $10^{16}$  ions/cm<sup>2</sup> was assumed to be representative of the ITER first wall. The concentration of tritium at the surface was assumed to be zero, that is the recycle flux was diffusion controlled in contrast to surface recombination controlled.

The down stream insulating barrier was assumed to have a high permeation resistance. Insulators are known to possess high permeation resistance,<sup>5</sup> however, there is evidence that radiation can significantly enhance migration of hydrogen in insulators.<sup>6</sup> The possibility of a significant loss in permeation resistance during irradiation was evaluated by considering a variable permeation reduction factor compared to V. Because Li is considered as a coolant and because Li has a high affinity for hydrogen, the coolant boundary condition did not require consideration of hydrogen uptake from the coolant to the V structure.

Transmutation rates were calculated from the STARFIRE first wall spectrum<sup>7,8</sup> and for an alloy composition of V- 4 Ti - 4 Cr and for pure Be. The total production of hydrogen isotopes was calculated to be 18.7 appm/dpa for the V alloy and 3.7 appm/dpa for Be.

### Calculations of Hydrogen Uptake

The calculated concentration profiles of hydrogen uptake in the multilayered structure are shown in Figures 2 and 3 for the mechanisms of implantation and transmutation, respectively.

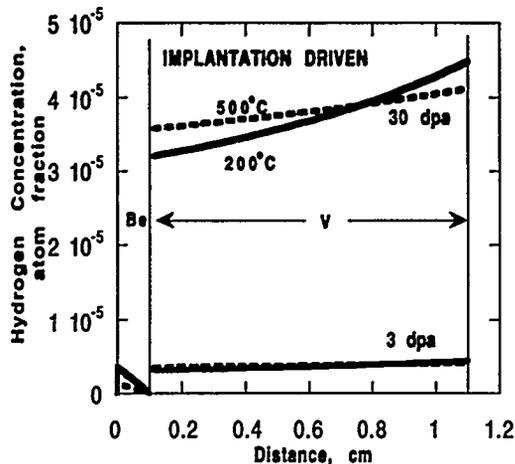


Figure 2. Implantation driven uptake of hydrogen isotopes. Profiles are shown at coolant temperatures of 200°C (solid) and at 500°C (dashed). The upper curves are at 30 dpa, whereas the lower curves are at 3 dpa. The profiles in Be are at steady state and do not change with dose.

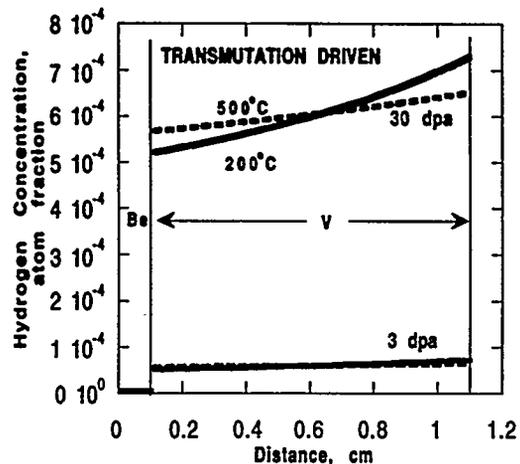


Figure 3. Transmutation driven uptake of hydrogen isotopes. Profiles are shown at coolant temperatures of 200°C (solid) and at 500°C (dashed). The upper curves are at 30 dpa, whereas the lower curves are at 3 dpa. The profiles in Be are at steady state and do not change with dose.

Coolant temperatures of 200°C and 500°C were assumed at 3 and 30 dpa based on a dpa rate of  $3 \times 10^{-7}$  dpa/s. The hydrogen isotope concentration achieves levels of about 40 appm from implantation and about 600 appm from transmutation. The concentration profile in V is caused by the assumed temperature gradient. Vanadium is an exothermic absorber of hydrogen and therefore exhibits a lesser solubility in the hotter plasma-side region. Increasing the coolant temperature from 200°C to 500°C does not change the average hydrogen isotope concentration in the V layer but does change the concentration profile slightly. The dose dependence of the maximum hydrogen concentration is shown in Figure 4 for both uptake mechanisms. A linear dose dependence is indicated.

#### Effects of Uncertainty in Assumed Parameters

Uncertainty in this analysis lies mainly in the assumed material characteristics of Be, V and the insulating layer. In addition, the material parameters are based on measured characteristics of unirradiated materials, whereas hydrogen uptake will occur in irradiated materials.

The depth of implanted hydrogen isotopes into Be controls the fraction of ions that are recycled to the plasma or permeated into the underlying V. The linear dose dependence seen in Figure 4 indicates that the incubation time to achieve a steady state concentration in the Be is short compared to the lifetime of a first wall. The low solubility in Be compared to V results in a near zero hydrogen isotope concentration in the Be at the Be/V interface. At steady state, the permeation flux is equal to the implantation flux multiplied by the ratio of the implantation depth to the Be layer thickness. Therefore, the implantation flux is inversely proportional to the Be layer thickness. Reducing the Be layer thickness by a factor of two increases the permeation flux to the V by a factor of two.

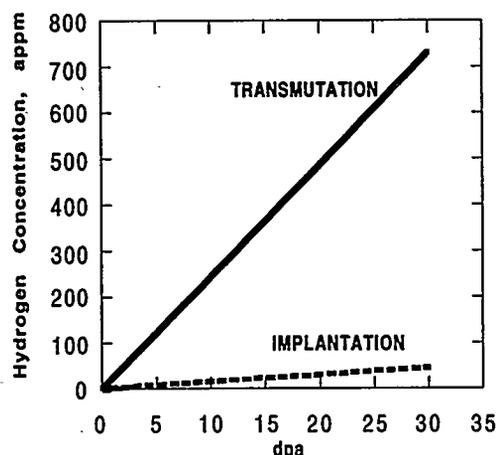


Figure 4. The dose dependence of the maximum hydrogen isotope concentration for both implantation driven and transmutation driven mechanisms.

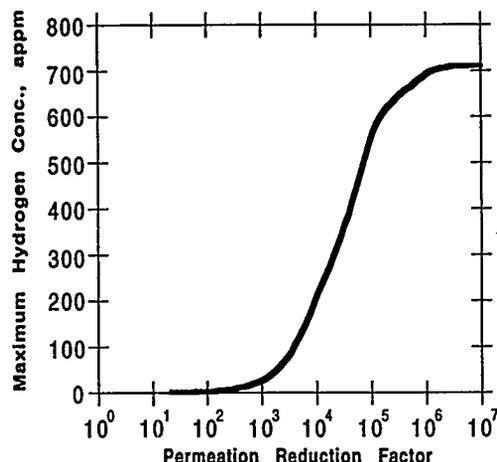


Figure 5. The dependence of the maximum hydrogen isotope concentration on the assumed permeation reduction factor in the last 1 mm of V at the coolant interface.

The effect of surface recombination limits on the recycle flux was examined. Control by bulk diffusion implies that formation of molecular hydrogen on the surface from recombination of atomic hydrogen is fast and does not influence the releases rate of hydrogen from the Be coating. If recombination were found to be a limiting factor, the fraction of hydrogen taken up by the V would be greater than indicated in this analysis. As expected for endothermic hydrogen absorbers, like Be, the recombination influence was not found to be significant for the recombination parameters included in the DIFFUSE code.

Permeation and solubility measurements of hydrogen in V have revealed conflicting results because of the sensitivity of hydrogen absorption to surface condition of the V sample.<sup>9</sup> Careful control of the V surface condition has revealed that hydrogen absorption in V is exothermic and that diffusion is rapid even at room temperature. The present calculations are not influenced by the surface condition because each surface is coated with either Be or an insulating layer. Furthermore, the uptake mechanism does not involve absorption at a surface. For implantation the ions are implanted through the surface and for transmutations the hydrogen isotopes are created internally. Therefore, the present analysis is not subject to the known uncertainties associated with permeation measurements in V.

An assumed high permeation resistance for the insulating barrier may be influenced by radiation-induced hydrogen diffusion and permeation. Enhanced diffusion of hydrogen in insulators is associated with ionization states that promote migration. Effects of radiation on hydrogen transport in insulators at DEMO and ITER relevant temperatures have not been established. Therefore, the effect of variation in the assumed permeation resistance of the coolant barrier on the calculated hydrogen isotope concentration was calculated and is shown in Figure 5. For these transmutation-induced calculations, the last (coolant-side) 1 mm of V was assumed to have a reduced permeation rate defined by a permeation reduction factor. It is necessary to reduce the

permeation by a factor of 1000 to obtain significant concentrations of hydrogen isotopes in the V layer. A permeation reduction factor of  $10^6$  is equivalent to a perfect permeation resistance for the coolant barrier. Therefore to ensure that only insignificant levels of hydrogen accumulate in V, it is necessary to establish that the insulating barrier have permeation rate fast enough to allow flow of hydrogen isotopes to the coolant. The barrier permeation rate must not be less than three orders of magnitude of the V permeation rate.

#### FUTURE WORK

No future work is planned.

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