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Hydrogen permeation through vanadium alloy V–4Cr–4Ti 'in situ' of reactor irradiation

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Abstract

The influence of reactor irradiation hydrogen interaction with a vanadium alloy was studied by means of a hydrogen permeation technique. It is shown that reactor irradiation results in a decrease of the apparent diffusion coefficients and permeation constants for vanadium alloy V–4Cr–4Ti. © 2000 Elsevier Science B.V. All rights reserved.

1. Introduction

Vanadium based alloys are attractive structural materials for lithium blanket of future thermonuclear reactors. For this purpose it is necessary to have data on the parameters of hydrogen isotope retention and permeation in vanadium alloys at the conditions of reactor irradiation.

2. Experimental and results

The influence of reactor irradiation on hydrogen interaction with a vanadium alloy was studied by hydrogen permeation experiments. The sample was a disk of V–4Cr–4Ti alloy with a diameter 26 mm (effective diameter of sealing is 16 mm) and a thickness 1 mm.

In-pile experiments were carried out in the IVG.1M reactor at the Kazakhstan Nuclear Center. The set-up and its control scheme are shown in Figs. 1 and 2. Experiments were carried out in the reactor core. The irradiation duration (time of the experiment) was 6 h. The conditions of the experiments are shown in Table 1. The neutron spectrum in the reactor core is shown in Table 2.

Before the reactor experiments a set of pre-irradiation control experiments at zero reactor power level was carried out. The results of the control experiments revealed a good reproducibility of the measured parameters of hydrogen permeation.

The power history of the reactor run was as follows (see Fig. 3):

1. reactor power level increase up to 6 MW and establishment of experimental permeation curve at 823 K;
2. reactor power level decrease down to zero level (reactor shutdown) and repeat the permeation experiment at the same temperature;
3. second reactor power level increase up to 6 MW and completion of a series of measurements of hydrogen permeation parameters at temperatures in the range 823–723 K;
4. obtaining a hydrogen permeation curve at 6 MW of reactor power;
5. reduction of power to zero (reactor shutdown) at a steady state permeation flux.

After in-pile experimental investigations of the post-irradiation permeation on the same vanadium alloy sample was carried out. The calculated values of hydrogen permeation V–4Cr–4Ti – apparent diffusion coefficients and permeation constants are given in Figs. 4 and 5.

It can be seen the irradiation results in the reduction of apparent diffusion coefficients and permeation

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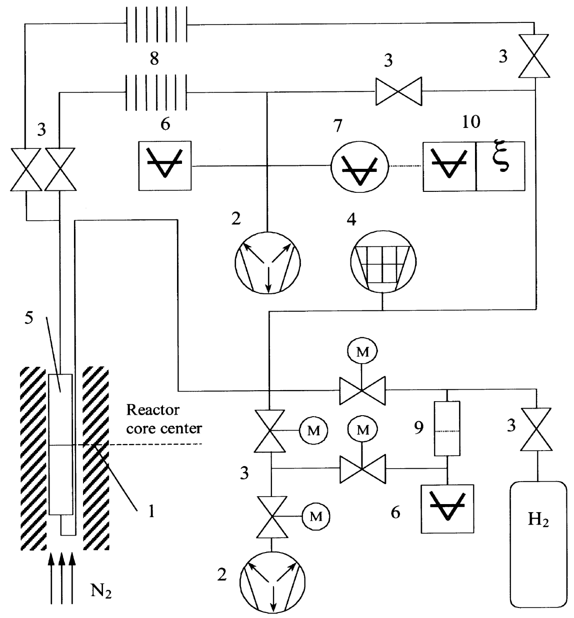

Fig. 1. Experimental facility 'Liana': 1 – reactor core center, 2 – ion sputtering pump, 3 – vacuum valves, 4 – rotation pump, 5 – experimental ampoule, 6 – vacuum gauge, 7 – flexible bellows, 8 – hydrogen palladium silver bellows, 9 – mass-spectrometer gauge, 10 – interface + IBM PC AT.

Table 2
Neutron spectra of IVG.1M reactor at the power level 10 MW

No.	Energy range (MeV)	Neutron flux (n/cm^{2}s)
1	$0.00–0.25\times10^{-6}$	1.56×10^{14}
2	$0.25–0.84\times10^{-6}$	2.50×10^{12}
3	$0.84–1.87\times10^{-6}$	6.3×10^{12}
4	$1.87–5.10\times10^{-6}$	6.3×10^{12}
5	$5.10–1.39\times10^{-5}$	6.3×10^{12}
6	$1.39–3.76\times10^{-5}$	6.21×10^{12}
7	$3.73–10.3\times10^{-5}$	6.16×10^{12}
8	$10.3–20.0\times10^{-5}$	6.1×10^{12}
9	$0.20–1.11\times10^{-3}$	9.01×10^{12}
10	$1.11–5.91\times10^{-3}$	9.07×10^{12}
11	$5.91–17.5\times10^{-3}$	5.70×10^{12}
12	$1.75–3.80\times10^{-2}$	7.44×10^{12}
13	$3.80–7.60\times10^{-2}$	5.02×10^{12}
14	$0.76–1.53\times10^{-1}$	5.72×10^{12}
15	$1.53–3.00\times10^{-1}$	6.5×10^{12}
16	$3.00–6.00\times10^{-1}$	7.23×10^{12}
17	0.60–1.10	5.78×10^{12}
18	1.10–1.91	6.55×10^{12}
19	1.91–3.14	1.18×10^{12}
20	3.14–4.95	1.1×10^{12}
21	4.95–7.69	2.5×10^{11}

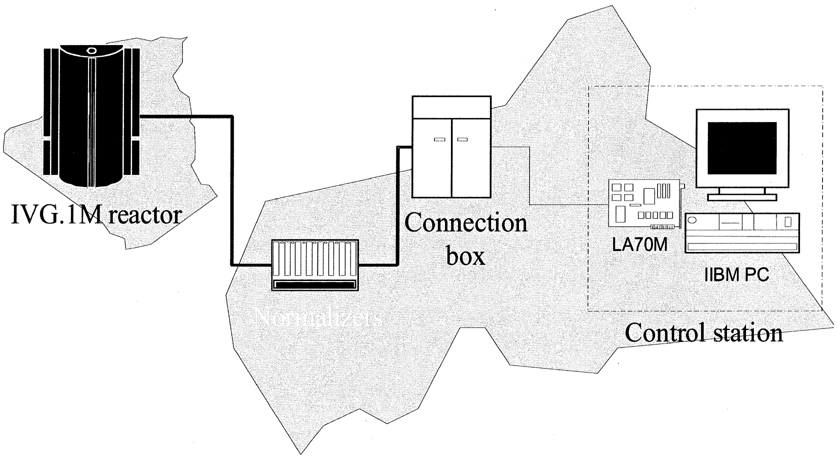

Fig. 2. Control scheme of 'Liana' installation.

Table 1
The conditions of hydrogen permeation experiments

Experiment conditions	Pre-irradiation experiments	In-pile experiments	Post-irradiation experiments
Temperature range (K)	723–873	723–873	723–873
Input hydrogen pressure (Pa)	10–50	10–50	10–50
Background pressure in the vacuum chamber (Pa)	$10^{-4}–10^{-6}$	$10^{-4}–10^{-6}$	$10^{-4}–10^{-6}$
Reactor power (MW)	0	6	0

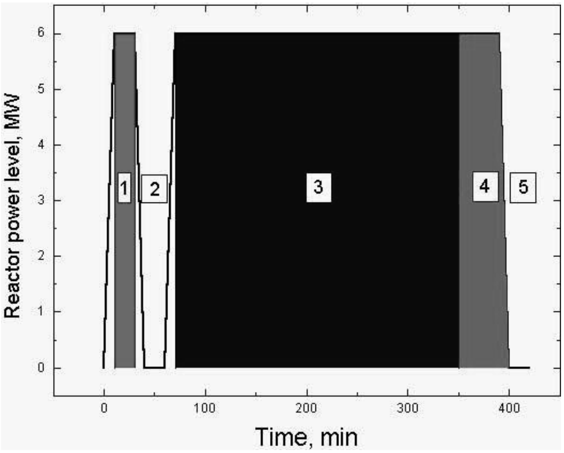

Fig. 3. Cyclogram of in-pile experiments (see the text).

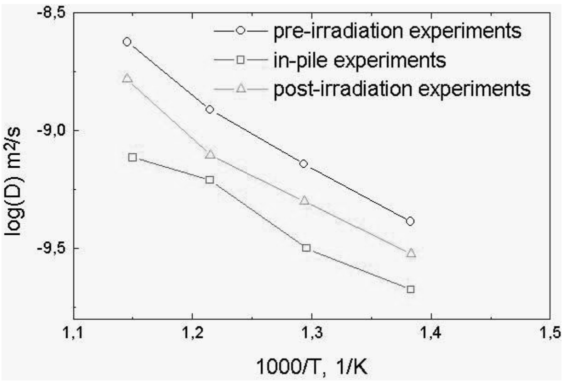

Fig. 4. Temperature dependence of apparent diffusion coefficients of V–4Cr–4Ti.

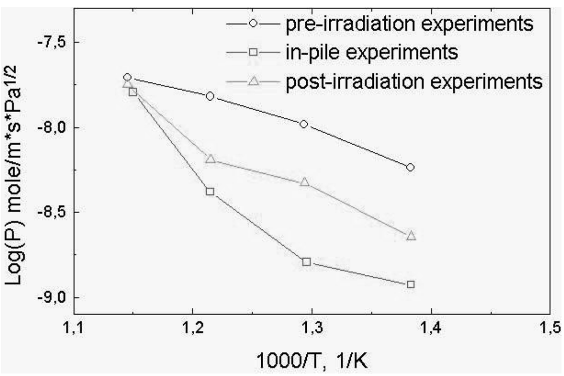

Fig. 5. Temperature dependence of permeation constants of V–4Cr–4Ti.

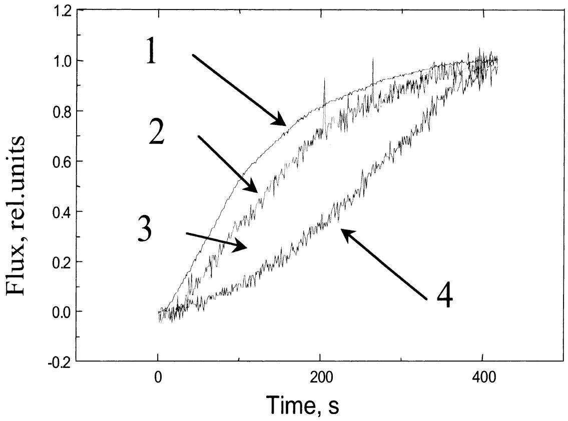

Fig. 6. Comparison of the initial kinetics of hydrogen permeation curves at the different stages of the experiment ($T=$ 823 K); 1 – pre-irradiation experiment, 2 – post-irradiation experiment, 3 – the curve during reactor shutdown, 4 – in-pile experiment.

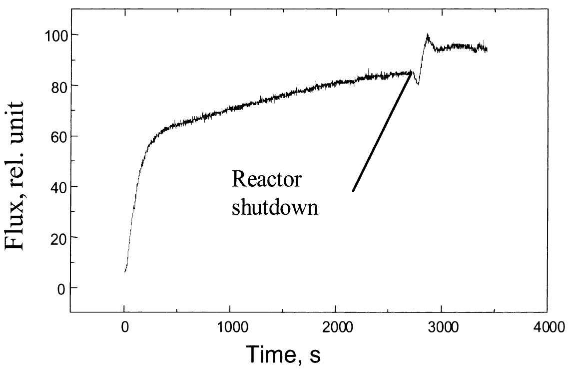

Fig. 7. Illustrates the change in permeation increase and the kinetics when the reactor power is reduced to zero during steady state permeation.

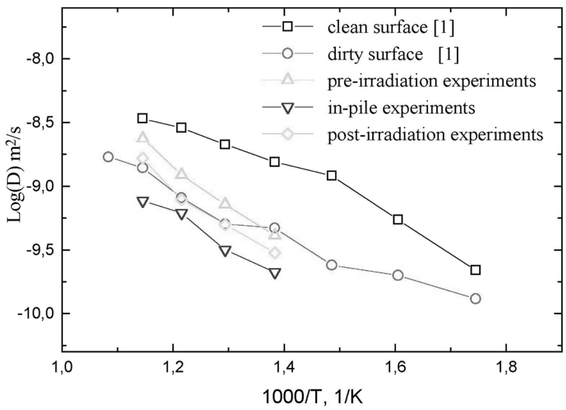

Fig. 8. Temperature dependence of apparent diffusion coefficients of V–4Cr–4Ti depending on the sample surface state.

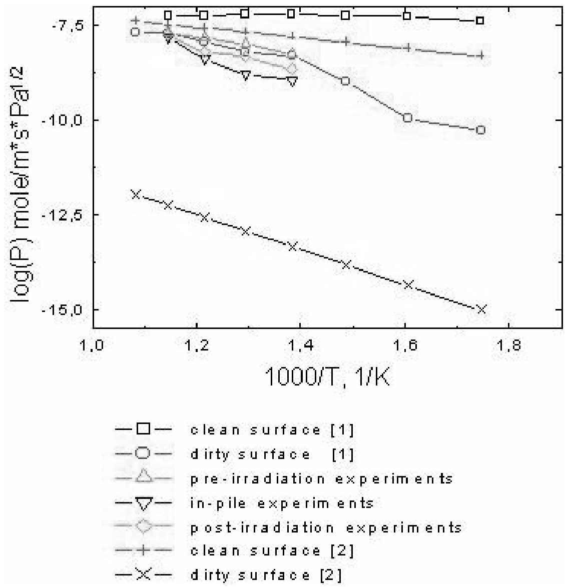

Fig. 9. Temperature dependencies of permeation constants of V–4Cr–4Ti depending on the sample surface state.

constants for the whole range of the experiment temperatures. Post-irradiation experiments revealed that the values of hydrogen permeation and diffusion of the vanadium alloy after irradiation were increased to a certain extent in comparison with these values during irradiation, but did not achieve the values obtained in pre-irradiation experiments. The reduction of apparent diffusion coefficients of hydrogen through vanadium alloy during irradiation is clearly seen from Fig. 6, where the initial kinetics of normalized permeation curves at the temperature 823 K at the different stages of experiments are compared. It is seen that the pre-irradiation curve achieved steady-state at largest rate, and the in-pile permeation curve – at the smallest rate (see Fig. 7).

The effect of reactor irradiation – decreasing the apparent diffusion characteristics and permeation constants of hydrogen may be caused by change in surface condition state on hydrogen permeation [1,2] (see Figs. 8 and 9). The values of hydrogen permeation parameters can change several orders of magnitude depending on the surface state.

It is quite possible that during a reactor irradiation the changes in the rates of hydrogen interaction with the sample surface could take place that results in the observed effect of permeation parameters decreasing.

3. Conclusions

Experiments on reactor irradiation influence on hydrogen interaction with V–4Cr–4Ti alloy revealed that expose to reactor irradiation resulted in a decrease of the effective diffusion coefficients and permeation constants for this alloy. The detailed description of the reasons of reactor irradiation influence on V4Cr4Ti is still not completed and will be discussed in the next paper where the results of experimental set will be presented to confirm that the observed effect is connected with the changes of the sample surface state during its in-pile irradiation.

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