PPPL--1948

DE83 006508

THEORY OF BULK GETTERING

R. J. Knize and J. L. Cecchi

Princeton University

Plasma Physics Laboratory

Princeton, NJ 08544

ABSTRACT

A general theory describing bulk getter operation is presented. The theory includes the effects of getter surface reactions and getter bulk diffusion. Exact numerical solutions are presented for the particular cases of pumping and desorption. In addition, approximate analytical solutions are derived and used to illustrate the characteristics of the particular operational regimes. The theory is applied to the analysis of the pumping and desorption behavior of the Zr-Al alloy bulk getter. The predictions of the theory are in excellent agreement with the experimentally measured Zr-Al performance.

DISCLAIMER

This document contains information which has been determined to be exempt from public release under the provisions of the Freedom of Information Act, 5 U.S.C. 552. It is the policy of the Princeton Plasma Physics Laboratory to make available to the public information which is not exempt from public release. This document is being made available to the public for informational purposes only. It is not to be distributed outside the laboratory without the express written permission of the Laboratory Director. The Princeton Plasma Physics Laboratory is a research institution of the United States Government. It is not a part of the United States Government and is not subject to the provisions of the United States Government. It is not a part of the United States Government and is not subject to the provisions of the United States Government. It is not a part of the United States Government and is not subject to the provisions of the United States Government.

REPRODUCTION OF THIS DOCUMENT IS UNLIMITED

Rey

I. INTRODUCTION

Many residual gases such as H_2 , N_2 , and O_2 will react with various solids to form stable, bound compounds. Such gettering processes were first utilized in the late nineteenth century to improve the vacuum within a carbon filament lamp and thereby extend its useful lifetime.¹ Getters have been used subsequently in a variety of applications such as vacuum tubes,² ultra high vacuum systems,³ and controlled fusion devices.⁴ In addition, the basic processes which are relevant to gettering are also important in solid storage of hydrogen,⁵ certain inert gas purification systems,⁶ and plasma wall interactions in fusion devices.⁷

The two most common forms for getters are vaporized thin metallic films and bulk metals.⁸ The former pump primarily by adsorption on the active surface of a fresh film, although some bulk diffusion does occur. Bulk getters rely on diffusion into the material to provide considerable capacity. In addition, especially for hydrogen, bulk getters often can be thermally desorbed. Although Ti film getters can be desorbed also, their subsequent use is generally limited by surface contaminants.⁹

In this paper we present a theory of bulk getter operation. The theory assumes that pumping proceeds by dissociative absorption followed by bulk diffusion. Desorption occurs by diffusion from the bulk to the surface and subsequent associative desorption from the surface. While primarily intended for hydrogen, the theory is, in principal, applicable to any diatomic molecule, providing its surface-kinetic parameters and bulk diffusivity are known for the particular getter material. Alternatively, if the pumping or desorption behavior is known for a getter, the material parameters can be determined. The theory is also applicable to solid hydrogen storage systems and getter-type inert gas purifiers, both of which typically involve bulk diffusive processes.

II. GETTER MODEL

The operation of a material as a getter will be governed by the surface kinetics and bulk diffusion of the gettered species. These processes can be described by three parameters dependent upon the getter material, temperature, and gas species: the sticking probability, the solubility, and the bulk diffusivity. In addition, the getter operation will depend upon external parameters including the gas influx rate and the backup system pumping speed. The model presented in this section expresses the spatial and temporal behavior of the gettered species bulk concentration and the chamber pressure in terms of the aforementioned parameters.

We consider a planar getter of thickness L mounted inside an externally pumped chamber with gas feed as shown schematically in Fig. 1. The getter is assumed to be mounted on a substrate ($x=0$ surface) so that pumping and desorption occur at the $x=L$ surface only. Our results can be easily extended to a getter of thickness $2L$ ($-L \leq x \leq L$) with two active surfaces, and can be generalized to more complicated configurations in a straightforward manner.

The concentration of the gettered species in the bulk of the material at position x and time t is $c(x,t)$ and obeys the diffusion equation

$$D \frac{\partial^2 c(x,t)}{\partial x^2} = \frac{\partial c(x,t)}{\partial t} , \quad (1)$$

with D the diffusivity. The initial condition for Eq. (1) is

$$c(x,0) = c_0(x) , \quad (2)$$

where $c_0(x)$ depends upon the past history of the getter. The boundary conditions will be expressed in terms of the particle flux $\Gamma(x,t)$, where,

$$\Gamma(x,t) = -D \frac{\partial c(x',t)}{\partial x'} \Big|_{x'=x} \quad (3)$$

The flux at the back face ($x=0$) is

$$\Gamma(0,t) = 0 \quad (4)$$

and the flux at the front face ($x=L$) is

$$\Gamma(L,t) = \Gamma_D(t) \quad (5)$$

where $\Gamma_D(t)$ will be dependent upon the surface kinetics. For the usual case of dissociative absorption, the equation describing the surface kinetics will be

where X is the gettered species, Y is the getter material, and k_i and k_0 are, respectively, the absorption and desorption rates per unit surface area. The incident absorbed flux Γ_i is then given by

$$\Gamma_i = k_i P(t) \quad (7)$$

where $P(t)$ is the gas pressure of X_2 . Expressed in kinetic parameters¹⁰ and the sticking probability s , we have

$$\Gamma_i = s \left(\frac{n\bar{v}}{4} \right), \quad (8)$$

where n is the gas density and $\bar{v}$ is the average molecular speed. The desorption flux Γ_o is

$$\Gamma_o = k_o [c(L,t)]^2. \quad (9)$$

Using Eqs.(7) and (9), Sievert's Law¹¹ for equilibrium ($\Gamma_i = \Gamma_o$) can be derived:

$$P_{eq} = K [c_{eq}]^2, \quad (10)$$

where P_{eq} and c_{eq} are the corresponding equilibrium pressure and surface concentration, respectively. The equilibrium constant $K = k_o/k_i$ is a measure of the solubility. The difference in the fluxes Γ_i and Γ_o is equal to the flux into the getter in Eq. (5):

$$\Gamma_D = \Gamma_i - \Gamma_o. \quad (11)$$

The time dependence of the gas pressure P is described by¹²

$$V \frac{dP}{dt} = [F - A(\Gamma_i - \Gamma_o) - PS], \quad (12)$$

where V is the chamber volume, and F is the gas flow into the chamber. A is the getter surface area, and S is the pumping speed of the external pump.

The operation of the getter is described by the solution to Eqs. (1) and (12), and will depend upon the material parameters s , K , and D , and on the

external parameters S and F . In the following two sections we will explore the details of two particular cases which illustrate typical modes of getter operation and which can be useful for extracting measurements of fundamental getter parameters. These two cases are: getter pumping at constant pressure, and getter desorption at constant external pumping speed. The solutions to these two cases will be presented in normalized forms to facilitate a variety of applications.

III. CONSTANT PRESSURE PUMPING

For this case we take $S=0$ and $P(t) = P_0$. We express Eq. (1) in dimensionless form:

$$\frac{\partial^2 C(\chi, \tau)}{\partial \chi^2} = \frac{\partial C(\chi, \tau)}{\partial \tau}, \quad (13)$$

where

$$\chi = x/L, \quad (14)$$

and

$$\tau = Dt/L^2, \quad (15)$$

are the normalized position and time, respectively. The normalized concentration $C(\chi, \tau)$ is given by

$$C(\chi, \tau) = c(x, t)/c_0, \quad (16)$$

with

$$c_o = (P_o/K)^{1/2} . \quad (17)$$

being the final or equilibrium concentration. We assume that the getter is initially unloaded so that the normalized initial condition is

$$C(x,0) = 0 , \quad (18)$$

and the normalized boundary conditions are

$$\frac{\partial C(x,\tau)}{\partial x} \Big|_{x=0} = 0 , \quad (19)$$

and

$$\frac{\partial C(x,\tau)}{\partial x} \Big|_{x=1} = -H [1 - C(1,\tau)]^2 . \quad (20)$$

The dimensionless parameter H is

$$H = \frac{k_i P_o}{D c_o / L} , \quad (21)$$

and contains all the parameters describing the system. From the form of Eq. (21), it can be seen that H is the ratio of the surface-limited absorbed flux to the diffusion-limited flux.

Owing to the quadratic boundary condition, [Eq. (20)], Eq. (13) cannot be solved analytically. It is informative, however, to examine the solution to the linearized problem: $1 - C^2 = (1+C)(1-C) \sim (1-C)$ for which an analytical

solution is possible. This simple solution explicitly exhibits the characteristic behavior for limiting regimes and is in good agreement with an exact numerical solution which will be discussed subsequently. With the linearized boundary condition, we can use the solution derived for the analogous heat transport equation, and write the normalized flux as¹³

$$\frac{\partial C}{\partial X} \Big|_{X=1} = - \sum_{n=1}^{\infty} \frac{2H^2}{H(H+1) + \alpha_n^2} \exp[-\alpha_n^2 \tau], \quad (22)$$

where the α_n 's are the roots of the transcendental equation

$$\alpha_n \tan \alpha_n = H. \quad (23)$$

In the limit $H \ll 1$, where the surface-limited absorbed flux is much less than the diffusion-limited flux, the pumped flux is from Eqs. (3), (5), and (22)

$$\Gamma_D = k_i P_o \exp[-H \tau] \approx k_i P_o \exp\left[-\frac{k_i P_o}{Lc_o} t\right]. \quad (24)$$

This solution shows the expected result that the pumping speed per unit area is initially k_i and then decreases as the getter fills up. For this case, the getter fills up as $\tau \sim H^{-1}$ or $t \sim Lc_o/k_i P_o$, consistent with the surface kinetic limiting regime. When $H \gg 1$, diffusion dominates, and for times such that the higher order transients become negligible ($\tau \gtrsim 0.1$), the flux is

$$\Gamma_D = \frac{2k_i P_o}{H} \exp[-(\pi^2/4)\tau] \approx \frac{2Dc_o}{L} \exp[-\pi^2 Dt/4L^2]. \quad (25)$$

This equation exhibits an initial pressure dependent pumping speed, $2D/(KP_0)^{1/2}L$. The pumping speed will decrease as the getter fills up on the diffusion-normalized time scale, τ .

The exact solution to Eq. (13) with the quadratic boundary condition, Eq. (20), must be solved numerically. Using Duhamel's Theorem,¹⁴ we can write the bulk atomic concentration in terms of a singular nonlinear Volterra integral equation¹⁵:

$$C(\chi, \tau) = C_i(\chi) - \int_0^\tau B(\chi, \tau - \tau') \Phi[C(1, \tau')] d\tau', \quad (26)$$

where C_i is the normalized initial concentration which is zero for the present case. The kernel $B(\chi, \tau)$ is given by

$$B(\chi, \tau) = 1 + 2 \sum_{n=1}^{\infty} (-1)^n \cos(n\pi\chi) \exp(-n^2\pi^2\tau), \quad (27)$$

and $\Phi[C(1, \tau')]$ is the normalized flux, which in the present case is given by Eq. (20).

Equation (26) has been solved numerically by first determining the surface concentration $C(1, \tau)$ from Eqs. (26), (27), and (20) by successive iteration. The general solution of $C(\chi, \tau)$ follows from a straightforward integration of Eq. (26) utilizing the previously determined $C(1, \tau)$. Concentration profiles at various normalized times are plotted for $H=0.1$ in Fig. 2a and $H=10$ in Fig. 2b. The $H=0.1$ case is limited by surface kinetics. Here the diffusion is sufficiently fast so that the profiles are uniform. In this limit the getter fills up to ~63% of its equilibrium concentration when $\tau = H^{-1}$ as in Eq. (24). This corresponds to $t = c_0 L / k_1 P_0$. The $H=10$ case is diffusion limited. The corresponding concentration profiles show a

strong χ dependence for $\tau < 1$, with the bulk filling up to $\sim 63\%$ when $\tau = 1$ as seen in the analytic linearized solution, Eq. (25).

In Fig. 3, the normalized pumping speed Σ , where

$$\Sigma = \Gamma_D / (k_i P_O) , \quad (28)$$

is plotted as a function of τ for a variety of H values from 0.1 to 10. After an initial time, Σ decreases exponentially with a rate σ given by

$$\sigma = -d \ln \Sigma / d\tau , \quad (29)$$

which is plotted in Fig. 4 as a function of H . For $H \ll 1$, $\sigma \sim H$, while in the other limit of $H \gg 1$, $\sigma \sim \pi^2/4$. From measurements of Σ and σ for various values of H , the parameters k_i , K , and D can be determined. The value of σ from the linearized solution is plotted in Fig. 4 also.

In Fig. 5, Σ is plotted as a function of H for various degrees of getter loading. The latter quantity, λ , is expressed as

$$\lambda = \int_0^1 C(\chi, \tau) d\chi . \quad (30)$$

For all values of λ , the falloff of Σ with H occurs for $H \gtrsim 1$. This region, in which the pumping speed decreases with pressure, corresponds to the diffusion-limited regime.

IV. DESORPTION

For desorption we take $F=0$ and S equal to the pumping speed of the backup system which is used to evacuate the chamber during this operation. The

VdP/dt term in Eq. (12) will be important for a time $t \lesssim V/S$. Since this is usually much shorter than any of the other times of interest, we neglect this term. Using Eqs. (7), (9), and (12), the pressure can then be expressed in terms of the surface concentration $c(L,t)$ as,

$$P(t) = (S/S_T) Kc(L,t)^2, \quad (31)$$

where S_T is the equivalent series pumping speed defined by

$$\frac{1}{S_T} = \frac{1}{S} + \frac{1}{k_1 A}. \quad (32)$$

Utilizing the normalization conventions of Sec. III [Eqs. (14)-(17)], we can write the normalized flux boundary condition at $\chi=1$ as

$$\left. \frac{\partial C(\chi, \tau)}{\partial \chi} \right|_{\chi=1} = -G[C(1, \tau)]^2, \quad (33)$$

where

$$G = \left(\frac{S_T K_C^2}{A} \right) / \left(\frac{Dc_0}{L} \right). \quad (34)$$

The constant G is the ratio of the surface-limited outflux to the diffusion-limited outflux, with $c_0=c(x,0)$ being the initial, uniform concentration. The boundary condition at $\chi=0$ is the same as Eq. (19), while the initial condition is

$$C(\chi, 0)=1. \quad (35)$$

Owing to the quadratic boundary condition, Eq. (33), an exact analytical solution to Eq. (13) cannot be obtained for the desorption case. Approximate analytical solutions can be derived in the two limits of small and large times. For $\tau \ll 1$ we use Eqs. (26), (33), and a suitable transformation of Eq. (27) in order to write the integral equation for $C(1, \tau)$ ¹⁶:

$$C(1, \tau) = 1 - \int_0^\tau \frac{G[C(1, \tau')]}{\pi^{1/2} (\tau - \tau')^{1/2}} d\tau' . \quad (36)$$

The solution to Eq. (36) can be derived from a power series expansion in powers of $\tau^{1/2}$. Then, for small times, where we neglect terms of order τ , we can write the normalized surface concentration at τ as

$$C(1, \tau) \sim \left[1 - \frac{2}{\pi^{1/2}} G \tau^{1/2} \right] , \quad (37)$$

or, using dimensional quantities,

$$c(1, \tau) \sim c(L, 0) \left[1 - \frac{2}{\pi^{1/2}} \left(\frac{S_T K c_0}{A} \right) \left(\frac{t}{D} \right)^{1/2} \right] . \quad (38)$$

This solution, which is similar in form to that of the surface temperature of a cooling semi-infinite solid, shows the dependence of the outgassing on the bulk diffusivity.

When $\tau \gg 1$, from Eqs. (26), (27), and (33), the normalized surface concentration is given approximately by¹⁶

$$C(1, \tau) = 1 - \int_0^\tau G[C(1, \tau')]^2 d\tau' , \quad (39)$$

which is equivalent to the differential equation

$$\frac{\partial C(1,\tau)}{\partial \tau} = -G[C(1,\tau)]^2. \quad (40)$$

The solution to Eq. (40) is

$$C(1,\tau) = [G\tau + C^{-1}]^{-1}, \quad (41)$$

where $C \sim 1$ is an integration constant which depends upon the solution for small times. In terms of dimensional quantities, Eq. (41) can be written as

$$c(L,t) = [\alpha t + (c_0')^{-1}]^{-1}, \quad (42)$$

where $\alpha = S_T K/M$ and $c_0' \sim c_0$ depends upon the solution for small times. This solution shows the expected result that for $t \gg L^2/D$, the outgassing will be limited by surface kinetics.

Numerical solutions valid for all values of τ were derived using techniques similar to those in Sec. III. The surface concentration was determined for several values of G , from which the bulk concentration and the chamber pressure can be determined. Figure 6a shows the bulk concentration for $G=0.1$ and Fig. 6b shows this quantity for $G=10$. The effect of diffusion is clearly evident for small times in the $G=10$ case. In Fig. 7 the time dependence of $C(1,\tau)$ for $G=0.1$ and $G=10$ is plotted for small τ and shows good agreement with the linearized result, Eq. (35). Figure 8 shows that $C(1,\tau)$ agrees with Eq. (39) for $\tau \gg 1$. These results indicate that for $G < 1$ the desorption is nearly independent of diffusion and is mainly determined by the surface kinetics. For $G > 1$, the desorption exhibits a strong dependence on the diffusivity. The behavior of the chamber pressure $P(t)$ follows from Figs. 7 and 8 and Eq. (31).

V. APPLICATIONS

In this section we illustrate the results of the previous sections by analyzing the behavior of the St1010 Zr-Al alloy non-evaporable bulk getter,¹⁷ which pumps hydrogen isotopes reversibly and impurities (C,N,O) irreversibly. These getters will be utilized in the Tokamak Fusion Test Reactor to control hydrogenic recycling and reduce plasma impurities.¹⁸

In this application the getters may be subjected to high hydrogen pressures which will result in diffusion-limited pumping. Figure 9 is a plot of the predicted H_2 pumping speed for Zr-Al as a function of pressure for a variety of getter loadings as shown. The predictions are based upon values of K and D determined from desorption experiments^{19,20} which are described below. These curves exhibit the characteristic behavior of the pumping speed falling as $P^{-1/2}$ when $H \gg 1$. A detailed experimental investigation of the pressure dependence of the pumping speed, reported elsewhere,²¹ shows excellent agreement with the present theory. Equivalently, the values for the diffusivity and equilibrium constant inferred from these pumping speed measurements agree in detail with those of the desorption measurements.

During the operation of this getter, it is important to limit the hydrogen loading to 20 Torr-l/g or less, in order that the embrittlement limit of the getter is not reached.²² This is accomplished by periodically raising the getter temperature from the nominal operating value of 400° to 700°C and desorbing with a backup pump. Figure 10 shows the measured chamber pressure P (plotted as $P^{1/2}$) for a hydrogen loaded getter as a function of desorption time t (plotted as $t^{1/2}$). For small times, the behavior follows that predicted by Eq. (38) for diffusion-limited desorption. From the slope of this curve, the value of D for hydrogen in Zr-Al at 700°C was determined to be $1.8 \times 10^{-6} \text{ cm}^2 \text{ s}^{-1}$. Measurements of D for both hydrogen and deuterium over the

temperature range of 500°-750°C are reported in Ref. 20. After the initial diffusion limited desorption, $p^{1/2}$ varies as t^{-1} , consistent with Eq. (42). The curve in this region yields a value for K of $1.9 \times 10^{-3} \text{ Torr} \cdot (\text{Torr} \cdot \text{l/g})^{-2}$, which is in agreement with static measurements.¹⁹

VI. SUMMARY AND DISCUSSION

We have presented a theory of bulk getter operation, which includes both surface absorption/desorption kinetics and bulk diffusion. For the case of pumping at constant pressure, the theory predicts that the pumping speed is independent of pressure when the surface-limited absorbed flux is less than the diffusion-limited flux. In the opposite regime, the pumping speed varies as $p^{-1/2}$. Initially, desorption exhibits diffusion-limited behavior. Subsequently, the process is surface-limited and the concentration decreases as t^{-1} .

Exact numerical solutions have been presented for a wide variety of parameters characterizing pumping and desorption scenarios. These are generally applicable to any bulk getter. Additionally, approximate analytical solutions have been presented. These solutions are useful for conveniently estimating getter performance in limiting operational regimes, and for illustrating the underlying physical processes.

The experimentally observed behavior of the Zr-Al alloy bulk getter is described accurately by the present theory. The characteristics of both pumping and desorption for a wide range of conditions are predicted closely by this model using a single set of getter parameters K, D, and s. This consistent agreement for the entire range of getter operation comprises substantial evidence for the validity of the theory.

Acknowledgments

This work was supported by U.S. DoE Contract DE-AC02-76-CHO3073.

References

1. S. Dushmann (revised by V. L. Stout and T. A. Vanderslice), in Scientific Foundations of Vacuum Technique, edited by J. M. Lafferty, (Wiley, N.Y., 1962) p. 622.
2. P. della Porta, in Advances in Electron Tube Techniques, edited by D. Slater, Proc. Sixth Nat. Conf., Sept. 1962 (Macmillan, N.Y., 1963).
3. C. Benvenuti and J. C. Decroux, Proc. 7th Int. Vac. Congr. and 3rd Int. Conf. Solid Surfaces, (International Atomic Energy Agency, Vienna, 1977) p.85.
4. J. L. Cecchi et al., J. Nucl. Mater., 111&112, 305 (1982).
5. J. J. Reilly, in Hydrogen: Its Technology and Implications, Transmission and Storage of Hydrogen Vol. II, edited by K. E. Cox and K. D. Williamson, Jr. (CRC Press, Boca Raton, 1977).
6. L. Rosai and M. Borghi, J. Vac. Sci. and Technol. 11, 347 (1974).
7. F. Waelbroeck, P. Wienhold, and J. Winter, J. Nucl. Mater., 111&112, 185 (1982).
8. A. Roth, Vacuum Technology (North-Holland, Amsterdam, 1976) p. 259f.
9. M. E. Malinowski (private communication).
10. S. Dushman, Scientific Foundations of Vacuum Technique. edited by J. M. Lafferty (Wiley, N.Y., 1962) p. 14.
11. A. Sieverts, Z. Metallkd 21, 37 (1929).

12. A. Roth, *ob. cit.*, p. 65.
13. H. S. Carslaw and J. C. Jaeger, Conduction of Heat in Solids (Oxford University Press, Oxford, 1976) p.114f.
14. D. V. Widder, Advanced Calculus (Prentice-Hall, Englewood Cliffs, 1965) 73.
15. W. R. Mann and F. Wolf, *Quart. Appl. Math* 9, 163 (1951).
16. A. L. Crosbie and R. Viskanta, *Int. J. Heat Mass Transfer* 11, 305 (1968).
17. B. Ferrario and L. Rosai, Proc. 7th Int. Vac. Congr. and 3rd Int. Conf. Solid Surfaces (International Atomic Energy Agency, Vienna, 1977) p. 359.
18. J. L. Cecchi, *J. Nucl. Mater.* 93&94, 28, (1980).
19. R. J. Knize, J. L. Cecchi, and H. F. Dylla, *J. Vac. Sci. and Technol.*, 20, 1135 (1982).
20. R. J. Knize and J. L. Cecchi, *J. Nucl. Mater.* 111&112, 645 (1982).
21. J. L. Cecchi and R. J. Knize, Princeton Plasma Physics Laboratory Report PPPL-1959, 1982, and *J. Vac. Sci. and Technol.* (in press).
22. R. J. Knize, J. L. Cecchi, and H. F. Dylla, *J. Nucl. Mater.* 103&104, 539 (1981).

Figure Captions

- FIG. 1. Schematic diagram of a bulk getter and associated vacuum chamber. The enlargement shows the absorption, desorption, and diffusion fluxes.
- FIG. 2. Normalized concentration profiles $C(x, \tau)$ at various normalized times τ for $H=0.1$ (a) and $H=10$ (b).
- FIG. 3. Natural log of the normalized pumping speed $\bar{S}$ as a function of normalized time τ for various values of H . The exponential decay rate σ is noted for each curve.
- FIG. 4. Exponential decay rate σ of the pumping speed as a function of H . The dotted lines show the linearized solutions explained in the text.
- FIG. 5. Normalized pumping speed $\bar{S}$ as a function of H for various degrees of fractional getter loading λ defined by Eq. (30).
- FIG. 6. Normalized concentration profiles $C(x, \tau)$ during desorption at various normalized times τ for $G=0.1$ (a) and $G=10$ (b).
- FIG. 7. Initial dependence of the normalized surface concentration $C(1, \tau)$ for $G=0.1$ and $G=10$. The dashed lines show the linearized approximate solutions.
- FIG. 8. Normalized time dependence of the normalized surface concentration $C(1, \tau)$ for $G=0.1$ and $G=10$. The dashed lines show the linearized approximate solutions.
- FIG. 9. Predicted pressure dependence of the normalized hydrogen pumping speed of Zr-Al at 400°C for two fractional getter loadings λ .
- FIG. 10. Measured H_2 pressure during desorption of Zr-Al at 700°C. The solid line is the prediction of the theory.

Fig. 1

82 P 0275

Fig. 2

Fig. 3

82 P0278

Fig. 4

82 P 0290

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10