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TRITIUM AND HELIUM BEHAVIOR IN IRRADIATED BERYLLIUM*

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ABSTRACT

Large quantities of Be (>100 metric tons) are planned for use in the ITER blanket design to enhance tritium breeding and to act as a thermal barrier between coolant and breeder. Tritium retention/release and He-induced swelling are important issues in blanket design. The data base on tritium and helium behavior in Be is reviewed. New data on tritium retention/release and He bubble growth are presented for Be irradiated to 5×10^{22} n(E > 1 MeV)/cm² at -75°C and postirradiation-annealed for 700 hours at 500°C. A model (diffusion/desorption) is proposed and tested against the data base to determine tritium diffusivity and the desorption rate constant. Similarly a model for He-induced swelling is developed and tested against the data base. The dependence of tritium retention and release on He content and impurities (e.g. BeO) is also explored.

I. INTRODUCTION

Conceptual designs for experimental fusion reactors such as the International Thermonuclear Experimental Reactor (ITER) specify the use of large quantities (>100 metric tons) of Be neutron multiplier to enhance tritium breeding in lithium ceramics. In some designs the Be is also used as a thermal barrier between coolant and ceramic breeder to enhance tritium release and to minimize tritium inventory in the ceramic.¹ Over a 3 MW-a/m² lifetime of a machine, as much as 2 kg of tritium are generated. Local He concentrations can be as high as 1.5×10^4 appm (1.5 at.%). The tritium retention and release at normal operating temperatures

(100-500°C) and possible release at overpower type temperatures (>500°C) is of great interest in safety analyses. Be swelling is also a concern, particularly for designs in which Be serves as a thermal barrier for breeder temperature control.

In this work, the data base on hydrogen isotope behavior in unirradiated Be (Jones and Gibson² and Abramov, Riehn, Thompson and Smeltzer³), in ion-bombarded Be (Langley⁴ and Wampler⁵), and in irradiated Be (Baldwin, Slagle, and Gelles⁶) is reviewed. In addition, the data on He-induced swelling in irradiated Be (Beeston et al.⁷⁻⁸) are reviewed. New data on tritium and helium behavior are also presented for Be irradiated to 5×10^{22} n(E > 1 MeV)/cm² at -75°C and post-irradiation annealed for 700 hours at 500°C.

A diffusion/desorption model is developed and tested against the tritium release data for the purpose of estimating the tritium diffusion coefficient and the tritium desorption rate constant. An equilibrium-swelling model is also proposed (and validated) for determining He-induced swelling in irradiated Be as a function of temperature and retained He. The effects on tritium retention of He content, impurities (e.g. BeO) and microstructure (e.g. grain size and as-fabricated porosity) are also discussed.

II. REVIEW OF PREVIOUS DATA

A. Hydrogen-isotope Behavior

Jones and Gibson² studied the behavior of tritium in unirradiated, arc-cast Be which had been exposed to tritium gas at high temperature (e.g. 826°C) and pressure (e.g. 2120 Pa) for a period of time (e.g. 24 hours). The samples were then annealed in step-wise fashion at 400, 500, 600, 800, and 900°C for time steps of 50-100 hours. The solubility of tritium in Be was low (0.22 appm) under the

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tritium soaking conditions, relatively insensitive to temperature, and dependent on the square root of the tritium pressure. The tritium retentions after each step anneal were 0.183 (400°C), 0.161 (500°C), 0.136 (600°C), 0.044 (800°C), and ~0 (900°C). Using the long-time release data at each anneal and a one-dimensional plate model for their 2.5-cm-diam. by 0.79-cm-thick disk, Jones and Gibson derived the diffusivity coefficient listed in Table 1. Also listed in Table 1 is the diffusivity coefficient derived by Billone using the short- and intermediate-time Jones and Gibson data, along with an equivalent sphere model of radius 0.726 cm. Both of these diffusivities are compared to those⁹ of other hexagonally-close-packed (hcp) metals (α -Zr and α -Ti) and high atom density metals (Ni and Cu) in Fig. 1. The Jones and Gibson values appear low.

Abramov et al.³ investigated deuterium permeation and diffusion in thin (0.1 mm) high grade (99%) and extra-grade (99.8%) hot pressed Be samples. Multilayer permeation theory was used to model the Be and BeO layers. Their results, which are in good agreement with Billone's interpretation of the Jones and Gibson data, are shown in Table 1.

Several studies⁴⁻⁵ have been performed on hydrogen-isotope release from thin (1 mm) cold (followed by hot) isostatically pressed Be samples which had been bombarded by 3 keV

Table 1. Tritium Properties Derived from Previous Experiments

	JONES & GIBSON	WAMPLER	BALDWIN ET AL.	ABRAMOV ET AL.
Method	Stepped-anneal	Stepped-anneal	Stepped-anneal	Permeation
Temp., °C	300-900	25-600	300-611	347-502
Time Step, h	25-100	0.17	20-200	---
Diffusivity				
D_0 , m^2/s	3.0×10^{-11} (1.73×10^{-9}) ^a	---	---	6.7×10^{-9} 8.0×10^{-9}
Q , $kJ \cdot mol^{-1}$	18.5	---	---	28.4 35.1
Solubility				
S_0 , appm-Pa ^{-0.5}	1.9×10^{-2}	---	---	---
Q_s , $kJ \cdot mol^{-1}$	-1.82×10^{-3}	---	---	---

a- Re-analyzed by Billone.

Figure 1. H-isotope diffusion in selected metals. T_m is the absolute melting temperature.

deuterium ions. The range of implanted deuterium was only $\sim 6 \times 10^{-2}$ μm . Wampler⁵ found a room-temperature saturation at ~ 31 at.% deuterium. These samples, along with those implanted with deuterium to a maximum local concentration of ~ 3 at.%, were step-annealed with steps of 25°C for 10 minutes each. For the 3-at.% Be, very little deuterium was released for $T \leq 350^\circ C$. At 600°C $\sim 90\%$ of the deuterium had been released. With an estimated grain size of 10 μm and an implantation depth of only $\sim 6 \times 10^{-2}$ μm , these experiments are clearly surface-experiments which reveal very little about hydrogen isotope behavior in the Be bulk. However, the results may be very useful for modeling of surface release phenomena.

Baldwin et al.⁶ studied tritium release from thin (2.4-3.2 mm) wafers cut from hot-pressed Be samples (1.7 wt.% BeO) which had been irradiated to $\sim 5 \times 10^{22}$ $n(E > 1 \text{ MeV})/cm^2$ in the Advanced Test Reactor (ATR). These samples contained 2500 appm (I_0) tritium. Starting at 300°C for 20-120 hours, the temperature was increased in steps of $\sim 100^\circ C$ for 20-200 hours. Their results, identified here as Be tests #1 and #2 (Fig. 2), show that very little ($< 1\%$) tritium is released for $T \leq$

511°C and most of the tritium (80-98%) is released in a burst mode after several hours at 611°C. Photomicrographs of sample #2 after 148 hours at 611°C and 17 h at 700°C showed the presence of large (0.5-3 μm) He bubbles suggesting that the released tritium was vented through interconnected pathways created by He bubble interlinkage.

Figure 2. Tritium release from Be samples irradiated to $\sim 5 \times 10^{22} \text{ n(E} > 1 \text{ MeV)/cm}^2$ at $\sim 75^\circ\text{C}$ and annealed at indicated temperature. Initial tritium content was 2500 appm.⁶

B. He Behavior

Numerous investigations have been made into the He-induced swelling behavior of Be irradiated in thermal and fast fission reactors. Generally, the results are reported in terms of volume strain ($\Delta V/V_0$) or length change ($\Delta L/L_0$) vs. fast ($E > 1 \text{ MeV}$) fluence. Many of these studies involve irradiation at low temperature followed by post-irradiation anneals for periods of 10 min. to 24 hours. The He content is calculated with conversion factors ranging from 2000-6000 appm (He)/ 10^{22} n/cm^2 for fast neutrons. The conversion factor depends on the reactor spectrum at the particular location in which the Be was irradiated.

For the blanket region of fusion reactors, it is very important to be able to predict the Be swelling as a function of retained helium (I_a in appm) and temperature. Thus, the conversion factor used to calculate He concentration from fission-reactor fluence is also very important. Most of the He in irradiated Be comes from the $(n,2\alpha)$ reaction which has a threshold energy of 2.7 MeV. The cross-

section for this reaction peaks at $\sim 0.66 \text{ b}$ at 3.25 MeV. Thus a detailed fission-reactor spectrum for the fast neutrons is required in order to calculate accurately the He content of Be samples tested in fission reactors.

Other sources of He in Be are from the lower-cross-section reaction (n,α) , from (n,α) reactions in Li impurities, from tritium decay leading to ^3He and from He trapped in Be during fabrication in a He environment. The (n,α) reaction in Be has a threshold energy of 0.71 MeV and a peak cross-section of $\sim 0.11 \text{ b}$ at $\sim 3 \text{ MeV}$. Thus, the total He content is generally higher than that calculated from the $(n, 2\alpha)$ reaction alone.

For the reasons mentioned above, only Be swelling data for which the He content was measured directly are reviewed and used in the current modeling. These data sets include ATR-tested Be and EBR-II-tested Be. For ATR Be ($\sim 1.7 \text{ wt.}\% \text{ BeO}$, $\sim 25 \mu\text{m}$ grain diameter, $\sim 100\%$ dense, hot-pressed), Beeston⁷ reported the results of $\Delta L/L_0$ measurements on 59 samples irradiated to $1.3\text{-}3.5 \times 10^{22} \text{ n/cm}^2$ (fast) and $\Delta V/V_0$ (based on density changes) measurements on 6 samples irradiated to $3.0\text{-}3.5 \times 10^{22} \text{ n/cm}^2$ (fast). The irradiation temperature was $\sim 75^\circ\text{C}$. Using the conversion factor of 6000 appm (He)/ $10^{22} \text{ n(E} > 1 \text{ MeV)/cm}^2$ measured by Baldwin in the current work for ATR-tested Be, Beeston's correlation may be rewritten in terms of He content (I_a in appm) as

$$\Delta V/V_0 = (0.086 \pm 0.031)(I_a/10^3)^{1.035}, \% \quad (1)$$

In addition to measuring length and/or density changes for these low temperature irradiations, one-hour post-irradiation anneals were performed on several samples. Based on density measurements before and after annealing, the results showed no significant volume changes for 1.814×10^4 appm He at 200°C ($1.55\% \pm 1.54\%$) and for 1.915×10^4 appm He at 300°C ($1.50\% \pm 1.65\%$). For 1.995×10^4 appm He at 400°C and 2.065×10^4 appm He at 500°C , the volume changes were $1.63\% \pm 3.23\%$ and $1.42\% \pm 5.49\%$, respectively.

Perhaps a more interesting data set⁸ for fusion reactor applications comes from ATR-type Be irradiated at temperature ($427\text{-}487^\circ\text{C}$) in the EBR-II fast reactor to $1.1\text{-}2.0 \times 10^{23}$ appm He. Based on direct measurement of He in the samples, the conversion factor for this reactor is 1540 appm (He)/ $10^{22} \text{ n(E} > 1 \text{ MeV)/}$

cm². These samples exhibited swelling values of 0.05-0.86 vol. % based on immersion density measurements.

III. NEW DATA

Stepped-anneal tests are useful for scoping the behavior of tritium in irradiated Be. However, they present certain challenges in data analysis. In particular, how much is the release at one temperature (e.g. 500°C) dependent upon the release at lower temperatures? Also, have the samples really come to equilibrium during the 20-200 hour anneals? In addition to tritium behavior, it was recognized from earlier tests⁶ that the behavior of He in Be may influence tritium release. It became clear that it is important to characterize He content and He bubble growth after a long isothermal anneal. Therefore, Be test #3 was designed as an isothermal anneal at 500°C for 700 hours. The sample used was similar to those used in previous tests⁶ except that it was thinner (1.31 mm).

A. Tritium Data

Figure 3 shows the tritium release (R) curve from the current experiment, identified here as Be #3 Test, at 500°C for ~700 hours. As with previous cases, the sample contained 2500 appm tritium and released ~1% of the initial tritium (I_0). The uncertainty band is based on a very careful analysis of possible baseline drift in the ion chambers used to measure tritium in the He + 0.1 % H₂ purge stream (0.1 MPa and 100 scm³/min flow rate). Two ion chambers (200 cm³ and 100 cm³) were connected in series to obtain the data.

Figure 3. Tritium release at 500°C from a 1.31-mm thick sample of Be containing 2500 appm tritium.

A persistent problem in the use of ionization chambers for quantitative tritium measurements is the memory effect of continually-changing tritium retention on the internal surfaces. Previous results (Fig. 2) are based on a best estimate of a single baseline. The current results (Fig. 3) take into account initial and final baselines. Obviously, the effects of baseline uncertainties are significant in evaluating the long-time release characteristics.

B. Helium Data

All of the experiments to date in this work have been performed on Be samples cut from a single ATR-irradiated specimen (10-mm diameter by 30-mm length). Some were used for tritium release measurements, while others were used for tritium and helium content, as well as pre-annealing sample characterization. The irradiated (5×10^{22} n/cm²) Be was 97% dense implying a He-induced swelling of 3%. This is consistent with Beeston's correlation developed for $\phi \leq 3.5 \times 10^{22}$ n/cm². The He content was measured by an analytical method described previously¹⁰ except that the isotopic dilution spike was Ne and not ³He. This allowed mass spectrometer measurement of ⁴He and ³He and removed the possibility of ³He skewing of the results. The samples were 10 mm in diameter with thicknesses of 2 and 0.2 mm. The results were very consistent ($\pm 2\%$) and gave 3.0×10^4 appm (⁴He) and 1.7×10^3 appm (³He).

As reported previously⁶, the pre-annealed samples with ~3 at.% He showed no signs of He bubbles, while the high-temperature (611°C for 148 hours followed by 700°C for 17 h) annealed samples exhibited micron-size (0.5-3 μ m) bubbles. Figure 4 shows the SEM micrograph of the Be #3 specimen after 669 hours at 500°C. He bubbles are clearly present and range in diameter from 0.05-0.8 μ m. The microscopic swelling associated with such bubbles is ~2%.

IV. ANALYTICAL MODELS AND DATA ANALYSIS

A. Tritium Release

Recall that most of the tritium (~99%) is retained in the Be samples even after long anneals at $T \leq 511^\circ\text{C}$. It is difficult to model the tritium release without knowing the mechanisms for tritium retention in both unirradiated and irradiated Be. The burst release of tritium observed by Baldwin et al.⁶ at 611°C suggests that the tritium may have been

trapped in He bubbles. However, the unirradiated samples of Jones and Gibson² contained no He and exhibited high (≥70%) retention for $T \leq 500^\circ\text{C}$. Impurities (especially oxygen) may have contributed to the Jones and Gibson results.

Figure 4. SEM micrograph of the fresh fractured surface of Be #3 sample after 700-h anneal at 500°C .

For the purpose of analyzing the release data, a simple diffusion/desorption model is proposed. The model assumes that a discrete amount of tritium (R_w) is available for release at any given temperature. The desorption in the form of HT is assumed to obey first order kinetics because $H/T \gg 1$. The diffusion is assumed to be one-dimensional (i.e. plate geometry) with the characteristic length (l in m) being the plate half-thickness. The analytical solution for this problem for the fractional release (R/R_w) is derived from Carslaw and Jaeger¹¹ as:

$$f_r = 1 - 2 \sum_{n=1}^{\infty} h^2 \beta_n^{-2} [\beta_n^2 + h(h+1)]^{-1} \exp(-\beta_n^2 t / \tau_1) \quad (2)$$

where

$$\beta_n \tan \beta_n = h$$

$$h = kl/D, \tau_1 = l^2/D$$

$$D = D_0 \exp(-Q/RT), \text{ m}^2/\text{s}$$

$$k = k_0 \exp(-Q_d/RT), \text{ m/s}$$

In using Eq. 2 to analyze tritium release data it is useful to examine its short- and long-time limits. For short times ($t/\tau_1 < 0.33$ and $f_r < 0.65$), the release fraction is proportional to $t^{1/2}$ as $h \rightarrow \infty$ (i.e., diffusion-limited release). For $h \rightarrow 0$ (i.e., desorption-limited release), the short-time [$t/(l/k) < 0.02$ and $f_r < 0.02$] solution is proportional to t . At intermediate values of h (diffusion/desorption limited), f_r is proportional to t^n where $0.5 \leq n \leq 1$. The long-time solutions ($t/\tau_1 > 0.16$ and $f_r > 0.41$ for diffusion and $t/(l/k) > 0$ for desorption) for $1-f_r$ go to a simple exponential for the whole range of h .

Even with allowing h to vary from 0 to ∞ in Eq. 2, it was impossible to match the time-dependent behavior in Fig. 3. Therefore, short-time, intermediate-time, and long-time data were used in the analysis to determine values of D and k . A reasonable fit to the short-time ($t < 10$ h) data was obtained by letting $D = 1.7 \times 10^{-12}$ ($1.18 - 2.85 \times 10^{-12}$) m^2/s . The slope of the long-time ($t > 100$ h) data on a semi-log plot implied that $D \geq 4.6 \times 10^{-14}$ ($2.7 \times 10^{-14} - 1.5 \times 10^{-13}$) m^2/s and/or $k \geq 1.8 \times 10^{-10}$ ($1.0 - 5.8 \times 10^{-10}$) m/s . However, the uncertainty in these data is high because of the cumulative uncertainty in the baseline. As seen from Eq. 2 the release fraction f_r varies as the ratio $h = kl/D$, allowing a range of possible D and k values. Ideally, a unique pair of D and k should give the best fit of the model to the data set. Finally, the intermediate-time ($0.3 < t < 20$ h) data was fit best with a diffusion-controlled model with $D = 5.8 \times 10^{-13}$ m^2/s . These results are summarized in Table 2.

Table 2.
Summary of D and k values derived
from Baldwin#3 Data Set

PORTION OF RELEASE CURVE USED	D (m^2/s)	k (m/s)
Short-time ($t < 10$ h)	1.7×10^{-12}	-
Intermediate-time ($0.3 < t < 20$ h)	5.8×10^{-13}	-
Long-time ($t > 100$ h)	$\geq 4.6 \times 10^{-14}$	$\geq 1.8 \times 10^{-10}$

Figure 5 shows a comparison of the model predictions to the data at intermediate time. Notice that the log-log slope of the data changes continuously with time whereas the model has a slope of $\frac{1}{2}$ for $t < 50$ h.

Figure 5. Tritium release from Be #3 sample at 500°C.

It is not clear at this point in time whether the model is inadequate for predicting tritium release from Be or whether uncertainties in the ion-chamber baseline (particularly with time) distort the time-dependence of the release curve. The model assumes a discrete amount of tritium (R_∞) is available for release at the beginning of the anneal. Any significant time dependence of R_∞ due to "detrapping" would affect the release-vs.-time curve. The data interpretation assumes a unique time-independent baseline for the ion chambers. Any time-dependent drift in the ion-chamber baseline could distort the release-vs.-time curve. Both model and experimental uncertainties will be explored in more depth in future work. Also, the treatment of the BeO surface layer as a separate diffusion/desorption medium will be explored.

B. Helium-Induced Swelling

The purpose of this section is to use a fundamental model for inert gas behavior in materials to describe the helium-induced swelling in Be for temperature and He-concentration regimes below which large swelling and/or He gas release occurs. For this work, the retained He (I_a) is assumed to be equal to the generated He (G_a in 10^3 appm). At low temperature, Be swelling is assumed to vary essentially linearly with G_a (incompressible

regime). As the temperature is increased, gas atoms and small bubbles become more mobile leading to the growth of larger (i.e., compressible regime) bubbles through coalescence. At each temperature and G_a , a unique equilibrium size bubble is assumed in order to simplify the analysis. With this one-bubble-size approach, grain boundary bubbles are not distinguished from matrix bubbles. The fundamental solution to this problem is derived to be

$$\Delta V/V_0 = A G_a [1 + B G_a^{0.5} T^{1.5} \exp(-Q_a/RT)], \quad (3)$$

where A, B, and Q_a are to be determined from data.

In selecting data sets for the determination of A, B, and Q_a , care was taken to use only those data sets for which the retained He was measured directly. For the EBR-II tested Be,⁸ the measured He corresponded to $1540 \text{ appm}/10^{22} \text{ n}(E > 1 \text{ MeV})/\text{cm}^2$. For the ATR-irradiated Be used in this work and Ref. 6, the fast neutron fluence of the irradiated samples was $(5.0 \pm 0.2) \times 10^{22} \text{ n/cm}^2$ and the total ($^4\text{He} + ^3\text{He}$) content was $(3.15 \pm 0.05) \times 10^4 \text{ appm}$. Using just the ^4He content gives a conversion ratio of $(6.0 \pm 0.2) \times 10^3 \text{ appm}/10^{22} \text{ n/cm}^2$.

In Eq. 3, the linear term is replaced by the "nearly" linear term of Beeston (Eq. 1) to insure a good fit to all of the low temperature data. This data set includes He concentrations in the range $(7.8-20.6) \times 10^3 \text{ appm He}$. It gives excellent agreement with the 3% swelling measured for the pre-annealed sample used in this work with $30 \times 10^3 \text{ appm He}$. The B and Q_a values were then determined from the EBR-II data ($427 \leq T \leq 487^\circ\text{C}$ and $1.1 \leq G_a \leq 2.0, 10^3 \text{ appm}$). The resulting correlation is

$$\Delta V/V_0 = (0.086 \pm 0.031) G_a^{1.035} \cdot [1 + 22.2 G_a^{0.5} T^{1.5} \exp(-9322/T)], \% \quad (4)$$

The agreement between Eq. 4 and the EBR-II data is shown in Fig. 6 (dark circles). The open circle at 3.0% $\Delta V/V_0$ is from the pre-annealed swelling from the sample used in this study. The remaining open circles are for the ATR samples which were subsequently annealed

for one hour at temperatures from 200-500°C. These are shown by the triangles in the figure. The agreement of the correlation with the EBR-II data is acceptable, but not excellent. The agreement with pre-and post-anneal ATR sample data is quite good for $T < 500^\circ\text{C}$. At 500°C and $C_a = 20.6 \times 10^3$ appm, the measured swelling was only 5.26% after one-hour at 500°C, while the correlation predicted 29%. The microscopic swelling implied by the visible bubbles in Fig. 4 for 30×10^3 appm Be after 700 h at 500°C is estimated to be ~2%. Thus, it is clear that the correlation overpredicts the swelling for $C_a \geq 10^4$ appm and $T \geq 500^\circ\text{C}$. However, it is certainly useful as a design tool as it gives an upperbound on the swelling data.

Figure 6. Comparison of swelling correlation to EBR-II and ATR data.

V. CONCLUSIONS

The results for tritium release from a dense highly-irradiated Be sample (2500 appm tritium and 3×10^4 appm helium) annealed for 700 h at 500°C are consistent with previous studies in that only ~1% of the retained tritium was released. Internal and/or external oxide concentrations (1.7 wt.% BeO) and/or He defects/bubbles may contribute to the high levels of retained tritium in irradiated Be. These issues, along with the possible effects of fabricated interconnected porosity and grain size, will be investigated in future studies.

In analyzing the time-dependence of the small fraction of tritium which was released, a diffusion/first-order-surface-desorption model was used. No single set of diffusion (D) and desorption (k) coefficients were found to match the whole data set. Analyses were performed to match short- and long-time slopes of the release data, as well as the release data itself at intermediate times (0.3-20 h). It is not clear at this time whether uncertainties in the short-time data (low levels of tritium release), uncertainties in the long-time data (time-dependent shift of ion-chamber baseline) or inadequacies of the diffusion/desorption model are responsible for discrepancies between model predictions and data. The range of possible diffusion coefficients to match different segments of the data is $\sim 3 \times 10^{-14}$ to $\sim 1 \times 10^{-12}$ m²/s with an intermediate-time value of $\sim 6 \times 10^{-13}$ m²/s. A bound on the desorption coefficient is $k > 1 \times 10^{-10}$ m/s. Future work will focus on minimizing the experimental uncertainty and improving the retention/release models.

The He/fluence ratio was measured to be $(6.0 \pm 0.2) \times 10^3$ appm (He)/ 10^{22} n(E > 1 MeV)/cm². For ATR-irradiated Be, SEM micrographs of fresh fractured surfaces revealed bubbles of diameter 0.05-0.8 μm and pore volume of ~2% associated with these bubbles after 700 hours at 500°C for samples containing 30×10^3 appm He. A correlation was developed (based on a fundamental model) for He-induced swelling vs. temperature and He content. The correlation matches the data reasonably well at low temperature for $C_a \leq 30 \times 10^3$ appm He. For $T \geq 500^\circ\text{C}$, the correlation gives an upperbound on He swelling at the high ($C_a > 10^4$ appm) He concentrations.

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AUTHOR INSTRUCTIONS

- A. Title (all capitals centered)
- B. Title (if needed)
- C. Author's name and company/organization
- D. Street address and city number
- E. Telephone
- F. Telex
- G. Fax
- H. E-mail address

COLUMN 1

COLUMN 2

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