LEGIBILITY NOTICE

A major purpose of the Technical Information Center is to provide the broadest possible dissemination of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state, and local governments. Non-DOE originated information is also disseminated by the Technical Information Center to support ongoing DOE programs.

Although large portions of this report are not reproducible, it is being made available only in paper copy form to facilitate the availability of those parts of the document which are legible. Copies may be obtained from the National Technical Information Service. Authorized recipients may obtain a copy directly from the Department of Energy's Technical Information Center.
TITLE
The Effects of Exchange Gas Temperature and Pressure on the Beta-Layering Process in Solid Deuterium-Tritium Fusion Fuel

AUTHORS
J. K. Hoffer, L. R. Foreman, J. D. Simpson, T. R. Pattinson

SUBMITTED TO
Physica B

DISCLAIMER
This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

Los Alamos National Laboratory
Los Alamos, New Mexico 87545
THE EFFECTS OF EXCHANGE GAS TEMPERATURE AND PRESSURE ON THE BETA-LAYERING PROCESS IN SOLID DEUTERIUM-TRITIUM FUSION FUEL

James K. HOFFER and Larry R. FOREMAN
Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

John D. SIMPSON and Ted R. PATTINSON
KMS Fusion, Inc., Ann Arbor, Michigan 48106, USA

It has recently been shown that when solid tritium is confined in an isothermal enclosure, self-heating due to beta decay drives a net sublimation of material from thick, warmer layers to thin, cooler ones, ultimately resulting in layer thickness uniformity. We have observed this process of "beta-layering" in a 50-50 D-T mixture in both cylindrical and spherical enclosures at temperatures from 19.6 K, down to 11.6 K. The measured time constants are found to depend on the 3He content as suggested by recent theoretical predictions. When using an enclosure having low thermal conductivity, the ultimate layer uniformity is found to be a strong function of the exchange gas pressure. This is due to the presence of thermal convection in the exchange gas and consequent temperature anisotropy at the solid layer surface.

1. INTRODUCTION

The concept of beta-layering was first introduced by Miller(1) in 1975. A one-dimensional theory was formalized by Martin et al.(2) in 1985. It proposed that in a chamber partially filled with deuterium and tritium (DT) fuel and cooled to below the triple point, an automatic redistribution of the solid occurs. Because of self-heating due to the absorption of beta particles, thick layers of solid DT tend to have warmer interior surfaces than do thin ones. A net sublimation of material from thick sections to thin ones takes place, expressed as

\[ \delta(t) = \delta_0 e^{-t/r}, \]

where \( \delta_0 \) is the initial anisotropy in the layer thickness and the rate constant \( r = H_s/q \), where \( H_s \) is the heat of sublimation and \( q \) is the self-heating rate. Hoffer and Foreman(3) first observed the effect in pure tritium, confirming eq. 1. Those experiments, and subsequent ones in a 50-50 mixture of DT(4), showed that the equilibrium rate was also a function of the helium content. Recently, Barenz(5) has extended Martin's formalism to account for the diffusion of DT vapor across the interior void space in the presence of stagnant 3He gas. He also arrives at Eq. 1, with \( r = H_s/q + r_3 \), where

\[ r_3 = \frac{(r-d) \cdot k_s \cdot R \cdot T \cdot P_3}{d \cdot q \cdot D \cdot P \cdot (dP_3/dt)} \]

In this equation, \( r \) is the inner radius of the enclosure, \( d \) is the equilibrium solid layer thickness, \( k_s \) is the thermal conductivity of the solid, \( R \) is the gas constant, \( T \) is the temperature and \( P_3 \) is the partial pressure of 3He in the vapor space. \( D \) is the diffusivity of the DT-3He binary gas system. \( P_D \) is the vapor pressure of DT, and \( P = P_D + P_3 \) is the total pressure. If we assume that all the 3He produced by tritium decay is in the vapor space, then \( P_3 \) will increase every day by

\[ \frac{dP_3}{dt} = 1.537 \times 10^{-4} c_s R T f_s/(1-f_s), \]

where \( c_s \) is the solid density, and \( f_s \) is the fraction of volume occupied by the solid. Using properties for DT compiled by Souers(6), we have estimated \( r_3 \) for both cylindrical and spherical geometries, for various values of \( f_s \), as shown in Table 1. The value \( f_s = 0.88 \) corresponds to the case where an enclosure is filled with liquid DT and then frozen. Note that the effects of 3He increase dramatically below 16 K.

<table>
<thead>
<tr>
<th>T (K)</th>
<th>( H_s/q ) (min)</th>
<th>( T_3 ) (cyl.) (min/day)</th>
<th>( T_3 ) (sph.) (min/day)</th>
<th>( f_s = 0.88 )</th>
<th>( f_s = 2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0</td>
<td>24.74</td>
<td>51300</td>
<td>40800</td>
<td>18600</td>
<td>34200</td>
</tr>
<tr>
<td>12.0</td>
<td>25.18</td>
<td>2740</td>
<td>2180</td>
<td>992</td>
<td>1980</td>
</tr>
<tr>
<td>14.0</td>
<td>25.62</td>
<td>343</td>
<td>273</td>
<td>124</td>
<td>244</td>
</tr>
<tr>
<td>16.0</td>
<td>26.07</td>
<td>73.2</td>
<td>58.3</td>
<td>26.5</td>
<td>53.0</td>
</tr>
<tr>
<td>18.0</td>
<td>26.51</td>
<td>22.2</td>
<td>17.7</td>
<td>8.08</td>
<td>15.4</td>
</tr>
<tr>
<td>19.0</td>
<td>26.91</td>
<td>13.3</td>
<td>10.7</td>
<td>4.89</td>
<td>9.29</td>
</tr>
<tr>
<td>19.79</td>
<td>26.91</td>
<td>9.45</td>
<td>7.52</td>
<td>3.42</td>
<td>6.06</td>
</tr>
</tbody>
</table>

Table 1. Time Constants for Beta-Layering
2. TEMPERATURE EFFECTS - EXPERIMENTAL PROCEDURES

We made use of the previous apparatus and optical technique (3,4), i.e., a copper cylinder sealed with sapphire windows, to insure isothermal boundaries and good optical access. To minimize the effects of $^3$He accumulation, the DT mixture was purified in a Pd bed prior to each series of experiments. This removed the $^3$He so well that we could fill the cylinder completely with liquid DT prior to freezing. However, it was impractical to purify the DT mixture following beta-layering at each different temperature, and thus slight accumulations of $^3$He gas could not be prevented.

3. TEMPERATURE EFFECTS - EXPERIMENTAL RESULTS

We initially interpreted the results shown in Fig. 1 as a temperature effect in "fresh" DT (i.e., DT having no $^3$He impurity) and we fitted the data with an Arrhenius expression. However, the Bernat model outlined above suggests a better interpretation, namely that there is virtually no effect of temperature on the rate of beta-layering in pure DT, but that the effect of $^3$He accumulating in the vapor space is so strongly temperature dependent that even minuscule amounts of $^3$He will dominate the rate of beta-layering below $-14$ K. Figure 1 shows values of $\tau$ calculated from Eq. 2 at times corresponding to the beginning and the end of each experiment. The close agreement with our measured values shows that the model describes the physics of beta-layering in isothermal enclosures remarkably well.

4. PRESSURE EFFECTS - PROCEDURES AND RESULTS

In the second set of experiments, the copper cylinder was replaced by a hollow lexan sphere having the same volume. This is characteristic of prototype inertial confinement fusion (ICF) reactor targets. In both sets of experiments, the DT containers were thermally linked to the cryostat by $^4$He gas at a pressure of $-600$ torr. But, with the poorly conducting lexan sphere, a large asymmetry in the equilibrium layer thickness, $\delta_m$, was observed. Suspecting that this was an effect of convection in the $^4$He exchange gas, we conducted a series of experiments at decreasing pressures until relatively symmetric layers were achieved, as shown in Fig. 2. The slight anisotropy remaining below $-5$ torr is probably due to the metal fill tube and support tube attached to the poles of the sphere.

REFERENCES


(5) T. P. Bernat, private communication.