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BLISTERING EFFECTS IN NEUTRAL INJECTION SYSTEMS OPERATED WITH
HELIUM AND HYDROGEN GASES: A PRELIMINARY ASSESSMENT

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BLISTERING EFFECTS IN NEUTRAL INJECTION SYSTEMS OPERATED WITH HELIUM AND HYDROGEN GASES: A PRELIMINARY ASSESSMENT

ABSTRACT

We assessed the practical effects of blistering and flaking in neutral injection systems. These effects will soon be more important because of energy increases in systems now under development and because of their operation with fast helium ions as well as hydrogen and deuterium ions. We focused on two main effects: enhanced erosion rate and possible voltage breakdown from sharp flakes and gas emission.

We expect that blistering and flaking will occur in high-energy helium injection systems but do not presently have sufficiently clear results to know whether this will seriously affect the operation. If abnormal problems involving voltage breakdown or erosion are encountered during helium operation, the affected surfaces should be examined by microscope to determine if blistering is responsible.

INTRODUCTION

Blistering effects¹ in neutral injection systems will soon become more important for two reasons: the increase in energy of systems now under development and the operation of these systems with fast helium ions as well as hydrogen and deuterium ions. Injector operation with helium has several advantages,² the most important being that only one specie of helium ion He^+ is normally produced in an ion source (in comparison with the three hydrogen ion species H^+ , H_2^+ , and H_3^+).

However, blistering and flaking of electrodes and targets are more severe under helium bombardment because of the negligible solubility of helium in metals. Consequently, small bubbles of helium gas may form under the electrode surface. These may burst open, forming sharp metal flakes and releasing a puff of gas. Our main concerns with injection systems are the enhanced erosion rate and the possibility of voltage breakdown from sharp flakes and gas emission.

In this paper, we will conduct a preliminary assessment of the importance of these effects under operating conditions of injectors and associated beam-direct converters. It is premature to predict the effects under all conditions,

since the severity of blistering and flaking depends on factors such as the material, temperature, and surface conditions and the energy, angle of incidence, and intensity of bombarding particles. We will freely quote Sandia specialists³ on blistering without documenting the evidence behind each statement. We will not seriously attempt to differentiate between scientific terms such as true solubility and effective solubility, since we will assess the practical effects of blistering and flaking.

EXPOSURE RATES

George Thomas of Sandia has computed that blistering and flaking will occur under monoenergetic normal-incidence helium bombardment from 60 to 120 keV after exposures of 0.1 to 0.14 C/cm². This computation (by unpublished methods) applies to four target materials (nickel, copper, molybdenum, and tungsten) at temperatures from ambient to about one-third absolute melting temperature.

We may compute the operating time required for such exposures by dividing 0.1 to 0.14 C/cm² by the current density of fast-helium bombardment. Three interesting examples follow:

- Ion source grids are designed to undergo minimum bombardment. In principle, grid bombardment can be totally eliminated for primary beam ions but not for secondary ions produced by the ionization and charge exchange of background gas. Bombarding current densities have been computed for a designed reactor injector⁴ somewhat similar to the Lawrence Berkeley Laboratory 120-kV source. Computed current densities were only 1 to 3 mA/cm² because the grids were designed for minimum interception. Therefore, the predicted operating time before grid blistering begins may be 30 to 100 s during optimized operation. Grid bombardment will be more severe under tune-up conditions.
- The positive collector electrode of an inline-beam direct converter is designed to collect the charged ion beam at a current density up to 10 mA/cm². Blistering will begin after about 10 s of beam operation. This may not be serious because the ions will decelerate before they arrive at the collector and thermionic and secondary electrons will be electrostatically trapped at positive high voltage.

- Blistering of negative electrodes in a direct converter (because of ions produced from background gas) may be more critical. This problem can be minimized several ways if it is well understood. Bombardment rate can be reduced by a sufficiently low gas pressure.

Blistering rate is greatest if helium atoms are implanted at a uniform depth within the metal so they build up a high local concentration. One can significantly reduce blistering if implantation is by grazing incidence or energy-spread bombardment. A rough surface may also reduce blistering by spreading out implantation depth. For these reasons, the above exposure estimates may be the lower limits for the onset of blistering.

FLAKE THICKNESS

Flake thickness will be determined by the penetration depth of helium ions in the target material. For example, the flake thickness for nickel and tungsten bombarded by helium at normal incidence follows:

Helium beam energy (keV)	Flake thickness (μ)	
	Nickel target	Tungsten target
60	0.2	0.1
120	0.36	0.29

EROSION RATE

Erosion rate equals flake thickness multiplied by helium beam intensity divided by 0.1 to 0.14 C/cm² for each blistering layer. This implies that the effective sputtering coefficient due to blistering will be about 1 to 3 — about 100 times greater than the classical sputtering coefficient. On the average, at least one atom of the metal target will be lost for each helium ion impact.

As an example, we asked George Thomas to compute the lifetime of 0.001-in. nickel plating on our 120-kV direct-conversion electrodes under helium bombardment at 30° angle of incidence. This result was not extremely alarming — at 10 mA/cm² helium bombardment, we can expect nickel plating to survive for 300 to

3000 shots of 0.5 s pulse duration (depending on electrode potential and incidence angle). This erosion rate is tolerable for an experiment but not for a reactor application.

EFFECT OF TEMPERATURE ON VARIOUS TARGET MATERIALS

The effect of temperature on a number of metals has been shown to scale in proportion to the absolute melting temperature. The most serious condition occurs when operating temperature is less than one-third absolute melting temperature. At higher temperatures, bubble growth can proceed within the metal, causing less severe damage to the target.

This phenomenon will reduce the blistering effect for high-power pulsed beams, since surface temperature will instantaneously be high during the beam pulse. However, gas emission may occur during this pulse as surface temperature rises.

VOLTAGE HOLDING

Miley,⁵ in a study of voltage-holding of blistered wires, found that the ultimate voltage-breakdown limit was not seriously reduced although blistering caused significant increases in prebreakdown currents. However, Miley's tests did not include the *in situ* radiation-voltage experiments he recommended. Voltage-holding of a surface under bombardment during blistering has not yet been investigated. Some of the obvious problems are breakdown due to the sharp edges of flakes and puffs of re-emitted helium gas and vaporized metal.

THERMIONIC EMISSION, MELTING, AND VAPORIZATION OF FLAKES UNDER BOMBARDMENT

A thin flake bombarded by a beam will rise in temperature to a level limited by radiation, melting, or its vaporization. If the flake is 0.2 μ thick, the temperature rise will occur in less than 1 ms. The least desirable condition is thermionic emission from a negative electrode. This will occur steady-state if the heat load on the thin flake is from 50 to 200 W/cm^2 , assuming an emissivity of 0.3. This may occur on ion-source grids⁴ or direct converter electrodes. If the heat load is greater than this, the flake will melt or vaporize within 1 ms. During the temperature rise, up to 10^{12} gas atoms will be emitted from each flake.

BLISTERING BY HYDROGEN AND DEUTERIUM

Blistering by hydrogen and deuterium bombardment rarely occurs because of the increased solubility of hydrogen and deuterium. George Thomas believes this may occur in tungsten but not in nickel.

CONCLUSION

The situation is not sufficiently clear to predict with certainty whether blistering and flaking will seriously affect our injection systems with high-energy helium. We should examine our negative electrodes and targets by microscopy after our helium experiments. Some of the danger signs we may look for are abnormal voltage-holding problems, beam erosion, or a frosty appearance on exposed surfaces.

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