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by

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TEMPERATURE THRESHOLDS FOR SURFACE BLISTERING OF PLATINUM AND STAINLESS STEEL EXPOSED TO CURIUM-242 ALPHA RADIATIONS*

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Introduction and Summary

Implantation of helium in materials exposed to alpha-emitting radionuclides such as Cm-242 causes surface blistering at elevated temperatures.[1,2] The temperature thresholds for such blistering are of practical importance to the selection of suitable container materials for radionuclides, and are of fundamental interest with regard to the mechanisms of helium blistering of materials in radiation environments. The purpose of this investigation was to establish temperature thresholds for surface blistering of platinum and stainless-steel container materials by post-irradiation heating of specimens exposed at room temperature to alpha particles from an external Cm-242 source. These thresholds were compared with (1) the analogous temperature thresholds for surface blistering of materials exposed to external beams of accelerator helium ions, and (2) thresholds for swelling and grain-boundary cracking of materials in which helium is generated internally by (n,α) reactions during reactor exposures.

This investigation showed that on post-irradiation heating, the temperature thresholds for surface blistering of specimens exposed to Cm-242 corresponded closely with the thresholds for surface blistering of similar specimens exposed to external beams of accelerator helium ions that yielded the same concentrations of implanted helium. The temperature thresholds for blistering by either Cm-242 alpha particles or accelerator helium ions were, however, considerably higher than the corresponding thresholds for swelling and related grain-boundary cracking of materials by internal helium generation during neutron exposures. The higher temperature thresholds for blistering of helium-implanted specimens by external radiation sources were attributed to restraints on surface distortions accompanying blistering by the unexposed underlying material.

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Experimental Procedures

The helium-implanted specimens were obtained, as previously described,[1] by exposure of platinum metal disks (0.002 inch thick) to the 6-MeV alpha particles from 50% pure Cm-242 oxide deposits within Type 304L stainless steel containers. Storage for up to 311 days near room temperature exposed the platinum disks to 5×10^{17} α/cm^2 and the stainless steel containers to 3×10^{18} α/cm^2, and implanted helium in concentrations ranging from maxima of about 1 atom % and 5 atom %, respectively, at the specimen surfaces to zero at the 10-to-15-μm range of the alpha particles. Segments of exposed specimens were heated at successively higher temperatures after irradiation to establish thresholds for surface blistering caused by the implanted helium. Exposure and temperature conditions for the specimens are shown in Table I. Surfaces of the specimens were examined after exposure and post-exposure heating by optical and scanning electron microscopy. Exposed but unheated specimens showed no surface damage.

Results of Post-Irradiation Heating Tests

Heating the platinum specimens at temperatures up to 1200°C in air produced only grain boundary pores. These pores were increasingly evident at higher temperatures in both exposed and unexposed areas of the specimens. At 1300°C and above, however, the exposed areas of the platinum specimens developed well-defined surface blisters, along with large (5 μm) holes, as shown in Fig. 1. The surface distortions produced by blistering exhibited contours outlining apparent grain boundaries. Metallographic sections showed the blistering to be caused by agglomeration of helium into relatively large (1 to 10 μm) bubbles within a 10-μm-thick surface layer of the specimens (Fig. 2).

Heating the exposed stainless steel specimens up to 800°C produced no well-defined surface blistering, but at 900°C and above, exposed areas of the stainless steel specimens developed a blistered surface increasingly distorted at higher temperatures (Fig. 3). Metallographic examination of cross sections revealed a porous surface layer about 15 μm thick with helium agglomerated into many small (about 1 μm) bubbles (Fig. 4).

Discussion

The temperature thresholds for blistering and related surface distortion of platinum and stainless steel specimens produced by heating after exposures at room temperature to Cm-242 were compared with (1) blistering thresholds for similar metals (Al, Pd, V, Nb, Mo, Ti, and stainless steel) exposed over a wide temperature range

to accelerator helium ions,[3] and (2) the thresholds for swelling and related grain boundary cracking of metals (Al-Li, Mg-Li, Cu-B alloys and Be) due to internal helium generation by neutron exposures.[4] In spite of fundamental differences in the depth distribution of implanted helium and the differing temperatures of helium implantation, the temperature thresholds for blistering by Cm-242 alpha radiation corresponded closely to the thresholds for blistering by accelerator helium ions. The concentration of helium implanted by exposure to Cm-242 is a maximum at the specimen surface and decreases linearly to zero at depths equal to the 10-to-15-μm range of the alpha particles.[2] Temperature thresholds for blistering of the platinum and stainless steel specimens corresponding to the maximum implanted helium concentrations were $0.77T_m$ and $0.63T_m$, respectively, where T_m is the melting temperature in °K. The concentration of helium implanted by exposure to accelerator helium ions is a maximum near the end of the much lower range of the 20-to-300-keV helium ions employed. Blistering thresholds for specimens exposed to the accelerator helium ions ranged from about $0.8T_m$ for 1 atom % implanted helium to less than $0.1T_m$ for 50 atom % implanted helium. These temperature thresholds generally accommodated the blistering thresholds for specimens exposed to Cm-242 alpha particles as well. The resulting correlation represents a fundamental temperature-dependence for surface blistering of materials by simple external helium sources, for comparison with the behavior of materials implanted with helium by other means.[5,6]

In contrast, the temperature thresholds for surface blistering by either Cm-242 alpha particles or accelerator helium ions are significantly higher than the threshold temperatures for swelling and cracking by internal helium generation during neutron exposure. Experience with magnesium-lithium,[7] aluminum-lithium,[8] and copper-boron alloys,[9] and with beryllium metal[10] is represented schematically in Fig. 5, which shows temperature thresholds for significant swelling or grain-boundary cracking as a function of helium content. These thresholds range from about $0.7T_m$ at low helium concentrations (0.2 atom %) to less than $0.5T_m$ at intermediate helium concentrations (2 atom %). These thresholds are significantly lower than the blistering thresholds for materials exposed to external helium sources. Although the blistering produced by the external helium sources probably represents a more pronounced distortion, requiring higher helium concentrations than the grain boundary swelling and cracking resulting from internal helium generation, the higher swelling thresholds for surface blistering may be attributed to restraints by the unexposed underlying metal.

It is concluded that materials such as platinum and stainless steel can be used at higher temperatures without deleterious effects in environments that generate helium from external

radiation sources than in environments generating helium from internal radiation sources.

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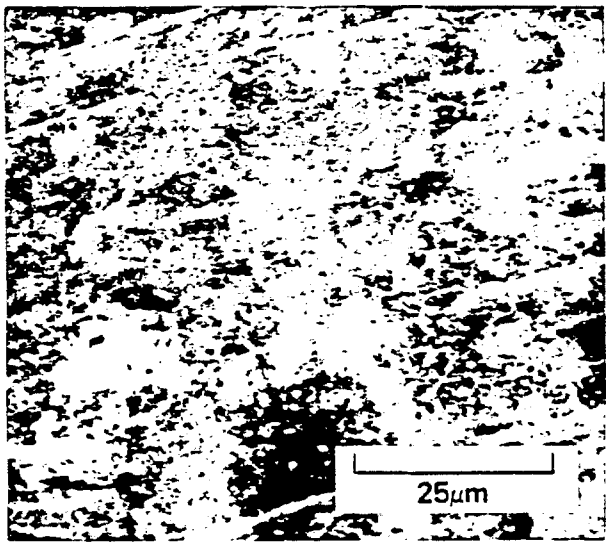
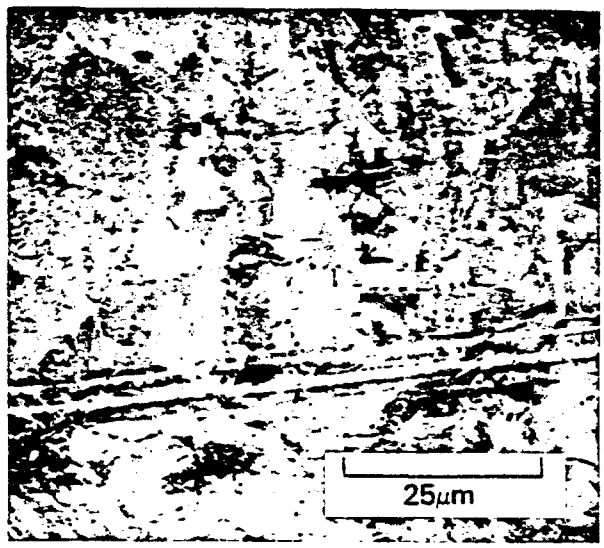
Table 1

Exposure and Temperature Conditions for Specimens Exposed to Cm-242 Alpha Radiation

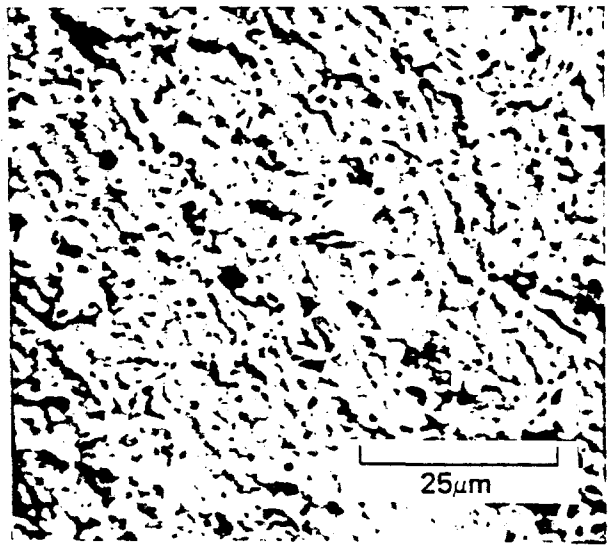
Specimen	Alpha Exposure		Temp. of Post-Expos. Heating, °C	Surface Blistering
	α/cm^2	He, atom %		
Platinum	5×10^{17}	about 1	--	None
			1100	None
			1400	Moderate
Platinum	Unexposed	-	--	None
			1100	None
			1400	None
Platinum	5×10^{17}	about 1	--	
			1600	Heavy
Platinum	Unexposed	-	--	None
			1600	None
Platinum	5×10^{17}	about 1	--	None
			1200	None
			1300	Moderate
Platinum	Unexposed	-	--	None
			1200	None
			1300	None
Stainless Steel	3×10^{8}	about 5	--	None
			500	None
			800	None
			900	Moderate
			1000	Heavy



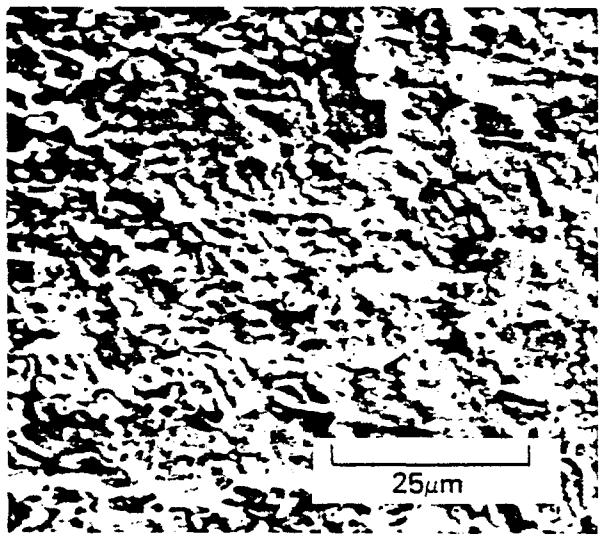
Heated at 1100 °C



Heated at 1200 °C



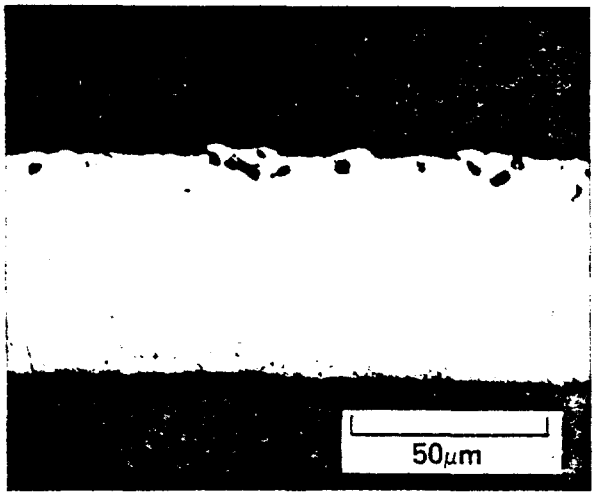
Heated at 1300 °C



Heated at 1400 °C

Fig. 1. Platinum Surfaces Heated After Exposure to Cm-242 Alpha Radiation (Maximum 1 atom % He). Note blistering threshold at about 1300 °C.

Heated at 1300 °C



Heated at 1600 °C

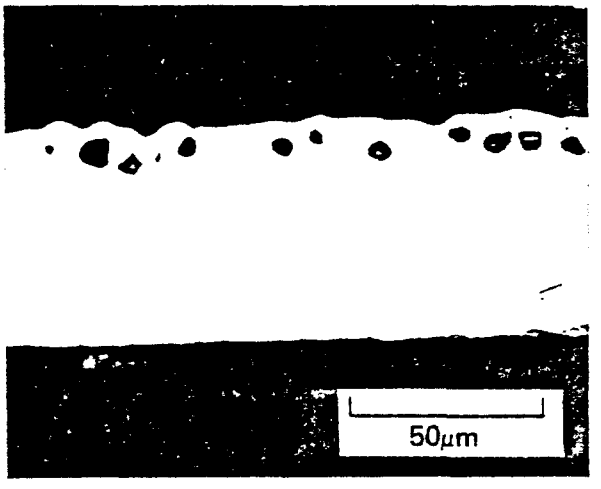


Fig. 2. Cross Sections of Platinum Specimens Heated After Exposure to Cm-242 Alpha Radiation

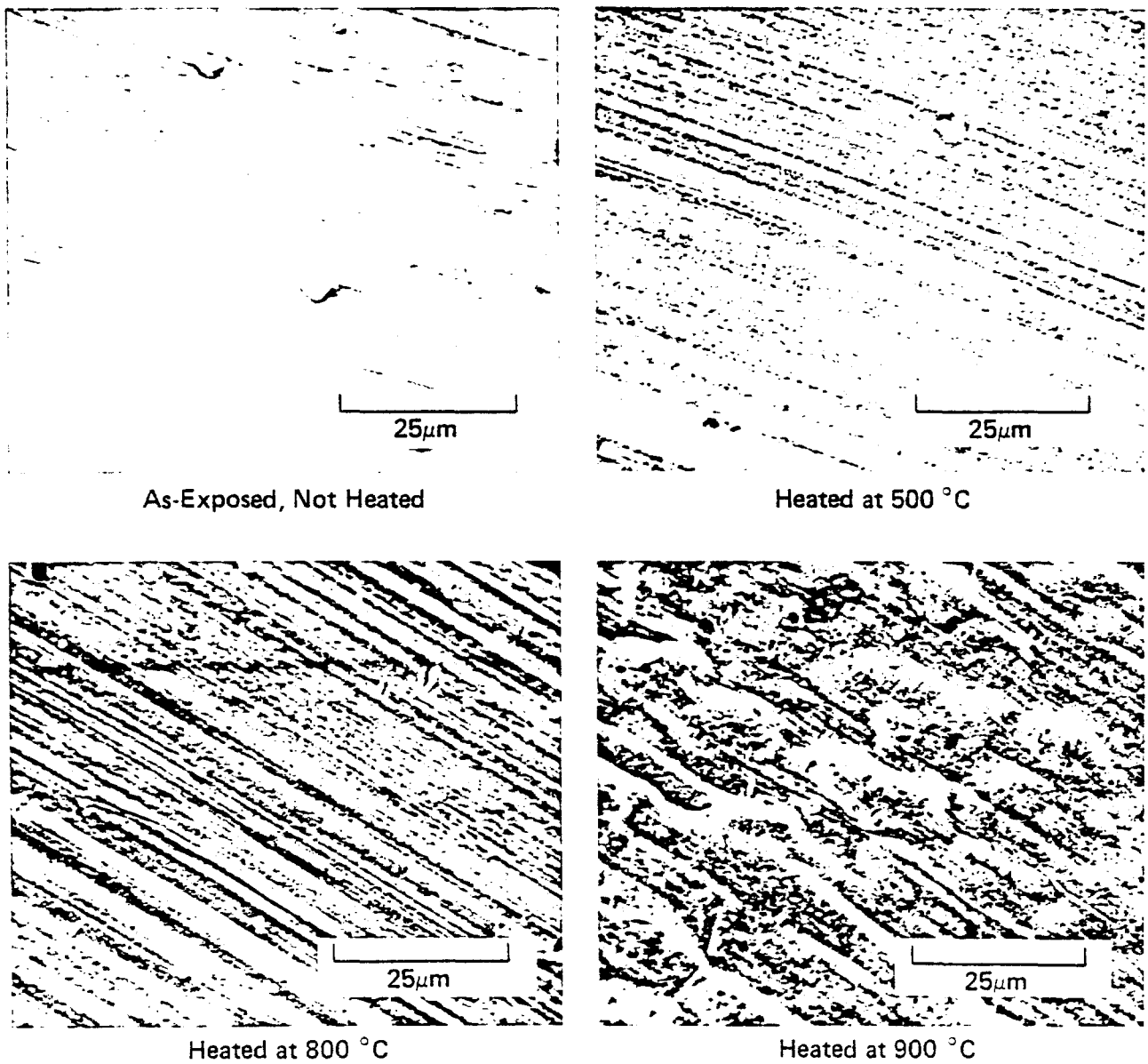


Fig. 3. Stainless Steel Surfaces Heated After Exposure to Cm-242 Alpha Radiation (Maximum 5 atom % He). Note blistering threshold at about 900 °C.

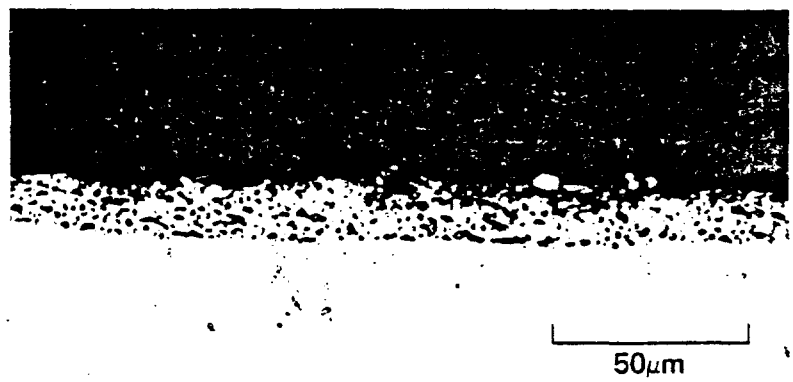


Fig. 4. Cross Section of Stainless Steel Specimen Heated at 1000 °C After Exposure to Cm-242 Alpha Radiation

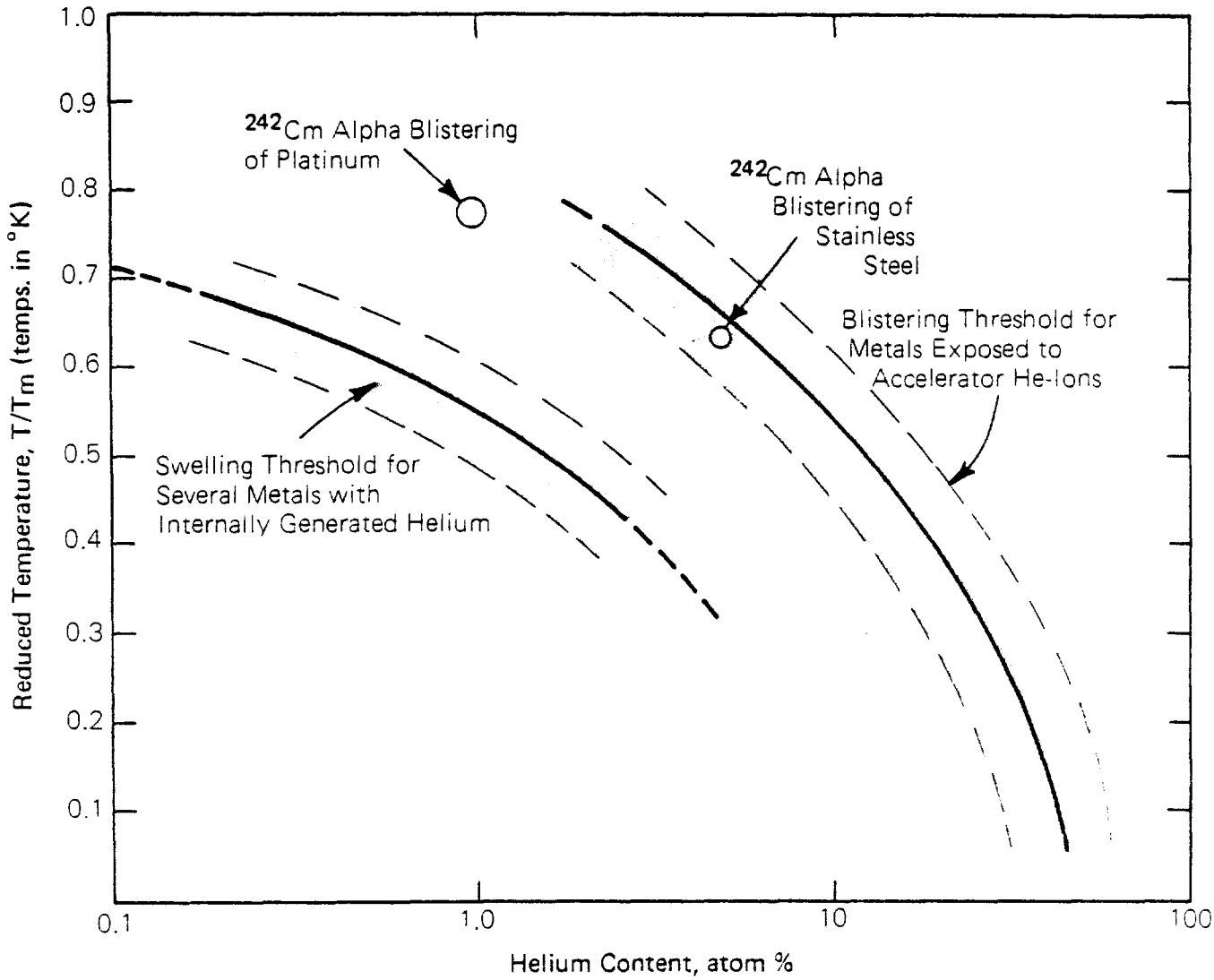


Fig. 5. Threshold Temperatures for Swelling and Blistering of Helium-Implanted Metals