DISCUSSION

W. L. Bell[1] (*written discussion*)—Analyses of channel traces in deformed irradiated Zircaloys have indicated that slip planes of the type $\{10\bar{1}1\}$ and $\{11\bar{2}2\}$ may be operative. Single trace analyses using the images and electron diffraction patterns of Williams and Gilbert[2] resulted in the following observations[3]: at a fluence of 8×10^{20} neutron (n)/cm^2 ($E > 1$ MeV) channel traces were clearly $\{1\bar{1}00\}$ indicating prismatic slip. At a fluence of 8×10^{21} n/cm^2 the traces were invariably closest to $\{11\bar{2}2\}$, but $\{10\bar{1}1\}$ and $\{1\bar{1}00\}$ traces were arranged nearby making elimination of these difficult. However, there was one instance wherein a channel trace was 1 deg away from a $\{11\bar{2}2\}$ trace while being 15 deg away from the nearest traces of the planes $\{10\bar{1}1\}$ and $\{1\bar{1}00\}$. Other possibilities were not considered.

Figure 16 shows a dislocation channel observed in Zircaloy cladding irradiated to a fluence of 2.35×10^{21} at 327°C and subjected to a closed end burst test[4] at 343°C. Three distinct channel directions are observable indicating that cross-slip has occurred. Two trace analyses were performed on these channels for zone axes $[4\bar{5}16]$ and $[2\bar{7}53]$, 37 deg apart. The changes in trace directions were consistent with the movement of poles normal to the direction $[11\bar{2}3]$ and allowed the elimination of other poles which appeared as possibilities for one or the other zone axes. The slip planes for the traces shown are analysed as two well-defined $\{10\bar{1}1\}$ planes connected by an intermediate cross-slip plane near, but not exactly, $(1\bar{2}1\bar{2})$. Thus, there is evidence for the passage of $(\vec{c} + \vec{a})$ dislocations in irradiated materials. These $(\vec{c} + \vec{a})$ slip systems have been discussed by Tenckhoff[5] as becoming operative at elevated temperature under restraint, and Akhtar[6] found pyramidal slip involving $(\vec{c} + \vec{a})$ on $\{10\bar{1}1\}$ during compression of zirconium along the c-axis above 550 to 600°C. Our results indicate that $(\vec{c} + \vec{a})$

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[2]Williams, C. D. and Gilbert, R. W. in *Radiation Damage in Reactor Materials*, IAEA Vienna, International Atomic Energy Agency, Vol. 1, 1969, p. 235.

[3]Bell, W. L., private communication to C. D. Williams.

[4]Rieger, G. F., private communication.

[5]Tenckhoff, E., *Zeitschrift fuer Metallkunde*, Vol. 63, 1972, p. 192.

[6]Akhtar, A., *Journal of Nuclear Materials*, Vol. 47, 1973, p. 79.

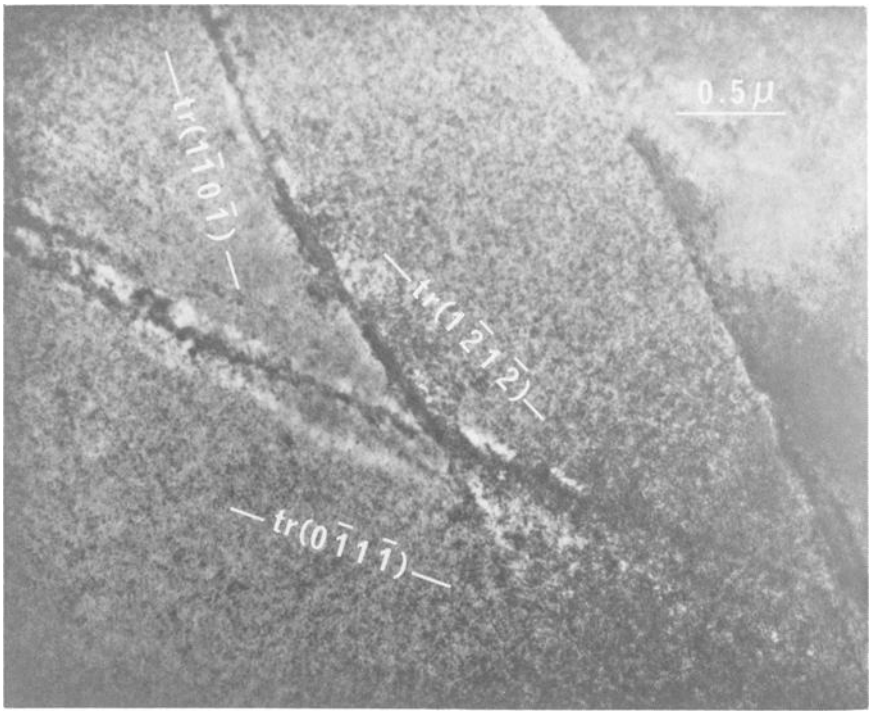

FIG. 16—*500 KeV electron micrograph of channels in burst irradiated Zircaloy fuel cladding. Operating reflection is* ($1\bar{1}0\bar{1}$).

slip is an important deformation mode in closed end burst tests of irradiated cladding even though the test temperature may be considerably lower than previously reported for such slip.

Twins have also been observed in this and other burst tubing similarly irradiated and tested. Traces of twin lamellae were often observed parallel to $\{10\bar{1}2\}$ traces and $\{11\bar{2}1\}$ has been observed once. Both of these have been mentioned by Tenckhoff in the text for tension along the basal pole. Diffraction pattern twin spots have been obtained which match twinning on $\{10\bar{1}1\}$; this twin plane has been reported by Tenckhoff[7], the text, and by Akhtar[6] for compression along the basal pole. Twin lamellae parallel to $\{11\bar{2}5\}$ traces were found occasionally which did not overlap the traces of the planes more commonly expected.

E. Tenckhoff (author's closure)—The findings of W. L. Bell are a further confirmation for the existence of $(\vec{c}+\vec{a})$ type Burgers vectors (that is, pyramidal slip) in zirconium and Zircaloy. They corroborate the points on possible irradiation effects for slip mechanisms in Zircaloy tubing under reactor service conditions, given in the text of the paper.

[7]Tenckhoff, E., *Zeitschrift fuer Metallkunde, Vol. 63, 1972, p. 729.*