DISCUSSION

David Franklin[1] —The decrease in strain that you have observed may be due to a combination of the specimen geometry of your samples and a decreasing ability of the material to work-harden. Deformation becomes restricted to smaller sections of the specimen as the difference in the ultimate stress and the yield stress is decreased. Essentially, one is decreasing the effective gage length of the sample. As deformation is restricted to smaller regions, the extension of the sample decreases.

R. T. King (author's closure)—We agree. The problem of specimen geometry is an unknown factor, and almost certainly the work-hardening coefficient is reduced by irradiation. The ductility values we quote are useful only for indicating changes from one dogbone specimen to another. These pseudo-ductilities should certainly not be considered as engineering design data.

R. M. Mayer[2] —We wish to report some preliminary observations on the effect of substitutional solutes on the nucleation of voids in aluminum. Dilute alloys of nominal concentration 0.2 percent atomic were cast from zone-refined aluminum using either high-purity silicon or high-purity indium. All samples were irradiated at the same time in the same rig to a dose of 2.5×10^{20} n/cm^2 (E>0.1 MeV) at 50 C (112 F) in the MTR reactor Safari-I.

Transmission electron microscopy revealed more polyhedral-shaped voids in the aluminum/indium alloys (Fig. 7) than in the zone-refined aluminum, but none were observed in the aluminum/silicon alloy. Numerous dislocation tangles and a large number of small dislocation loops were observed in the latter (Fig. 8). These changes in microstructure have been confirmed by the changes in mechanical properties, namely, the yield stress and the steady-state creep rate.

In aluminum, clusters are not produced directly in the displacement spikes, but as the result of the random agglomeration of vacancies or interstitials. When solute atoms are added, each solute atom does not act as a nucleation center, and this is similar to the case of adding boron to graphite and subsequently irradiating.[3]

A possible explanation of the enhanced nucleation is as follows: An aluminum

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[3] Brown, L. M., Kelly, A., and Mayer, R. M. in *Philosophical Magazine*, Vol. 19, 1969, p. 721.

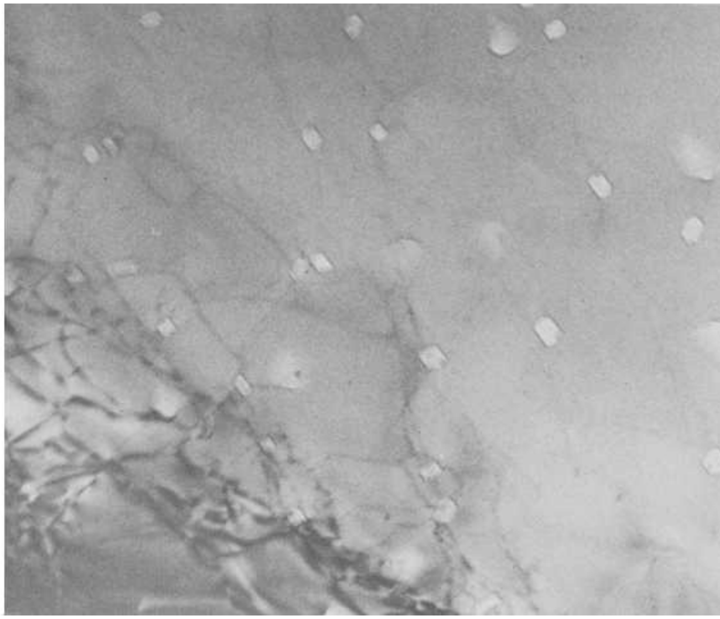

FIG. 7– *Voids in an Al-0.2In alloy irradiated 2.5 x* 10^{20} *n/cm*^{2} *(*E $>$ *0.1 MeV) at 50 C (122 F). Magnification x100 000.*

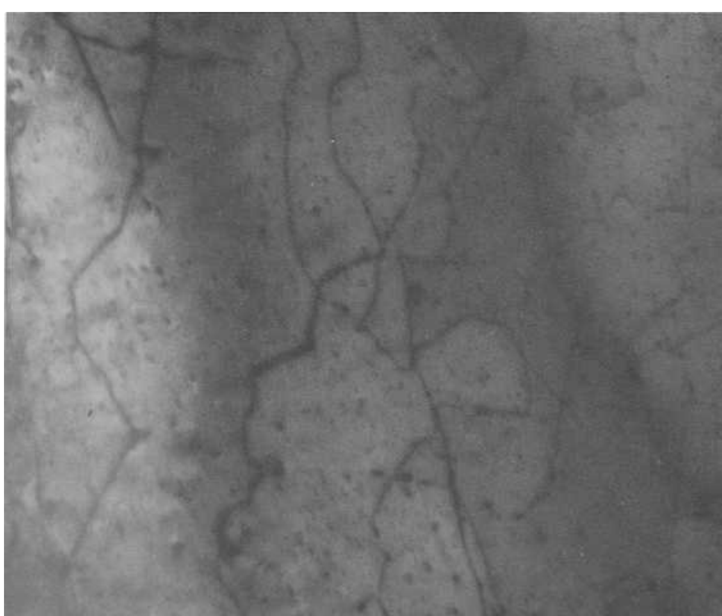

FIG. 8– *Dislocation loops and lines in an Al-0.2Si alloy irradiated 2.5 x* 10^{20} *n/cm*^{2} *(*E $>$ *0.1 MeV) at 50 C (122 F). Magnification x100 000.*

interstitial atom migrating through the lattice will associate with a stationary substitutional solute atom for part of its lifetime. One can therefore consider two types of nucleation—homogeneous nucleation when one unbound interstitial meets another unbound interstitial and heterogeneous nucleation when an unbound interstitial encounters another interstitial already associated with a solute atom. The greater the solute concentration, the more important the latter process becomes.

The same type of nucleation processes can also occur for the vacancies. An increase in void concentration will result provided that there is sufficient gas to prevent the vacancy clusters from collapsing into dislocation loops.

To the list of processes of void nucleation considered by Stiegler in a recent review,[4] one must add "nucleation due to substitutional solutes." Moreover, different substitutional solutes have different effects on the nucleation of voids and clusters. Whether voids are seen in a given material after a particular neutron dose will depend *inter alia* on which solutes or impurities are present.

R. T. King (authors' closure)—Solutes or impurities undoubtedly do influence void formation in aluminum. At ORNL we have established that the threshold fluence for the onset of voids increases with decreasing purity. We have also examined the effects of some specific elements. Helium and hydrogen promote void formation but we have not yet found a substitutional element that enhances void formation. Magnesium is a strong deterrent. Mayer's observations on the effects of iridium and silicon are interesting but whether their effectiveness arises from these elements in substitutional solid solution is questionable. Both iridium and silicon form eutectics with aluminum and have low solid solubilities, about 0.02 atomic percent iridium at 560 C (1040 F) and about 0.05 atomic percent silicon at 250 C (482 F). The influence of silicon is surprising since silicon is created as a transmutation product during irradiation and we find that in high-purity aluminum such silicon, even at levels greater than 0.2 percent, does not prevent development of voids. Moreover, we have found voids in a number of commercial aluminum alloys containing silicon concentrations up to 0.66 atomic percent as major impurity or as alloying addition.

[4] Stiegler, J. O., presented at the International Conference on Radiation-Induced Voids in Metals, Albany, N. Y., June 1971, to be published.

[5] Hansen, M., *Constitution of Binary Alloys*, McGraw-Hill, New York, 1958, pp. 100 and 132.