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SWELLING OF HIGH-NICKEL Fe-Ni-Cr ALLOYS IN EBR-II

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(CONTRIBUTION TO DAFS QUARTERLY)

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H. R. Brager and F. A. Garner (Hanford Engineering Development Laboratory)

1.0 Objective

The objective of this effort is to identify the origins of the compositional dependence of swelling in simple ternary alloys.

2.0 Summary

Swelling data on Fe-Ni-Cr alloys with nickel in the 35-75 wt% range has been obtained to fluences as large as 2.2×10^{23} n/cm^2 ($E > 0.1$ MeV) (∿110 dpa). At 15% chromium the swelling rate at 35, 45 and 75% nickel continues to increase with accumulating exposure, most clearly approaching 1%/dpa at ∿35% nickel. The minimum often observed in swelling at ∿45% nickel appears to be due to a maximum in the duration of the transient regime at this composition. Decreasing the chromium level from 15 to 7.5% extends the transient regime even further.

3.0 Program

Title: Irradiation Effect Analysis (AKJ)
Principal Investigator: D. G. Doran
Affiliation: Hanford Engineering Development Laboratory

4.0 Relevant Program Plan Task/Subtask

Subtask II.C.1 Effect of Material Parameters on Microstructure

5.0 Accomplishments and Status

5.1 Introduction

In another report the compositional sensitivity of neutron-induced swelling in annealed Fe-Ni-Cr alloys was reported for nickel levels of $\leq$35 wt% and exposures of $\leq$60 dpa.[1]

With the exception of Fe-35.5Ni-7.5Cr and Fe-34.5Ni-15.1Cr, the swelling data for these alloys clearly demonstrate that the primary influence of composition lay only in the duration of the transient regime that preceeded steady-state swelling (at a rate of $\sim$1%/dpa, essentially independent of both temperature and composition).

The data for the two alloys mentioned above (as well as two other alloys at 45 and 75% nickel content) were judged to be insufficient at those exposure levels to determine whether the lower swelling observed in them was a consequence only of an extended transient regime or also a reduction in the post-transient swelling rate relative to that of other Fe-Ni-Cr alloys.

Limited additional data are now available for these four alloys at exposures ranging from 75 to 110 dpa. The new swelling data tabulated in Table 1 were obtained by immersion density measurements on small microscopy disks irradiated in sodium-filled subcapsules in EBR-II.

5.2 Results

As shown in Figure 1 the swelling rate of Fe-34.5Ni-15.1Cr at 427 and 482°C is clearly approaching 1%/dpa similar to that observed at lower nickel levels. The determination of the eventual swelling rates at 400° and 454°C requires the acquisition of higher fluence data but the swelling rate at 510°C appears to be decelerating. Figure 2a provides a clue to the cause of this behavior, however, in that there clearly is a densification of 1% or more in progress. Since these are bulk density measurements it is most

TABLE 1

HIGH FLUENCE SWELLING DATA FOR FOUR TERNARY ALLOYS

	Temperature (°C)	$\phi t/10^{22}$ (E > 0.1 MeV)	dpa**	$\frac{\Delta V}{Vo}$ %
Alloy E37				
Fe-35.5Ni-7.5Cr	400	15.2	75	1.71
	454	15.8	79	1.93
	650	21.8	109	0.31
Alloy E22				
Fe-34.5Ni-15.1Cr	400	15.2	76	16.2
	427	14.5	73	21.9
	482	17.4	87	20.8
	593	22.0	110	2.90
	650	21.8	109	4.42
Alloy E23				
Fe-45.3Ni-15.0Cr	400	15.2	76	2.38
	427	14.5	73	8.19
	482	17.4	87	9.42
	538	20.3	102	5.26
	593	22.0	110	1.09
Alloy E24				
Fe-75.1Ni-14.6Cr	427	14.5	73	9.03
	510	21.0	105	21.1
	593	22.0	110	4.13*
	593	22.0	110	2.37*
	650	21.8	109	31.0

*Two separate and nominally identical specimens irradiated in the same packet, indicating the sensitivity of swelling at high temperature to ambient conditions.

**The displacements per atom listed in this column are approximate values only and assume that 5 dpa = 10^{22} n cm^{-2} (E > 0.1 MeV).

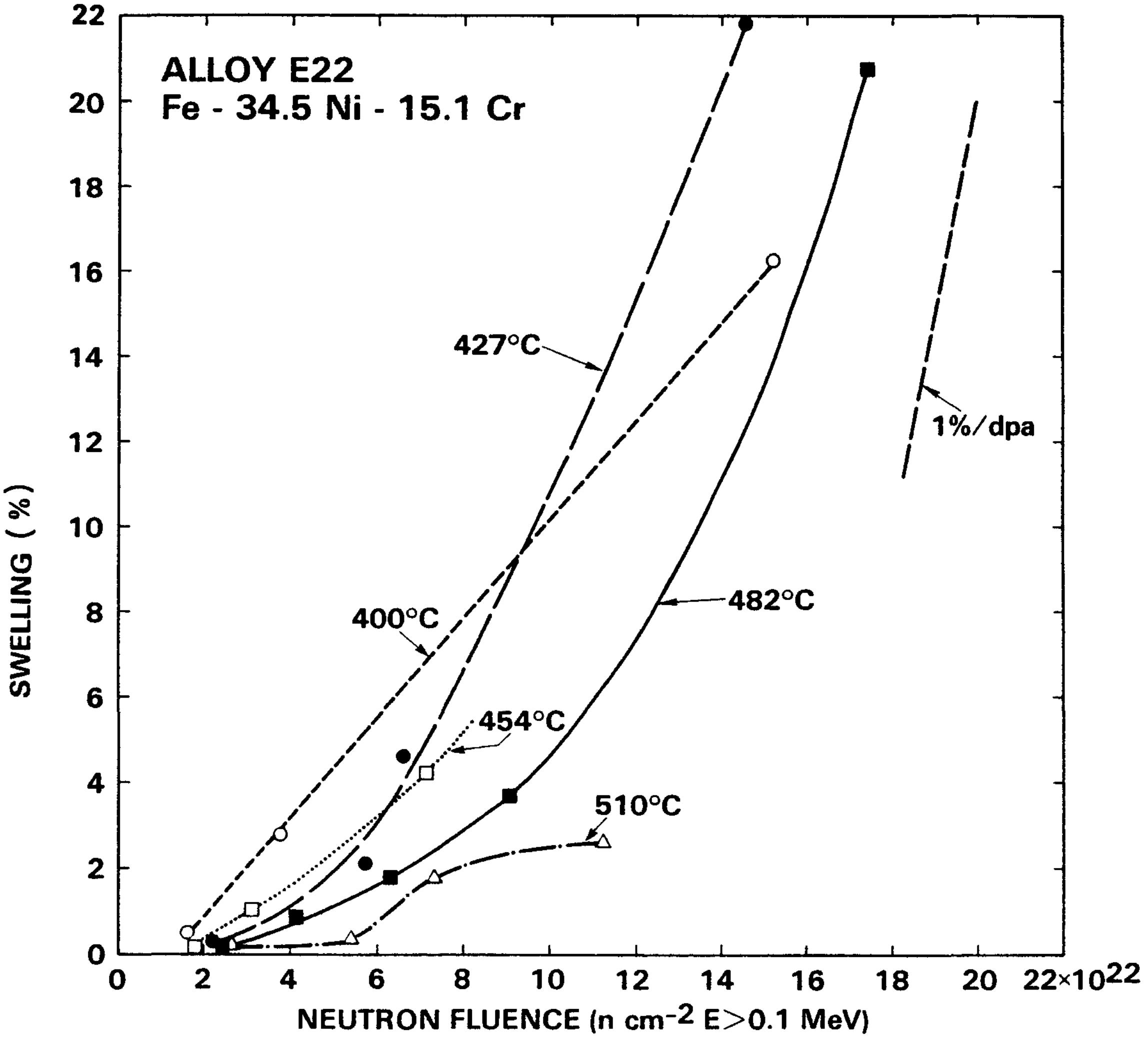

FIGURE 1. Swelling of Fe-34.5Ni-15.1Cr (Alloy E22) in EBR-II in the Range 400-510°C.

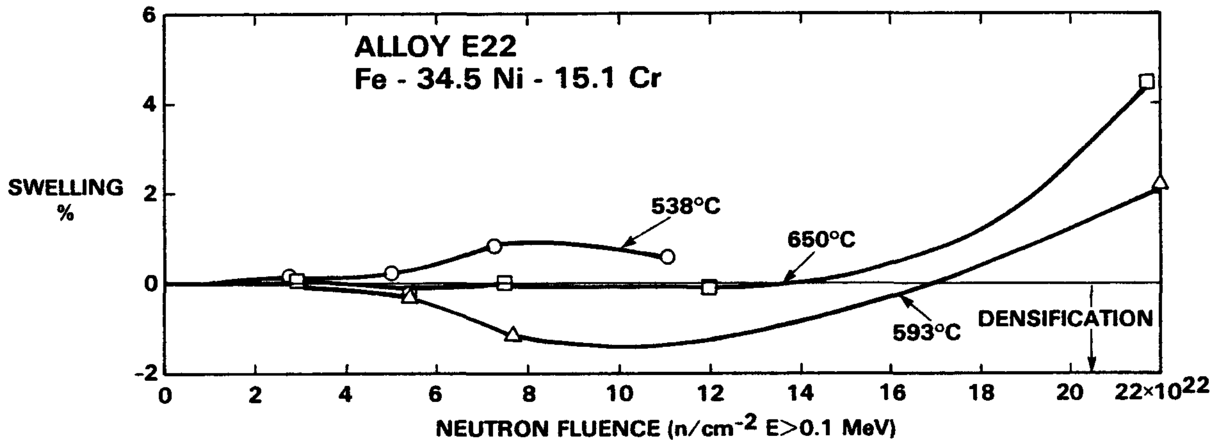

FIGURE 2a. Swelling and Densification of Fe-34.5Ni-15.1Cr (Alloy E22) in EBR-II in the Range 538 - 650°C.

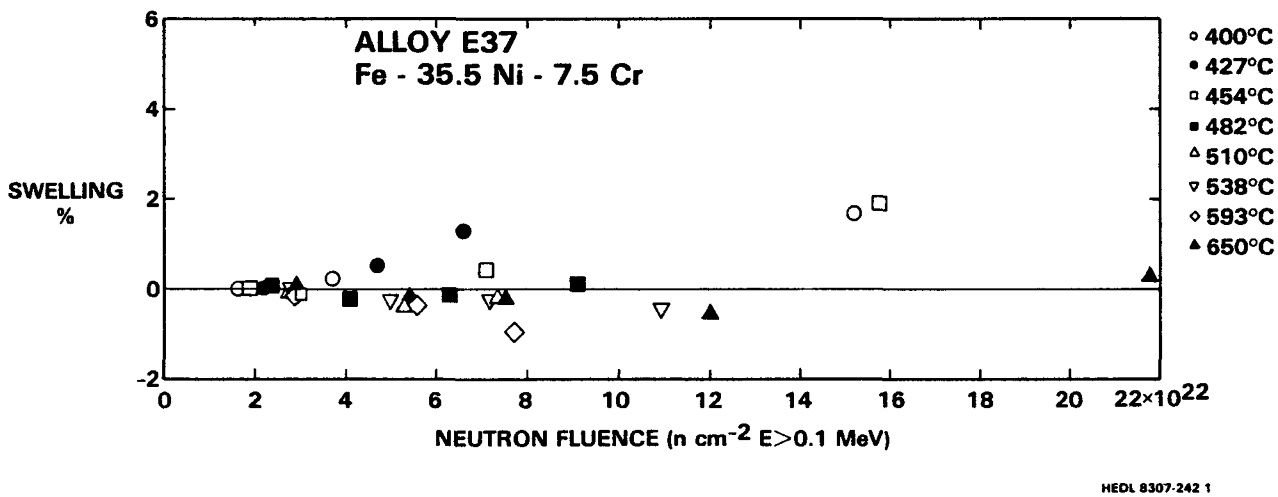

FIGURE 2b. Swelling and Densification of Fe-35.5Ni-7.5Cr (Alloy E37) in the Range 400 - 650°C.

likely that the apparent saturation of swelling at 510°C and apparent reduction at 538°C represents the competitive action of two separate processes: swelling and densification. The cause of the densification has been shown elsewhere to be microsegregation to both higher and lower nickel levels about a minimum in density that exists at ∿40% nickel.[2-4]

Figure 2b shows that the transient and densification regimes of Fe-35.5 Ni-7.5Cr persist to higher fluence levels than obtained to date. The swelling in general is lower than that of the Fe-35.5Ni-15.1Cr alloy, a result consistent with both neutron[1,2] and ion[5] experiments reported earlier.

Figures 3 and 4 shows that at ∿15% chromium and high nickel levels the swelling rate slowly increases with increasing exposure. At 75% nickel one observes that there is a regime of temperature (400 - 538°C) in which the swelling is relatively insensitive to temperature but at higher temperatures the transient regimes of swelling tend to become longer. At 35% nickel the same general trend is also observed. A noteable exception to this trend is seen at 650°C at 75% nickel.

In general it appears that the incubation periods of Fe-15Cr-XNi alloys at temperatures above 510°C exhibit a broad maximum at 45% nickel. This is consistent with a shallow minimum in swelling at that composition observed in ion irradiations.[5]

5.3 Conclusions

For Fe-15Cr-XNi alloys the swelling rate continues to accelerate with accumulating neutron exposure, even at nickel levels of 35-75 wt%, with about 1%/dpa as the upper limit. The minimum at ∿45% in ion-induced swelling previously reported by Johnston[5] appears to arise from a maximum in duration of the transient regime of swelling. Decreasing the chromium level from 15.1 to 7.5% chromium extends the transient regime to even higher fluences.

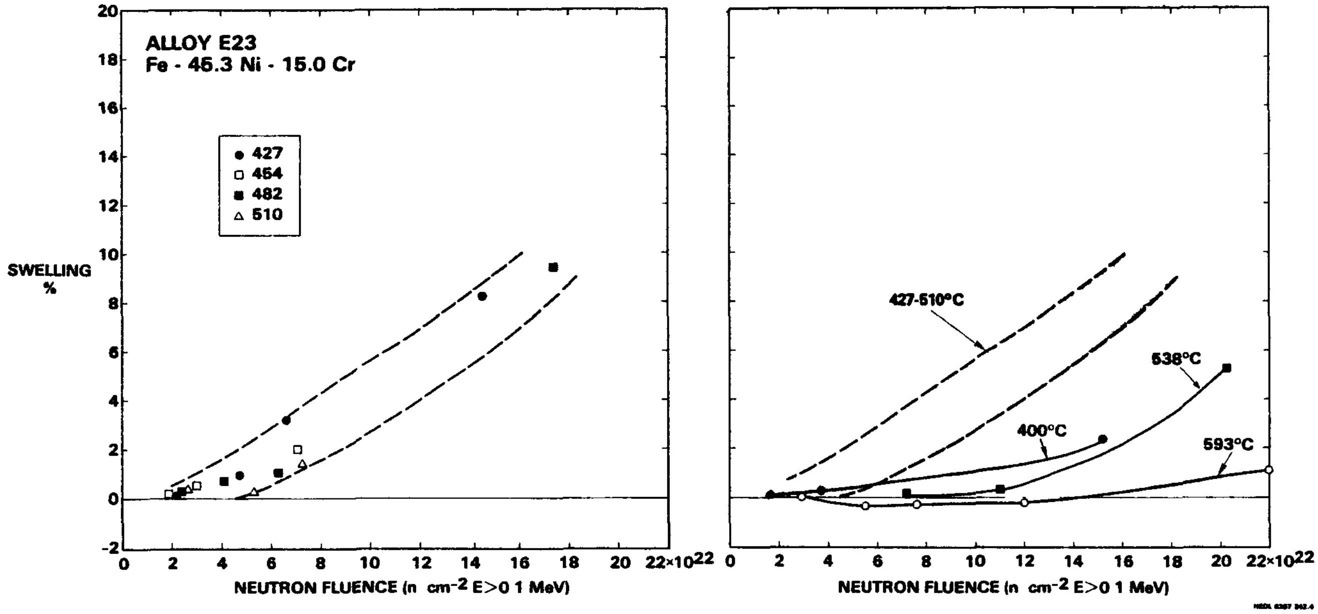

FIGURE 3. Swelling of Fe-45.3Ni-15.0Cr (Alloy E23) in EBR-II.

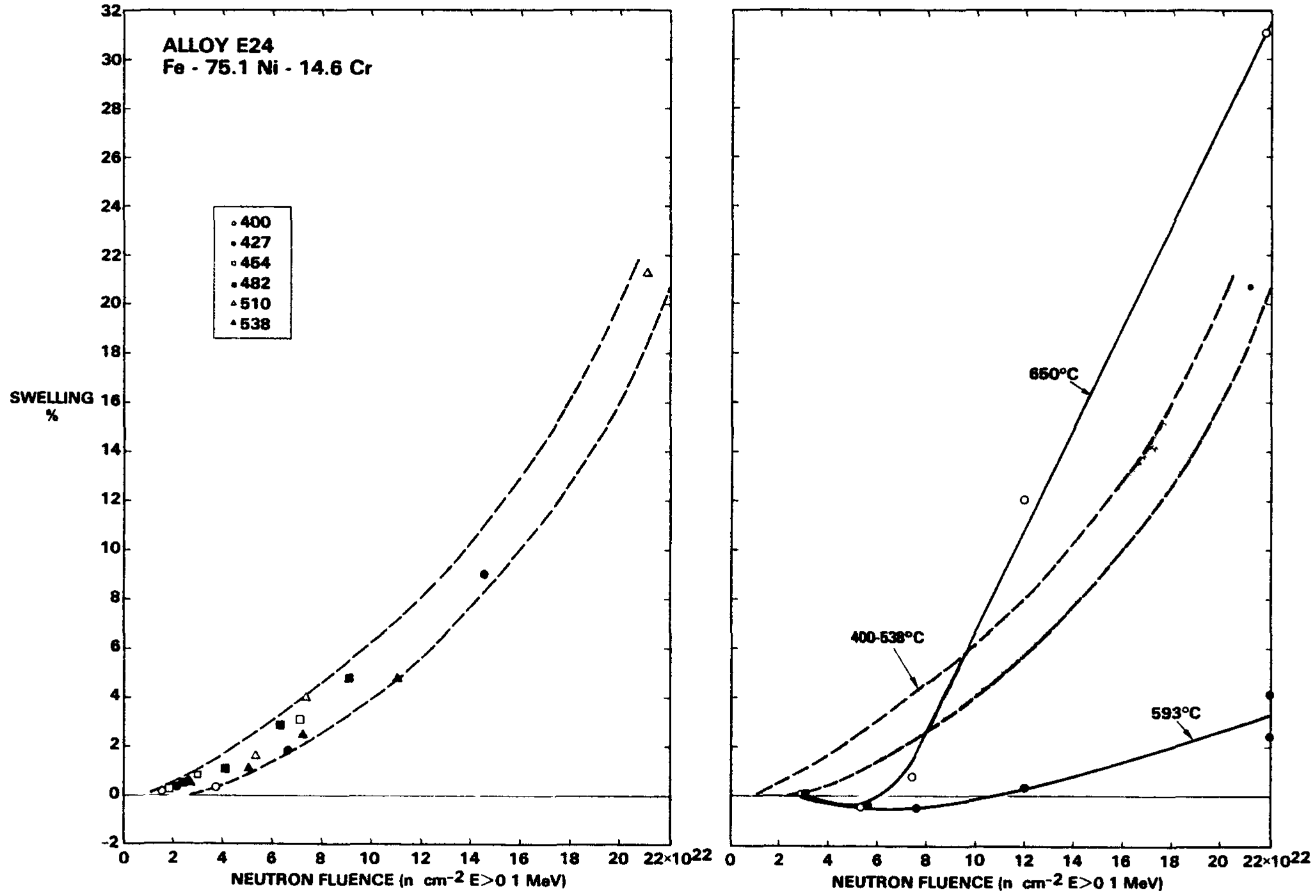

FIGURE 4. Swelling of Fe-75.1Ni-14.6Cr (Alloy E24) in EBR-II.

6.0 References

1. F. A. Garner, "Dependence of Swelling on Nickel and Chromium Content in Fe-Ni-Cr Ternary Alloys," this report.

2. H. R. Brager and F. A. Garner, "Dependence of Swellings of Fe-Ni-Cr Alloys on Chromium and Nickel Content," DAFS Quarterly Progress Report, DOE/ER-0046/11, p. 221.

3. H. R. Brager and F. A. Garner, "Radiation-Induced Evolution of Fe-Ni-Cr Alloys," DAFS Quarterly Progress Report, DOE/ER-0046/12, p. 170.

4. H. R. Brager and F. A. Garner, "Microsegregation Induced in Fe-35.5 Ni-7.5Cr Irradiation in EBR-II," this report.

5. W. G. Johnston, T. Lauritzen, J. H. Rosolowski and A. M. Turkalo, Effect of Metallurgical Variables on Void Swelling, General Electric Co. Report 76CRD019, January 1976.

7.0 Future Work

The origins of the composition dependence of swelling in the Fe-Ni-Cr system will be described in terms of the compositional dependence of both vacancy diffusivity and elemental segregation to voids.

8.0 Publications

None.