ORNL—DWG 80-17709

RESISTANCE OF $(Fe,Ni)_3V$ LONG-RANGE-ORDERED ALLOYS TO RADIATION DAMAGE*

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SUMMARY

The $(Fe,Ni)_3V$ long-range-ordered (LRO) alloys (path D) are being developed at ORNL for possible application as a first-wall material for a fusion reactor. Alloys with different Fe/Ni ratios have been screened for their resistance to radiation by irradiating them with 4 MeV Ni ions to 70 dpa at temperatures from 525 to 680°C. Helium (8 at. ppm/dpa) and deuterium ions (28 at. ppm/dpa) were simultaneously injected to better simulate fusion reactor conditions. Alloy LRO-16 (31 wt % Ni) contained sigma phase and showed swelling behavior similar to the 20%-cold-worked 316 stainless steel that was used as an internal standard. LRO-20 (39.5 wt % Ni), without sigma phase, swelled slightly less than the 316 stainless steel. Both alloys demonstrated noticeably lower swelling behavior when their composition was changed to include 0.4 wt % Ti. The mechanism whereby swelling was decreased by the titanium addition is not known at this time. All of the LRO alloys retained their ordered structure after 70 dpa, as long as the irradiation temperature was below the critical ordering temperature of approximately 670°C. In addition to small cavities, the irradiation produced small dislocation loops and dislocation segments in the LRO alloys. In one alloy (LRO-16), the VC precipitates were redistributed by the irradiation. Future work will include neutron irradiations of the LRO alloys and experiments focusing on the effect of titanium additions on swelling. The degree of order in the alloys will be measured using electron diffraction techniques and correlated with radiation effects. Finally, the effect of using ferrovanadium starting material on the microstructure and radiation resistance of LRO alloys will be investigated.

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MICROSTRUCTURAL STUDIES OF LRO ALLOYS

Alloy	Designation	TEM	Tensile	Radiation	dpa	Temperature Range (°C)	Helium Range (at. ppm)
1. $(Cr_{0.78}Fe_{0.22})_3V$	LRO-1	✓		4 MeV Ni^{++}	70	570–750	200*
2. $(Fe_{0.61}Ni_{0.39})_3V$	LRO-16	✓		4 MeV Ni^{++}	70	525–680	560*
$(Fe_{0.61}Ni_{0.39})_3V$ + 0.4 wt % Ti	LRO-35	✓		4 MeV Ni^{++}	70	525–680	560*
$(Fe_{0.49}Ni_{0.51})_3V$	LRO-20	✓		4 MeV Ni^{++}	70	525–680	560*
$(Fe_{0.49}Ni_{0.51})_3V$ + 0.4 wt % Ti	LRO-37	✓		4 MeV Ni^{++}	70	525–680	560*
3. $(Fe_{0.52}Ni_{0.38}Co_{0.10})_3V$	LRO-15	✓	✓	Neutrons ORR (MFE-2)	7	250,350, 550	50–170
$(Fe_{0.61}Ni_{0.39})_3V$	LRO-16	✓	✓	Neutrons ORR (MFE-2)	7	250,350, 550	50–170
4.	LRO-16	✓		Neutrons MFE-30-32	10,20, 40	300,400, 500,600	1200–7700
	LRO-35	✓		HFIR: Neutrons MFE-30-32	10,20, 40	300,400, 500,600	1200–7700
	LRO-20	✓		HFIR: Neutrons MFE-30-32	10,20, 40	300,400, 500,600	1200–7700
	LRO-37	✓		HFIR: Neutrons MFE-30-32	10,20, 40	300,400, 500,600	1200–7700

*Simultaneously injected.

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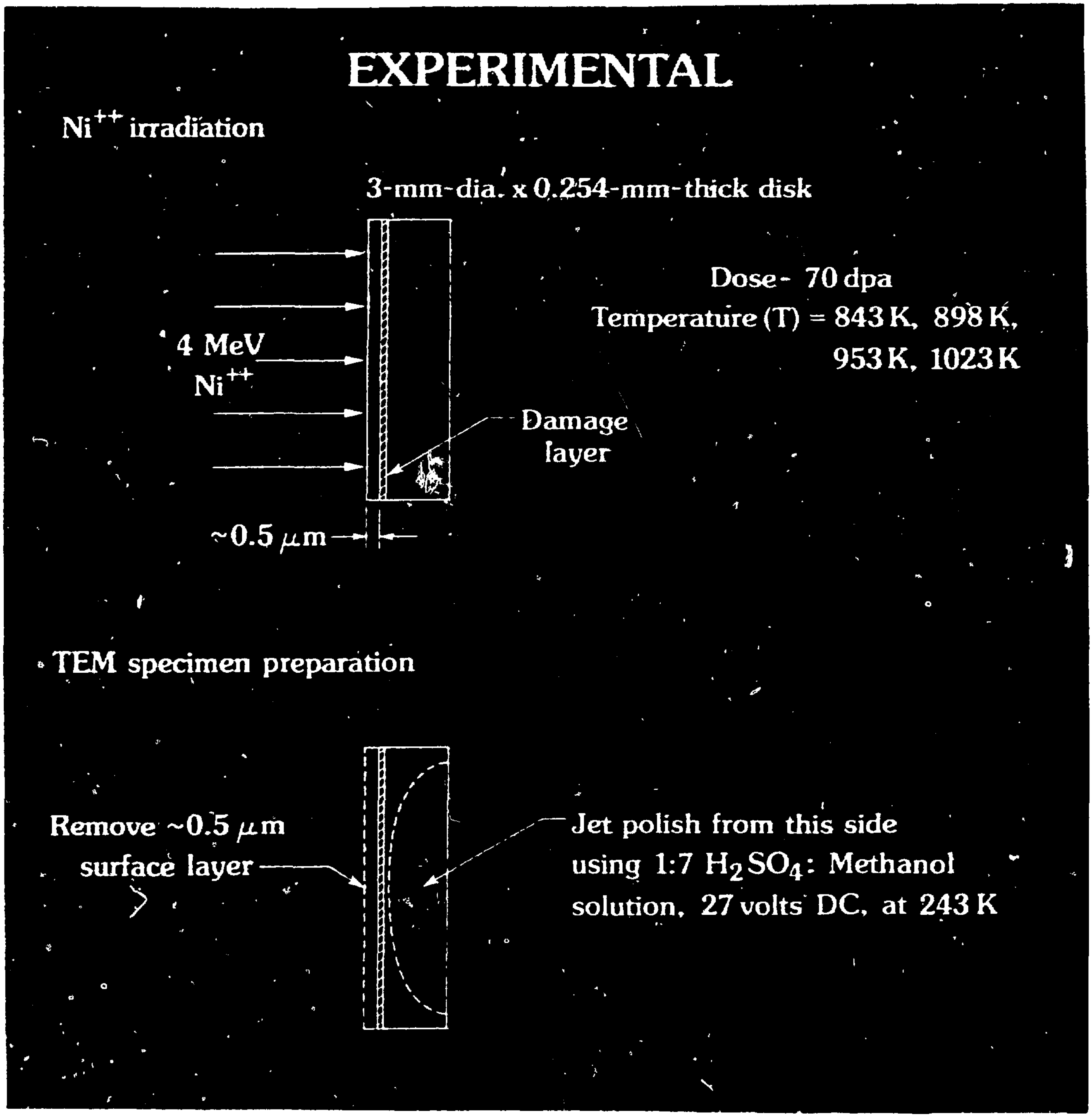
ALLOY COMPOSITION

Run	Alloy	Fe	Ni	V	Ti	Cr	Mo	Mn	C
I	LRO-16	46.1	31.0	23.0	--	--	--	--	Impurity
I	LRO-35	45.3	31.8	22.6	0.4	--	--	--	Impurity
II	LRO-20	37.6	39.5	22.9	--	--	--	--	Impurity
II	LRO-37	37.6	39.5	22.4	0.4	--	--	--	Impurity
I and II	D0316SS	Bal	13	--	0.005	18	2.0	1.9	0.05


EXPERIMENTAL
Ni++ irradiation
3-mm-dia. x 0.254-mm-thick disk
4 MeV Ni++
Dose - 70 dpa
Temperature (T) = 843 K, 898 K, 953 K, 1023 K
Damage layer
~0.5 μm
TEM specimen preparation
Remove ~0.5 μm surface layer
Jet polish from this side using 1:7 H2SO4: Methanol solution, 27 volts DC, at 243 K

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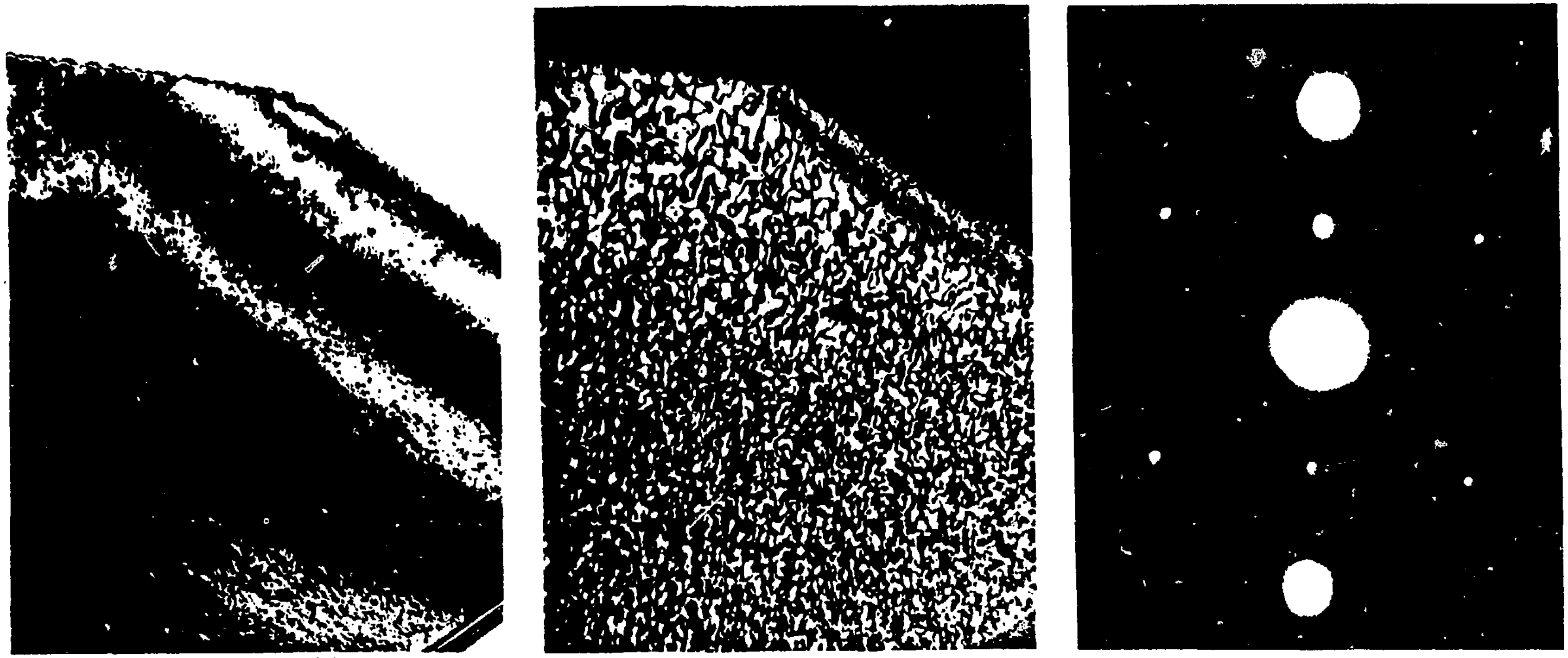
ORDERED DOMAINS IN LRO-16



Bright Field   0.5 μm   Superlattice Dark Field   SAD SHOWING {100} REFLECTIONS

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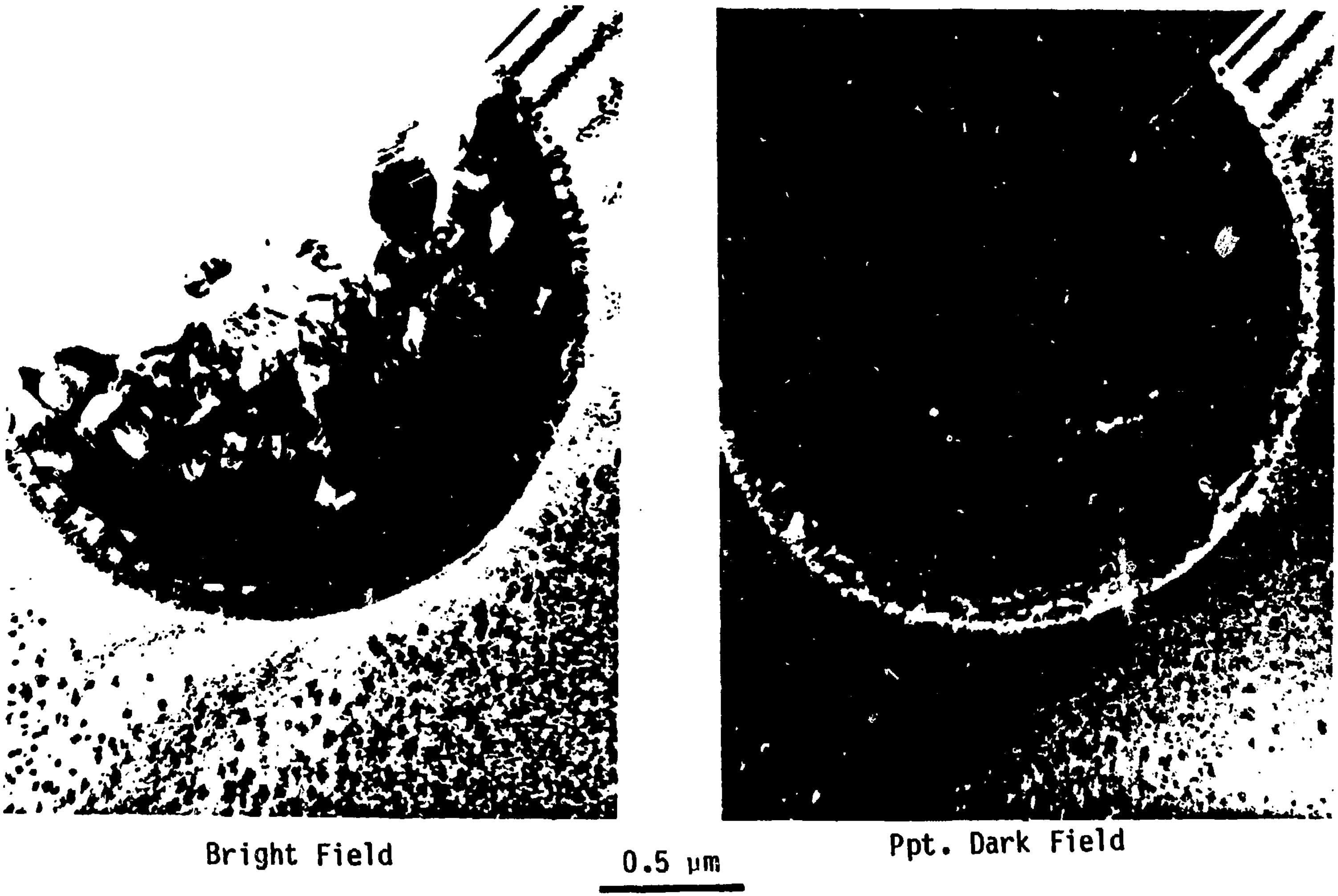
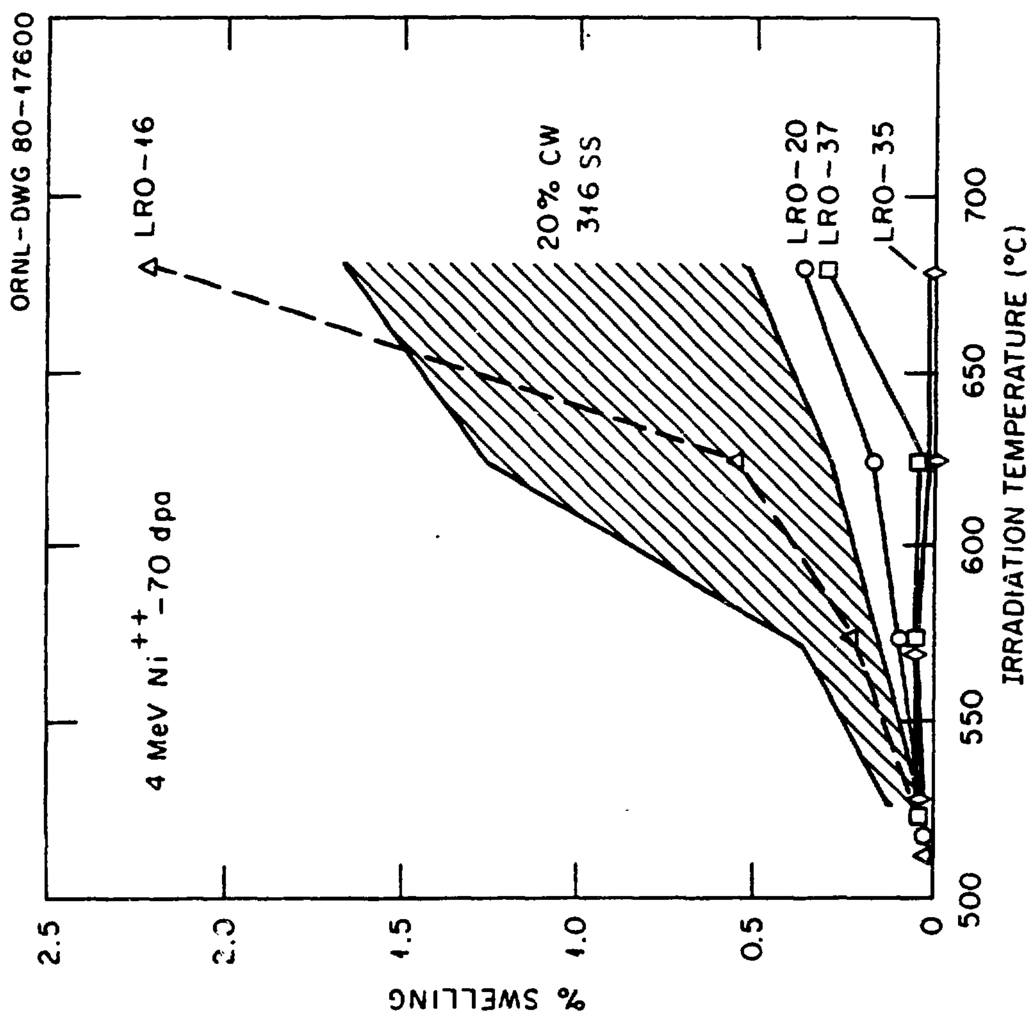
SIGMA PHASE IN LRO-16



Bright Field

0.5 μm

Ppt. Dark Field


ORNL-DWG 80-17600
4 MeV Ni^{++}-70 dpa
LRO-46
20% CW
316 SS
LRO-20
LRO-37
LRO-35
% SWELLING
2.5
2.0
1.5
1.0
0.5
0
500
550
600
650
700
IRRADIATION TEMPERATURE (°C)

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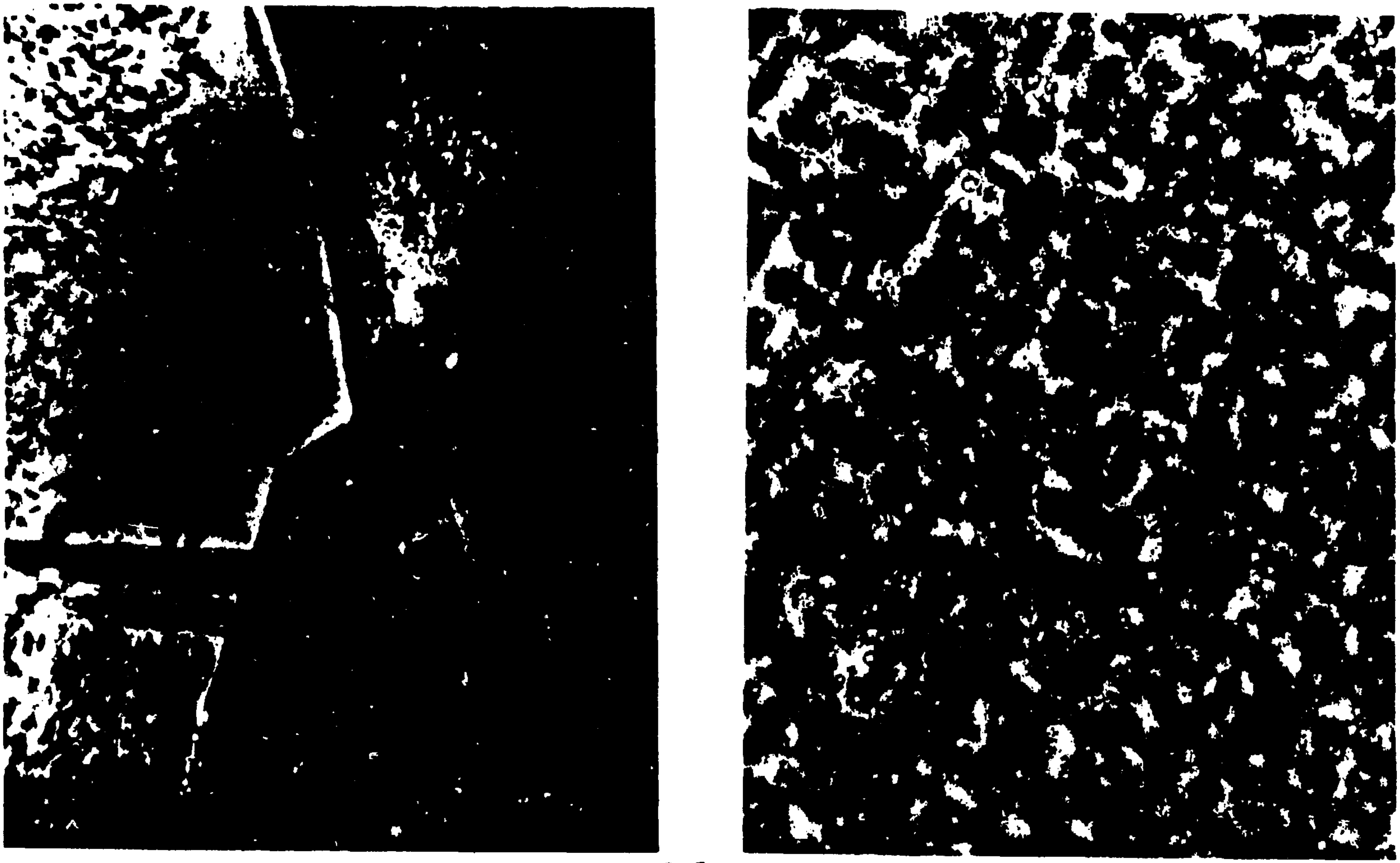
LRO-16



Before Irradiation

0.5 μm

After Irradiation with

4 MeV Ni^{++}, 70 dpa, 625°C

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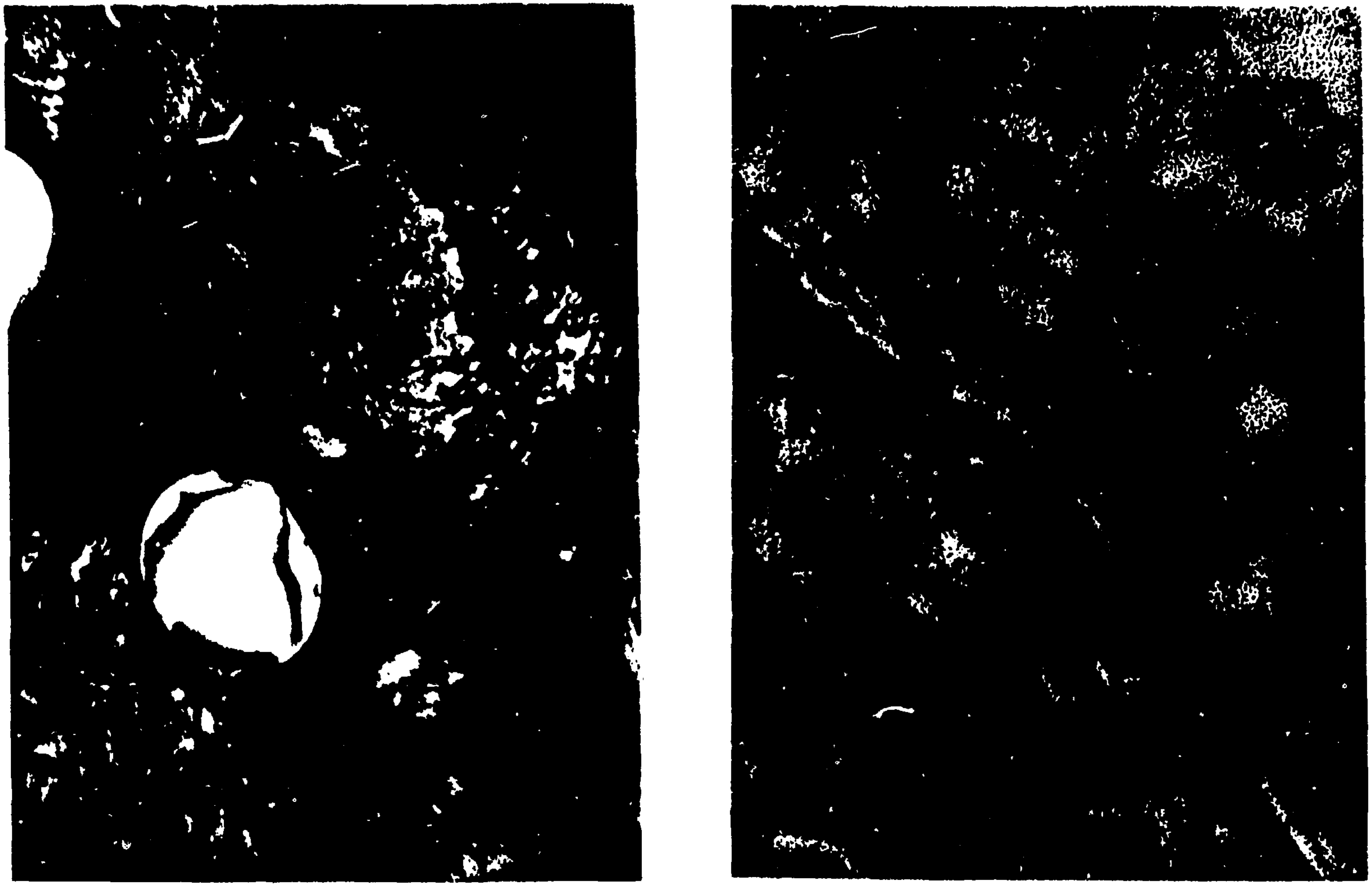
LRO-35



Before Irradiation 0.5 μm After Irradiation with

4 MeV Ni^{++}, 70 dpa, 625°C

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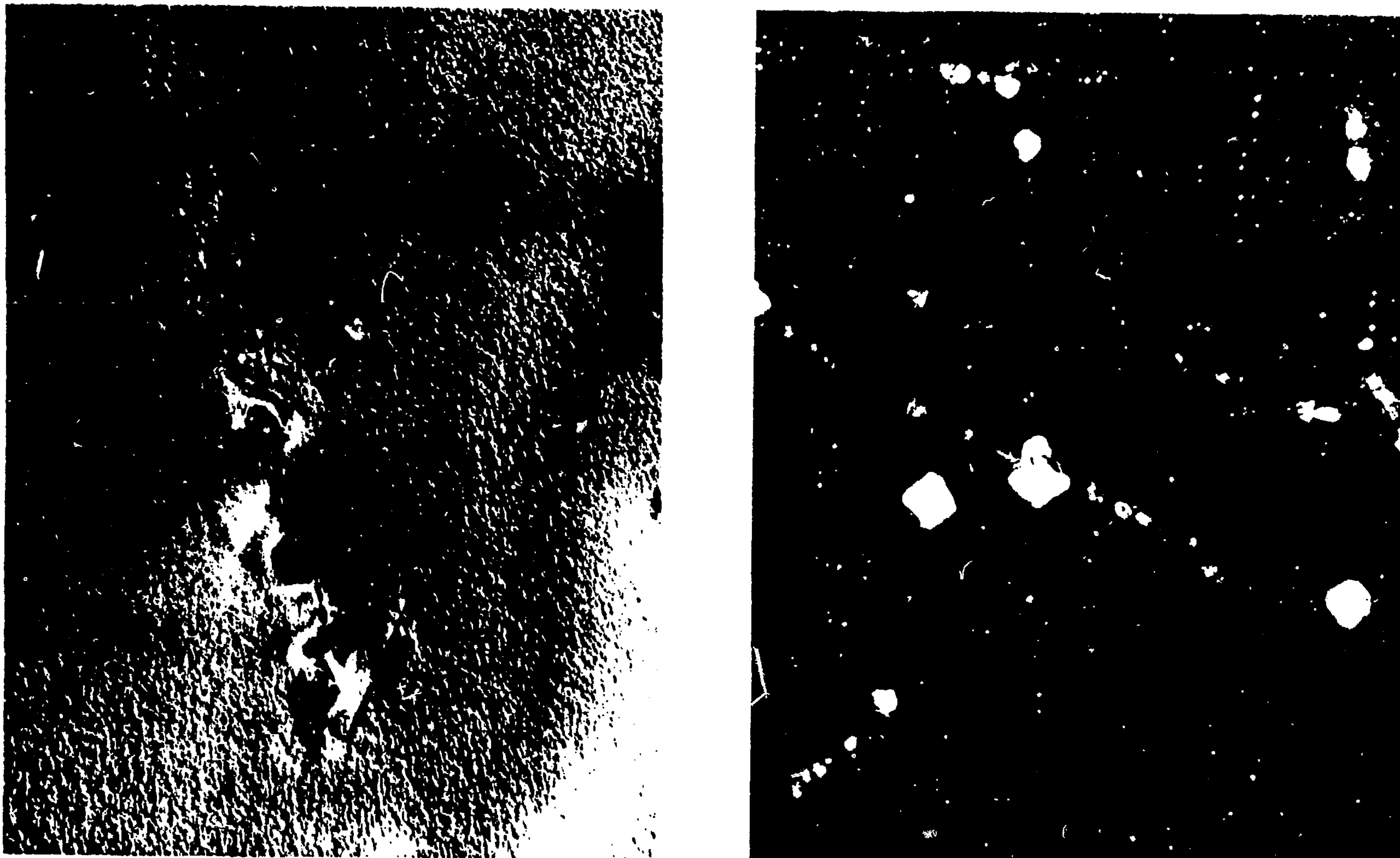
LRO-20

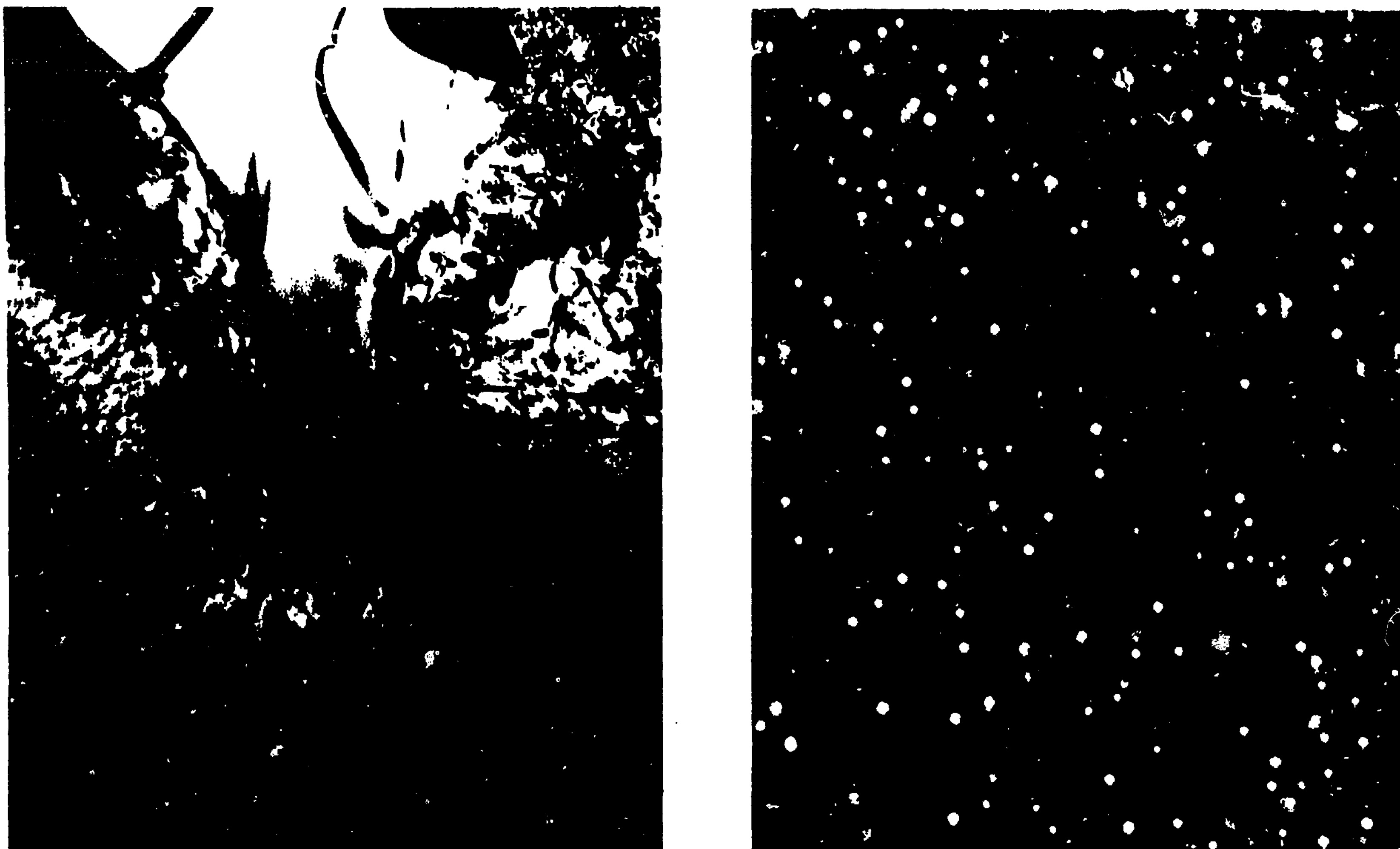


Before Irradiation   0.5 μm   After Irradiation with

4 MeV Ni^{++}, 70 dpa, 625°C

ORNL–DWG 80 .7681

LRO-37



Before Irradiation   0.5 μm   After Irradiation with

4 MeV Ni^{++}, 70 dpa, 625°C

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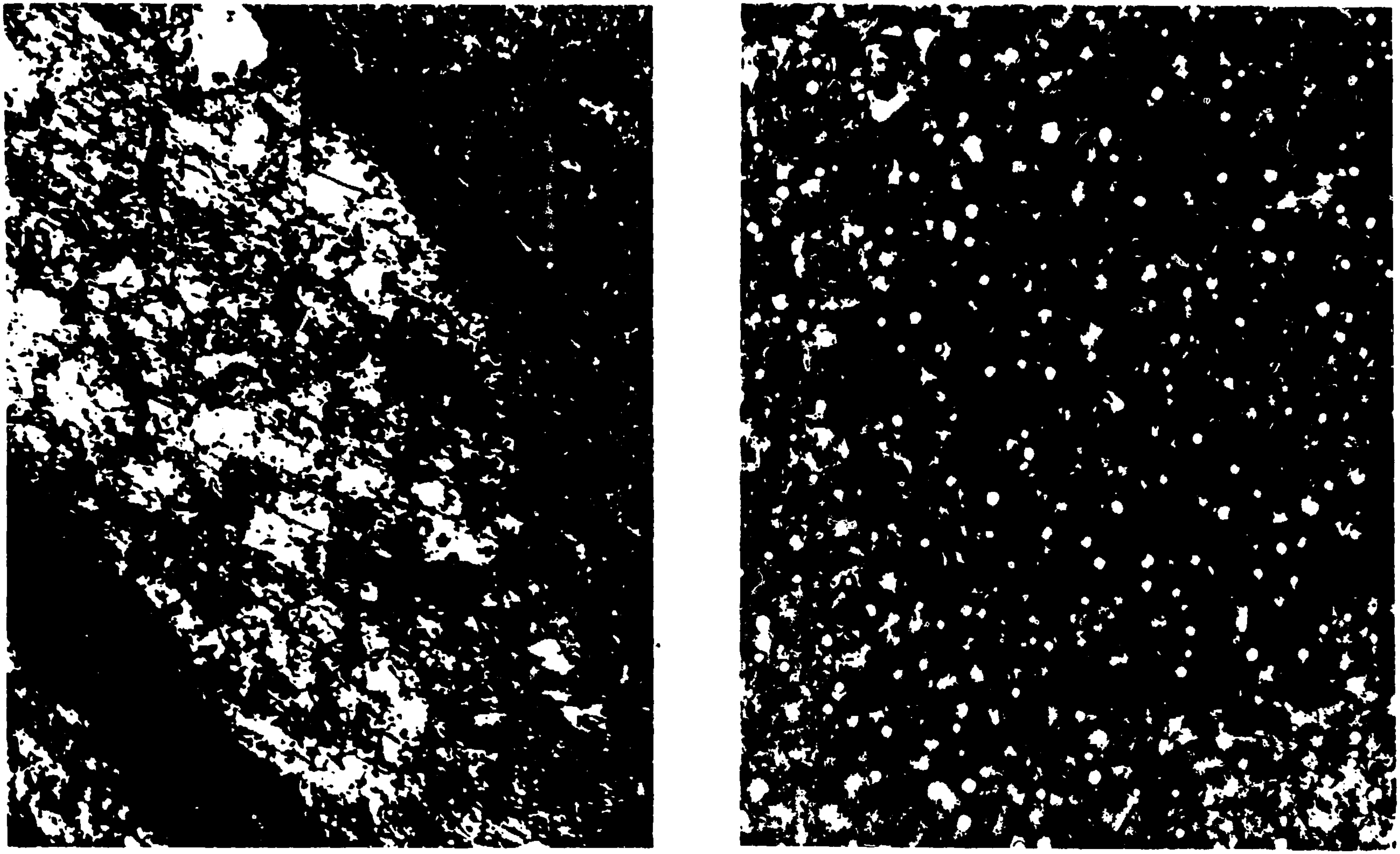
20%-COLD-WORKED 316 SS

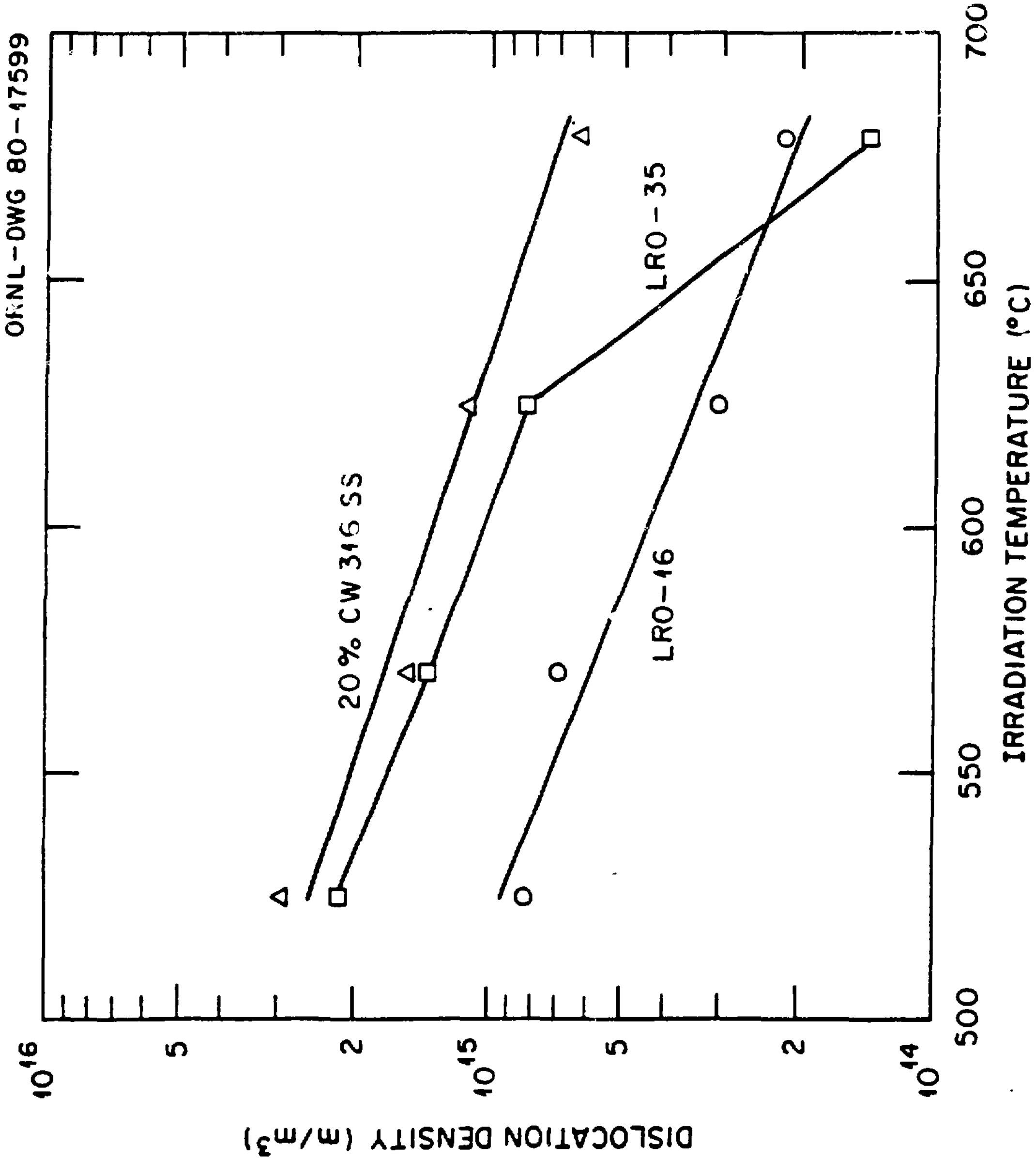


Before Irradiation

0.5 µm

After Irradiation with

4 MeV Ni^{++}, 70 dpa, 625°C


ORNL-DWG 80-17599
20% CW 316 SS
LRO-35
LRO-16
IRRADIATION TEMPERATURE (°C)
500
550
600
650
700
DISLOCATION DENSITY (m/m³)
10¹⁶
5
2
10¹⁵
5
2
10¹⁴

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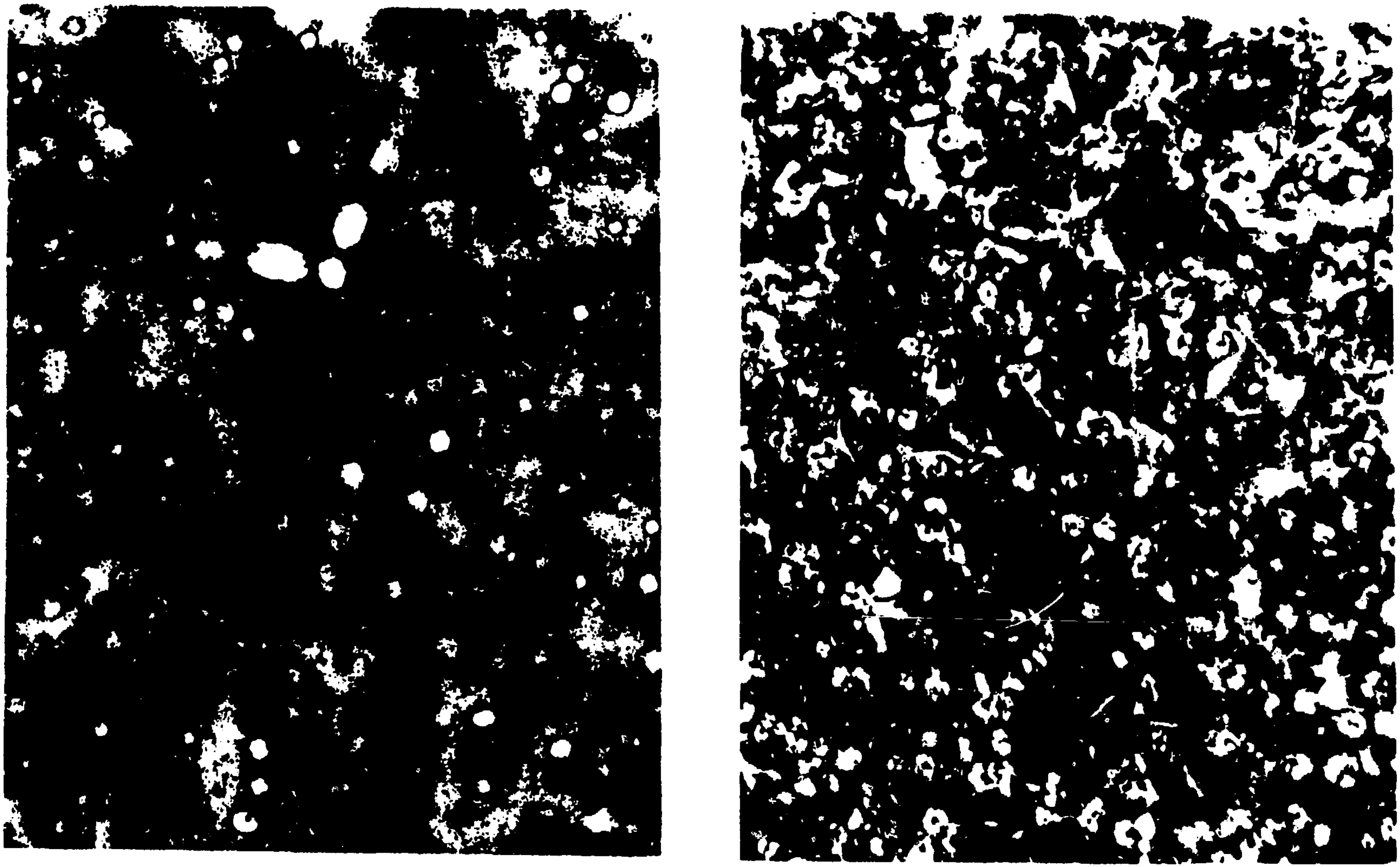
CAVITIES IN LRO-16 DECORATED WITH VC



Bright Field 0.3 μm Ppt. Dark Field

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CONCLUSIONS

- $(Fe_xNi_y)_3V$ LONG-RANGE-ORDERED ALLOYS ARE QUITE RESISTANT TO SWELLING WHEN BOMBARDED WITH 4 MeV Ni^{++} AND SIMULTANEOUSLY INJECTED WITH He^+ AND D_2^+ AT 525 to 680°C

- SMALL Ti ADDITIONS TO THE LRO ALLOYS APPEAR TO IMPROVE THEIR RESISTANCE TO SWELLING CAUSED BY IRRADIATION WITH 4 MeV Ni^{++}

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UPCOMING WORK

MICROSTRUTURAL STUDIES WILL BE CONDUCTED TO:

- DETERMINE THE EFFECT OF REACTOR EXPOSURE (NEUTRONS) ON THE MICROSTRUCTURE AND TENSILE PROPERTIES OF LRO ALLOYS
- DETERMINE THE OPTIMUM AMOUNT OF Ti ADDITION AND THE MECHANISM WHEREBY IT REDUCES SWELLING
- SHOW THE EFFECT OF USING FERROVANADIUM STARTING MATERIAL ON LRO ALLOY MICROSTRUCTURE
- DETERMINE THE DEGREE OF ORDER IN LRO ALLOYS USING ELECTRON DIFFRACTION TECHNIQUES AND RELATING IT TO RADIATION EFFECTS