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SECOND PHASE PRECIPITATION IN IRRADIATED TYPE 316 STAINLESS STEEL CLADDING

MASTER

By

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INTRODUCTION

Differences were noted in the appearance of the cladding in commercially produced full size FFTF fuel pins irradiated in the General Electric Test Reactor (GETR) compared to HEDL produced fuel pins when metallographically examined.[1] The fuel pins were irradiated under supposedly identical conditions. However, when cladding samples from all the pins were etched with KOH, the commercially fabricated fuel pins showed extensive amounts of intermetallic phase, presumably sigma, around the entire circumference in the type 316 20% cold worked stainless steel. (Slide 1) The companion HEDL pins, however, had considerably smaller amounts of sigma phase present. The intermetallic phase appeared to be more dense on the inside of the cladding and on the side of the pin facing the reactor core, consistent with the higher temperatures experienced in those areas of the fuel pin.

Two different types of cladding were used to fabricate the fuel pins. (Slide 2) HEDL-produced pins were clad with T-lot, a steel produced in the FFTF cladding developmental programs, while the vendor pins were clad with "Core 1 steel," the prototypic cladding for the FFTF. Both are 20% cold worked type 316 stainless steel.

(Slide 3) In all cases, there was more second phase formation in the Core 1 steel than in T-lot cladding. This could result from differing irradiation conditions between the individual test capsules or from differences in material performance. T-lot was produced using iron butts, ferrochromium, iron-molybdenum butts, and ferrosilicon , refined by means of an oxygen lance process in an electric arc furnace. Core 1 steel was made from electrolytic iron, metallic nickel, chromium and silicon melted in an oxygen/argon gas process utilizing manifolded mutiple gas inlets which allows greater control over the removal of tramp elements and impurities. Consequently, T-lot has a greater percentage of tramp impurities than Core 1 steel. This can be seen in the next slide which shows the chemical composition of the two types of stainless steel used as cladding. (Slide 4) Also, T-lot which clad the HEDL fuel was significantly lower in manganese, silicon and chrome and higher in molybdenum than the Core 1 steel which clad the vendor pins.

Laboratory annealing studies were conducted on cladding from the same lots of material used to fabricate the fuel pins and on cladding sections removed from the plenum area of the irradiated fuel pins to help establish the cause of the observed differences in the GETR tests.

Half-inch sections removed from the plenum areas of the low burnup pins (∿12 MWd/kgM) were annealed for 100 and 300 hours at both 760° and 815°C. These annealing conditions were chosen based on previous studies to produce the greatest differences in the amount of second phase precipitate formation between the two types of cladding. (Slide 5) The results showed that the two types of cladding behaved quite differently with respect to second phase precipitation. T-lot cladding had less sigma phase than Core 1 steel at all comparable annealing conditions. Longer annealing times and higher temperatures increased the size and density of the second phase in both types of steel. (Slide 6)

A large group of samples was metallographically examined to quantitatively evaluate second phase precipitation in 20% cold worked type 316 stainless steel. Unirradiated samples of N-lot (from the same heat of material as T-lot) and Core 1 steel had previously been annealed at temperatures ranging from 538°C to 815°C for 100 to 8000 hours. These samples were etched with KOH and from the data a perspective on the precipitate characteristics of the material was obtained. The quantity of second phase precipitate in Core 1 steel equaled or exceeded that in N-lot cladding. (Slide 7) The second phase precipitate formed initially in Core 1 steel annealed for 5000 hours at 595°C, but did not appear in the N-lot material until temperatures reached 650°C for 6000 hours. At high temperatures and long annealing times, the amount of sigma phase in N-lot cladding began to equal that in comparably annealed samples of Core 1 steel. (Slide 8) There was little change in the structure of Core 1 steel samples annealed at 816°C longer than 100 hours. (Slide 9)

Photomicrographs from irradiated samples which were annealed showed amounts of precipitation quite comparable to the unirradiated samples. This indicates that under the conditions of this study irradiation has little effect on this second phase precipitate.

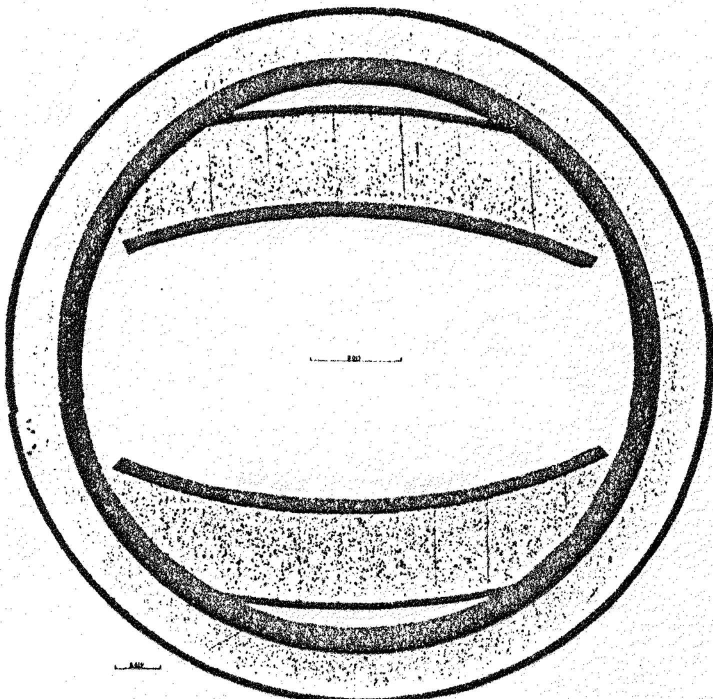
Area fraction measurements of second phase precipitates were made from the photomicrographs. The next slide (Slide 10) shows a representative photomicrograph from each of the area fraction ranges into which the data were grouped. The tabulated data were plotted in the next slide for both types of steel. (Slide 11) The graphs show the difference in time and temperature requirements for formation of the second phase in Core 1 steel versus N-lot cladding. The intermetallic phases began to precipitate at 700°C by 300 hours in Core 1 steel but it took 1000 hours for precipitation in the N-lot material.

The observations from these studies (Slide 12) show that Core 1 steel is more prone to the formation of second phase precipitate and suggest that the difference noted in the fuel pins were the result of the different types of cladding employed. The amount of second phase precipitation observed for each type steel was consistent with the irradiation conditions calculated from thermocouple data.

REFERENCES

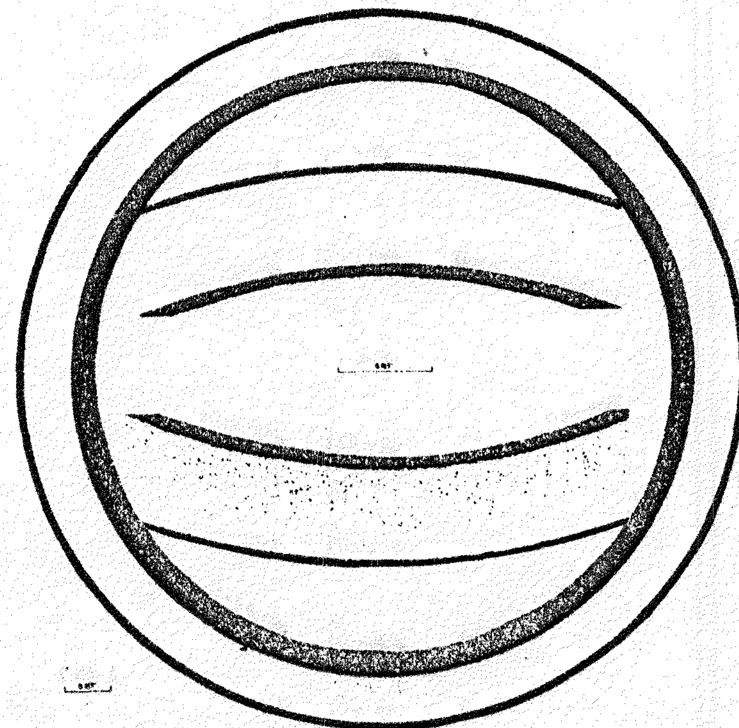
1. J. W. Hales, et al, "Performance of Commercially Produced Full Size FFTF Fuel Pins in GETR", Trans. Am. Nucl. Soc., 27, p. 238, (1977).

DIFFERENCES IN SECOND PHASE PRECIPITATION IN IRRADIATED TYPE 316 20% CW STAINLESS STEEL CLADDING



ETCHED WITH KOH

- CORE 1 STEEL
- VENDOR PRODUCED
- 37.0 MWd/KgM



- T-LOT CLADDING
- HEDL PRODUCED
- 37.0 MWd/KgM

HEDL 7803-259.a0

SLIDE 1

CLADDING USED IN GETR/RAFT TEST: 20% COLD WORKED TYPE 316 STAINLESS STEEL

<u>T AND N LOT</u>
- HEDL PRODUCED PINS
- DEVELOPMENTAL CLADDING USED ON MAJORITY OF EXPERIMENTAL PINS IN EBR II.
- OXYGEN LANCE PROCESS IN ELECTRIC ARC FURNANCE USING IRON BUTTS.

<u>CORE 1 STEEL</u>
- COMMERCIALLY PRODUCED PINS.
- PROTOTYPIC CLADDING FOR FFTF
- OXYGEN/ARGON GAS INLETS USING ELECTROLYTIC IRON

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SUMMARY OF EXAMINATION RESULTS

IN ALL CASES THERE WAS MORE SECOND PHASE PRECIPITION IN CORE 1 STEEL THAN IN T-LOT CLADDING

REASONS FOR DIFFERENCES

- DISSIMILAR TEST CAPSULE TEMPERATURES
- DIFFERENCES IN MATERIAL PERFORMANCE

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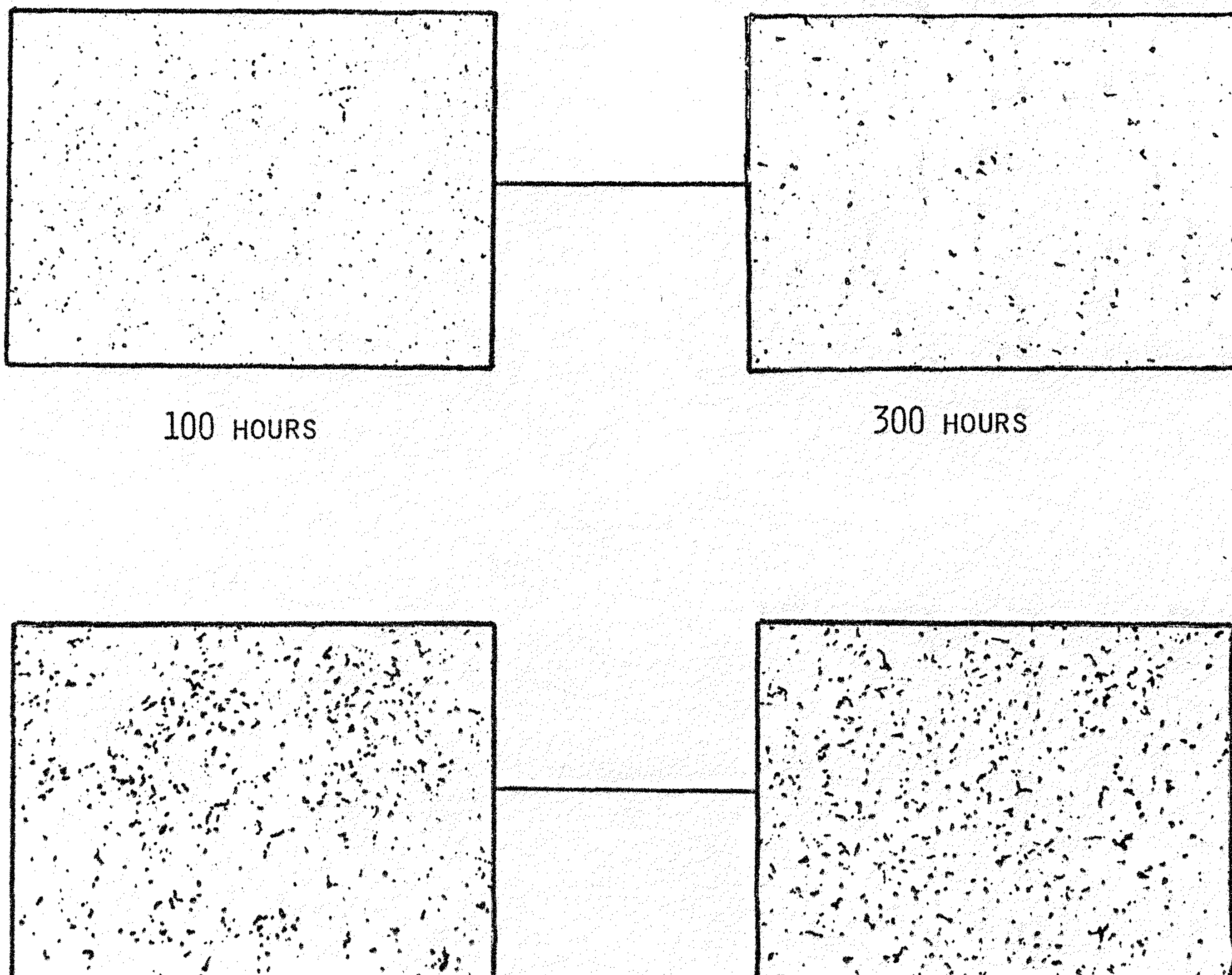
SLIDE 3

CHEMICAL COMPOSITIONS OF CLADDING USED
IN THE GETR/RAFT VENDOR FUEL TEST

	Developmental Cladding T-lot, N-lot (Heat #87210)	FFTF Prototypic Cladding Core 1 Steel (Heat #81590)
Carbon	0.053%	0.057%
Manganese	1.46%	1.60%
Silicon	0.46%	0.52%
Chromium	16.48%	17.38%
Nickel	13.65%	13.71%
Molybdenum	2.41%	2.31%
Arsenic	2-12 parts per million	0.2-0.4 parts per million
Cobalt	300-500	100
Columbium	0.2-0.7	<0.1
Copper	600-800	<100
Nitrogen	40-70	30-50
Phosphorus	80-160	20-50
Sulfur	50-90	30-50
Tantalum	<0.3	<0.3
Tin	1-2	0.1-0.5
Titanium	<50	<50
Vanadium	30-15	2-7

SLIDE 4

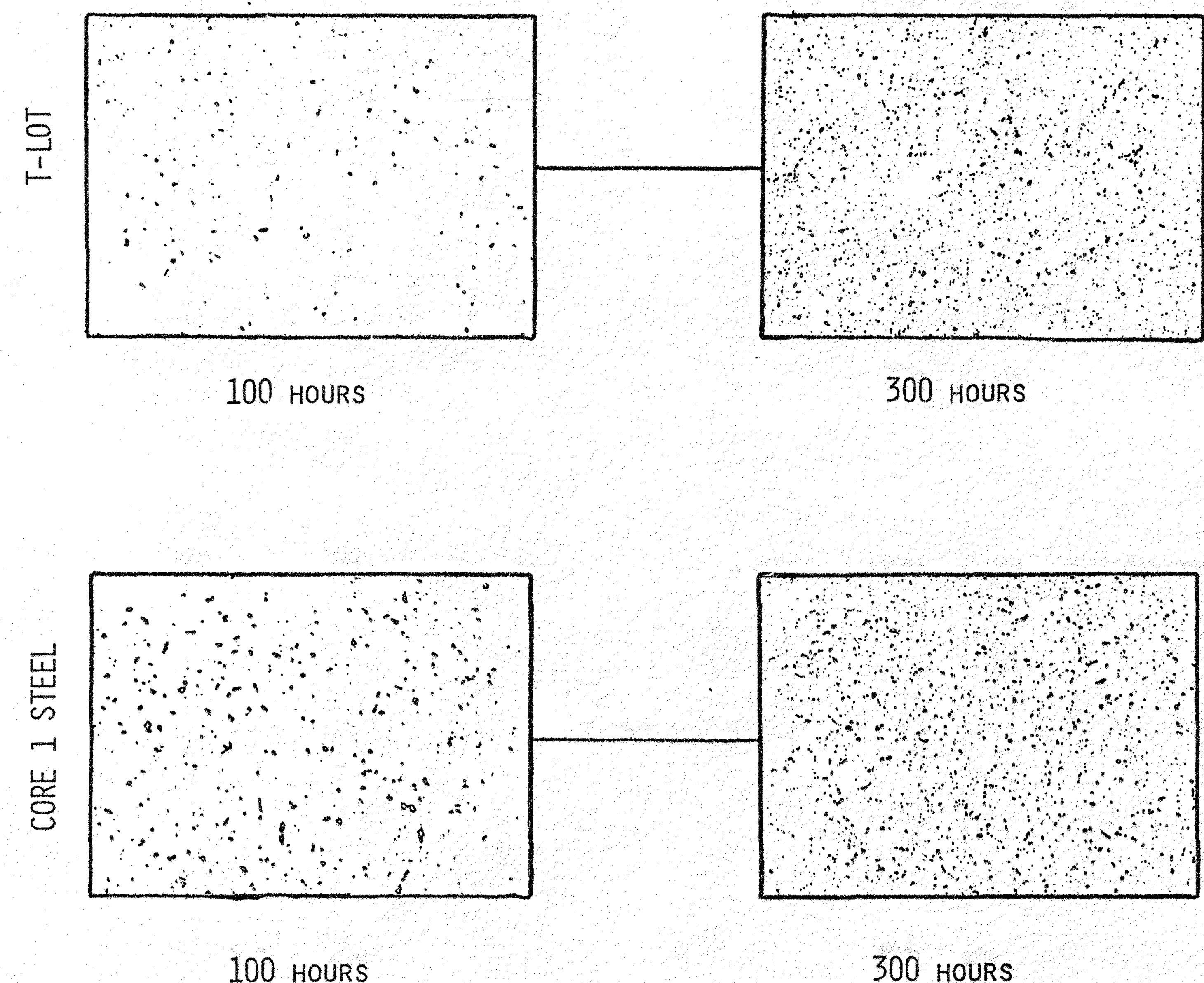
GETR / RAFT PLENUM SAMPLES ANNEALED AT 760°C



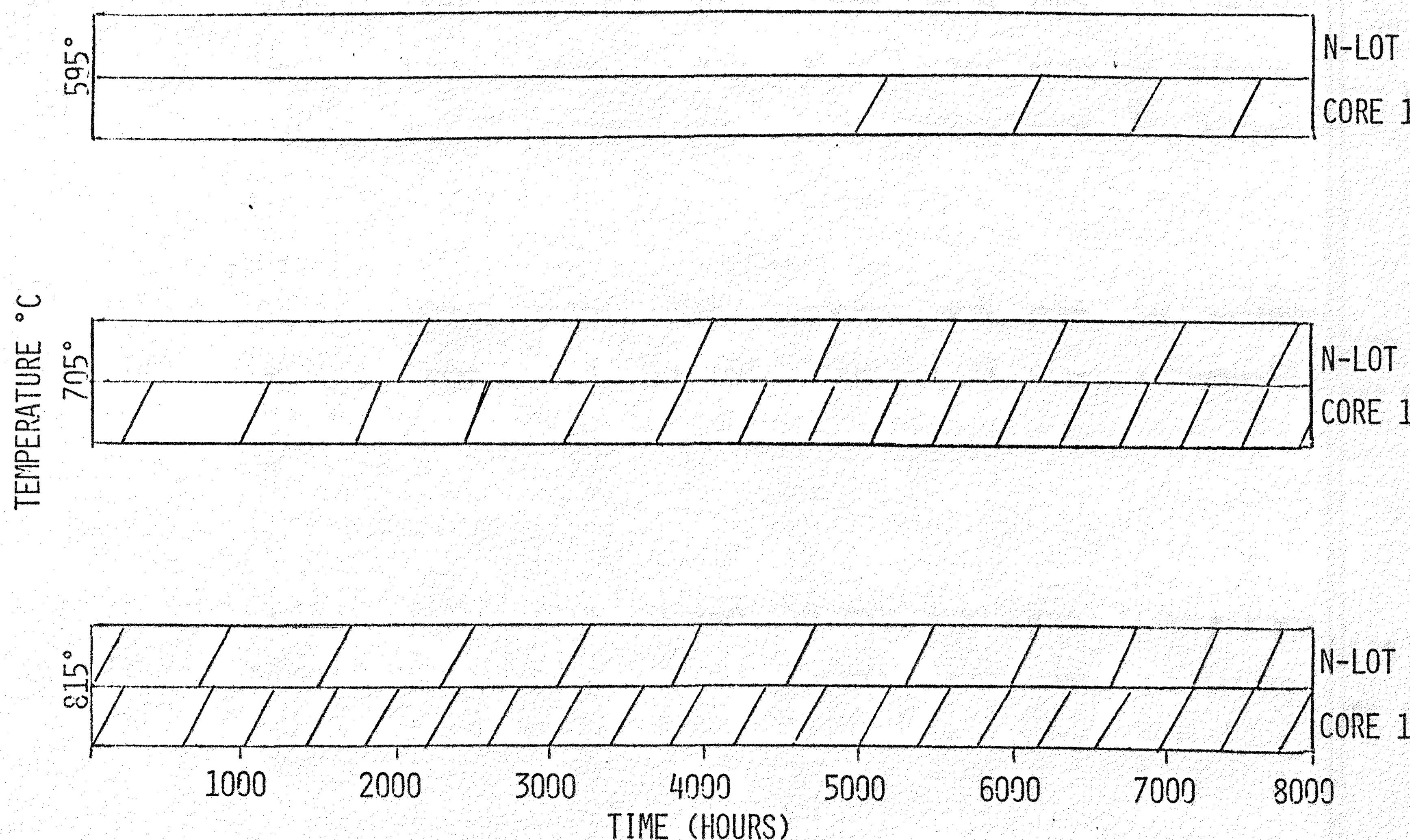
T-LOT: 100 HOURS, 300 HOURS

CORE 1 STEEL: 100 HOURS, 300 HOURS

GETR / RAFT PLENUM SAMPLES ANNEALED AT 815°C

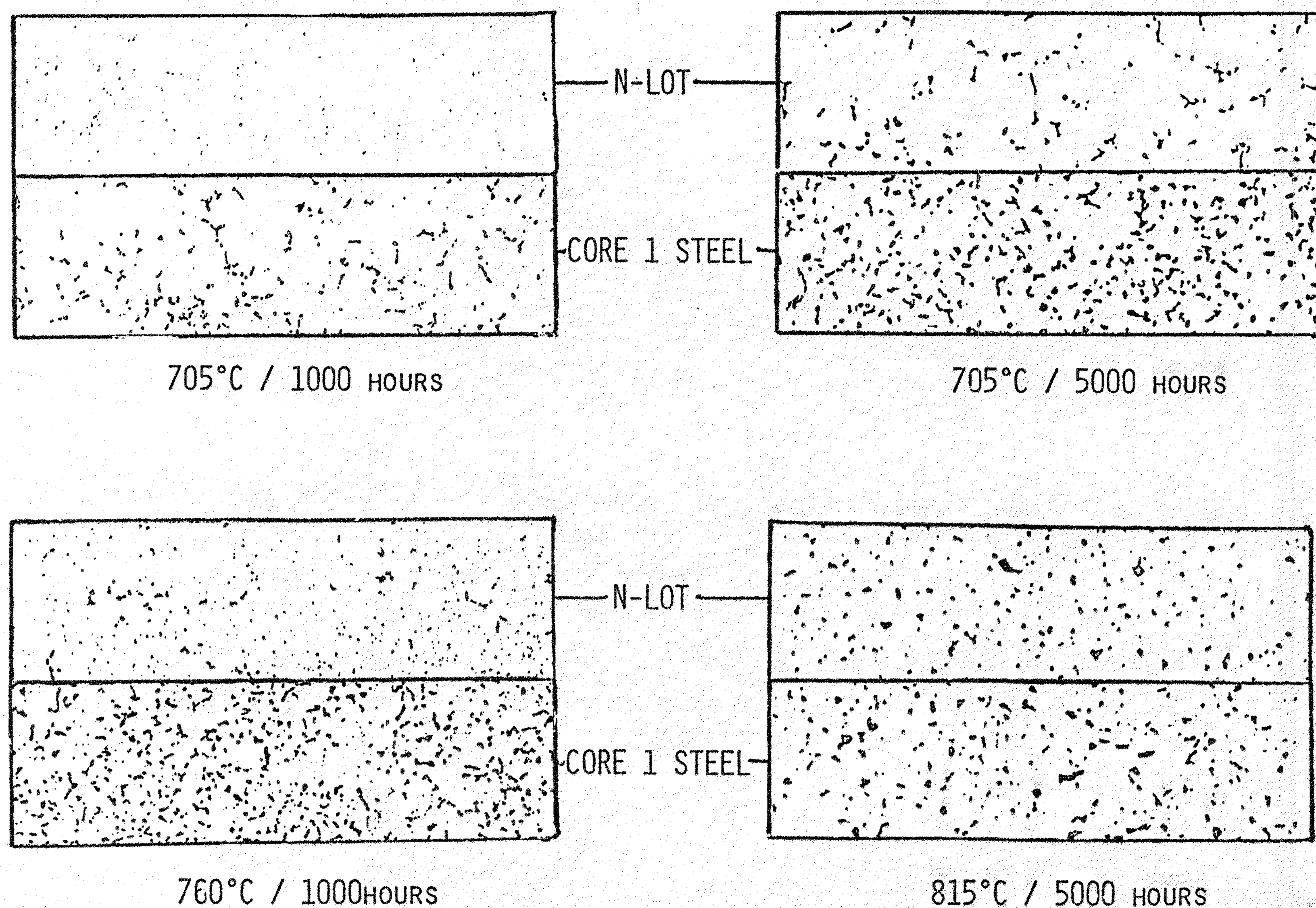


SECOND PHASE PRECIPITATION IN N-LOT AND CORE 1 STEEL CLADDING

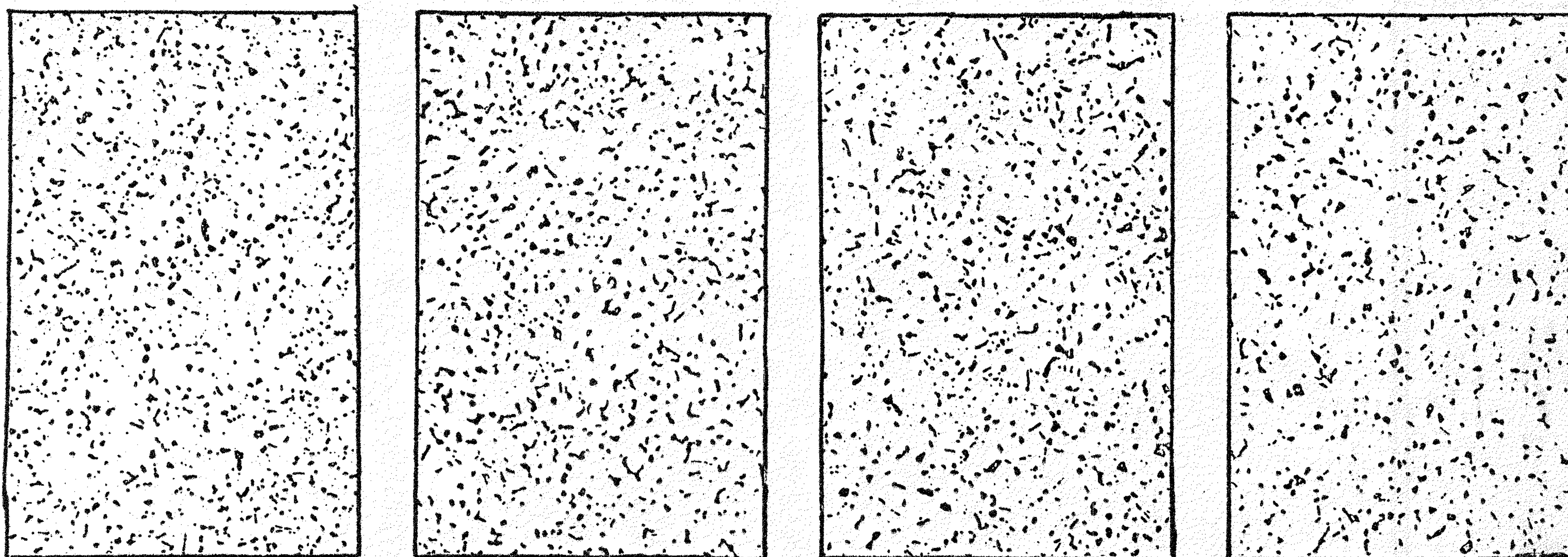


SLASHES INDICATE SECOND PHASE

ANNEALED N-LOT AND CORE 1 STEEL

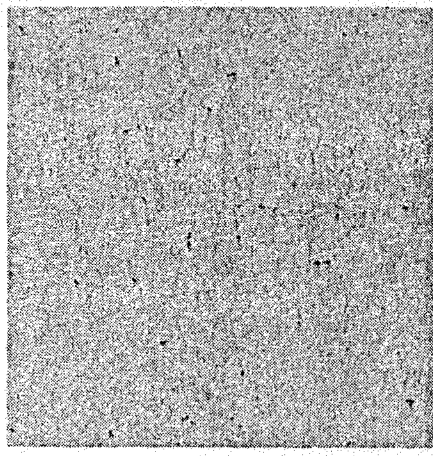


UNIRRADIATED CORE 1 STEEL ANNEALED AT 815°C

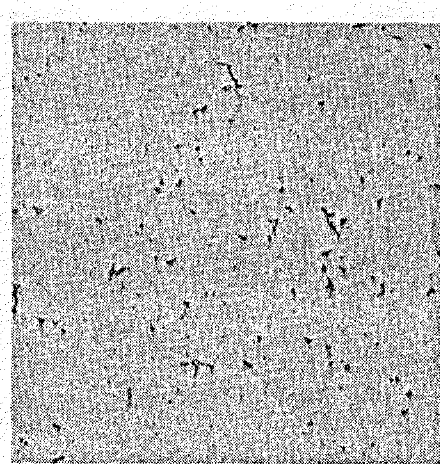


1000 HOURS   2000 HOURS   3000 HOURS   5000 HOURS

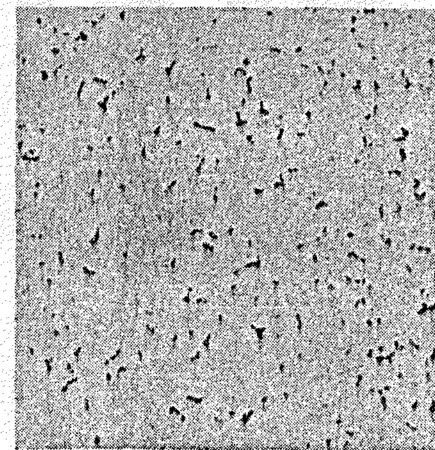
EXAMPLES OF AREA FRACTION MEASUREMENTS OF SECOND PHASE



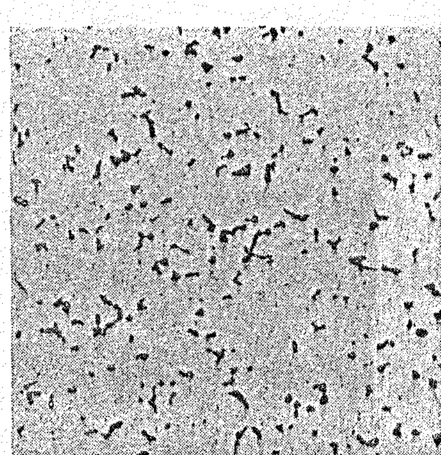
0-0.5%



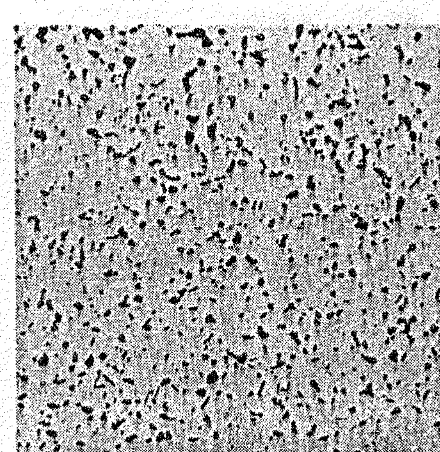
0.5-1.5%



2-3%



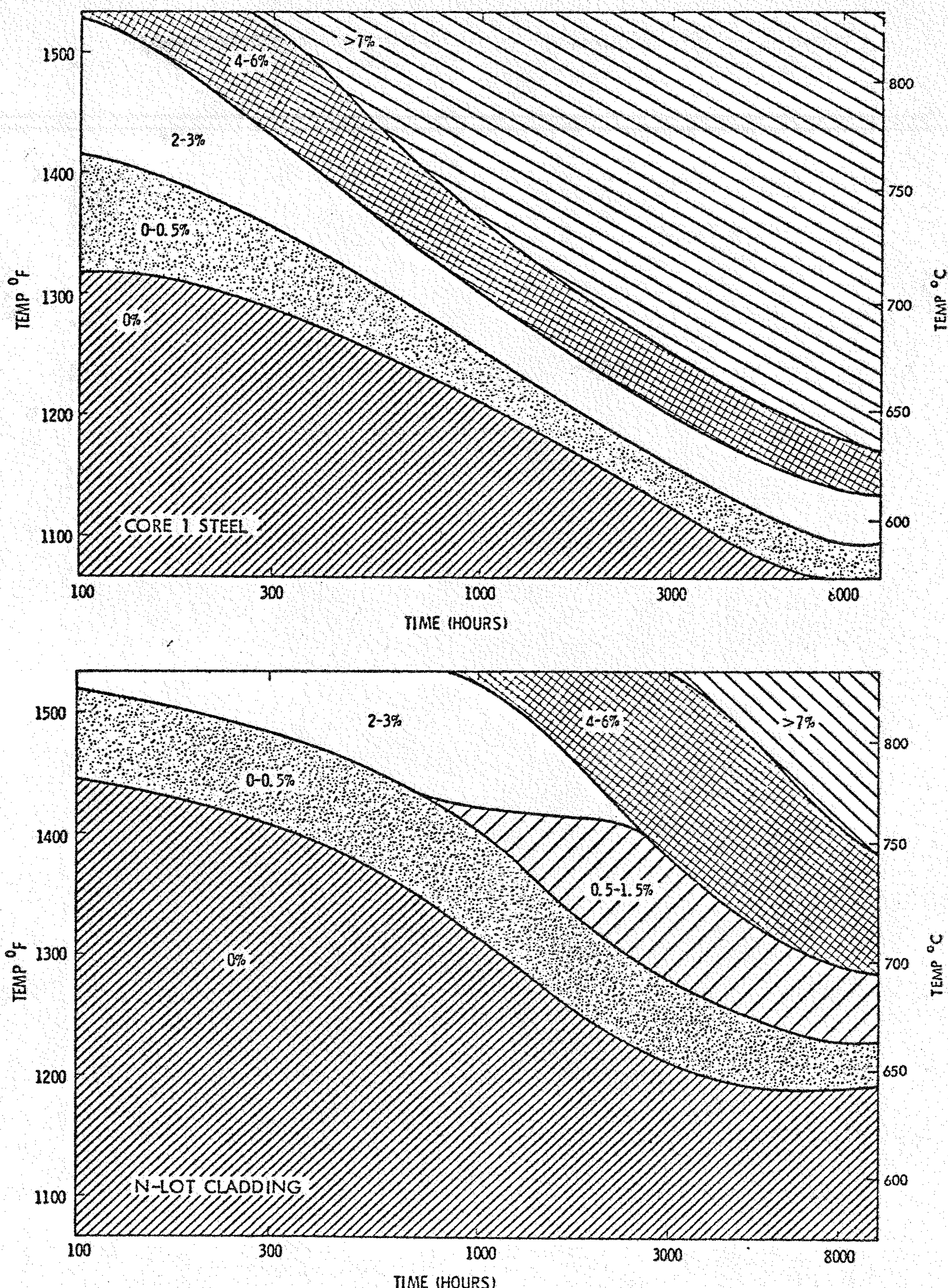
4-6%



>7%

250X

HEDL 7707-174.1



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SECOND PHASE PRECIPITATION KINETICS IN 20% COLD-WORKED TYPE 316 STAINLESS STEEL.

SLIDE 11

SUMMARY

Difference in Second Phase Precipitaition were the result of Compositional Difference

- Core 1 steel is more prone to Second Phase Precipition than T- Lot Cladding.

Dissimilarities in GETR/RAFT Test due to Cladding Variations

Annealing Studies Confirm Irradiation Temperatures