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Corrosion Behavior of Copper-Base Materials in a Gamma-Irradiated Environment

Final Report

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CORROSION BEHAVIOR OF COPPER-BASE MATERIALS IN A GAMMA-IRRADIATED ENVIRONMENT: FINAL REPORT

Wayne H. Yunker

ABSTRACT

Specimens of three copper-base materials were corrosion tested with gamma radiation exposure dose rates in the range of 1.9 x 10^3 R/h to 4.9 x 10^5 R/h. Materials used were pure copper, 7% aluminum bronze and 30% copper-nickel. Exposures were performed in moist air at 95 °C and 150 °C and liquid Well J-13 water at 95 °C, for periods of up to 16 mo. Specimens were monitored for uniform weight loss, stress-induced corrosion and crevice corrosion. Specimen surfaces were examined visually at 10X magnification as well as by Auger Electron Spectroscopy, x-ray diffraction and metallography. Corrosion was not severe in any of the cases. In general, the pure copper was corroded most uniformly while the copper-nickel was the least reproducibly corroded.

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1.0 SUMMARY

Over 400 specimens, made from three copper-base materials, were exposed to three corrosion environments in a gamma radiation field. The environments approximated those expected during the early, mid, and late periods of storage of nuclear waste in the tuff formation inside of Yucca Mountain near the Nevada Test Site (NTS). The work was performed in support of the Nevada Nuclear Waste Storage Investigations (NNWSI) Project under the direction of the Lawrence Livermore National Laboratory (LLNL). The three materials used were pure copper, 7 wt% aluminum copper alloy, and 30 wt% copper-nickel alloy. The object of the tests was to observe the corrosion behaviors of these materials under a variety of conditions and specimen configurations and in a radiation field that was at least 10 times stronger than expected under storage conditions in order to enhance any radiation effects. Specimen types used were weight loss, crevice, tear drop, and electrochemically prepitted. Environments consisted of moist air at 150 °C, air that was nearly saturated with water vapor at 95 °C, liquid Well J-13 water at 95 °C, and the liquid-gas interface at 95 °C. A data base was created that specifies all conditions and observations for each specimen. Analyses were also made of the gas and liquid phase compositions. Exposure times ranged from 1 mo to 16 mo and gamma exposure dose rates from 1.9×10^3 R/h to 4.9×10^5 R/h.

Corrosion damage was relatively mild during these time intervals. No evidence of stress-induced corrosion was found. Underfilm corrosion features were seen with the aluminum bronze and the copper-nickel alloy. The defects in the electrochemically prepitted specimens tended to disappear with general corrosion, rather than grow. In general, the most severe corrosion occurred on specimens in the gas phase at 95 °C that was very nearly saturated with water vapor. Metallographic examination showed some pitting of the aluminum bronze and the copper-nickel alloy. Surface examination of the pure copper specimens

showed isolated pitting only. General corrosion rates varied from 0.01 mil/yr to 0.15 mil/yr at 10,000 h exposure. Both linear and parabolic corrosion rates were seen. X-ray diffraction of the oxide formed on pure copper showed both CuO and Cu_2O. The compound $(Cu_{0.2}\ Ni_{0.8})O$ was identified on one nickel alloy specimen. Auger electron spectroscopy of several very thin corrosion films showed oxide with layers having different compositions. There was no excessive corrosion at the gas-liquid interface. However, where isolated drops of water may have formed during part of a test, more severe local corrosion appeared. The corrosion of the copper-nickel alloy was the most severe in appearance and the least reproducible.

2.0 INTRODUCTION

The U.S. Department of Energy (DOE) is evaluating the feasibility of using copper-base materials in the construction of containers for high-level radioactive waste for permanent, geologic disposal. The disposal site being considered is at Yucca Mountain, adjacent to the NTS. For this evaluation, the corrosion behaviors of several candidate materials need to be determined in chemical, physical, and radiological environments similar to those in the proposed repository site. The experiments described here were conducted during fiscal years (FY) 1985 and 1986 at Westinghouse Hanford Company (Westinghouse Hanford) located in Richland, Washington. They are part of the NNWSI Project under the direction of LLNL.

The primary objective of this work is to measure the corrosion rates and behaviors of selected copper-base materials in gamma radiation fields under conditions that are similar to those expected in the proposed repository. These experiments were designed to produce as much quantitative and qualitative corrosion data as possible, in a short time. Resources were focused on exploratory experiments that produced severe corrosion rather than on tests that used large numbers of specimens (for statistical purposes) or on parallel experiments without gamma radiation.

The environmental conditions expected for nuclear waste containers buried in the proposed repository have been described.[1] Briefly, the site is in a layer of tuff rock (a welded, devitrified volcanic ash) permeated by air, water vapor, and some condensed water. The reference horizon at the proposed site is about 200 m above the static water table. Water used for these experiments is from Well J-13 near Yucca Mountain on the NTS. The composition of this water is presented in Table 1. The radiation doses expected initially at the burial container surfaces range from about 5×10^3 rd/h for defense high-level waste to about 2×10^4 rd/h for commercial spent fuel. For the early years of burial, the temperatures at the surfaces of many of the packages are expected to exceed the boiling point of water (95 °C) at the

TABLE 1

WELL J-13 WATER COMPOSITION*

Impurity	Concentration (mg/l)
Silicon	27.0
Sodium	43.9
Calcium	12.5
Potassium	5.1
Magnesium	1.9
Lithium	0.042
Strontium	0.035
Iron	0.006
Aluminum	0.012
Bicarbonate	125.0
Sulfate	18.7
Chloride	6.9
Nitrate	9.6
Fluoride	2.2

*Reference groundwater composition for tuff repositories (based on composition of Jackass Flats Well J-13 at the Nevada Test Site). The pH is slightly alkaline (7.6).

Source: J. Delaney, "Reaction of Topopah Spring Tuff with J-13 Water: A Geochemical Modeling Approach Using the EQ3/6 Reaction Path Code," UCRL-53631, Lawrence Livermore National Laboratory, Livermore, California, March 1985.

elevation of the reference horizon. The radiation field and temperature will decrease with time. When the temperature of the waste package reaches 95 °C, the radiation dose rates in many of the packages will have decreased to about 2×10^2 rd/h.

The interaction of gamma radiation with aqueous environments produces a host of transient radicals, ions, and stable molecular species. These have been thoroughly described in Reference 2. Radiolysis of air-saturated Well J-13 water is expected to result in an oxidizing environment with O_2 (from air) and H_2O_2 as the dominant species. Much smaller concentrations of O_2^-, HO_2, $\cdot OH$, H_2, $H\cdot$, and e_{aq}^- are also generated. In the moist air phase, nitric acid and various oxides of nitrogen are formed and can dissolve in any liquid water phase that is present. These radiation-induced changes in the chemical environment can be expected to alter the normal rates or mechanisms of corrosion.

Early results and a description of this work have been published.[3,4] Most of that information has been repeated here to provide a more complete view of the program results. The few details not repeated are referenced in the text. Some of the preliminary interpretations previously offered have been revised in the light of this more complete data set.

3.0 EXPERIMENTAL

3.1 ENVIRONMENT

For these experiments, gamma radiation fields in the range of 1.9×10^3 to 4.9×10^5 R/h were used. This was supplied by a ^{60}Co gamma radiation source (Figure 1). The flux calibration values are shown in Figure 2. These values had been obtained using an ion chamber and thermoluminescent dosimeters and are traceable to a National Bureau of Standards (NBS) certified source. No additional calibrations were made for these tests. The corrosion specimens were located in the lowest 30 in. of each tube. The other environmental conditions used were: 1) an air-water vapor mixture at 150 °C; 2) a water-vapor-saturated air phase at 95 °C, and 3) liquid Well J-13 water at 95 °C. The two gas phases had similar dew points. Condition 1 represents early life repository conditions and conditions 2 and 3 represent the conditions after several hundred years.

3.2 CORROSION CELLS

3.2.1 Specimens

The compositions of the three materials selected for study are shown in Table 2. Over 400 weight loss, crevice, and tear drop (stressed) specimens were exposed for periods of from 1 mo to 16 mo. The specimen configurations are shown in Figure 3. The mating surfaces of the crevice specimens were polished with 600-grit abrasive to within ±0.05 mm (0.002 in.) of flatness. The tear drop specimens were prepared by the single stressing method[5] and fusion-welded with a tungsten inert gas (TIG) electrode.

3.2.2 Support Cages

All specimens were mounted on high-purity aluminum-oxide spacers in specimen support cages as shown in Figures 4, 5, and 6. The cages were 127 mm (5 in.) high and just fit into the 95-mm (3 3/4-in.) diameter space of a containment

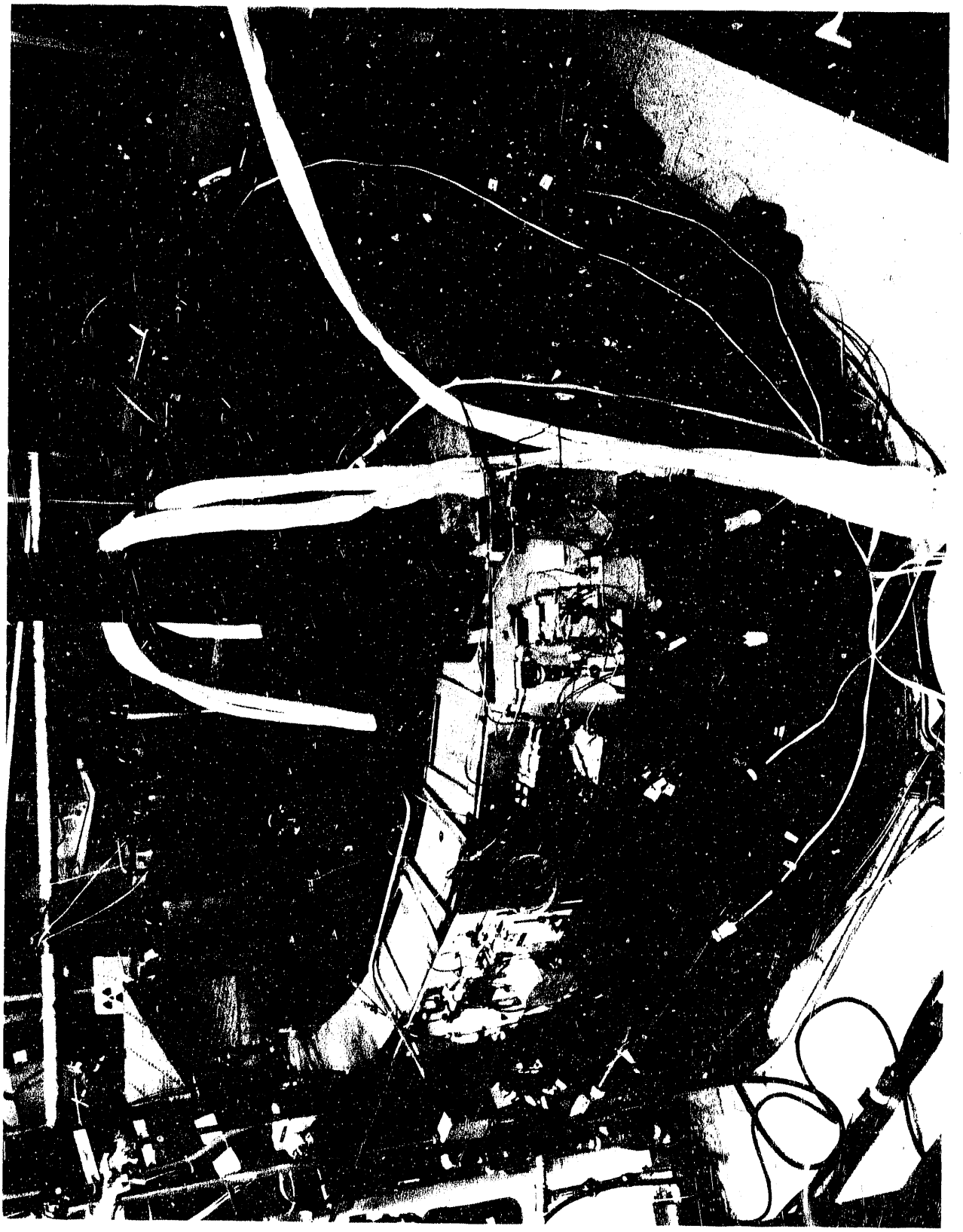

FIGURE 1. Cobalt-60 Gamma Irradiation Facility in the 3730 Building at Westinghouse Hanford Company.

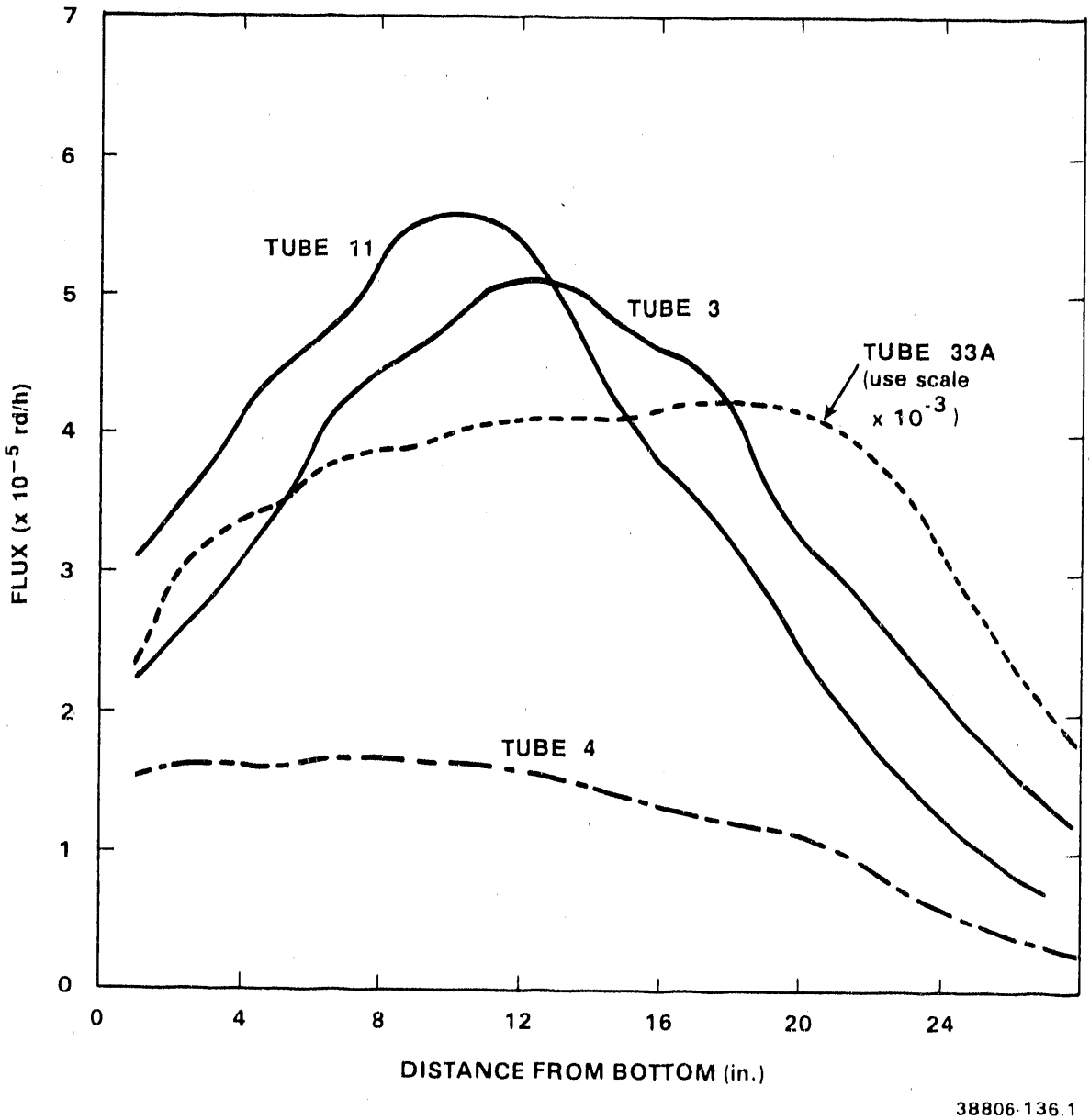

FIGURE 2. Gamma Irradiation Flux versus Distance from the Bottom of the Irradiation Tubes.

TABLE 2

NOMINAL COMPOSITION OF CORROSION SPECIMENS

Element	Alloy Composition (wt%) CDA* 101/102	CDA 613/614	CDA 715
Aluminum		6.75	
Cadmium	0.001 max		
Carbon			0.04
Cobalt		0.01	
Copper	99.99 min**	90.82	69.18
Iron		2.46	0.53
Lead	0.001 max	0.01	0.01
Manganese		0.16	0.51
Mercury	0.0001 max		
Nickel		0.05	29.6
Phosphorus	0.0003 max		0.002
Sulfur	0.0018 max		0.01
Tin		0.2***	
Zinc	0.0001 max	0.01	0.07

*Copper Development Association (CDA) identification number.
**Equals 99.95 for CDA 102.
***Only in CDA 613.

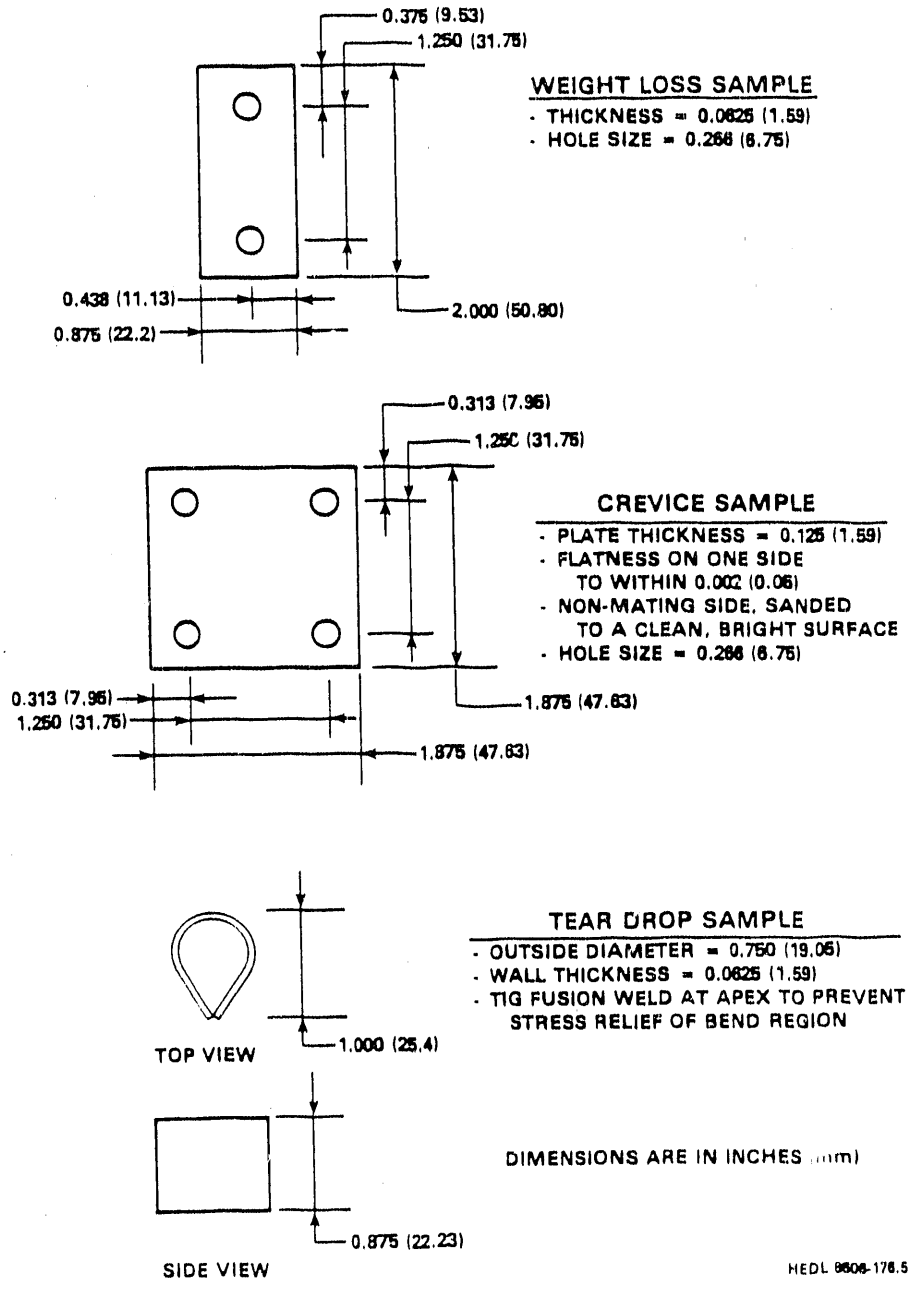

FIGURE 3. Sketches of the Weight Loss, Crevice, and Tear Drop Corrosion Specimens.

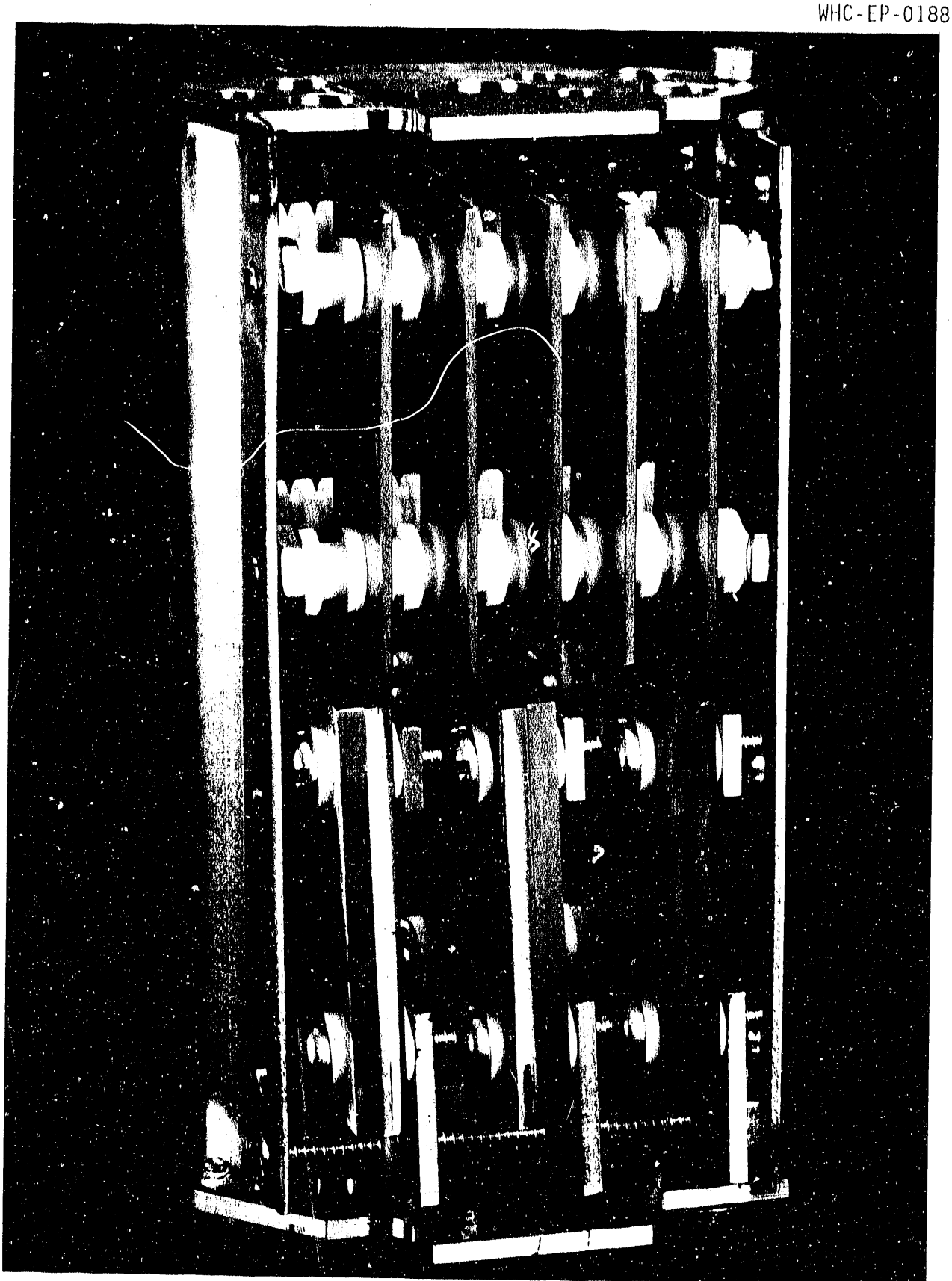

FIGURE 4. Weight Loss and Crevice Specimens Assembled in a Support Cage. (Spacers are made of high-purity aluminum oxide.)

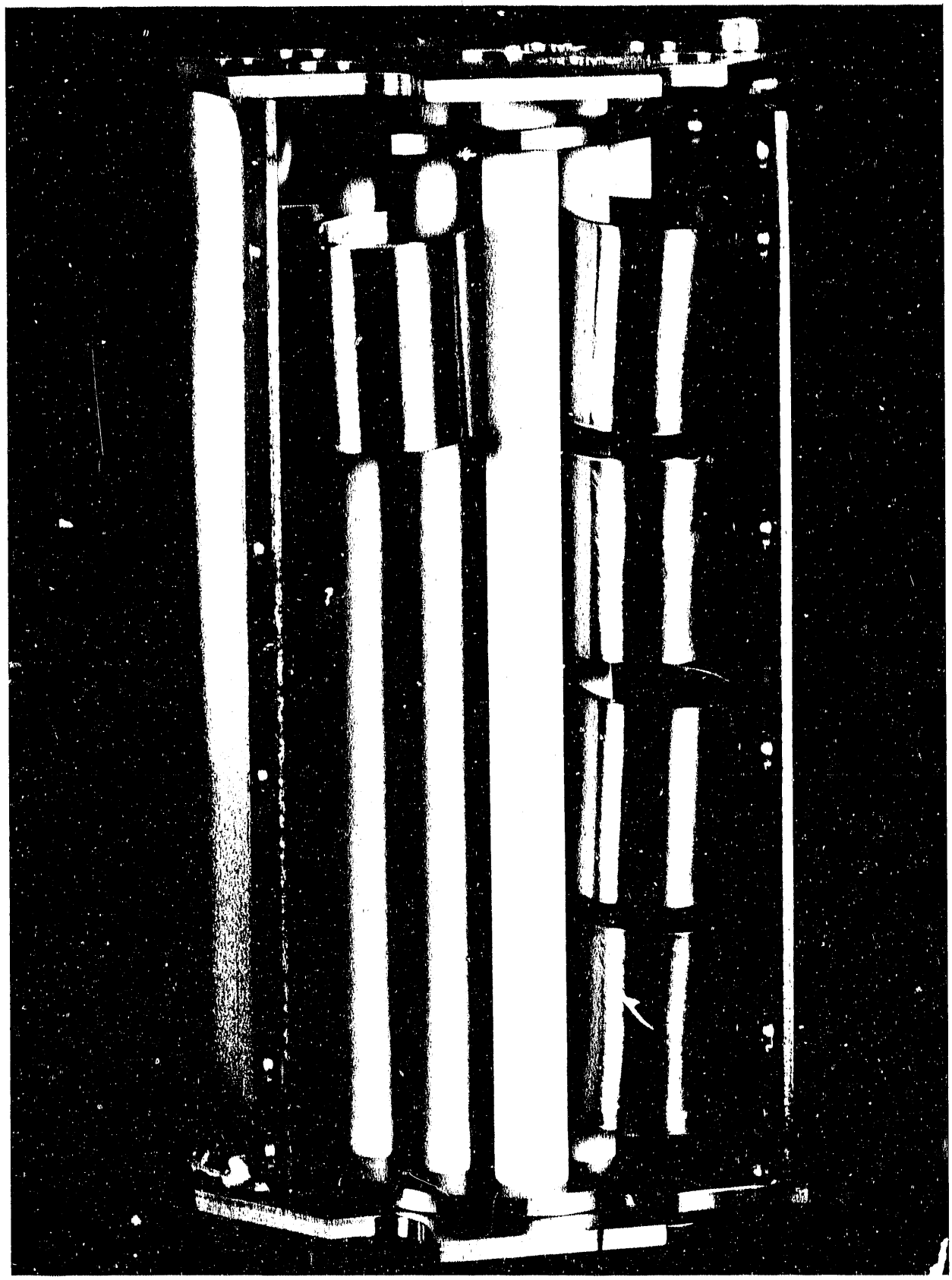

FIGURE 5. Tear Drop Specimens Mounted in a Support Cage. (Spacers are made of high-purity aluminum oxide.)

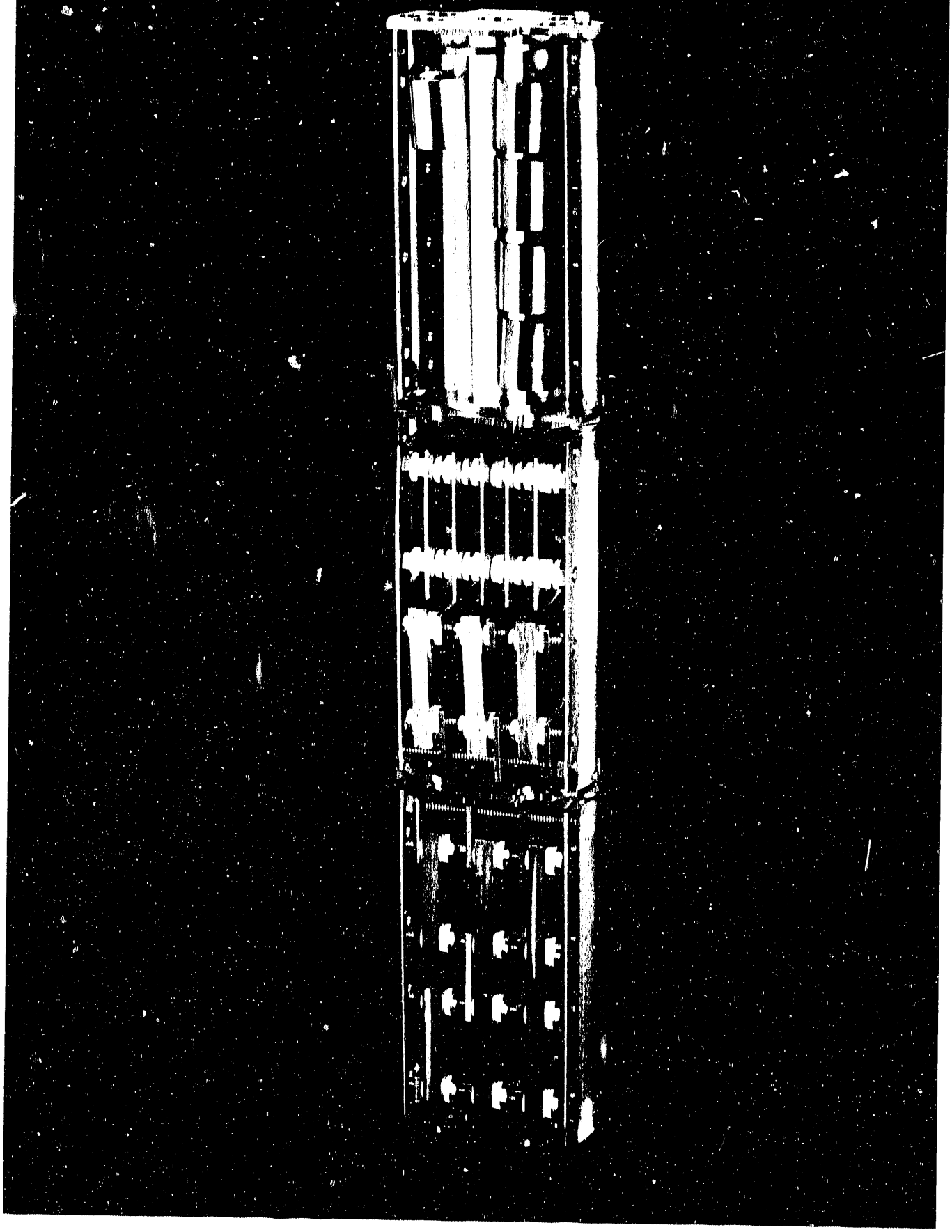

FIGURE 6. Three Specimen Cages Stacked as in a Corrosion Vessel. Neg 8503864-1cn

vessel (see below). All metal parts were made of the same alloy as the enclosure vessel. The six cages stacked into a vessel could be placed in any vertical order to provide flexibility in the exposures given to the specimens. The cages had a standard design and could hold any of the three types of specimens. The cage capacities were: 16 tear drop specimens, 6 crevice specimens, 56 weight loss specimens, or 3 crevice with 28 weight loss specimens.

As the cages were lowered into a vessel, a keying arrangement aligned and held each cage in position in the vessel to ensure that the specimens were not in contact with the thermowell tube and gas ventilation tube. Because the operation of transferring a vessel into and out of the gamma irradiation tubes required considerable handling and movement of the vessel, all specimens were physically restrained in their mountings to prevent any metal-to-metal contact.

3.2.3 Vessels

Environmental control for the corrosion specimens was maintained in the sealed pressure vessels that were lowered into the exposure tubes of the Cobalt-60 Gamma Irradiation Facility.[6] Permanent mounting of the stainless steel exposure tubes ensured that the flux calibrations were reproducible. The stainless steel tubes contained air at about 24 °C.

A schematic of the vessels is shown in Figure 7 and a photograph is shown in Figure 8. Metals used were titanium and Monel* 400. The titanium vessels were fabricated with full-penetration electron beam and TIG welds to eliminate internal crevices. The outer protective containers for the vessels and their electrical heaters were made of 304 stainless steel. The two 3.2 mm (1/8-in.) outside diameter gas lines, made of Inconel** 600, connected the vessels to

*Monel is a trademark of Huntington Alloy Products, Inc., International Nickel Company, Inc.

**Inconel is a trademark of Huntington Alloy Products, Inc., International Nickel Company, Inc.

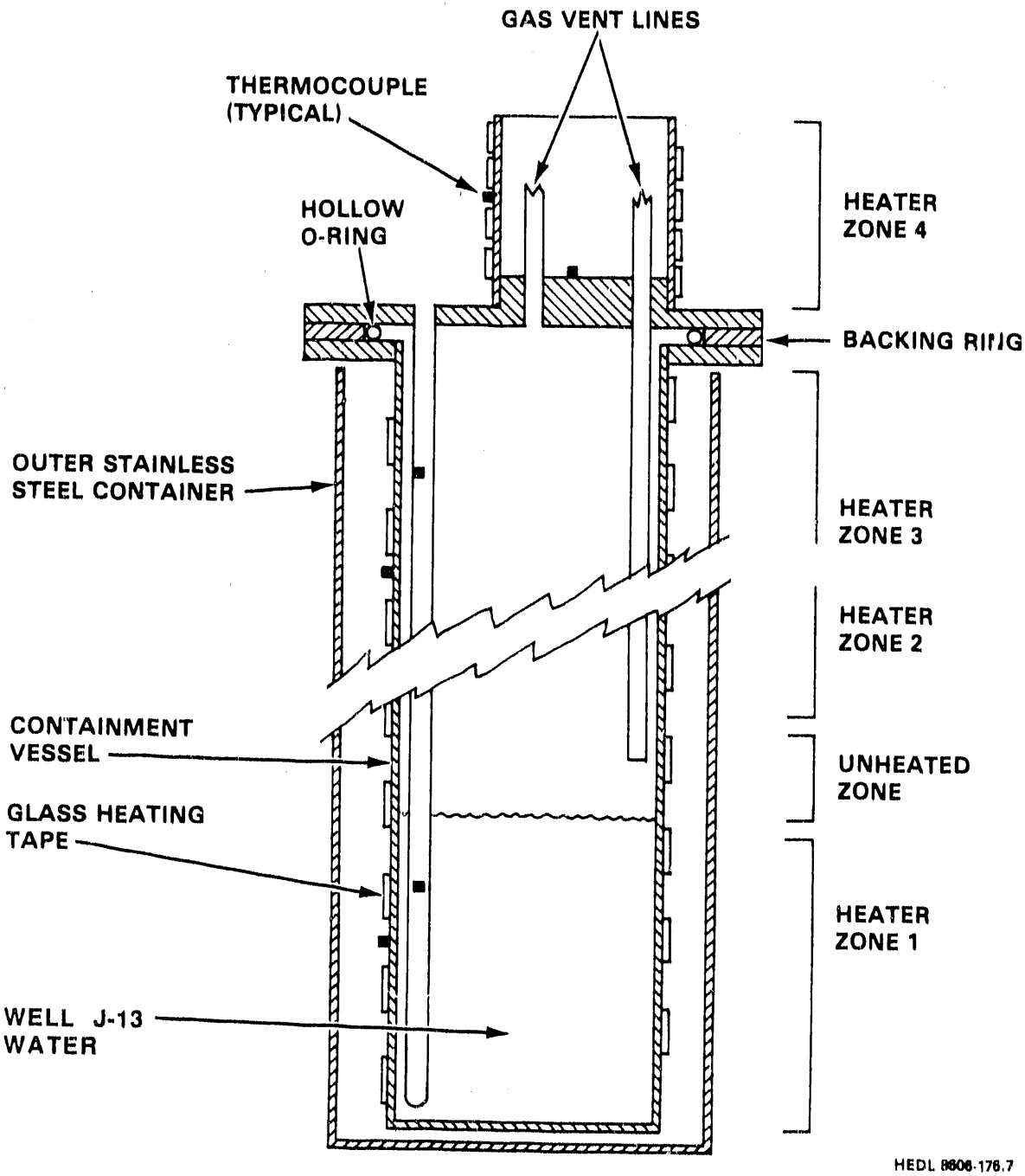

FIGURE 7. Schematic of a Corrosion Vessel.

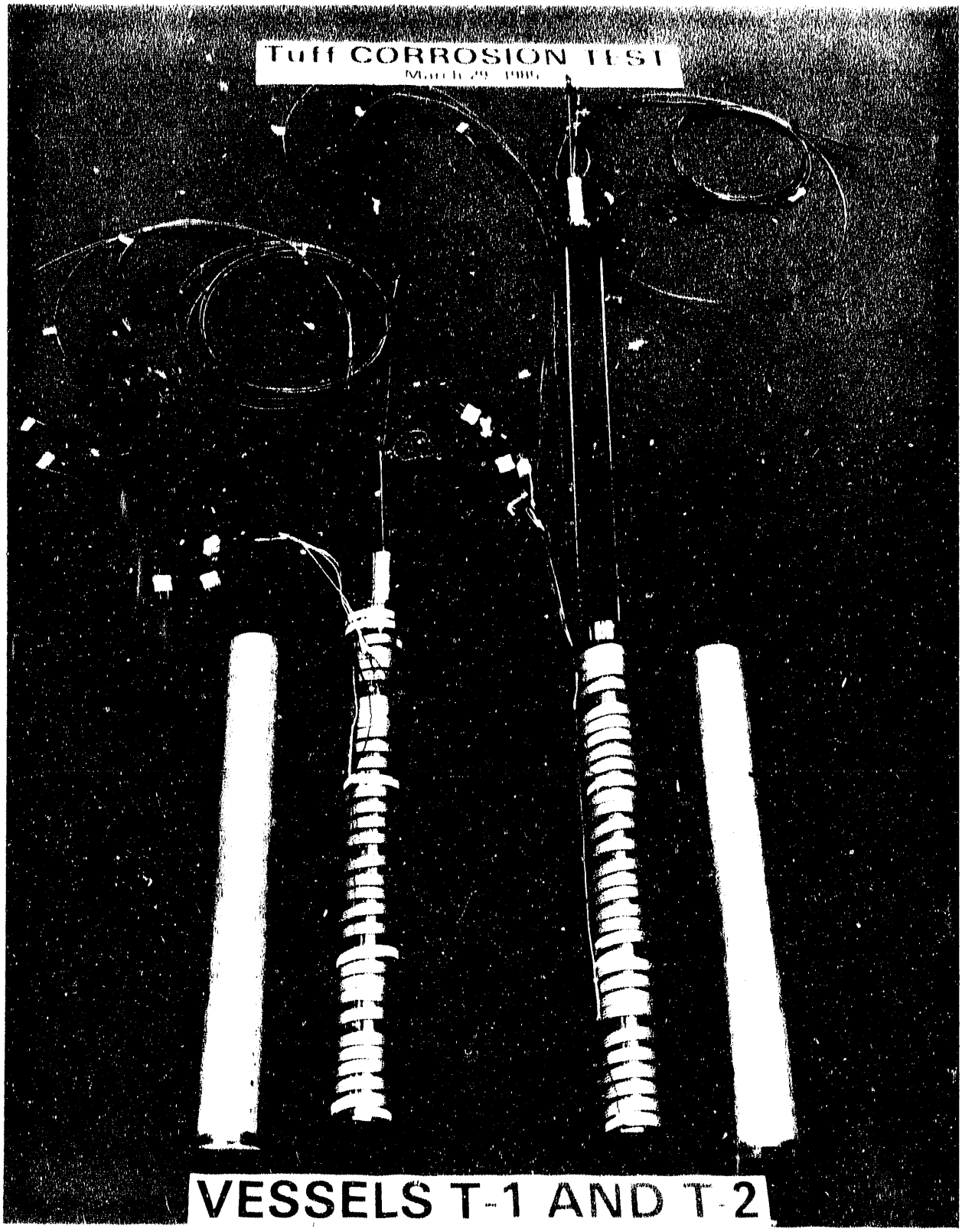

FIGURE 8. Two Corrosion Vessels with the Stainless Steel Guard Vessel Removed. (The lid of the right-hand vessel is also removed.)

the pneumatic control panels on the operating floor of the laboratory. The vessels were sealed by hollow metal O rings made of 321 stainless steel and plated with a 0.05-mm (2-mil) thick layer of nickel.

To prevent refluxing of water on the underside of the vessel lid and in the gas line connections just above the lid, heat was supplied to the top of the vessel by a glass-insulated heating tape wrapped around a brass cylinder. The 127-mm (5-in.) high cylinder formed a heated enclosure for the gas line connections and conducted heat to the vessel lid. A thermocouple mounted on the upper surface of the lid was used to determine the set point for the heater controller.

For vessels containing a liquid water phase, particular care was needed to prevent condensation of liquid on the surfaces of specimens that were mounted in the gas phase of the vessel. Such condensation can have a marked effect on the observed corrosion behavior. The tall, narrow gas chamber in these vessels normally promotes the formation of a vertical temperature gradient and stagnation of the gas in this space. The design and operation techniques used in the experiment to prevent this were: 1) a 64-mm (2-1/2 in.) gap between the top of the water, the water heater zone, and the lowest specimens in the gas space, the lower end of the gas phase heater, and 2) an independent, two-zone heating of the gas space. By careful adjustment of the three heater controllers, thermal convection was created in the gas space to mix the gas, maintain a more nearly uniform temperature distribution, and maintain a gas temperature slightly greater (3 °C-estimated) than the dew point.

3.3 SUPPORT EQUIPMENT

The experiment support equipment was mounted on three racks as shown in Figure 9.

3.3.1 Gas System

Gas circulation from the pneumatic control panel and through a vessel was ensured since one gas vent was on the vessel lid and the other was located

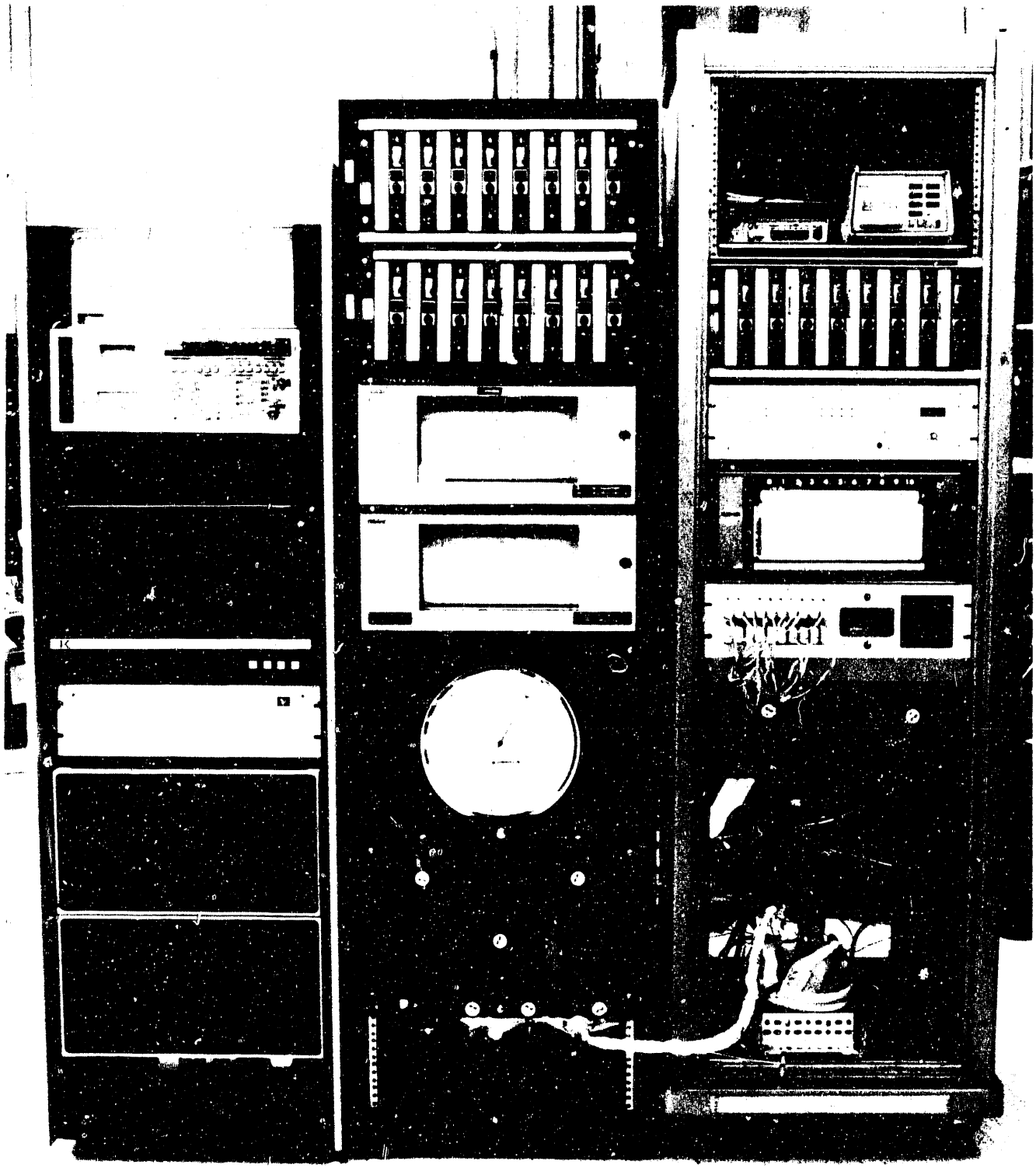

FIGURE 9. Experiment Support Equipment. (The data logger is in the left-hand cabinet. The other cabinets contain the temperature controllers, recorders, and gas manifolds.)

about 25 mm (1 in.) above the water level, or bottom of the vessel. The two 3.2-mm (1/8-in.) diameter gas lines from each vessel were attached to separate gas control manifolds. A schematic of two manifolds is shown in Figure 10. This arrangement allowed for gas sampling, purging of the gas space and calibration of the pressure transducers under operating conditions. Each vessel was protected from overpressure with a Nupro* series CPA adjustable pressure relief valve.

3.3.2 Heaters and Controllers

All six heaters on each vessel installation were individually controlled by Research, Inc., Model 639B three-function controllers**. Control thermocouples were banded to the outside of the vessel, or gas lines, between wraps of the heating tape. The controller set points were adjusted to produce the desired temperature values on the immersion thermocouples inside of the vessel. The immersion thermocouples were spring loaded against the inside walls of their immersion tube to assure minimum temperature error. The calibrations of the immersion thermocouples were verified before an experiment by operation of the vessel when it was filled with water at the normal boiling point. The 3.2-mm (1/8-in.) tubes, 7.6 to 12.2 m (25 to 40 ft) in length, were trace heated with metal-sheathed resistance heating cables. All parts of a gas manifold that were directly connected to the vessel were trace heated with glass-covered resistance heating tape. The manifolds and gas lines were maintained at about 115 °C to prevent moisture condensation. The extra thermocouples installed on the equipment to check the trace heating were monitored on a multistation thermocouple readout panel.

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*Nupro series CPA adjustable pressure relief valve is a trademark of the Nupro Company, Willoughby, OH.

**Model 639B three-function controller is a trademark of Research, Inc.

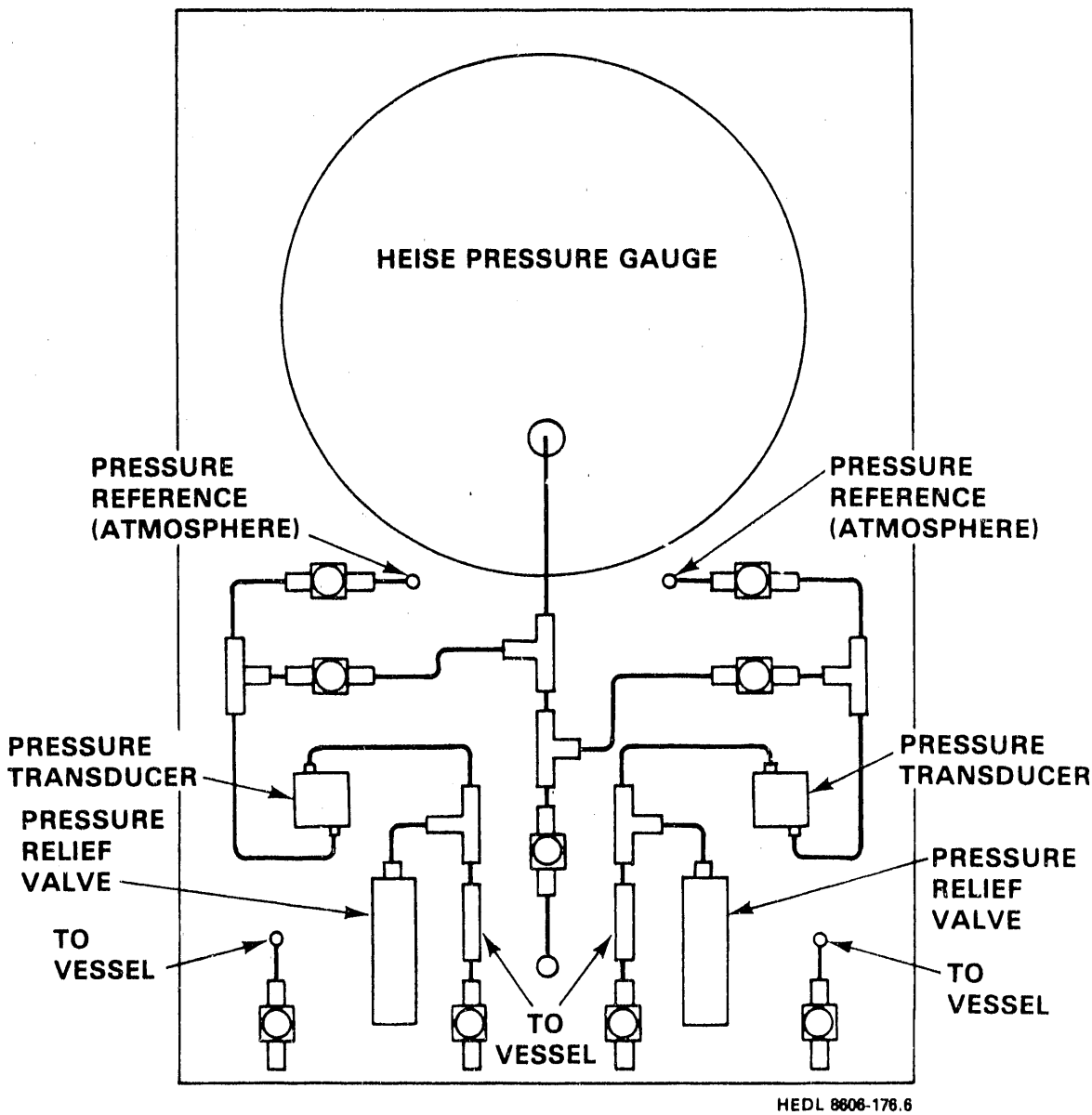

FIGURE 10. Schematic of Two Gas Manifold Systems.

3.3.3 Data Systems

System condition values were measured hourly by a Fluke Model 2240A data logger[a] and recorded on nine-track magnetic tape by a Kennedy Model 1600 recorder[b]. Periodically, the data tapes were read by a Kennedy Model 9832 tape deck[c] and the data transmitted to a Sperry[d] 1100/40 computer for processing. Details of the data channels and output records are given in Reference 3. To provide backup records for the vessel temperatures and to detect temperature transients that might occur between recordings by the data logger, the midlevel immersion thermocouple voltage from each vessel was recorded on an Esterline Model L1102S strip chart recorder[e]. The pressure in each vessel was measured with a Validyne Model CD280 Multichannel Carrier Demodulator[f] with Model DP-7 and DP-15 variable reluctance, differential pressure transducers that used the air atmosphere as a reference. Calibration of these units was made under operating conditions with a calibrated, 690 kPa (100-lb/in^2) Heise[g] gauge, readable to less than 0.69 kPa (0.1 lb/in^2). Finally, a telephone callout system was installed that would automatically call one of several key personnel if any abnormal value of temperature or pressure occurred in any vessel or if electrical power was interrupted.

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[a]Fluke Model 2240A data logger is a trademark of John Fluke Manufacturing Company, Inc.

[b]Kennedy Model 1600 recorder is a trademark of an Allegheny International Corporation

[c]Kennedy Model 9832 tape deck is a trademark of an Allegheny International Corporation

[d]Sperry is a trademark of UNISYS

[e]Esterline Model l11025 strip chart recorder is a trademark of Scientific Columbus, Inc.

[f]Validyne Model CD280 Multichannel Carrier Demodulator is a trademark of Validyne Engineering Corporation

[g]Heise gauge is a trademark of Dresser Industries, Newtown, CT.

3.4 PROCEDURES AND TECHNIQUES

3.4.1 Specimens

3.4.1.1 General Treatments

Each new specimen was engraved with a unique serial number that identifies origin and composition throughout all phases of exposure and examination. A record was kept of the specific location of each specimen in each cage, vessel, and experiment. The serial number code is XYZZZ where:

X = Alloy
- 1 = CDA 101/102 - pure copper
- 2 = CDA 613/614 - aluminum bronze
- 3 = CDA 715 - 30% nickel-copper

Y = Specimen type
- W = Weight loss
- B = Bend (tear drop)
- C = Crevice

ZZZ = Serial number

Specimens were prepared for use by ultrasonic cleaning in xylene, then hand polished with 600-grit silicon carbide paper and rinsed several times in absolute ethyl alcohol; one rinse was in the ultrasonic cleaner. All specimen cages, hardware, and vessels were cleaned in a similar manner. The ceramic hardware was etched in 30% nitric acid at approximately 80 °C, rinsed in demineralized water several times, and baked in a vacuum oven overnight at approximately 200 °C. When specimens were loaded into their respective cages, the spatial arrangement of each specimen type assured that adjacent specimens were of different alloys.

Specimen cages removed from an experiment were isolated in closed containers and taken to the laboratory for disassembly and specimen replacement. New specimens were mounted with clean ceramic spacers. To minimize bias, speci-

mens of each type and alloy were examined in as large a group as possible and without regard for exposure history.

Oxide films were removed according to ASTM G1-81:[7] 1 to 3 min in a deaerated, hydrochloric acid solution (1:1) at room temperature. Separate solutions were used for each alloy. After the films were removed, the specimens were rinsed in demineralized water, rubbed hard by hand with a lint-free cotton cloth, rinsed again in absolute ethyl alcohol, and air dried.

3.4.1.2 Crevice Specimens

Crevice specimen pairs were not washed or rinsed after removal from the vessel. The pairs were kept tightly bolted together until ready for examination. After the pairs were opened, a careful, visual examination was made of all inner surfaces, using a 10X magnifier. A color photograph was made of one inside and one outside surface of each specimen. Specimens were cut by a hand-operated hacksaw for analysis and examination.

3.4.1.3 Tear Drop Specimens

After the oxide films were removed, each specimen was given a careful, visual examination with the aid of a 10X magnifier. Color photographs were made (up to 10X magnification) of any features of particular interest. The specimens were examined for microcracks by fluorescent dye penetrant per ASME code.[8] The specimens were then cut with a hand-operated hacksaw for analysis and examination.

3.4.1.4 Weight-Loss Specimens

Specimens were lightly rinsed with demineralized water and dried overnight in air. Weighings were made before the corrosion exposure (after final cleaning and polishing), before removal of the oxide film (after rinsing and drying), after the oxide film was removed, and after a second acid treatment of equal length to the first treatment (to correct for the metal loss by the acid). A color photograph was made of one side of each specimen before oxide removal.

After the oxide film was removed, a close visual inspection was made of all surfaces, using a 10X magnifier. Color photographs were taken following the same procedure used on the tear drop specimens.

In each 95 °C experiment, one set of weight-loss specimens was mounted so that half of the metal was in Well J-13 water and the other half was in the gas phase. Twenty-seven specimens were exposed at approximately 4 x 10^5 R/h for 1, 3, and 9 mo. Nine others were exposed at approximately 4 x 10^3 R/h for 3 1/2 mo. After their exposures to the corrosion environments, the specimens were cut in half lengthwise with a hand-powered hacksaw. The oxide film was removed from one piece and the metal surface examined visually using a 10X magnifier. Some of the pieces were sectioned and polished for metallographic examination.

3.4.1.5 Electrochemically Prepitted Specimens

A set of weight loss and tear drop specimens of each of the three materials was electrochemically prepitted at LLNL and then placed in the gamma corrosion experiments at Westinghouse Hanford Company. The prepitting was performed in a synthetic Well J-13 type water solution prepared as shown in Table 3. The pitting was accomplished by raising the electrochemical potential of a specimen by steps to several hundred millivolts above the measured corrosion potential. The ranges of process times and voltages used are summarized in Table 4. These specimens were not included in the Westinghouse Hanford marking system described above or included in the data base in the Appendix. The variations in the pitting conditions used produced a variety of pitting structures and was consistent with the program objectives, i.e., to determine the corrosion effects on a variety of specimens. At Westinghouse Hanford, the specimens were mounted in the all-titanium vessel T-3 and exposed to conditions similar to those that existed in vessel T-1 (i.e. 95 °C, liquid and gas phases). The oxide film removal process mentioned above was modified for these specimens. The hydrochloric acid etch was a 30-s exposure in a high-energy ultrasonic bath. This was followed by a 30-s rinse in the ultrasonic bath, followed by the normal rinse sequence. After the oxide films were

TABLE 3

COMPOSITION OF SYNTHETIC WELL J-13 TYPE WATER
(Used only for electrochemical prepitting)

Chemical	Quantity*
Sodium bicarbonate	17.0
Potassium nitrate	1.5
Sodium chloride	1.2
Potassium sulfate	3.36
Sodium fluoride	0.508
pH range:	8.17 to 8.64

* grams/liter of solution (molal)

removed and visual observations were made, the tear drop specimens that had received the 6-mo exposures were sectioned, polished, and given metallographic examinations.

3.4.1.6 Metallographic Examinations

Metallographic sectioning and examinations were made to determine whether the surface corrosion features were related to any breakdown of the structure of the underlying metal. The metallography also complements the other types of examinations performed. This sampling provided a limited view only of possible metal structures and should not be considered a comprehensive examination of the specimens.

The 37 specimens selected for examination included examples from each subgroup of alloy and environmental condition. Specimens were mounted, sectioned, and polished using standard metallographic techniques. After the specimens were carefully examined, unusual features were photographed (magnification range 5X to 400X). The specimen surfaces were then etched with a mixture of about

TABLE 4

RANGES OF MEASURED CORROSION AND PITTING POTENTIALS USED BY LAWRENCE LIVERMORE NATIONAL LABORATORY FOR PREPARATION OF PREPITTED SPECIMENS

	Corrosion Potentials (mV vs. SCE)		Pitting Potential Sequence (mV vs. SCE)			
Material (CDA No.)	Weight Loss Specimens	Tear Drop Specimens	Starting Potential	Size of Step Increase	Final Potential	Time At Final Value (min)
102	-63 to -76	-77 to -100	-100	50 mV/5 min to 100 mV/5 min	+400	10 - 25
613	-135 to -172	-119 to -147	+500	50 mV/5 min to 150 mV/5 min	+1,200	8 - 18
715	-129 to -150	-125 to -168	+750	250 mV/5 to 18 min	+1,100	5 - 20

19 vol% concentrated nitric acid and concentrated formic acid to reveal the grain structures. After the specimens were reexamined, additional photographs were made, as appropriate.

3.4.1.7 Visual Examinations

All specimen surfaces were carefully examined under good lighting, using a 10X magnifier. Descriptions of specimen conditions and special features were recorded. A series of two-letter codes or descriptors was devised to condense this information into a usable form so that comparisons, groupings, and correlations could be made using the data base. A detailed description of the list is in Appendix A along with the data base. The descriptors are somewhat suggestive of their meaning, so that they can be strung together to make descriptive phrases. For example, "FWDKSPPT" reads "a few dark spots and pits."

While every effort was made to make the descriptors as explicit as possible, the system is qualitative, and there are overlaps in the definitions. However, the value of being able to easily analyze and compare specimen conditions with other experimental values in the data base was felt to outweigh the brief inconvenience of learning the codes. In particular, the notation of "pits" was used in cases where it was not clear whether the features were pits (with recognizable depth) or spots. Thus this entry is on the conservative side.

3.4.1.8 Air Water-Vapor at 150 °C

To establish the vessel T-2 atmospheric composition at the beginning of an experiment, the vessel was placed into the gamma field and all systems were brought to the operating temperatures. Compressed breathing air was humidified by sparging at 0.5 L/min through water at 75 °C to 80 °C, and then through a heated delivery system to the vessel. After three to five vessel volumes of gas had passed through the system, the vessel exit valve was closed, the system was pressurized to 1 to 2 lb^f/in^2 (gage), and the gas system was sealed. The small pressurization was used to detect leaks that

might develop in the system during the experiment. The gas was not changed during the 1-mo and 3-mo experiments. During the 6-mo exposure period, the vessel was repurged every 7 to 10 d (as above) with one vessel volume of humidified air.

3.4.1.9 Water-Saturated Air and Water at 95 °C

The specimen cages to be located in water were loaded into vessel T-1, T-3, or T-4. Well J-13 water was added to a predetermined level that would be across the middle of the interface specimens during the experiment. The remainder of the cages were loaded and the vessel was then sealed and lowered into the gamma tube. All heaters, except the water heater, were then energized and brought to their operating temperatures.

After the metal specimens had a chance to reach the system temperature (usually overnight), the water temperature was carefully increased without allowing it to reach the temperature of the gas space. Temperature values used for this were based on an estimated overall measurement uncertainty of ±1 C°. When the vessel was depressurized or gas samples were taken during an experiment, the water temperature was first cooled to about 30 °C to prevent a violent expansion of the water (from the pressure release) that would splash onto the specimens mounted in the gas phase.

As soon as a vessel was opened for specimen exchange, the gas phase cages were quickly removed and a pH meter electrode was lowered into the vessel. Several readings of the pH were made with reference to standard buffer solutions. Several samples of the water were then removed from the vessel pool with pipettes. Finally, the cages under water were removed, and the remainder of the water was poured into storage containers. The vessel was then swabbed several times with clean, lint-free cotton cloths and rinsed with deionized water several times, drained, and air-dried. Fresh Well J-13 water was used when the vessel was reloaded.

The seal surfaces for the O ring were hand polished with 600-grit silicon carbide paper before each experiment. The seal of a loaded vessel was given a

final leak check by pressurizing the vessel to 340 to 550 kPa [50-80 lb^f/in^2 (gage)], depending on the setting of the pressure relief valve, and by covering all the seal flange areas with a commercial bubble-forming liquid.

3.5 QUALITY ASSURANCE

The level of quality assurance for this work is level three as defined in Reference 9. The basic elements of this level include traceability of specimens from the foundry heat number to the experimental conditions and the final analyses of each specimen, calibrations of all primary measurement instruments to the NBS references, written laboratory procedures, and complete, indexed, laboratory records.

4.0 RESULTS

4.1 DATA BASE

All information regarding the specimens and their examinations was entered into a Symphony data base on an IBM Personal Computer (PC), for ease of data verification and analysis. The data base listing is shown in Appendix A along with an explanation of the codes and formats used. Elsewhere in this report, a shorthand notation is used for the exposure conditions for specimens:

MMM/P/N

where:

MMM = Nominal temperature in °C
P = Phase (G = gas; L = liquid)
N = Number of mo of exposure.

Table 5 summarizes the numbers of each type and alloy of the specimens that were processed.

4.2 VESSEL ENVIRONMENT

Since gamma irradiation alters the chemical composition of an air-water environment, measurements of the changes that occurred under these experimental conditions are essential for the characterization of the observed corrosion and the development of an understanding of the corrosion processes. In situ measurements of many of the expected species[2] were beyond the scope of these experiments. Values recorded were 1) vessel pressure versus time, measured hourly, 2) water and gas temperature, measured hourly, 3) gas composition, measured every few weeks, when excess vessel pressure was released [operating maximum was 340 kPa (50 lb^f/in^2 (gage)], and 4) liquid water composition, measured each time an experiment was interrupted for the exchange of corrosion specimens.

TABLE 5

NUMBERS OF EXPOSED SPECIMENS

Alloy	Specimen Type						
					Prepitted		
	Weight Loss	Inter-face	Tear Drop	Crevice	Weight Loss	Tear Drop	Totals
Copper	56	6	41	30	6	4	143
Al-Bronze	56	6	39	30	6	4	141
Ni-Cu	56	6	40	30	6	4	142
TOTALS	168	18	120	90	18	12	426

[1]Symphony, V1.1 is a trademark of Lotus Development Corporation.

4.2.1 Air-Water Vapor at 150 °C

There was no noticeable change in the gas pressure in vessel T-2 during the experiment beyond the daily fluctuations in the barometric (reference) pressure. To make reliable measurements of changes in the amount of gas versus time would have required more extensive instrumentation and thermostating of the system. Mass spectrometric analyses of the gas samples are shown in Table 6. After the first 1-mo and 3-mo experiments were completed, the gas was replenished every 7 to 10 d. (Note that water vapor was not determined by the sampling and analysis methods used.)

4.2.2 Air-Water Vapor At 95 °C

Examples of the rates and amount of pressure buildup in vessel T-1 are shown in Figure 11 for the titanium vessel used in the second part of a 7-mo experiment. The composition of the gas in the vessel was measured with a mass spectrometer. Samples were drawn into evacuated stainless steel bulbs after the connecting lines and manifold were purged with gas from the vessel. As mentioned above, the water vapor content cannot be reliably measured by this method. However, liquid water was always present in the vessel, hence its

TABLE 6

GAS COMPOSITION IN VESSEL T-2 AT 150°C

Gas	Gas Composition (vol %) Air	After 3-Month Experiment	After Last 4.5 Mo* of 6-Mo Experiment	15 Days After Previous Purge/ Replenishment of Vessel
Argon	0.95	0.79	0.04	0.08
Carbon dioxide	0.05	0.53	0.06	0.07
Carbon monoxide	<0.1	<0.1	<0.1	<0.1
Hydrogen	<0.01	<0.01	<0.01	<0.01
Methane	<0.01	<0.01	<0.01	<0.01
Nitrogen	78.0	80.1	80.2	80.1
Oxygen	21.0	18.6	19.7	19.7
Water vapor (not measured)	--	--	--	--

*Eight days after previous gas replenishment

NOTE: Analytical sensitivity for N_2O, NO_2, and NO was 0.02 vol% Ammonia (NH_3) was not present with water vapor.

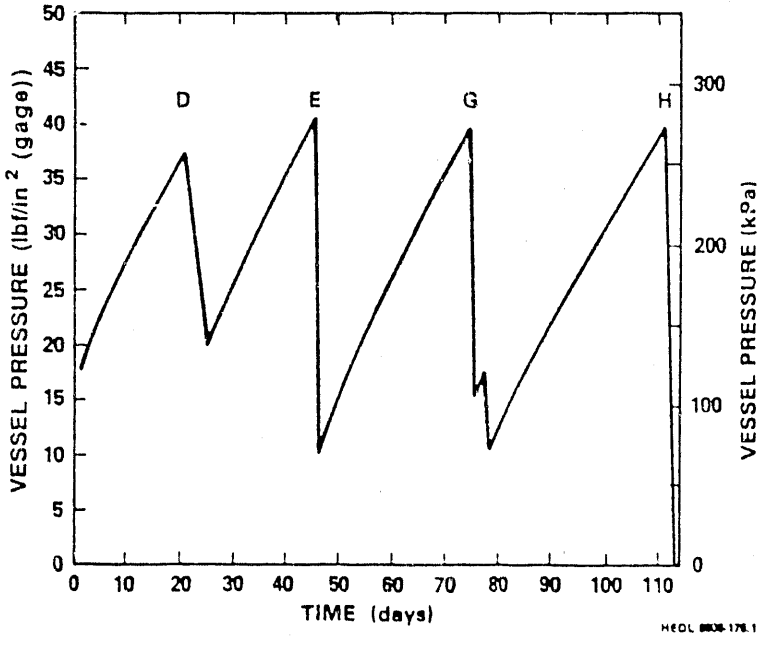

FIGURE 11. Gas Pressure Variation in Vessel T-1 (95°C) During the Last 3-3/4 Mo of the 7-Mo Experiment. The average rate of pressure increase is (1.0 $lb^f/in^2/d$) 6.9 kPa/d.

partial pressure was calculated from its temperature. The partial pressure of each gas in the vessel was calculated from the gas pressure and water temperature at the time of sampling and the measured composition of the sample. Results are shown in Table 7.

4.2.3 Liquid Water at 95 °C

Table 8 shows the chemical composition of the water solutions relative to the Well J-13. Note that the 30-d and 95-d values were from a Monel 400 vessel while the others were from titanium vessels. Cation analyses were made by an inductively coupled plasma (ICP) emission spectrometer and the anion analyses by anion chromatography. Samples were filtered before being analyzed. The analyses of some precipitates found in the early experiments have been discussed.(3)

4.3 METAL SPECIMENS

4.3.1 Stress-Assisted Cracking

The dye penetrant examination performed on the 121 corroded tear drop specimens and on three archive specimens revealed no evidence of surface cracking. Twenty of these specimens, regular and prepitted, were then cross sectioned, polished, and metallographically examined. No evidence of subsurface corrosion or cracking was seen. Details of these examinations are discussed below.

4.3.2 Crevice Corrosion

Ten specimens of each alloy were exposed to each of the three corrosion environments. The results of the visual observations of the local corrosion features seen on the crevice specimens are listed in the data base (Appendix A). These are also summarized in Tables 9 through 11. The width of the crevice corrosion penetration zone around the outer edge of the specimens is designated by the code "nM", where n is the corrosion zone width in milli

TABLE 7

GAS COMPOSITION IN VESSELS DURING CORROSION EXPERIMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
							Gas Composition in Vessels During Experiments (absolute atmospheres) Partial Pressures									
Sample Number	Date	Time	Vessel Water Temp (C)	Vessel Water Press (psia)	Vessel Total Press (psig)	Vessel Net Press (psia)	H2O	O2	N2	H2	CO2 (xE3)	Ar (xE3)	CO (xE3)	He (xE3)	CH4 (xE3)	Total Press
T1-A	09/05/85	10:00	97.0	13.2	47.5	49.0	0.90	0.84	0.84	1.65	8.00	1.33	<3.33	<0.33	<0.33	4.2
T1-C	11/12/85	08:00	97.5	13.4	36.3	37.6	0.91	0.62	0.26	1.67	0.51	0.77	<2.56	<0.26	<0.26	3.5
T1-D	01/08/86	10:00	94.5	12.0	37.8	40.5	0.82	0.76	0.81	1.16	19.27	2.75	<2.75	<0.28	<0.28	3.6
T1-E	01/31/86	08:00	95.3	12.4	30.3	32.6	0.84	0.62	0.71	0.88	8.65	0.44	<2.22	<0.22	<0.22	3.1
T1-G	03/04/86	10:00	94.9	12.2	17.1	19.6	0.83	0.37	0.41	0.55	2.93	0.13	<1.33	<0.13	<0.13	2.2
T1-H	04/09/86	09:00	94.9	12.2	39.2	41.7	0.83	0.87	0.37	1.59	2.27	<0.28	<2.84	<0.28	<0.28	3.7
T1-J	07/15/86	08:35	93.9	11.8	34.7	37.6	0.80	0.71	0.63	1.21	6.14	1.02	<2.56	<0.26	<0.26	3.4
T1-M	10/10/86	08:40	93.6	11.6	15.2	18.3	0.79	0.37	0.11	0.75	2.86	0.12	<1.24	<1.24	<1.24	2.0
T3-A	05/20/86	13:40	93.7	11.7	46.5	49.5	0.79	0.90	0.93	1.51	17.85	6.06	<3.37	<0.34	<0.34	4.2
T3-B	10/14/86		93.2	11.5	12.5	15.7	0.78	0.33	0.15	0.60	1.71	0.64	<1.07	<0.11	<0.11	1.8
T4-A	10/13/86	10:23	93.3	11.5	9.6	12.8	0.78	0.09	0.73	0.03	19.06	3.48	<0.87	<0.09	<0.09	1.7
T2-B	10/14/86	08:30						0.19	0.80	0.00	5.30	7.90	<1.0	<0.1	<0.1	1.0
T2-C	03/06/86	14:00						0.20	0.80	0.00	0.60	0.40	<1.0	<0.1	<0.1	1.0
T2-D	10/09/86	09:15						0.20	0.80	0.00	0.70	0.80	<1.0	<0.1	<0.1	1.0
CY-1	01/10/86							0.21	0.80	0.00	0.20	0.20	<1.0	<0.1	<0.1	1.0
Poom	03/05/86							0.21	0.78	0.00	0.50	9.50	<1.0	<0.1	<0.1	1.0
Book*								0.21	0.78		0.33	9.34				1.0

Explanation of table, by column number:

1-3,6 From the data records.

4 Temperature of water in vessel, under experimental conditions, before the gas sample was taken.

5 Water vapor pressure in the vessel, from temperature in col 4, calculated with the equation; log P(torr) = 8.689743 - 2167.71/T(K).

7 Total pressure of permanent gases in the vessel, under experimental conditions; col 6 - col 5 + 14.7.

8-16 Partial pressures of the constituent gases, under experimental conditions, just prior to sampling; Col 8 is from col 5.

17 Total of partial pressures under experiment conditions; sum of col 8 thru 16.

*Handbook of Chemistry and Physics, 57th ed., CRC Press, Cleveland, Ohio 1976.

TABLE 8

WATER COMPOSITIONS AT 95 °C

Exposure (Days)	0. J-13[a] (LLNL)	0. J-13[b] (HEDL)	30.	95.	115.[d]	25+128[e]	36+63[e]	9+95[e]
Container Material	--	--	Monel[c]400	Monel[c]400	Titanium	Titanium	Titanium	Titanium
pH	7.6	6.8	8.0	9.0	7.6	8.0	6.5	6.4
Species (wppm)								
F	2.2	2.1	1.4	0.38	0.78	0.32	0.68	1.80
Cl	6.9	7.0	5.8	2.5	3.6	15.0	2.4	6.8
NO_3	9.6	8.7	10.	2.5	18.8	5.2	17.5	0.62
SO_4	18.7	19.	6.2	1.8	4.4	2.5	5.4	13.1
NO_2 (est)	--	--	3.8	1.8	1.2	1.0	2.8	3.0
H_2O_2	--	--	<1.0	<1.0	--	--	--	--
Total C	--	23.	21.	8.4	9.7	11.4	6.6	23.7
Inorganic C	125.[f]	23.	21.	8.1	9.3	11.0	6.1	16.2
Al	0.012	<0.15	<0.15	<0.15	0.18	<0.08	<0.08	<0.08
Ba	--	<0.002	0.03	0.04	0.02	0.042	0.009	0.033
Ca	12.5	12.	9.8	2.7	3.9	6.8	4.6	4.5
Cu	--	<0.01	0.09	<0.01	0.03	0.16	0.59	0.76
Fe	0.006	<0.02	<0.02	<0.02	0.04	0.014	0.045	0.015
K	5.11	6.4	3.3	2.4	4.8	2.1	3.0	6.1
Li	0.042	0.07	0.06	<0.03	0.13	0.029	0.036	0.039
Mg	1.92	1.8	1.1	0.06	0.45	0.35	0.38	0.51
Mn	--	<0.005	<0.005	<0.005	<0.005	0.007	0.007	0.023
Na	43.9	41.	36.	17.	2.8	18.	18.	44.

TABLE 8 (CONTINUED)

Exposure (Days)	0.	0.	30.	95.	115.[d]	25+128[e]	36+63[e]	9+
Species (wppm)								
Ni	--	<0.03	2.1	0.06	0.23	0.036	0.2ɗ	0.34
Pb	--	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Si	27.0	30.0	0.54	0.49	1.45	0.92	3.6	2.1
Sn	--	0.15	0.15	<0.15	<0.15	<0.15	<0.15	<0.15
Sr	0.035	0.04	0.03	0.01	0.008	0.021	0.015	0.017
Anion/Cation Balance (milliequivalent wt./L)								
Total anions	2.9	2.8	2.4	0.88	1.3	1.5	1.1	2.0
Total cations	2.8	2.7	2.3	0.97	1.6	1.2	1.2	2.4

[a]Lawrence Livermore National Laboratory
[b]Westinghouse Hanford Company
[c]Monel is a trademark of Huntington Alloy Products, Inc., International Nickel Company, Inc.
[d]End of exposure for 7-mo experiment
[e]Vessel opened to air once for specimen changes, but water not sampled
[f]as bicarbonate

NOTE: Chromatographic column used did not provide adequate results for standard method. Used one point calibration only. Estimated accuracy of results is ±15%.
NH_4^+ was not determined.

TABLE 9

CREVICE SPECIMEN CORROSION: CDA 101/102

Specimen Number	Alloy Type (CDA No.)	Reaction Phase	Temperature (°C)	Exposure Time (mo)	Gamma Flux (R/hr x E-5)	Visual* Observations
1 C 24	102	G	95	3.2	2.5	ARLC1M
1 C 39	101	G	95	5.1	2.5	ARLC1M
1 C 33	101	G	95	7.4	0.67	ARLC1M
1 C 35	101	G	95	8.9	2.5	ARLC1M
1 C 12	102	L	95	1.0	4.1	LC1M
1 C 14	102	L	95	1.0	4.1	ARSMPTLC1M
1 C 26	102	L	95	3.2	4.1	ARLC1M
1 C 27	102	L	95	3.2	4.1	ARVSSPPT?/ARLC1M?
1 C 43	101	L	95	3.5	0.037	ARLC1M
1 C 40	101	L	95	3.5	0.037	ARLC1M
1 C 31	101	L	95	5.1	4.1	ARLC1M
1 C 15	102	L	95	8.0	4.9	ARLC1M
1 C 34	101	L	95	8.9	4.1	ARLC1M?

*Visual observation codes are defined in Appendix A and discussed in the text.

TABLE 10

CREVICE SPECIMEN CORROSION: CDA 613/614

Specimen Number	Alloy Type (CDA No.)	Reaction Phase	Temp-erature (°C)	Exposure Time (mo)	Gamma Flux (R/h x E-5)	Visual* Observations
2 C 5	614	G	150	1.5	1.6	ISLC/NF
2 C 32	614	G	150	2.1	0.31	FWPTFL3M
2 C 34	614	G	150	5.6	1.5	ISLC
2 C 6	614	G	95	1.0	2.5	LCFL
2 C 23	613	G	95	3.2	2.5	ARLC
2 C 35	614	G	95	3.5	0.033	GELCFLPT
2 C 36	614	G	95	3.5	0.033	GELCPT
2 C 26	614	G	95	5.1	2.5	GESMPT?SPLC
2 C 24	614	G	95	7.4	0.67	GELCFL
2 C 28	614	G	95	7.4	0.67	GELCPTFL
2 C 11	614	G	95	8.0	2.5	GEPT/ARLC
2 C 29	614	G	95	8.9	2.5	GELCPTFL
2 C 15	614	L	95	1.0	4.1	ARLC1M/ISFL?/CUFM
2 C 13	614	L	95	1.0	4.1	ISLC1M
2 C 16	613	L	95	3.2	4.1	ARLC1M?/CUFM
2 C 22	613	L	95	3.2	4.1	ARLC1M?/NF/CUFM
2 C 25	614	L	95	3.5	0.037	ARLC1M/CUFM
2 C 27	614	L	95	3.5	0.037	ARPTLC1M/CUFM
2 C 37	614	L	95	5.1	4.1	LC1M?/CUFM
2 C 30	614	L	95	8.9	4.1	LC1M/CUFM

*Visual observation codes are defined in Appendix A and discussed in the text.

TABLE 11

CREVICE SPECIMEN CORROSION: CDA 715

Specimen Number	Alloy Type (CDA No.)	Reaction Phase	Temperature (°C)	Exposure Time (mo)	Gamma Flux (R/h x E-5)	Visual* Observations
3 C 10	715	G	150	1.2	4.6	ISLC/CLNF
3 C 4	715	G	150	6.1	0.75	GEVSPTIM/CLNF
3 C 15	715	G	95	1.0	2.5	FWLGLC/GEDKFM
3 C 28	715	G	95	3.5	0.033	ISLC/CLNF
3 C 37	715	G	95	3.5	0.033	FWXLLC1M/GEDKFM
3 C 30	715	G	95	5.1	2.5	FWFL5M
3 C 27	715	G	95	7.4	0.67	ARLCFL
3 C 26	715	G	95	7.4	0.67	ARPTLC/ARDKFM
3 C 8	715	G	95	8.0	2.5	CL/DKFMISLC1M
3 C 24	715	G	95	8.9	2.5	ARLCFL5M/GEDKFM
3 C 3	715	L	95	1.0	4.1	GEVSPT1M/CLNF
3 C 5	715	L	95	1.0	4.1	GESMPTLC2M
3 C 18	715	L	95	3.2	4.1	GESMMDLTSP/ARVSPT1M
3 C 23	715	L	95	3.2	4.1	GEVSPT1M
3 C 33	715	L	95	3.5	0.037	GEVSPT1M
3 C 35	715	L	95	3.5	0.037	ARVSPT1M
3 C 32	715	L	95	5.1	4.1	GEVSPT1M
3 C 13	715	L	95	8.0	4.9	ARVSPT1M/CLNF
3 C 25	715	L	95	8.9	4.1	GEVSPT2M/ARSMPT

*Visual observation codes are defined in Appendix A and discussed in the text.

meters. Some specimens also showed corrosion of the closely mated surfaces at locations inward from the edges of the specimens.

Crevice corrosion was seen only around the outer edges on the CDA 101/102 specimens and only on those exposed at 95 °C. Thirteen of the thirty specimens were thus affected.

Only 1 of the 12 corroded gas phase specimens of CDA 613/614 showed crevice corrosion around the outside edges; it had been exposed at 150 °C. Eight of the liquid phase specimens showed similar attack. The local corrosion found on the other gas phase specimens was in the midsurface regions of the mated surfaces, away from the edges. Included in these features were the filiform-like corrosion patterns that are also seen under the oxide films on the weight loss and tear drop specimens.

Ten of the nickel alloy (CDA 715) specimens showed local corrosion. Half of the 95/G specimens had local corrosion in the inner areas away from the edges of the paired plates. All of the local corrosion of the liquid phase specimens was in the crevice near their outer edges of the specimens.

In summary, crevice corrosion at the edge of the specimens occurred only on the CDA 101/102 specimens exposed in the gas phase, not on those from the liquid phase. The results from the aluminum bronze CDA 613/614 specimens were just the reverse. The CDA 715 nickel alloy showed crevice corrosion on both liquid and gas phase specimens but more regularly on those from the liquid phase. In the regions between the plates, but well away from the specimen edges, no local corrosion features were seen on pure copper. Some features were seen on the nickel alloy specimens, and local corrosion features were common in this region on the aluminum bronze specimens.

4.3.3 Prepitted Specimens

Three sets of prepitted specimens were visually examined:

- Those in an as-received condition from LLNL.
- Those that received 3-mo exposure
- Those that received a 6-mo exposure.

In general, the pits found were rather broad, having a ratio of pit depth to pit width value (aspect) of one or less. The distribution, density, and size of the pits varied considerably across the surfaces of the specimens; this likely is due to the variations in electrochemical conditions used in their preparation.

The exposure of the specimens to the irradiation corrosion environment in the Westinghouse Hanford Company gamma pit seemed to result generally in larger (broader) pits and fewer small pits. This suggests that the pitting initiation process did not continue under the irradiation corrosion environment. Under these conditions, the smaller pits would disappear as the metal near the pits was consumed. A dense population of larger pits would combine, but would eventually disappear by the general corrosion process. The metallographic examinations described above showed no evidence of intergranular penetration or corrosion and there was no evidence of stress-assisted cracking. The only cracks that were seen were related to mechanical deformations of the metal surface that apparently occurred before the corrosion experiments (i.e., in the manufacture of the specimens). There were differences in the behaviors of the different alloys, however.

On the CDA 101/102 specimens the pits were quite broad. Some of the larger pits (about 20 μm - 300 μm deep) showed roughness on their surfaces that was about 1/10 the scale of the pit size. This small-scale roughness may have been smoothed somewhat by the corrosion, but not substantially. The unpitted

surfaces were relatively smooth. Examples of these specimens are shown in Figures 12 and 13 (87520C and 87329C).

Some of the pits in the aluminum bronze (CDA 613/614) surfaces had a higher than average aspect, e.g., 3-5 (depth/width) and up to about 25 μm in depth. In general, the unpitted surfaces did not have the roughness found on the CDA 715 specimen. Significant differences were seen between the three types of specimens: as received, 3-mo, and 6-mo exposures. Examples are shown in Figures 14 and 15 (87521E and 87330E).

On the nickel alloy specimens (CDA 715), the original pits (as received) and those remaining after corrosion in the gas phase were quite rough and irregular. See Figures 16, 17, and 18 (87522D, 87328C, and 87328F). Undercutting of the specimen surfaces was common. However, pitted and unpitted surfaces on liquid phase specimens were considerably smoother. Pit depths ranged up to 50 μm. Other depressions, found up to 180 μm deep, likely were related to other mechanisms (e.g., mechanical damage to the metal or electrode clamps).

4.3.4 Interface Specimens

The location of the waterline was easily recognizable on these specimens, both with and without the oxide layers. In most cases, there was only a faint line across the bare metal surface, showing that there was very little difference in the general corrosion in this region. Local corrosion was quite evident on the specimens that received the most exposure (9 mo).

On pure copper, CDA 101/102, isolated areas of dark spots and pits were found just above and below the interface region. The section in Figure 19 (87302A) shows these pits to be about 5 μm deep. This is comparable with corrosion seen on some of the 95/G phase specimens. Also, it illustrates that some of the dark oxide deposits not removed by the HCl solution can actually cover pits or other forms of local corrosion. The corrosion of the CDA 613/614 specimens was about the same as for the CDA 101/102 specimens. Pits found were comparable, but there was more coloration of the metal surface under the

FIGURE 12. Surface Roughness After Electrochemical Prepitting of a CDA 102 Tear Drop Specimen and No Subsequent Corrosion Exposure (400X). Photo No. 87520C.

FIGURE 13. Surface Pitting on Electrochemically Prepitted CDA 102 Tear Drop Specimen After 6-Mo Exposure at 95 °C in the Liquid Water (Well J-13) Phase (400 X). Photo No. 87329C.

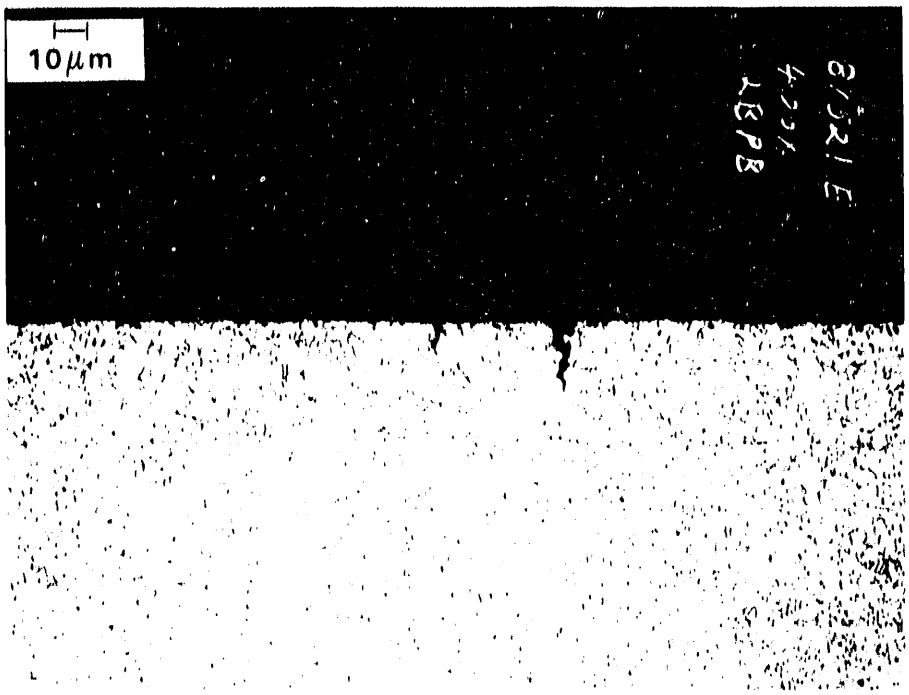

FIGURE 14. Surface Pitting After Electrochemical Prepitting of a CDA 613 Tear Drop Specimens and No Subsequent Corrosion Exposure (400X). Photo No. 87521E.

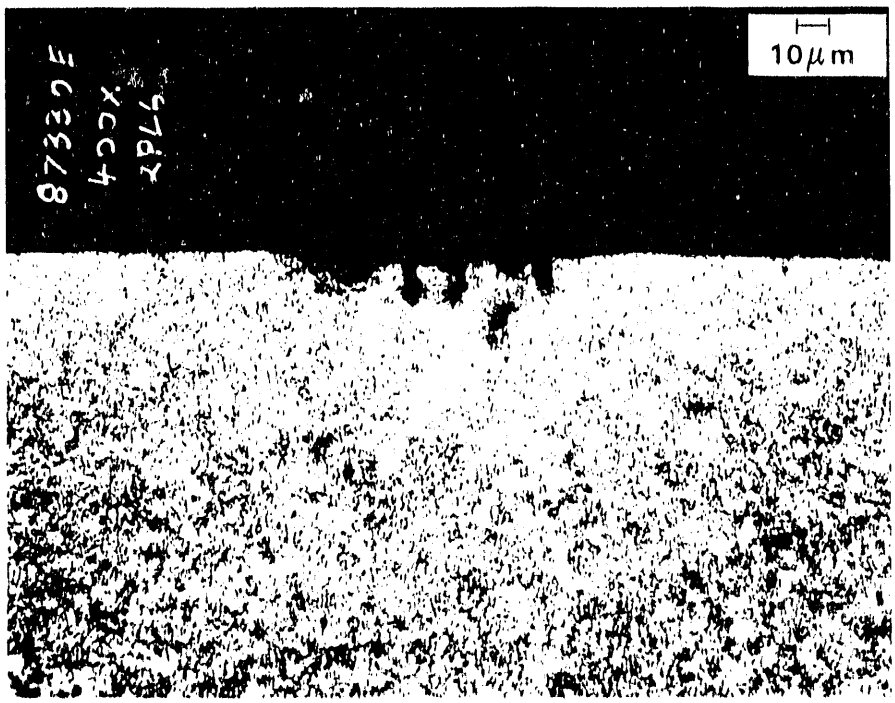

FIGURE 15. Surface Pitting on Electrochemically Prepitted CDA 613 Tear Drop Specimen After 6-Mo Exposure at 95 °C in the Liquid Water (Well J-13) Phase (400X). Photo No. 87330E.

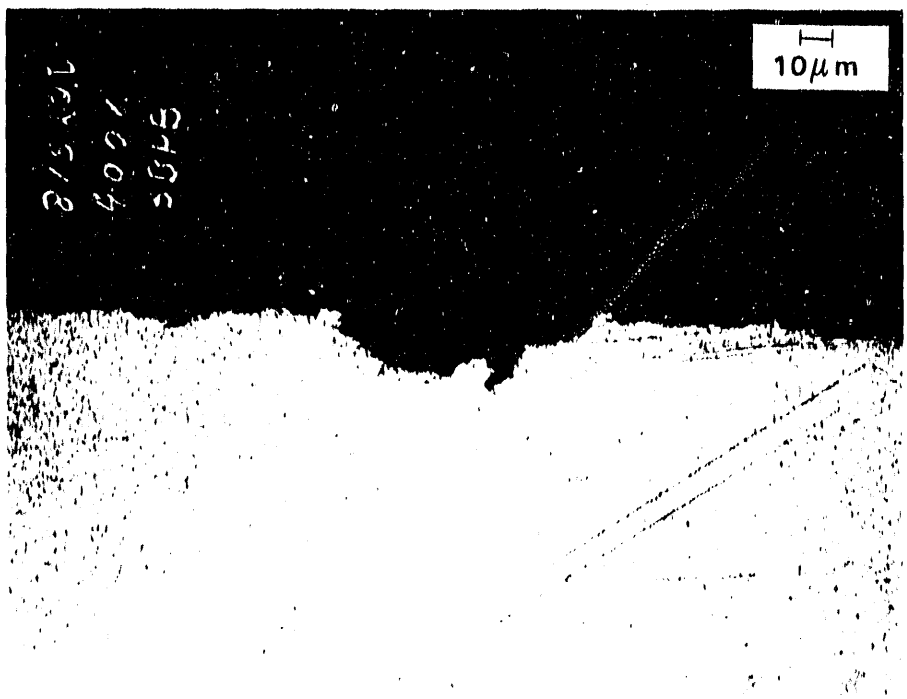

FIGURE 16. Surface Pitting After Electrochemical Prepitting of CDA 715 Tear Drop Specimens and Without Subsequent Corrosion Exposure (400X). Photo No. 87522D.

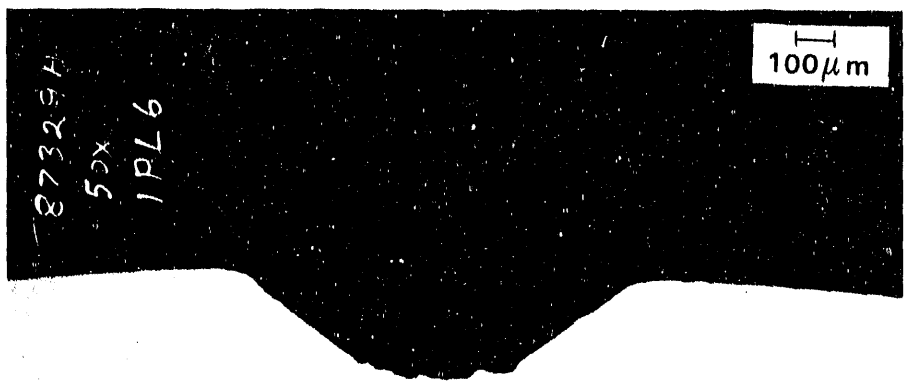

FIGURE 17. Surface Corrosion of Electrochemically Prepitted CDA 715 Tear Drop Specimen After 6-Mo Exposure at 95 °C the Gas Phase (50X). Photo No. 87329A.

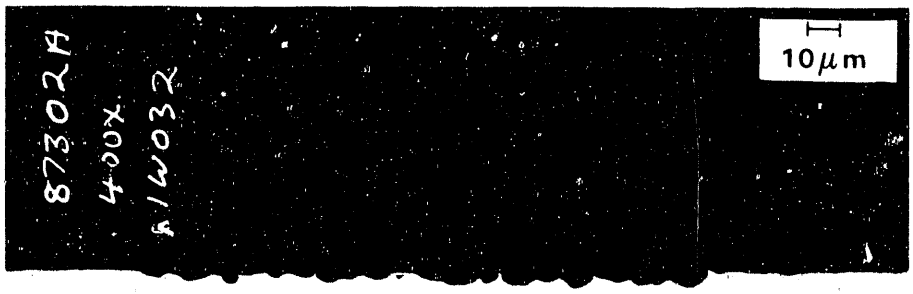

FIGURE 19. Surface Roughening on Specimen 1W032 Exposed for 9 Mo in the Liquid-Gas Interface at 95 °C. Photo No. 87302A.

FIGURE 20. The Front Surface of CDA 715 Specimen 3W00B at the Liquid-Gas Interface Position (5X). (The gas phase is at the top. The oxide film was removed from the piece on the right side.)

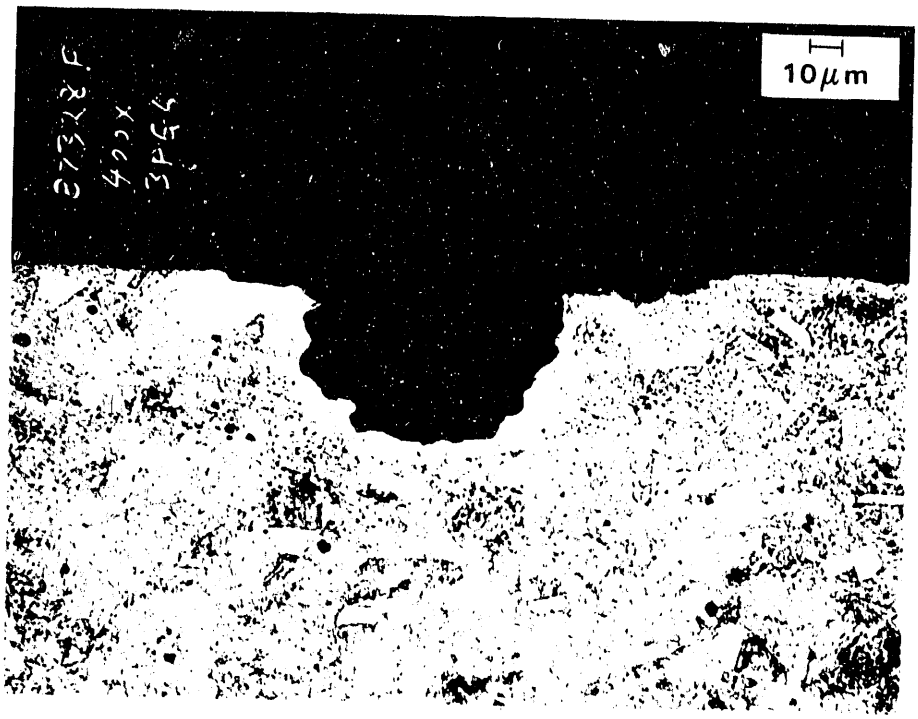

FIGURE 18. Surface Pitting of Electrochemically Prepitted CDA 715 Tear Drop Specimen After 6-Mo Exposure at 95 °C in the Gas Phase (400X). Photo No. 87328F.

oxide layer. There was extensive local corrosion of the interface region of the CDA 715 specimens that received 9-mo exposures. Figure 20 (page 127) shows an extensive crater formation. Figure 21 (87312E) shows the cross section of one crater and the grain structure of the underlying metal. The vertical dimension of the crater is about 25 μm. These corrosion features are comparable to those seen elsewhere on this alloy, reported below.

In summary, there is no enhanced local corrosion (e.g., metal thinning) at the interface of the gas and bulk water phases (i.e., beyond that observed on specimens totally immersed in either of the phases). Apparently the bulk water is efficient for buffering any acid picked up from the adjacent air phase as far as promoting extra corrosion is concerned.

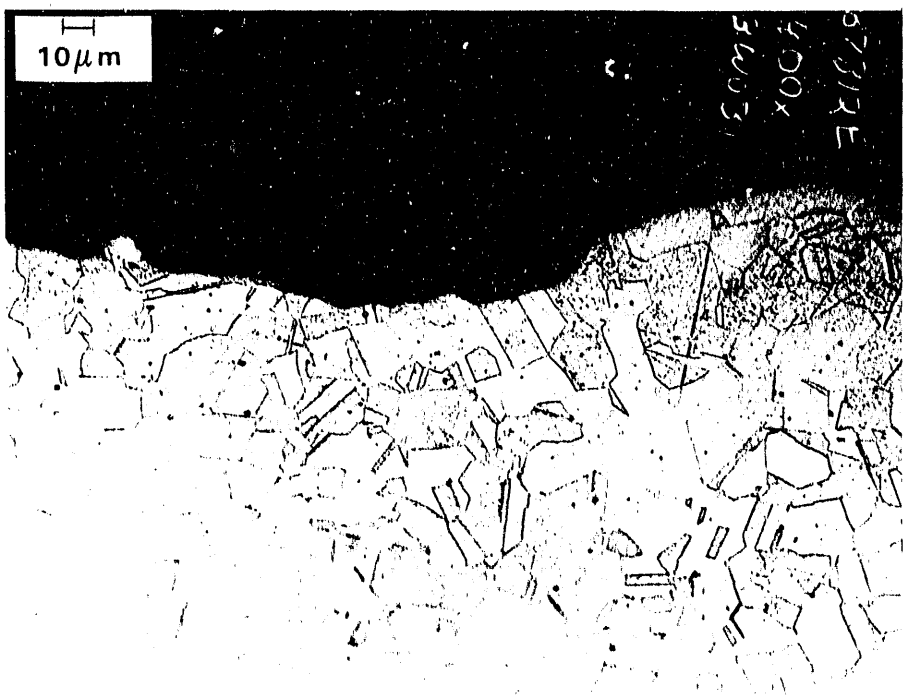

FIGURE 21. Section of Local Corrosion on Specimen 3W031 After 9-Mo Exposure in the Liquid-Gas Interface at 95 °C (400X). Photo No. 87312E.

4.3.5 Metallographic Examinations

From their metallographic examinations, none of the other specimens (not prepitted or interface) showed evidence of subsurface corrosion or cracking. However, there were differences between the alloys in general surface roughness and in the nature of the pits or the local corrosion features.

On the CDA 101/102 specimens, the 150/G specimens showed areas of general surface roughening to a depth of about 5 μm (Figure 22) (87301B). On the 95/G specimens, both narrow pits (Figure 23) (87303A) and broad pits (80 μm wide by 12 μm deep) were seen. These showed adherent corrosion products over the pits. Specimens from the 95/L environment showed surface roughening of about 5 μm in depth.

For the CDA 613/614 specimens, isolated areas of roughness were seen (depths <5 μm) on the 150/G specimens. The 95/G specimens, showed the most severe

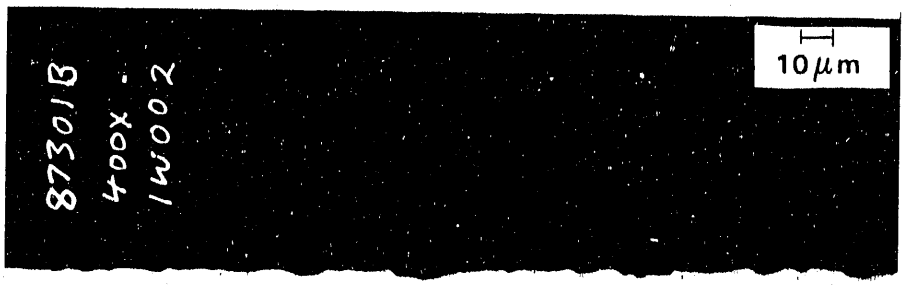

FIGURE 22. General Surface Roughening on Copper Specimen 1W002 After 14-Mo Exposure in the Gas Phase at 450 °C (400X). Photo No. 87301B.

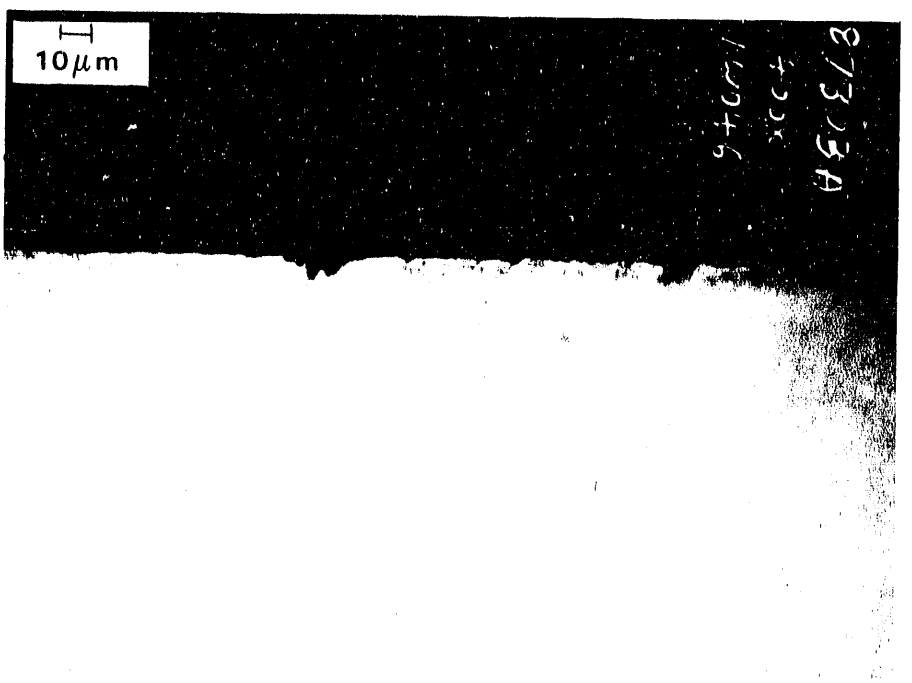

FIGURE 23. Pits in Copper Specimen 1W046 From 4-Mo Exposure in the Gas Phase at 95 °C (400X). Photo No. 37303A.

attack for this alloy. Both roughened surfaces (up to 100 μm in depth) (Figure 24) (87306A) and adherent deposits of corrosion product over a roughened surface were seen. The 95/L exposed specimens had surface roughening of about 10 μm and some areas with adherent corrosion products (Figure 25) (87308C) (about 375 μm wide and 25 μm deep).

On the CDA 715 specimens, the 150/G pieces showed surface roughness of about 13 μm and some isolated, broad pits. On the 95/G specimens, the surface roughness was about 40 μm and considerable undercutting of the surface was seen (Figure 26) (87323D). From 95/L specimens, roughness of about 15 μm was seen and undercutting was also present. Broad pits also were seen (Figure 27) (87314B).

A broad, smooth and symmetrical deformation was observed on most of the specimens (Figure 28) (87301A), including uncorroded archive specimens. The metal grain structure under these features was also compressed and oriented in layers concentric to the curved surface. These apparently resulted from the specimen fabrication process and were not created in these experiments. In some cases, cracks were seen within the area of compressed metal (Figure 29) (87310E). These features would eventually disappear as the metal was corroded to deeper regions that are uniform. However, this suggests that future testing should include articles that have been prototypically rolled, welded, extruded, or otherwise deformed for a major fraction of the wall thickness. Corrosion behavior in these areas may well be different from that on uniform material specimens.

4.3.6 Visual Observations

Results of all of the visual observations are shown in the data base (Appendix A), along with an explanation of the descriptors used. Detailed descriptions of the specimens that were examined early in the program are in the appendix of Reference 3. As an aid for comparing the corrosion behaviors of the three alloys in the three corrosion environments, the data base was sorted for the incidence of the descriptors for visually observed: 1) pits

FIGURE 24. Corrosion Surface of CDA 613 Specimen 2W013 From 13-Mo Gas Phase Exposure at 95 °C (50X). Photo No. 87306A.

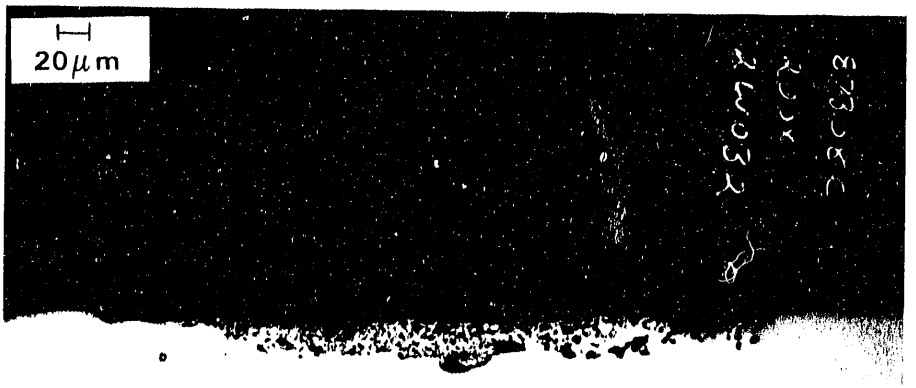

FIGURE 25. Adherent Corrosion Product on CDA 613 Specimen 2W032 After 7-Mo Exposure in Liquid Water at 95 °C (200X). Photo No. 87308C.

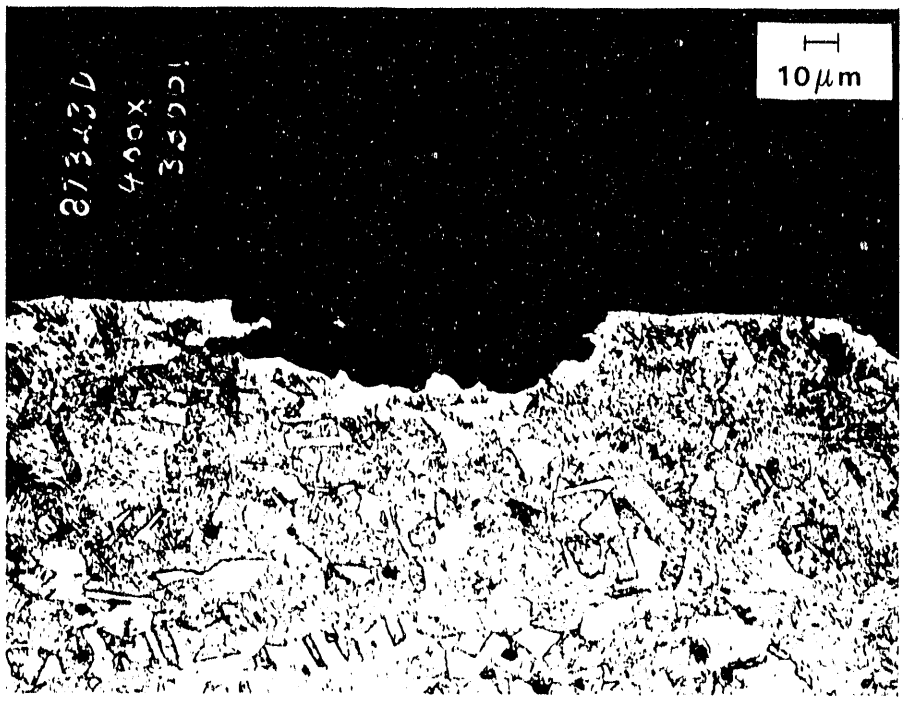

Figure 26. Pit Formed on CDA 715 Specimen 3B001 During 13-Mo Exposure in the Gas Phase at 95 °C. [Note undercut at left side of pit (400X)]. Photo No. 87323D.

FIGURE 27. Broad Pit and Surface Roughening of Specimen 3W047 After 9-Mo Exposure in Liquid Water at 95 °C (200X). Photo No. 87314B.

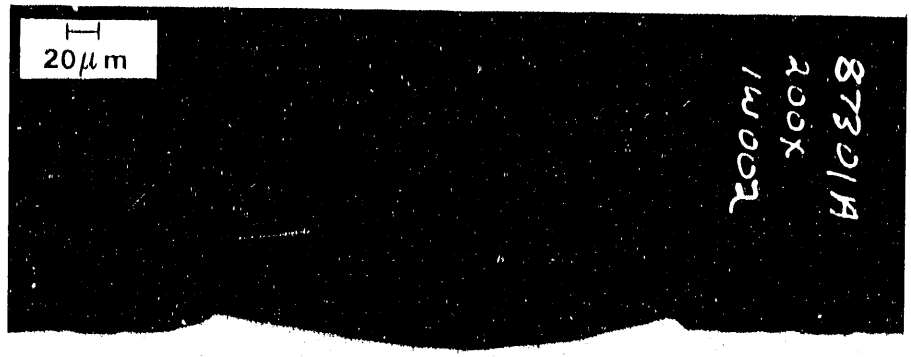

FIGURE 28. Broad Surface Deformations Seen on Most Specimens With and Without Corrosion Exposures (200X). Photo No. 87301A.

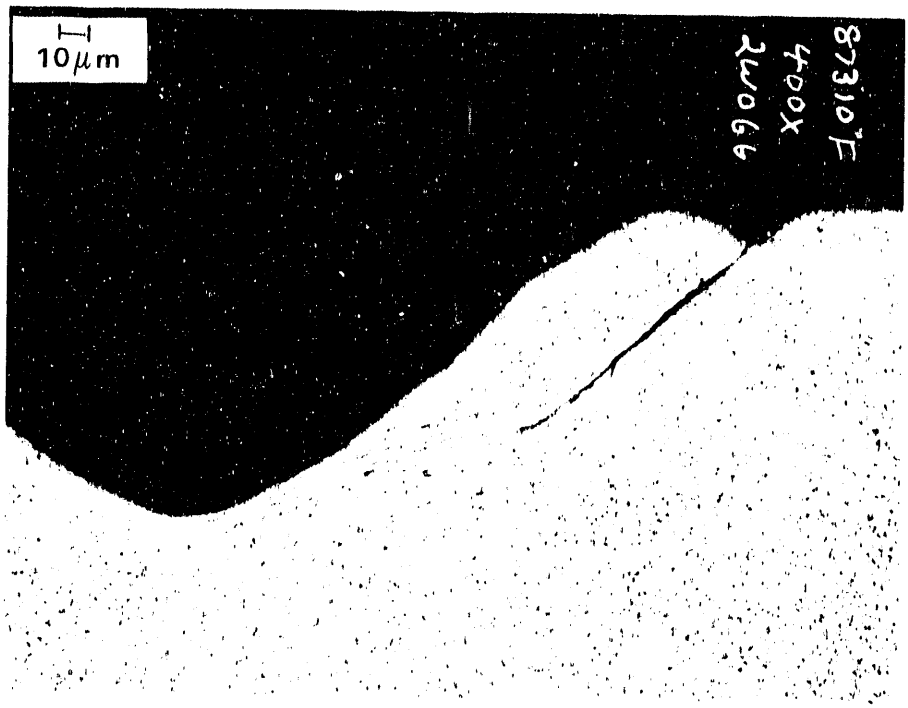

FIGURE 29. Surface Crack Associated with Compression Deformation of Specimen that Occurred Prior to Corrosion Experiments (400X). Photo No. 87310E.

(PT); 2) local corrosion (LC); 3) filiform-like features (FL); 4) no features (NF) or clear surface (CL); and 5) mosaic pattern (MP). Crevice, interface, and prepitted specimens were not included. Full listings of the results are shown in Appendix B. The numbers of occurrences of each feature are summarized in Table 12 as the percentages of the number of specimens in each category in each specimen/exposure-environment subgroup. The various feature types are assumed to occur as independent events. This comparison suggests that the CDA 101/102 material may have a more favorable corrosion behavior than the other materials from the standpoint of local corrosion.

While filiform-like corrosion was seen in the metal surface of the aluminum bronze, only a similar etched pattern was seen on the surface of the nickel alloy. The severe metal surface corrosion, seen on the nickel alloy and designated as MP, mosaic pattern, appears similar to an engraved relief pattern of parallel, but staggered, closely packed dash marks. This occurred mostly on the 95/G specimens and may be related to the greater spread that was found in the general corrosion rate data, discussed below.

Also, a review was made of the results from the very low-flux, (~3 x 10^3 R/h) specimens that had received 3.5 mo of exposure. On the CDA 101/102 specimens, the only corrosion feature seen was crevice corrosion starting around the edges of the 95/L exposed crevice specimens. There was a significant difference in the metal-oxygen ratio in the oxide layer, however. The metal oxide ratio of the three 95/G specimens averaged 1.34, while the three 95/L specimens averaged 0.86. For the CDA 613/614 specimens, all of the local corrosion features seen at higher flux levels and longer exposure times were seen on these specimens. The metal-oxygen ratios in the corrosion layer were nearly the same, 0.81 for the 95/L exposed specimens, and 0.98 for those exposed at 95/G. On the CDA 715 specimens, a variety of local corrosion features resulted from the 95/G environment. Crevice corrosion was found on the crevice specimens from the 95/L environment. Again the metal-oxygen ratios were nearly the same for the 95/G exposures (0.91) as for the 95/L (0.84).

TABLE 12

PERCENTAGE OF VISUALLY OBSERVED CORROSION FEATURES

Feature	Material CDA No.	Environment 150/G	95/G	95/L
CL	101/102	69.	21.	38
or	613/614	34.	0.	5.
NF	715	42.	12.	14.
LC	101/102	11.	24.	10.
	613/614	9.	53.	33.
	715	3.	79.	62.
PT	101/102	23.	55.	29.
	613/614	46.	59.	86.
	715	25.	42.	19.
FL	101/102		none	
	613/614	0.	34.	5.
	715	0.	6.	0.
MP	101/102		none	
	613/614		none	
	715	3.	24.	5.

Descriptors:
CL = Clear surface; NF = No features; LC = Local corrosion
PT = Pitting; FL = Filiform-like; MP = Mosaic pattern.

4.3.7 General Corrosion (Weight Loss)

The amount and average rates of metal corrosion and oxide growth were determined from the measured weight changes of the flat, rectangular (weight loss) specimens. These values are given in the data base (Appendix A) and are plotted in Figures 30 through 38. The visual examination of these specimens, before the oxide film was removed, showed that the corrosion was not at all uniform over the surface of the specimens. Also, crevice corrosion found around some of the support washers likely biased the results.

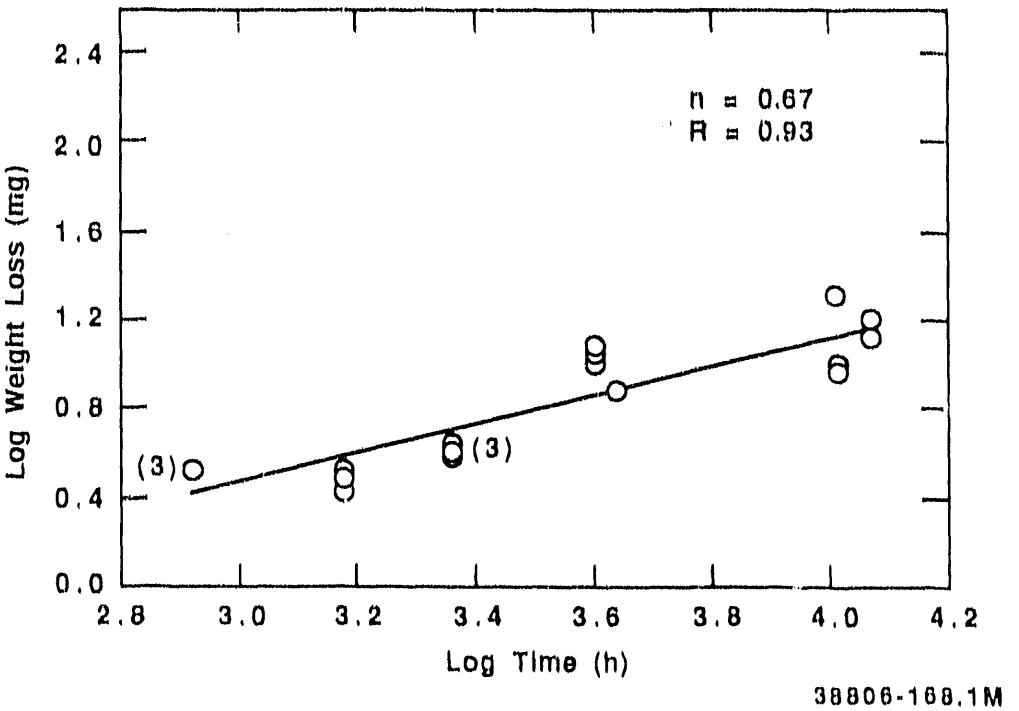

FIGURE 30. CDA 101/102 Corrosion at 150 °C in the Gas Phase.

NOTE: The following information applies to Figures 30 through 38.

(n) = multiple data points for one symbol or closely grouped symbols.

4.0 = nominal gamma radiation flux x_{10}^{-5} R/h in Figures 31, 34 and 37.

n = slope of curve - Equation (1) in text.

R = Correlation coefficient from linear regression.

+ = Data point not used in linear regression in Figures 32, 35 and 38.

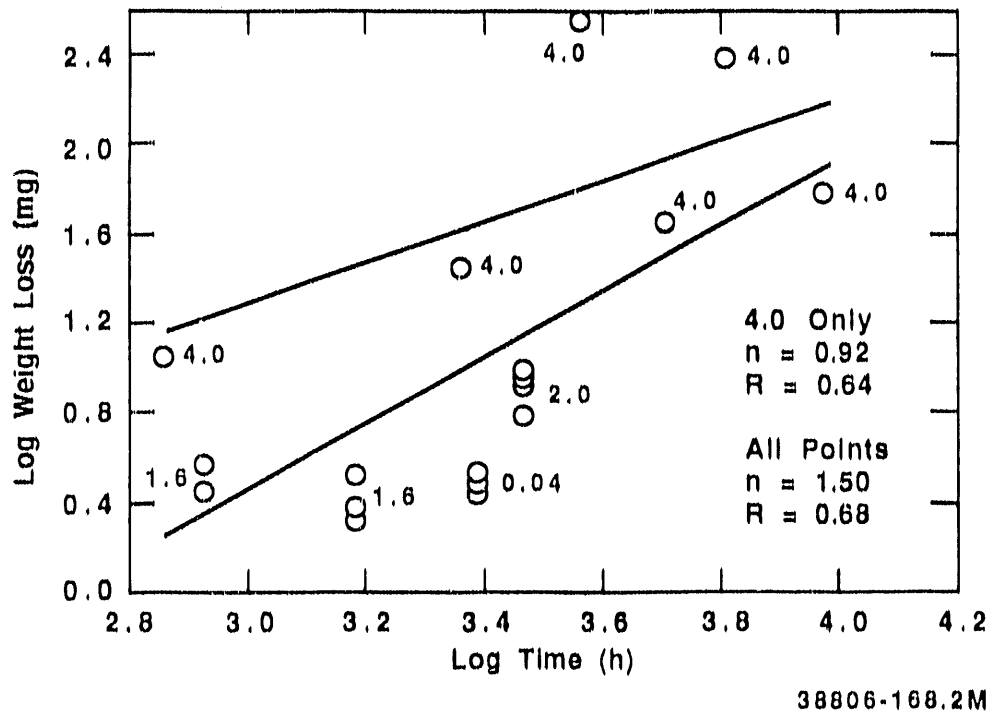

FIGURE 31. CDA 101/102 Corrosion at 95 °C in the Gas Phase. (See Note with Figure 30.)

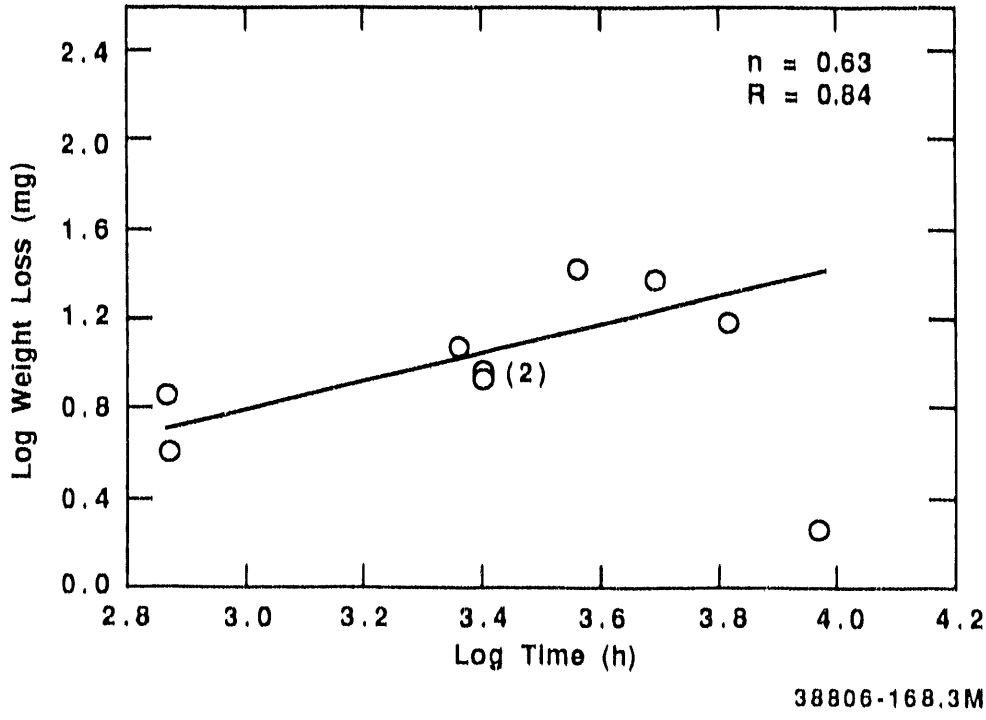

FIGURE 32. CDA 101/102 Corrosion at 95 °C in the Liquid Phase. (See Note with Figure 30.)

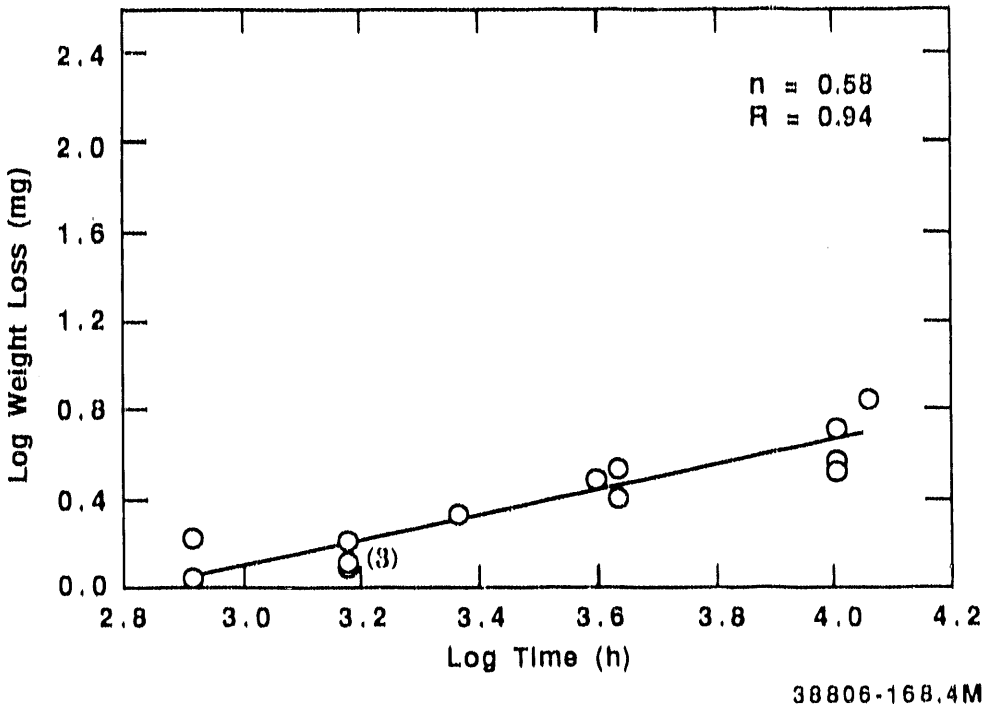

FIGURE 33. CDA 613/614 Corrosion at 150 °C in the Gas Phase. (See Note with Figure 30.)

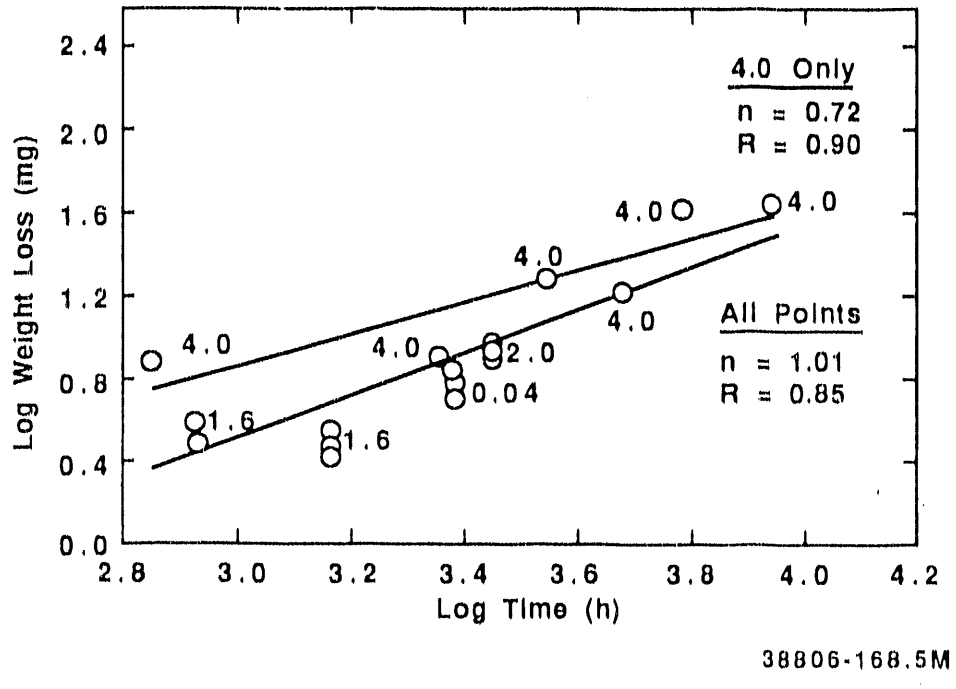

FIGURE 34. CDA 613/614 Corrosion at 95 °C in the Gas Phase. (See Note with Figure 30.)

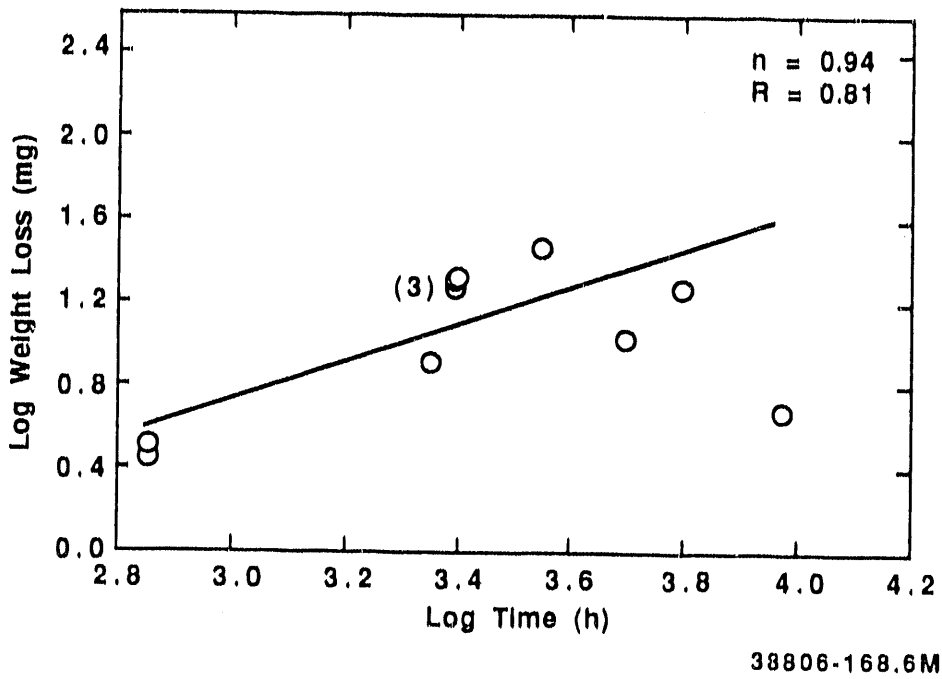

FIGURE 35. CDA 613/614 Corrosion at 95 °C in the Liquid Phase. (See Note with Figure 30.)

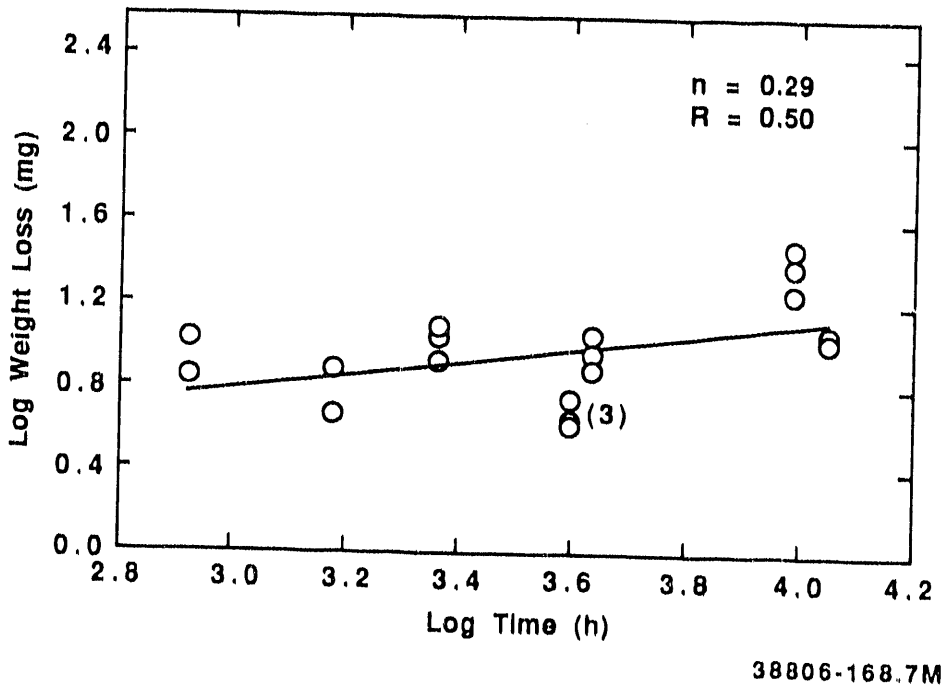

FIGURE 36. CDA 715 Corrosion at 150 °C in the Gas Phase. (See Note with Figure 30.)

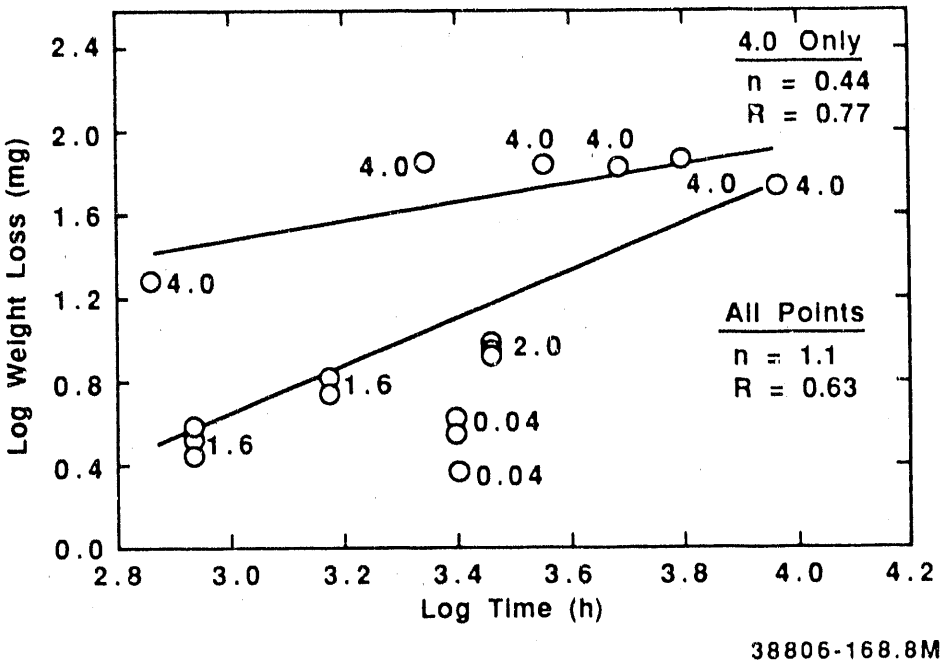

FIGURE 37. CDA 715 Corrosion at 95 °C in the Gas Phase.
(See Note with Figure 30.)

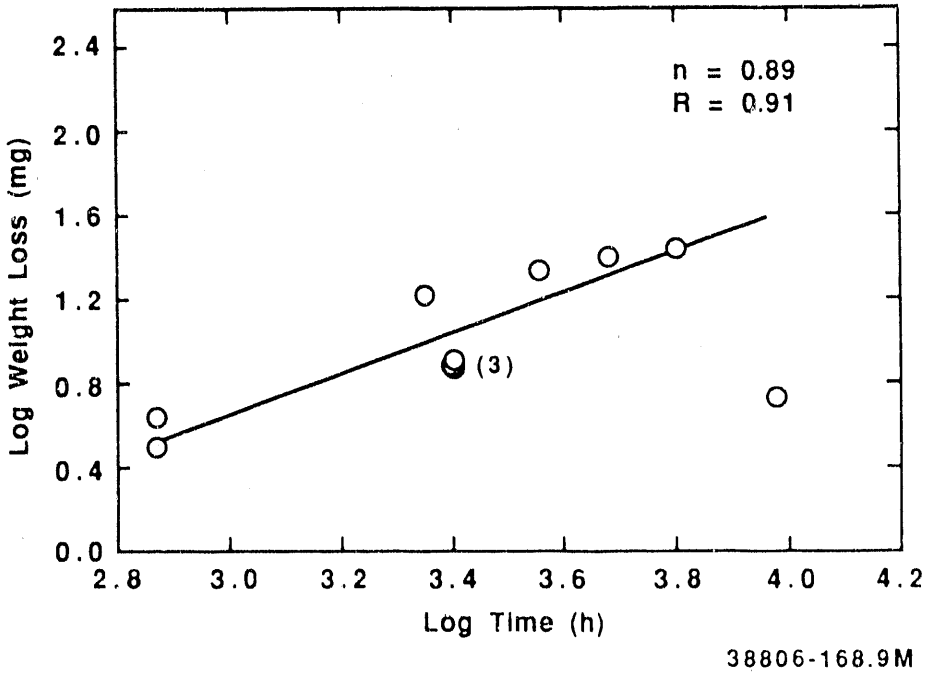

FIGURE 38. CDA 715 Corrosion at 95 °C in the Liquid Phase.
(See Note with Figure 30.)

From the equation:

$$W = k\ t^n + C \qquad (1)$$

where:

W = Weight lost by a specimen per unit area
t = Time
k and C are constants,

the order of the time dependency of the corrosion process (n) can be examined from a plot of log W vs. log t. A value of n = 1 indicates a linear process while n = 1/2 indicates a parabolic process. A linear regression analysis was used to estimate the value of "n" for each of the data subsets. These values and the correlation coefficients "R" are also shown in the figures. In general, the agreement of replicate values within each subset is considerably better than between adjacent subsets. Thus, the data scatter appears to be related to the corrosion process or subtle environment differences rather than to the methods of measurement.

No effect of radiation level could be seen in the data subsets from the 150/G and 95/L environments. However, in the data subsets from the 95/G environments, a general trend appears of increased corrosion with gamma radiation flux. The general data scatter and lack of data at intermediate exposures preclude assignment of a quantitative value to this effect. For these cases, a second linear regression analysis was made of the maximum flux data only.

4.4 OXIDE LAYERS

The third area of examination is the nature and composition of the oxide layers that formed on the various materials and under the different conditions. This information supplements the metal damage results by providing insight into how the corrosion process occurs and what changes might occur in the process with time and changes in the environment. The methods used were visual examination, calculation of the metal-oxygen ratio, Auger electron spectroscopy, and X-ray diffraction.

4.4.1 Visual

The oxide layers on the CDA 101/102 and CDA 613/614 specimens were generally tight and adherent. However, on some CDA 101/102 specimens, there were areas where the oxide dissolved much more slowly in the hydrochloric acid solution than was normal, indicating that the oxide structure was not uniform. The layer of oxide on CDA 715 appeared much heavier than on the other materials and had a flat black surface. The oxide on the 95/G exposed specimens was often covered with many small craters. Apparently small pieces of the oxide layer break loose from time to time. This may be related to the unusual mosaic pattern also seen on these specimens, as previously discussed.

4.4.2 Metal-Oxygen Ratios

Values of weight-of-metal-lost divided by net-weight-gained and multiplied by the atomic weight ratio give the metal-oxygen ratio (M/O). These were calculated for the general corrosion (weight loss) specimens. Values are given in Appendix A and summarized in Table 13. These values can indicate the internal consistency of the data and differences in compositions of the oxide layers in the different environments.

Since the layers were too thin to quantitatively separate from the base metal, the metal compositions of the CDA 613/614 and CDA 715 oxides were not determined and were assumed to contain only copper and oxygen. The ratios for the pure copper CDA 101/102, however, show the average stoichiometry of the oxide layer and can be compared with those estimated from X-ray diffraction and Auger electron spectroscopy results.

The oxide formed on CDA 101/102 exposed at 150/G appears to be Cu_2O compared with the CuO formed on the ones exposed in the 95/L phase. The oxide on the specimens exposed to 95/G may be mixed phases. The oxides formed on the other materials appear to be about the same, regardless of the reaction phase.

TABLE 13

SUMMARY OF METAL-OXYGEN RATIOS IN CORROSION LAYERS

Corrosion Conditions	Materials CDA 101/102	CDA 613/614	CDA 715
150/G	2.02 ± 0.31* 2.3**	1.06 ± 0.28	0.99 ± 0.18
95/G	1.63 ± 0.28 2.3**	0.94 ± 0.20	0.80 ± 0.13
95/L	0.94 ± 0.46	0.74 ± 0.34	1.06 ± 0.56
Overall	1.74 ± 0.71	0.99 ± 0.44	0.93 ± 0.31

*Standard deviation.
**From Auger electron spectrometry data.
NOTE: In all calculations, copper was assumed to be the only metal present.

4.4.3 X-ray Diffraction

X-ray diffraction was used for specific identification of the oxide phases in the corrosion layers. Lawrence Livermore National Laboratory examined 22 thin films from 1-mo and 3-mo exposed specimens.[3] Westinghouse Hanford Company examined 18 oxides from specimens that had 5-mo to 16-mo exposures. Most of the Westinghouse Hanford Company work was on powdered samples scraped from the metal specimens in order to eliminate the spectra from the base metal and to remove possible crystal orientation effects. Spectra of the base metals were also made to aid in resolving lines due to the base alloys. Most of the X-ray diffraction samples were taken from the outside surfaces of crevice specimens. Results are summarized in Table 14.

Both Cu_2O and CuO phases were identified on all samples except the following. Only CuO was found on the CDA 614 specimens exposed in a 95/L environment and on CDA 715 from the 95/G environment. The identification of Cu_2O on CDA 614

TABLE 14

SUMMARY OF X-RAY DIFFRACTION RESULTS:
OXIDE PHASES IDENTIFIED

Corrosion Conditions	Materials		
	CDA 101/102	CDA 613/614	CDA 715
150/G	16:Cu_2O,CuO	16:Cu_2O(?),CuO 16P:Cu_2O,CuO	16:Cu_2O,CuO 16P:Cu_2O,CuO, $(Cu_{0.2}Ni_{0.8})O$
95/G	8P:Cu_2O,CuO 5P:Cu_2O	8:Cu_2O(?),CuO 8P:CuO	8:CuO
95/L	5P:Cu_2O,CuO	5:CuO	5:Cu_2O,CuO

NOTE: The number starting each entry is the number of months of corrosion for that specimen. The "P" designates that the X-ray diffraction sample was on the metal plate. Other samples were powders, scraped from the metal plate.

from the 95/G environment is in question. Of particular interest was the identification of $(Cu_{0.2}Ni_{0.8})O$ phase on the CDA 715 specimen that had received an 150/G/16 exposure.

4.4.4 Auger Electron Spectroscopy

All of the Auger electron spectroscopy results have been reported.[3] Some of these are repeated here for emphasis and to update some of the previous interpretations. While the profiles of atomic composition vs. depth in the oxide layers differed between specimens, the most interesting results are shown in Figures 39 and 40. The very thin corrosion films show a layered oxide structure that has different compositions. The profile in a thin film on an exposed CDA 613 specimen (Figure 39) shows an aluminum-rich layer positioned between the copper oxide and the base metal. The profiles of an oxide film on exposed CDA 715 (Figure 40) show a layer high in nickel content over a layer relatively high in copper content. How these layers are

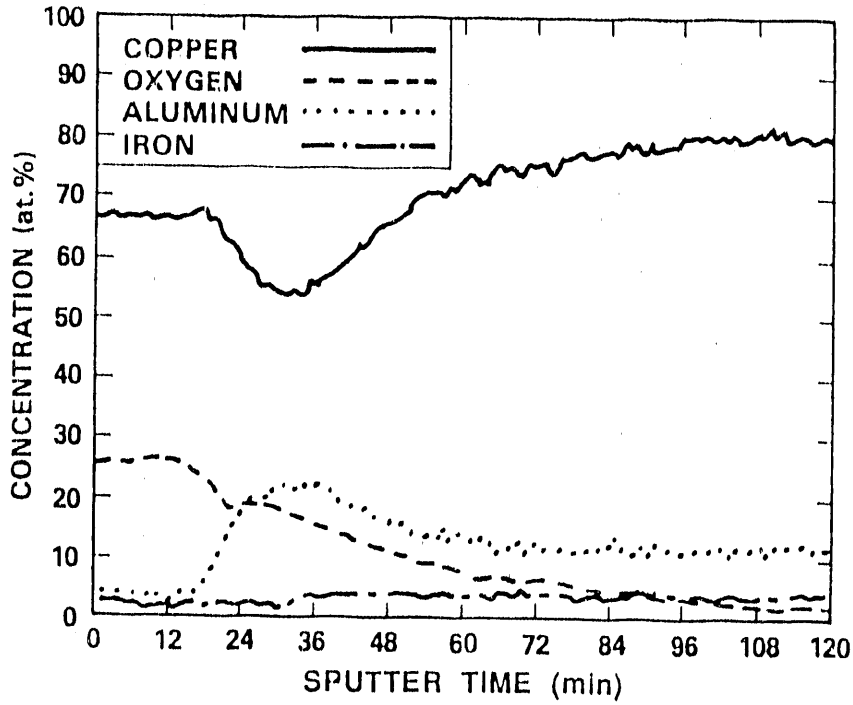

FIGURE 39. Concentration (atom percent) Profile of the Oxide Layer on a CDA 613 Specimen After 1 Mo in the Gas Phase at 150°C. Sputtering rate is the order of 10 nm/min.

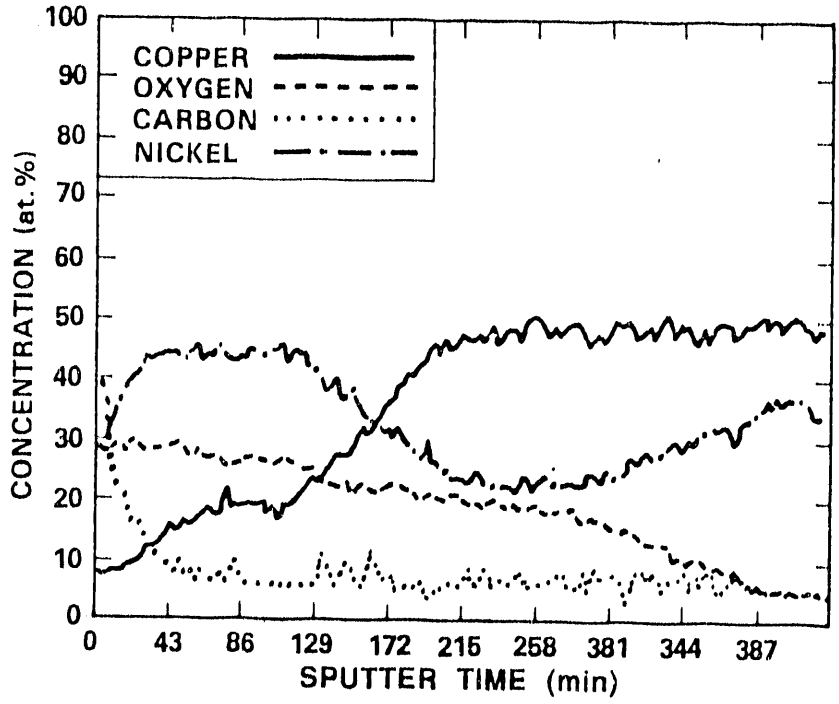

FIGURE 40. Concentration (atom percent) Profile of the Oxide Layer on a CDA 715 Specimen After 1 Mo in the Gas Phase at 95°C. Sputtering rate is the order of 10 nm/min.

distributed as the oxide layers grow was not determined. Since the Auger electron spectroscopy was tuned to the signal from each of the elements of interest as they occurred on the cleaned oxide surface, the data represent the elements in their chemically combined state. The nickel-copper oxide structure was seen by X-ray diffraction on a different specimen. However, no sign of aluminum oxide was seen in the X-ray diffraction data. The decline of the metal-oxygen ratio on the CDA 101/102 specimens was continuous and showed no bands or layers.

5.0 DISCUSSION

This program was basically a survey of the effects of gamma radiation on the corrosion behaviors of three copper-base materials. Since the data are to be used in a preliminary material selection process for nuclear waste barriers, the corrosion exposure conditions were selected to approximate the basic stages for a canister environment in tuff. These conditions were 1) air with a low relative humidity, 2) air at a lower temperature, near the water dew point and water boiling point, and 3) bulk water at its boiling point. The levels of radiation were selected to be much higher than expected in a repository, in order to emphasize possible radiation effects. In the relatively short time available for these studies, emphasis was given to observing as many behaviors as possible and to identifying the conditions that might be severe. These relatively brief exposure times may not have been sufficient for the formation of oxide layers that are characteristic of long-term steady state conditions. Nor was there time to sequence specimens through the succession of the three environments or to run parallel experiments without the presence of gamma radiation.

There is considerable literature on the oxidation of copper, especially at elevated temperatures (>200 °C). However, there is less known about the process at lower temperatures. The oxidation process becomes even more complex for alloys and in the presence of ionizing radiation. At higher temperatures, the normal oxidation of pure copper follows a parabolic time dependency [n = 1/2 in Equation (1)]. Copper ions migrate through the cation-deficient oxide lattice to react with oxygen near the surface of the oxide film. The oxide phase Cu_2O is thermodynamically stable under normal, atmospheric conditions. At lower temperatures, however, migration of the cations is controlled by the gradient of the electric field within the oxide lattice. The theory for this is reviewed in detail by Smeltzer and Young.[10] The oxidation is a logarithmically time-dependent process up to about 150 °C, has a cubic time dependence at increased temperatures, and follows a parabolic time dependence at 200 °C and above.[11]

In these experiments, it is possible that some of the ionized species produced in the moist air environment by the gamma radiation may migrate into the oxide lattice, whereas oxygen does not. Also, other alloy metals in the oxide layer will alter its electronic structure. Since the other metals in the copper alloys will not migrate through the copper oxide lattice at the same rate as copper, it is reasonable that some enrichments of component metals will occur in and under the oxide film. Hence, the oxidation properties expected in these experiments cannot be assumed to be the same as for normal air oxidation of pure copper.

By necessity, much of the fundamental data on the low-temperature oxidation that is likely to occur were taken on relatively thin films. While this information is important, it is the corrosion behaviors on materials with the thick films that are of greatest interest, since the majority of a waste container's service life is spent with a thick corrosion film. If it is assumed, conservatively, that the heavy film will break and allow the environmental constituents to penetrate to the underlying layers, then the process of healing such flaws is also of interest.

The three types of data recorded during these experiments are 1) corrosion environment, 2) metal degradation, and 3) oxide film composition. Of the three corrosion environments, 150/G, 95/G, and 95/L, the 95/G was the most difficult to control in terms of surface conditions on the specimens. This is primarily an experimental problem in temperature and humidity control in a large volume and under remote conditions. Accurate predictions of the sequence of atmospheric compositions in the proposed repository are essential for planning experiments that provide a close simulation.

A summary of observed corrosion behaviors is shown in Table 15. The corrosion rates are values at 10,000 h; the "P" and "L" refer to parabolic and linear time dependence of the corrosion processes (Equation 1), and the numbers are the observed stoichiometries of the oxides formed. In general, the overall corrosion rates are low. At 10,000 h, 0.15 mil/yr is the highest value. It is recognized that for log-log plots of the general corrosion data,

TABLE 15

SUMMARY OF CORROSION BEHAVIORS

Corrosion Conditions	Materials		
	CDA 101/102	CDA 613/614	CDA 715
150/G	0.02 mil/yr n = 0.67(P) M/O = 2.0±0.31	0.01 mil/yr n = 0.58(P) M/O = 1.1±0.28	0.02 mil/yr n = 0.29(P?) M/O = 1.0±0.18
95/G	0.15 mil/yr n = 1.5(L) M/O = 1.6±0.28	0.07 mil/yr n = 1.0(L) M/O = 0.94±0.12	0.10 mil/yr n = 1.1(L?) M/O = 0.80±0.13
95/L	0.04 mil/yr n = 0.63(P) M/O = 0.94±0.48	0.08 mil/yr n = 0.93(L) M/O = 0.74±0.34	0.07 mil/yr n = 0.91(L) M/O = 0.91±0.38

NOTE: Copper is assumed to be the only metal present in the oxide layer.

some of the data subsets have considerable scatter (low values of R). Future studies may indeed alter some of these findings. From the present results, however, the following observations are made.

5.1 GENERAL OBSERVATIONS

From these experiments, the most severe corrosion appears to be related to the presence of small amounts of liquid water on the metal surface, either in films or drops. Such small quantities can become concentrated with the corrosive species that are produced by the gamma radiation at the air/water interface and exceed any buffering capacity of the small amount of liquid water. This accelerated corrosion is in keeping with the modeling predictions presented by Van Konynenburg.[2] In contrast, dissolution of these same species in a bulk-water phase will produce a much more dilute solution that is uniformly distributed over an entire specimen. The bicarbonate ion in the Well J-13 water also buffers the pH.

Except for the pure copper specimens (CDA 101/102) at 150 °C (low humidity), the predominant oxide phase appears to be CuO, not the Cu_2O that is predicted by thermodynamics. While Cu_2O appears in most of the X-ray diffraction spectra, it is apparently not present in sufficient quantities to change the overall metal/ oxide ratios. It is also assumed that the other metals are not present in sufficient quantity in the oxide layers to significantly alter the M/O values.

There was no evidence of stress-assisted cracking of the tear drop specimens either from the dye penetrant examinations or from the metallographic examinations. Likewise, there was no additional corrosion of specimens at the interface between the gas and bulk liquid phases. What corrosion was seen in the interface region was comparable to that seen on other specimens mounted completely within the bulk phases. On those specimens that were electrochemically prepitted by LLNL prior to their gamma field corrosion, it appeared that the pits disappeared through the general corrosion processes rather than continuing to propagate. However, there was spontaneous pit formation on all three materials on the specimens that were not prepitted. Some of these pits were captured in the metallographic cross sections. However, thorough examinations and measurements of the pitting were not attempted. Seldom did pits cover an entire specimen with a uniform pattern. They often occurred only in certain regions of a specimen. The pits were normally quite broad, at least as wide as they were deep. In the visual examinations, the distinction of pits versus spots was sometimes difficult. Borderline cases were listed as pits, so as not to allow possible occurrences to go unrecorded.

While crevice corrosion occurred around the edges of the closely spaced pairs of plates, local corrosion also occurred in the mated surfaces well inside of the edges for CDA 613/614 and CDA 715. The metallographic examinations showed uneven corrosion in the region of nonuniform grain structure (e.g., where some surface compressions had occurred during specimen manufacturer). There was evidence of metal component enrichment in the fusion welds of the CDA 613. Although weld study was not part of the scope, no particular corrosion problems were seen in the metallographic examination of the sectioned

welds. It is concluded, however, that any future corrosion studies should include test items that contain the welds, deformation, deep crevices, etc., of a proposed applications design, along with specimens for general corrosion.

5.2 CDA 101/102

Corrosion of pure copper is quite similar under the 150/G and 95/L environments, although the oxide layer appears to be mostly CuO in the latter case. Under 95/G conditions, the corrosion is different. It appears to be a linear process, rather than a parabolic one, and appears to have about five times the rate at 10,000 h. It may be dependent on the level of the gamma flux under these conditions. The makeup of the oxide is intermediate to that produced under the other conditions. In the crevice specimens, local corrosion occurred only near the specimen edges and not in the inner regions of the space between the two plates. The surfaces of the prepitted specimens remained relatively smooth. There was some tendency for this material to pit, but it was not repeatable. The pits were broad. If these pits were due to some undetected impurity in the corrosion environment, then the impurity can be assumed to be at a very low concentration. Control of a significant (pit causing), trace impurity in the operating environment of a repository could be difficult. A few large, isolated pits were found to be from particles of foreign materials imbedded into the surfaces during manufacture of the specimens and not removed by the cleaning processes.

In the visual inspection of the low flux specimens, crevice corrosion was the only type of local corrosion found. Relative to the other materials, then, CDA 101/102 showed much less local corrosion at the low flux.

5.3 CDA 613/614

This aluminum bronze appears to oxidize regularly and relatively slowly in the 150/G phase. The CuO is the predominant product. The parabolic process in the 150/G environment becomes a linear process in the 95/G and 95/L environments. The apparent gamma flux dependency is also noticeable in the 95/G phase.

Considerable underfilm and other types of local corrosion were observed. As with the CDA 715 alloy, the oxide layer is apparently not homogeneous. Hence, it will be more difficult to characterize it under all possible repository conditions and sequences of geological events.

5.4 CDA 715

While the data from the 95/L environment show a well-behaved, linear rate of corrosion with the formation of CuO, the corrosion behaviors in the 150/G and 95/G environments are more ambiguous. The wide scatter in the data from the 95/G environment may be due partly to the gamma radiation dependence and also to a process whereby the small pieces of oxide that break off allow accelerated corrosion in that area. Overall, this may lead to the mosaic pattern found in the metal surface. The scatter in the group of data from the 150/G environment suggests that there is a yet-to-be-determined variable affecting those corrosion results. This may well be a consequence of the structure or properties of the oxide layer. These results suggest that the corrosion behavior of this material is complex under the conditions of those experiments.

6.0 REFERENCES

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APPENDIX A

DATA BASE

APPENDIX A

DATA BASE

The following tables contain the primary information on the identification, corrosion environment and experimental results for the specimens used in these experiments. Excluded are the specimens that were electrochemically pre-pitted by LLNL (see text). The information was entered into a Symphony* data base. It was then verified, examined, and extracted for presentation.
A column-by-column explanation of the tables follows. The entries are grouped by material and listed alphanumerically by specimen serial numbers.

*Symphony, V1.1 is a trademark of Lotus Development Corporation.

TABLE A1

EXPLANATION OF DATA BASE TABLES

Column	Contents
1	Alloy code: CDA 101/102 = 1; CDA 613/614 = 2; CDA 715 = 3.
2	Specimen form code: W = weight loss; B = tear drop; C = crevice.
3	Serial number within each subset of alloy and form.
	Note: Columns 1, 2 and 3 combine to make the unique specimen identification numbers.
4	CDA alloy identification number, from the chemical compositions.
5	ID number of vessel in which specimens were exposed (T-1, T-2, etc.)
6	Identification of the cage(s) in which specimens were mounted.
7	Exposure periods (sequential) for specimens (1 through 5).
8	Exposure phase: L = liquid; G = gas; I = interface.
9	Nominal temperature of exposure in ^{o}C.
10	Total exposure time (hours).
11	Total exposure time (months).
12	Nominal gamma exposure dose rates $X10^{-5}$ R/hr.
13	Measured weight loss (mg) - 'W' specimens only.
14	Measured corrosion film weight (mg) - 'W' specimen only.
15	Calculated corrosion rate mil/year - 'W' specimen only.
16	Metal-oxygen weight ratio - 'W' specimen only.
17	Analytical procedures used: A = Auger electron spectroscopy; X = X-ray diffraction; D = dye penetrant examination; M = metallographic examination; P = photograph(s). All specimens received a 10X visual examination.
18	Results of visual examination (see Table A-2 for the description codes.)

TABLE A-2

DESCRIPTOR CODES USED TO CHARACTERIZE THE SPECIMEN SURFACES FROM VISUAL EXAMINATIONS

The codes are pairs of letters as defined below. Adjacent codes describe one type of feature. "/"s separate the descriptions of different features. These are qualitative descriptors; there is overlap in some of the meanings. The descriptors are somewhat suggestive of their meaning; they should be strung together to make phrases. For example, "FWDKSPPT" reads a few dark spots and pits."

Abbreviation	Meaning
AR	Limited area of coverage
BK	Black appearance
CL	Clear, clean surface
CO	Coloration/stain, not opaque
CU	Copper colored
DD	Dense
DK	Dark appearance
FL	Filiform-like (underfilm corrosion n)
FM	Film - not opaque, full coverage
FW	A few, more than 5
GE	General coverage, most of specimen
IS	Isolated occurrence - fewer than 6
LC	Local corrosion, not FL, PT, etc.
LG	Large - greater than 10 mil
LT	Light/white in appearance
MD	Medium - range of 6 to 10 mil
MP	Mosaic pattern of corrosion
NF	No corrosion features
PT	Pit corrosion
RO	Rows of corrosion features
RS	Residue
RU	Roughened surface
SM	Small - range of 1 to 5 mil
SO	Smooth surface
SP	Spots
VS	Very small - less than 1 mil
WD	On weld
XL	Extra large - greater than 100 mil
nM	Located in band 'n' mm wide around the edge of a crevice specimen.

INDEX

Abbreviation	Meaning
Color:	
BK	Black appearance
CU	Copper colored
DK	Dark appearance
LT	Light/white in appearance
Coverage:	
DD	Dense
IS	Isolated occurrence - fewer than 6
FW	A few, more than 5
AR	Limited area of coverage
GE	General coverage, most of specimen
RO	Rows of corrosion features
WD	On weld
nM	Located in band 'n' mm wide around the edge of a crevice specimen.
Size:	
VS	Very small - less than 1 mil
SM	Small - range of 1 to 5 mil
MD	Medium - range of 6 to 10 mil
LG	Large - greater than 10 mil
XL	Extra large - greater than 100 mil
Surface:	
CL	Clear, clean surface
NF	No corrosion features
CO	Coloration/stain, not opaque
FM	Film - not opaque, full coverage
SO	Smooth surface
RU	Roughened surface
Features:	
FL	Filiform-like (underfilm corrosion n)
LC	Local corrosion, not FL, PT, etc.
MP	Mosaic pattern of corrosion
PT	Pit corrosion
SP	Spots
RS	Residue

TABLE A-3

CDA 101/102 DATA BASE

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (XE-2)	Wt Loss Film Wt (mg)	Cor Rt (mil/yr)	M/D	Analy	Visual Examination
1	B	1	101	2	J	3	G	150	4,416	6.1	1.2					GEVSDKSP
1	B	2	101	1	A	1	L	95	720	1.0	2.6				D	CL/FWDKSPPT?
1	B	3	101	2	BB	12345	G	150	11,593	16.1	2					ARBKSPPT
1	B	4	101	2	BB	12345	G	150	11,593	16.1	2				P	ARDKSPPT
1	B	5	101	1	A	1	L	95	720	1.0	2.6					GESMPT
1	B	6	101	2	J	1	G	150	836	1.2	3.1				D	CL/FWDKSP
1	B	7	101	1	F	1234	G	95	9,408	13.1	1.3				P	GEXLBKSP/PT
1	B	8	101	2	J	1	G	150	836	1.2	3.1					CL/FWRUWD
1	B	9	101	2	J	1	G	150	836	1.2	3.1					CL
1	B	10	101	1	A	1234	L	95	9,408	13.1	2.6					GESMLTDKSP/ARVSPT
1	B	11	101	1	F	1	G	95	720	1.0	1.3				ADP	ARSMPT/FWPT
1	B	12	101	2	J	345	G	150	8,423	11.7	1.2					CLNF
1	B	13	101	1	F	1	G	95	720	1.0	1.3					CL/FWSP
1	B	14	101	2	BB	1234	G	150	10,078	14.0	2.1					FWDKSPPT/FWLC
1	B	15	101	2	J	3	G	150	4,416	6.1	1.2					CL/ISMDSP
1	B	16	101	2	J	2	G	150	2,334	3.2	3.1				D	ISPT
1	B	17	101	2	J	2	G	150	2,334	3.2	3.1					CL
1	B	18	101	4	X	1	L	95	2,499	3.5	0.027					FWLGDKSP
1	B	19	101	1	F	23	G	95	5,016	7.0	1.3				P	GEMDBKSPPT?
1	B	20	101	1	F	2	G	95	2,280	3.2	1.3				D	ISPT/CL
1	B	21	101	2	J	2	G	150	2,334	3.2	3.1					CL
1	B	22	101	1	A	2	L	95	2,280	3.2	2.6				DP	CL/ARBKSP
1	B	23	101	1	A	23	L	95	5,016	7.0	2.6					ISBKSP
1	B	24	101	4	X	1	L	95	2,499	3.5	0.027					GELTMP/FWMDDKSP
1	B	26	101	4	V	1	G	95	2,499	3.5	0.019					FWMDDKLTSP/PT?
1	B	27	101	4	V	1	G	95	2,499	3.5	0.019					FWLGDKSP
1	B	28	101	2	B	5	G	150	1,515	2.1	1.5					CLNF
1	B	29	101	3	T	1234	G	95	5,304	7.4	4.6					PP Spacer;GESMPT/ARDKSP
1	B	30	101	3				95		0.0						Non-data;Spacer;GEDKSPPT
1	B	31	101	3	T	1234		95	5,304	7.4	4.6					Non-data;Spacer;GELCPT?/GEDKSP
1	B	32	101	4	X	1	L	95	2,499	3.5	0.027					ARSMSP/PT?
1	B	33	101	1	A	4	L	95	3,672	5.1	2.6				P	GEMDDKSP
1	B	34	101	1	F	34	G	95	6,408	8.9	1.3					GEXLDKSP
1	B	35	101	2	J	45	G	150	4,007	5.6	1.2					CLNF
1	B	36	101	1	F	34	G	95	6,408	8.9	1.3					GESMXLDKSP
1	B	37	101	2	J	45	G	150	4,007	5.6	1.2					CLNF
1	B	38	101	3	T	1234	G	95	5,304	7.4	4.6					PP Spacer;GELCPT/GEDKSP
1	B	39	101	1	A	34	L	95	6,408	8.9	2.6					GEMPLTSP/ARDKSPPT?
1	B	40	101	1	F	4	G	95	3,672	5.1	1.3					GEMPDKLTSP/PT?
1	B	41	101	1	A	34	L	95	6,408	8.9	2.6					GEMDLGDKSP
1	B	42	101	4	V	1	G	95	2,499	3.5	0.019					ARXLDKSP
1	B	43	101	3	T	2	G	95	2,183	3.0	4.6					GESMDKSPPT?

TABLE A-3

CDA 101/102 DATA BASE (cont.)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (1E-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/O	Analy	Visual Examination
1	C	2	102	2	N	1	G	150	836	1.2	1.6					AXP	NFCL
1	C	4	102	2	CC	12345	G	150	11,593	16.1	2.5					P	NFCL
1	C	6	102	2	H	3	G	150	4,416	6.1	0.75					P	NFCL
1	C	10	102	2	CC	12345	G	150	11,593	16.1	2.5					P	NFCL
1	C	12	102	1	B	1	L	95	720	1.0	4.1					AXP	LCIM
1	C	13	102	1	KO	123	G	95	5,736	8.0	2.5					P	ARDKRS/NFCL
1	C	14	102	1	D	1	L	95	720	1.0	4.1					P	ARSMPTLCIM
1	C	15	102	1	I	123	L	95	5,736	8.0	4.9					P	ARLCIM
1	C	16	102	2	P	1	G	150	836	1.2	4.6					P	NFCL
1	C	17	102	2	P	3	G	150	4,416	6.1	1.5					P	NFCL
1	C	19	102	1	K	1	G	95	720	1.0	2.5					AXP	NFCL
1	C	20	102	2	GG	1234	G	150	10,078	14.0	0.42					P	NFCL
1	C	21	102	2	H	2	G	150	2,334	3.2	1.6					AXP	NFCL
1	C	22	102	2	P	2	G	150	2,334	3.2	4.6					P	NFCL
1	C	24	102	1	O	2	G	95	2,280	3.2	2.5					AXP	ARLCIM
1	C	26	102	1	D	2	L	95	2,280	3.2	4.1					P	ARLCIM
1	C	27	102	1	D	2	L	95	2,280	3.2	4.1					AXP	ARVSSPPT?/ARLCIM?
1	C	29	101	3	U	1234	G	95	5,304	7.4	0.67					P	NFCL
1	C	30	101	2	P	45	G	150	4,007	5.6	1.5					P	NFCL
1	C	31	101	1	D	4	L	95	3,672	5.1	4.1					P	ARLCIM
1	C	32	101	4	E	1	G	95	2,499	3.5	0.033					P	NFCL
1	C	33	101	3	U	1234	G	95	5,304	7.4	0.67					P	ARLCIM
1	C	34	101	1	D	34	L	95	6,408	8.9	4.1					P	ARLCIM?
1	C	35	101	1	G	34	G	95	6,408	8.9	2.5					P	ARLCIM
1	C	37	101	2	E	5	G	150	1,515	2.1	0.31					P	NFCL
1	C	39	101	1	O	4	G	95	3,672	5.1	2.5					P	ARLCIM
1	C	40	101	4	M	1	L	95	2,499	3.5	0.037					P	ARLCIM
1	C	41	101	4	E	1	G	95	2,499	3.5	0.033					P	NFLC
1	C	42	101	2	H	45	G	150	4,007	5.6	0.75					P	NFLC
1	C	43	101	4	M	1	L	95	2,499	3.5	0.037					P	ARLCIM
1	W	1	101	1	I	1234	L	95	9,408	13.1	4.9	1.9	5.9	0.0036	0.12	P	ARSMB*SP
1	W	2	101	2	GG	1234	G	150	10,078	14.0	0.42	21.6	24.9	0.0380	1.65	P	GEPTLC/ARDKSP
1	W	3	101	1	I	34	I	95	6,408	8.9	4.9					P	
1	W	4	101	2	P	3	G	150	4,416	6.1	1.5	7.8	8.8	0.0310	1.96	P	CLNF
1	W	6	101	1	L	1234	G	95	9,408	13.1	4	57.8	68.1	0.1090	1.41	P	RU/ARDKRS
1	W	7	101	2	P	1	G	150	836	1.2	4.6	3.3	3.6	0.0700	2.80	P	FWDKSMSP
1	W	8	101	1	L	1	G	95	720	1.0	4					AP	
1	W	11	101	2	NHH	12345	G	150	11,593	16.1	0.98	14.3	16.2	0.0218	1.90	P	CL
1	W	12	101	1	I	1	L	95	720	1.0	4.9	6.6	7.5	0.1620	1.80	P	CL/FWLC
1	W	13	101	2	P	1	G	150	836	1.2	4.6					AXP	
1	W	14	101	2	NHH	12345	G	150	11,593	16.1	0.98	15.9	18.1	0.0243	1.82	P	CL
1	W	15	101	2	P	1	G	150	836	1.2	4.6	3.2	3.4	0.0680	4.00	AP	FWDKSMSP
1	W	16	101	2	P	3	G	150	4,416	6.1	1.5	7.6	8.8	0.0310	1.96	P	CLNF
1	W	17	101	1	L	1	G	95	720	1.0	4	10.5	12.1	0.2600	1.65	P	ARDKRSLC
1	W	18	101	1	L	1	I	95	720	1.0	4					P	"A" data on gas part
1	W	19	101	1	L	1	I	95	720	1.0	4					P	"A" data on gas part

TABLE A-3

CDA 101/102 DATA BASE (cont.)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (hr)	Time (mon)	Flux (E-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/O	Anal?	Visual Examination
1	W	20	101	1	L	1	I	95	720	1.0	4					AP	"A" data on liquid part
1	W	22	101	2	NHH	12345	G	150	11,593	16.1	0.98	15.8	18	0.0241	1.81	P	CL
1	W	23	101	2	GG	1234	G	150	10,078	14.0	0.42	9.6	10.9	0.0170	1.86	P	ARPTLC/ARDKSP
1	W	24	101	2	GG	1234	G	150	10,078	14.0	0.42	10.2	11.7	0.0180	1.71	P	GEPTLC/ARDKSP
1	W	25	101	1	I	1	L	95	720	1.0	4.9	4.4	5.1	0.1080	1.58	P	RU/ISDKSP/CL
1	W	26	101	2	P	2	G	150	2,334	3.2	4.6	4.3	4.9	0.0320	1.80	P	ISSP
1	W	27	101	2	P	2	G	150	2,334	3.2	4.6	4.8	5.2	0.0350	1.93	P	CL/FWSP/ISPT
1	W	28	101	2	P	2	G	150	2,334	3.2	4.6	4.3	4.8	0.0320	2.17	P	CL
1	W	29	101	1	L	2	I	95	2,280	3.2	4					P	"A" data on gas part
1	W	30	101	1	L	2	I	95	2,280	3.2	4					P	"A" data on gas part
1	W	31	101	2	P	3	G	150	4,416	6.1	1.5	7.8	8.7	0.0310	2.18	P	CLNF
1	W	32	101	1	I	34	I	95	6,408	8.9	4.9					P	
1	W	33	101	1	L	2	G	95	2,280	3.2	4	27.1	31.2	0.2100	1.66	AP	ARDKRS/ISRU
1	W	34	101	1	I	23	L	95	5,016	7.0	4.9	23	32.3	0.0800	0.62	P	GERU/ARVSPT
1	W	35	101	1	I	34	I	95	6,408	8.9	4.9					P	
1	W	36	101	1	L	23	G	95	5,016	7.0	4	46.2	54.7	0.1610	1.37	AP	FWBKSP/ARDKRS
1	W	37	101	1	I	2	L	95	2,280	3.2	4.9	10.9	13.9	0.0840	0.91	P	CL
1	W	38	101	1	L	2	I	95	2,280	3.2	4					P	"A" data on gas part
1	W	39	101	1	L	4	G	95	3,672	5.1	4	366.4	448.2	1.7605	1.13	P	RU/ARDKDP
1	W	40	101	4	Y	1	I	95	2,499	3.5	0.04					P	
1	W	41	101	3	S	3	G	95	860	1.2	1.6	2.7	3.1	0.0550	1.70	P	GEMDDKSPPT?
1	W	42	101	3	SS	12	G	95	2,927	4.1	2	8.3	9.6	0.0500	1.61	P	GEDKSPLCPT?
1	W	43	101	3	S	4	G	95	1,517	2.1	1.6	2.2	2.6	0.0255	1.38	P	ARSMBKSP
1	W	44	101	3	SS	12	G	95	2,927	4.1	2	8.7	10.1	0.0520	1.56	P	GEDKRSSPLCPT
1	W	45	101	2	P	45	G	150	4,007	5.6	1.5	10.2	11.6	0.0449	1.83	P	CL
1	W	46	101	3	SS	12	G	95	2,927	4.1	2	6.8	7.9	0.0410	1.56	P	GEDKRSSPLCPT?
1	W	47	101	4	W	1	G	95	2,499	3.5	0.041	2.7	3.1	0.0190	1.70	P	CL
1	W	49	101	3	S	3	G	95	860	1.2	1.6	2.7	3	0.0550	2.27	P	ARDKSPLCPT?/CL/FWSP
1	W	51	101	4	W	1	G	95	2,499	3.5	0.041	3.4	4	0.0239	1.43	P	CL
1	W	52	101	3	S	4	G	95	1,517	2.1	1.6	2.6	2.9	0.0300	2.18	P	GESMPT?DKSP
1	W	53	101	2	E	5	G	150	1,515	2.1	0.31	3.4	3.8	0.0394	2.14	P	CL
1	W	54	101	1	I	34	L	95	6,408	8.9	4.9	15	20.8	0.0411	0.65	P	GEXLDKSPLC
1	W	55	101	4	Y	1	L	95	2,499	3.5	0.04	9	11.6	0.0636	0.87	P	CL/GELTSP
1	W	56	101	2	E	5	G	150	1,515	2.1	0.31	3.2	3.5	0.0373	2.69	P	CL
1	W	57	101	1	I	4	L	95	3,672	5.1	4.9	25.5	31	0.1224	1.17	P	ARDKSP/RU
1	W	58	101	4	Y	1	L	95	2,499	3.5	0.04	9	11.6	0.0636	0.87	P	CL
1	W	59	101	2	P	45	G	150	4,007	5.6	1.5	9.6	11	0.0422	1.73	P	CL
1	W	60	101	2	P	45	G	150	4,007	5.6	1.5	11	12.3	0.0483	2.13	P	CL
1	W	61	101	4	Y	1	I	95	2,499	3.5	0.04					P	
1	W	62	101	1	L	34	G	95	6,408	8.9	4	218.5	257.2	0.6002	1.42	P	ARDKRS/GEXLLCPT?
1	W	63	101	4	Y	1	L	95	2,499	3.5	0.04	8.7	11.3	0.0613	0.84	P	CL
1	W	64	101	3	S	4	G	95	1,517	2.1	1.6	3.3	3.5	0.0383	4.15	P	CL/ARVSSPPT?
1	W	65	101	3	S	3	G	95	860	1.2	1.6	3.5	4	0.0720	1.76	P	GEDKSPLCPT
1	W	66	101	4	W	1	G	95	2,499	3.5	0.041	3	3.4	0.0211	1.69	P	CL
1	W	67	101	4	Y	1	L	95	2,499	3.5	0.04					P	
1	W	68	101	2	E	5	G	150	1,515	2.1	0.31	2.8	3.1	0.0326	2.35	P	CL

TABLE A-3

CDA 101/102 DATA BASE (Cont.)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (XE-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/O	Analy	Visual Examination
1	C	2	102	2	N	1	G	150	836	1.2	1.6						
1	C	4	102	2	CC	12345	G	150	11,593	16.1	2.5					AXP	NFCL
1	C	6	102	2	H	3	G	150	4,416	6.1	0.75					P	NFCL
1	C	10	102	2	CC	12345	G	150	11,593	16.1	2.5					P	NFCL
1	C	12	102	1	D	1	L	95	720	1.0	4.1					P	NFCL
1	C	13	102	1	KD	123	G	95	5,736	8.0	2.5					AXP	LC1M
1	C	14	102	1	D	1	L	95	720	1.0	4.1					P	ARDKRS/NFCL
1	C	15	102	1	I	123	L	95	5,736	8.0	4.9					P	ARSMPTLC1M
1	C	16	102	2	P	1	G	150	836	1.2	4.6					P	ARLC1M
1	C	17	102	2	P	3	G	150	4,416	6.1	1.5					P	NFCL
1	C	19	102	1	K	1	G	95	720	1.0	2.5					P	NFCL
1	C	20	102	2	GG	1234	G	150	10,078	14.0	0.42					AXP	NFCL
1	C	21	102	2	H	2	G	150	2,334	3.2	1.6					P	NFCL
1	C	22	102	2	P	2	G	150	2,334	3.2	4.6					AXP	NFCL
1	C	24	102	1	O	2	G	95	2,280	3.2	2.5					P	NFCL
1	C	26	102	1	D	2	L	95	2,280	3.2	4.1					AXP	ARLC1M
1	C	27	102	1	D	2	L	95	2,280	3.2	4.1					P	ARLC1M
1	C	29	101	3	-	1234	G	95	5,304	7.4	0.67					AXP	ARV5SPPT?/ARLC1M?
1	C	30	101	2	P	45	G	150	4,007	5.6	1.5					P	NFCL
1	C	31	101	1	D	4	L	95	3,672	5.1	4.1					P	NFCL
1	C	32	101	4	E	1	G	95	2,499	3.5	0.033					P	ARLC1M
1	C	33	101	3	U	1234	G	95	5,304	7.4	0.67					P	NFCL
1	C	34	101	1	D	34	L	95	6,408	8.9	4.1					P	ARLC1M
1	C	35	101	1	O	34	G	95	6,408	8.9	2.5					P	ARLC1M?
1	C	37	101	2	E	5	G	150	1,515	2.1	0.31					P	ARLC1M
1	C	39	101	1	O	4	G	95	3,672	5.1	2.5					P	NFCL
1	C	40	101	4	M	1	L	95	2,499	3.5	0.037					P	ARLC1M
1	C	41	101	4	E	1	G	95	2,499	3.5	0.033					P	ARLC1M
1	C	42	101	2	H	45	G	150	4,007	5.6	0.75					P	NFLC
1	C	43	101	4	M	1	L	95	2,499	3.5	0.037					P	NFLC
																P	ARLC1M
1	W	1	101	1	I	1234	L	95	9,408	13.1	4.9	1.9	5.9	0.0036	0.12	P	ARSMBKSP
1	W	2	101	2	GG	1234	G	150	10,078	14.0	0.42	21.6	24.9	0.0380	1.65	P	GEPTLC/ARDKSP
1	W	3	101	1	I	34	L	95	6,408	8.9	4.9					P	
1	W	4	101	2	P	3	G	150	4,416	6.1	1.5	7.8	8.8	0.0310	1.96	P	CLNF
1	W	6	101	1	L	1234	G	95	9,408	13.1	4	57.8	68.1	0.1090	1.41	P	RU/ARDKRS
1	W	7	101	2	P	1	G	150	836	1.2	4.6	3.3	3.6	0.0700	2.80	P	FWDKSMSP
1	W	8	101	1	L	1	G	95	720	1.0	4					AP	
1	W	11	101	2	NHH	12345	G	150	11,593	16.1	0.98	14.3	16.2	0.0218	1.90	P	CL
1	W	12	101	1	I	1	L	95	720	1.0	4.9	6.6	7.5	0.1620	1.80	P	CL/FWLC
1	W	13	101	2	P	1	G	150	836	1.2	4.6					AXP	
1	W	14	101	2	NHH	12345	G	150	11,593	16.1	0.98	15.9	18.1	0.0243	1.82	P	CL
1	W	15	101	2	P	1	G	150	836	1.2	4.6	3.2	3.4	0.0680	4.00	AP	FWDKSMSP
1	W	16	101	2	P	3	G	150	4,416	6.1	1.5	7.8	8.8	0.0310	1.96	P	CLNF
1	W	17	101	1	L	1	G	95	720	1.0	4	10.5	12.1	0.2600	1.65	P	ARDKRSLC
1	W	18	101	1	L	1	I	95	720	1.0	4					P	"A" data on gas part
1	W	19	101	1	L	1	I	95	720	1.0	4					P	"A" data on gas part

TABLE A-3

CDA 101/102 DATA BASE (Cont.)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Rods	Phase	Temp (C)	Time (h)	Time (mon)	Flux (XE-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/U	Analy	Visual Examination
1	B	1	101	2	J	3	G	150	4,416	6.1	1.2						GEVSDKSP
1	B	2	101	1	A	1	L	95	720	1.0	2.6					D	CL/FWDKSPPT?
1	B	3	101	-	BB	12345	G	150	11,593	16.1	2						ARBKSPPT
1	B	4	101	2	BB	12345	G	150	11,593	16.1	2					P	ARDKSPPT
1	B	5	101	1	A	1	L	95	720	1.0	2.6						GESMPT
1	B	6	101	2	J	1	G	150	836	1.2	3.1					D	CL/FWDKSP
1	B	7	101	1	F	1234	G	95	9,408	13.1	1.3					P	GEXLBKSP/PT
1	B	8	101	2	J	1	G	150	836	1.2	3.1						CL/FWRDWD
1	B	9	101	2	J	1	G	150	836	1.2	3.1						CL
1	B	10	101	1	A	1234	L	95	9,408	13.1	2.6						GESMLIDKSP/ARVSPT
1	B	11	101	1	F	1	G	95	720	1.0	1.3					ADP	ARSMPT/FWPT
1	B	12	101	2	J	345	G	150	8,423	11.7	1.2						CLNF
1	B	13	101	1	F	1	G	95	720	1.0	1.3						CL/FWSP
1	B	14	101	2	BB	1234	G	150	10,078	14.0	2.1						FWDKSPPT/FWLC
1	B	15	101	2	J	3	G	150	4,416	6.1	1.2						CL/ISMDSP
1	B	16	101	2	J	2	G	150	2,334	3.2	3.1					D	ISPT
1	B	17	101	2	J	2	G	150	2,334	3.2	3.1						CL
1	B	18	101	4	X	1	L		2,499	3.5	0.027						FWLGDKSP
1	B	19	101	1	F	23	G	95	5,016	7.0	1.3					P	GEMDBKSPPT?
1	B	20	101	1	F	2	G	95	2,280	3.2	1.3					D	ISPT/CL
1	B	21	101	2	J	2	G	150	2,334	3.2	3.1						CL
1	B	22	101	1	A	2	L	95	2,280	3.2	2.6					DP	CL/ARBKSP
1	B	23	101	1	A	23	L	95	5,016	7.0	2.6						ISBKSP
1	B	24	101	4	X	1	L	95	2,499	3.5	0.027						GELTMP/FWMDDKSP
1	B	26	101	4	V	1	G	95	2,499	3.5	0.019						FWMDDKLTSP/PT?
1	B	27	101	4	V	1	G	95	2,499	3.5	0.019						FWLGDKSP
1	B	28	101	2	B	5	G	150	1,515	2.1	1.5						CLNF
1	B	29	101	3	T	1234	G	95	5,304	7.4	4.6						PP Spacer;GESMPT/ARDKSP
1	B	30	101	3				95		0.0							Non-data;Spacer;GEDKSPPT
1	B	31	101	3	T	1234		95	5,304	7.4	4.6						Non-data;Spacer;GELCPT?/GEDKSP
1	B	32	101	4	X	1	L	95	2,499	3.5	0.027						ARSMSP/PT?
1	B	33	101	1	A	4	L	95	3,672	5.1	2.6					P	GEMDDKSP
1	B	34	101	1	F	34	G	95	6,408	8.9	1.3						GEXLDKSP
1	B	35	101	2	J	45	G	150	4,007	5.6	1.2						CLNF
1	B	36	101	1	F	34	G	95	6,408	8.9	1.3						GESMXLDKSP
1	B	37	101	2	J	45	G	150	4,007	5.6	1.2						CLNF
1	B	38	101	3	T	1234	G	95	5,304	7.4	4.6						PP Spacer;GELCPT/GEDKSP
1	B	39	101	1	A	34	L	95	6,408	8.9	2.6						GEMPLTSP/ARDKSPPT?
1	B	40	101	1	F	4	G	95	3,672	5.1	1.3						GEMPDKLTSP/PT?
1	B	41	101	1	A	34	L	95	6,408	8.9	2.6						GEMDLGDKSP
1	B	42	101	4	V	1	G	95	2,499	3.5	0.019						ARXLDKSP
1	B	43	101	3	T	2	G	95	2,183	3.0	4.6						GESMDKSPPT?

TABLE A-4

CDA 613/614 DATA BASE

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (hr)	Time (mpy)	Flux (E-5)	Wt Loss File (mg)	Wt Loss Pit (mg)	Cor Rt (mil/yr)	M/D	Anal	Visual Examination
2	B	1	613	2	BB	1234	G	150	10,078	14.0	2.1						GEDAFM/ISSP/ROWD
2	B	2	613	2	J	1	G	150	836	1.2	3.1						ARDAFM/ISSP
2	B	3	613	2	J	1	G	150	836	1.2	3.1					D	FWVSSPPT/ROCUCO
2	B	4	613	2	J	3	G	150	4,416	6.1	1.2						ROPT/CLNF
2	B	5	613	2	BB	12345	G	150	11,593	16.1	2					P	ARDAFM/ARVSSPPT
2	B	6	613	1	A	1	L	95	720	1.0	2.6						GEXLLTSPVSDAPT
2	B	7	613	1	F	1	G	95	720	1.0	1.3					ADP	FWFL/FWXLLC/ARSMPT
2	B	8	613	1	F	1234	G	95	9,408	13.1	1.3					P	GEFLPT/ROPTWD
2	B	9	613	2	J	3	G	150	4,416	6.1	1.2						GEVSLTSP
2	B	10	613	2	J	345	G	150	8,423	11.7	1.2						LTCLCO/CL
2	B	11	613	2	J	1	G	150	836	1.2	3.1						GEDAFMDASP
2	B	12	613	1	F	1	G	95	720	1.0	1.3						ARCUCO/FWPT
2	B	13	613	2	BB	12345	G	150	11,593	16.1	2						RODAWD/GEDAFM/GEVSSP
2	B	14	613	1	A	1	L	95	720	1.0	2.6					ADP	GELTMDSPSMPT/ROPTWD
2	B	15	613	1	A	1234	L	95	9,408	13.1	2.6					P	GEVSPT/ARCUCO
2	B	16	613	2	J	2	G	150	2,334	3.2	3.1						GEDAFM/CL
2	B	17	613	2	J	2	G	150	2,334	3.2	3.1					D	ROPT GEDAFM/ISSP
2	B	18	613	2	J	2	G	150	2,334	3.2	3.1						GEDAFM/CL
2	B	19	613	1	F	2	G	95	2,280	3.2	1.3					DP	GEFL/ARPT/ROPT
2	B	20	613	1	F	23	G	95	5,016	7.0	1.3					P	GEFL
2	B	22	613	1	A	23	L	95	5,016	7.0	2.6						ARCUCO/GEVSSPPT
2	B	23	613	1	A	2	L	95	2,280	3.2	2.6					DP	ARCUCO/GESMPT/ROPT
2	B	24	613	1	A	34	L	95	6,408	8.9	2.6						GESMPT/ISLC
2	B	25	613	2	J	45	G	150	4,007	5.6	1.2						GEDAFM/GEVSSP
2	B	26	613	4	V	1	G	95	2,499	3.5	0.019						GEDAFM/ARVSSP
2	B	27	613	4	X	1	L	95	2,499	3.5	0.027						CUCOSPWD/ARCUCO/GEVSSP
2	B	28	613	1	F	34	G	95	6,408	8.9	1.3						GEFL/GELTSP
2	B	29	613	1	A	4	L	95	3,672	5.1	2.6						ISPT/CUCO CL
2	B	30	613	4	V	1	G	95	2,499	3.5	0.019						GEDAFM
2	B	31	613	2	B	5	G	150	1,515	2.1	1.5						ARSMPT/GEDAFM
2	B	33	613	4	X	1	L	95	2,499	3.5	0.027						GESMSPPT
2	B	34	613	4	X	1	L	95	2,499	3.5	0.027						GESMSPPT/FWLGPT
2	B	35	613	4	V	1	G	95	2,499	3.5	0.019						ARDAFM/GELTDASP
2	B	36	613	1	A	34	L	95	6,408	8.9	2.6					P	GEVSPT/FWXLFL
2	B	37	613	1	F	4	G	95	3,672	5.1	1.3						ARCUCO/FWFL
2	B	38	613	1	F	34	G	95	6,408	8.9	1.3						GELGPT
2	B	39	613	3	*					0.0							* Non-data;PP Spacer;GEXLFLLC
2	B	40	613	3	I	1234	G	95	5,304	7.4	4.6						PP Spacer;GEXLFLLC
2	B	41	613	3	I	1234	G	95	5,304	7.4	4.6						PP Spacer;GEXLFLLC
2	B	42	613	3	*					0.0							PP Spacer;CL/ISLC/CUWD
2	B	43	613	2	J	45	G	150	4,007	5.6	1.2						CL ROPTWD/ARDAFM/FWPT

TABLE A-4

CDA 613/614 DATA BASE (Cont.)

Allo.	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (xE-5)	Wt Loss Film (mg)	Wt Film (mg)	Cor Rt (mil/yr)	M/O	Anal.	Visual Examination
2	C	2	614	2	H	3	G	150	4,416	6.1	0.75					P	CLNF
2	C	3	614	1	1	123	L	95	5,736	8.0	4.9					P	NF/CUFM
2	C	4	614	2	CC	12345	G	150	11,593	16.1	2.5					P	NF
2	C	5	614	2	N	1	G	150	836	1.2	1.6					AxP	ISLC/NF
2	C	6	614	1	*	1	G	95	720	1.0	2.5					AxP	LCFL
2	C	7	614	2	CC	12345	G	150	11,593	16.1	2.5					P	NF
2	C	9	614	2	P	3	G	150	4,416	6.1	1.5					P	NF
2	C	10	614	2	P	1	G	150	836	1.2	4.6					P	NF
2	C	11	614	1	KO	123	G	95	5,736	8.0	2.5					P	GEPT/ARLC
2	C	12	614	2	GG	1234	G	150	10,078	14.0	0.42					P	NF
2	C	13	614	1	D	1	L	95	720	1.0	4.1					AxP	ISLCIM
2	C	15	614	1	D	1	L	95	720	1.0	4.1					P	ARLCIM/ISPL?/CUFM
2	C	16	613	1	D	2	L	95	2,280	3.2	4.1					P	ARLCIM?/CUFM
2	C	17	613	2	H	2	G	150	2,334	3.2	1.6					AxP	NF
2	C	18	613	2	P	2	G	150	2,334	3.2	4.6					P	NF
2	C	22	613	1	D	2	L	95	2,280	3.2	4.1					AxP	ARLCIM?/NF/CUFM
2	C	23	613	1	D	2	G	95	2,280	3.2	2.5					AxP	ARLC
2	C	24	614	3	U	1234	G	95	5,304	7.4	0.67					P	GELCFL
2	C	25	614	4	M	1	L	95	2,499	3.5	0.037					P	ARLCIM/CUFM
2	C	26	614	1	D	4	G	95	3,672	5.1	2.5					P	GESMPT?SPLC
2	C	27	614	4	M	1	L	95	2,499	3.5	0.037					P	ARPTLCIM/CUFM
2	C	28	614	3	U	1234	G	95	5,304	7.4	0.67					P	GELCPTFL
2	C	29	614	1	D	34	G	95	6,408	8.9	2.5					P	GELCPTFL
2	C	30	614	1	D	34	L	95	6,408	8.9	4.1					P	LCIM/CUFM
2	C	32	614	2	E	5	G	150	1,515	2.1	0.31					P	FWPIPL3M
2	C	34	614	2	P	45	G	150	4,007	5.6	1.5					P	ISLC
2	C	35	614	4	E	1	G	95	2,499	3.5	0.033					P	GELCFLPT
2	C	36	614	4	E	1	G	95	2,499	3.5	0.033					P	GELCPT
2	C	37	614	1	D	4	L	95	3,672	5.1	4.1					P	LCIM?/CUFM
2	C	38	614	2	H	45	G	150	4,007	5.6	0.75					P	DAFM/NF
2	W	1	613	1	L	1	I	95	720	1.0	4					P	GEDAFM/GEVSDAPTSP
2	W	2	613	2	NHH	12345	G	150	11,593	16.1	0.98	6.9	8.7	0.0118	0.97	P	GEVSPTDASP/ARDAFM
2	W	3	613	1	L	1	I	95	720	1.0	4					P	"AT" data on gas part
2	W	4	613	2	GG	1234	G	150	10,078	14.0	0.42	5.3	7	0.0100	0.78	P	GEDAFM/ARCULC
2	W	5	613	2	GG	1234	G	150	10,078	14.0	0.42	3.8	5.1	0.0075	0.74	P	GEDAFM/ARCULC
2	W	6	613	2	NHH	12345	G	150	11,593	16.1	0.98	5.2	6.6	0.0089	0.94	P	GEDAFM/GEVSPTSP
2	W	7	613	2	P	3	G	150	4,416	6.1	1.5	2.6	3.3	0.0120	0.94	P	GEDAFM/CL
2	W	8	613	2	P	3	G	150	4,416	6.1	1.5	3.4	4.2	0.0150	1.07	P	GEVSPT/ARDAFM
2	W	9	613	1	I	34	I	95	6,408	8.9	4.9					P	
2	W	11	613	2	P	1	G	150	836	1.2	4.6	1.1	1.4	0.0260	0.92	P	FWVSSPPT
2	W	12	613	1	L	1	I	95	720	1.0	4					AP	"AT" data on liquid part
2	W	13	613	1	L	1234	G	95	9,408	13.1	4	44.9	54.5	0.0951	1.18	AP	GERB/FWILLC
2	W	15	613	1	I	34	I	95	6,408	8.9	4.9					P	
2	W	16	613	1	I	1	L	95	720	1.0	4.9	2.7	3.8	0.0740	0.62	P	GEVSSPPT/ARDAFM

TABLE A-4

CDA 613/614 DATA BASE (Cont.)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (hr)	Time (mon)	Flux (1E-5)	Wt Loss (mg)	Film wt (mg)	Cor Pt (mil yr)	M/O	Analy	Visual Examination
2	W	17	613	2	P 1		G	150	836	1.2	4.6					AXP	
2	W	18	613	2	NHH 12345		G	150	11,593	16.1	0.98	6.9	8.7	0.0118	0.97	P	ARC*FM/GESMPTSP
2	W	19	613	1	I 1234		L	95	9,408	13.1	4.9	4.7	13	0.0099	0.14	P	ISLC/GELTFM/GESMLTSP
2	W	20	613	1	L 1		G	95	720	1.0	4	7.9	9.6	0.2170	1.17	AP	ARCUCO/ISPT
2	W	21	613	1	I 1		L	95	720	1.0	4.9	3.2	4.5	0.0680	0.62	P	GEVSSPPT
2	W	22	613	2	P 1		G	150	836	1.2	4.6	1.7	2.1	0.0400	1.07	P	FWVSSPPT
2	W	24	613	2	GG 1234		G	150	10,078	14.0	0.42	3.6	4.8	0.0071	0.76	P	GEDKFM/FWLCLTSP
2	W	25	613	1	L 1		G	95	720	1.0	4					AXP	
2	W	26	613	2	P 2		G	150	2,334	3.2	4.6	2.3	2.9	0.0196	0.97	P	GEDKFM/ISSP
2	W	27	613	2	P 2		G	150	2,334	3.2	4.6	2.3	2.8	0.0196	1.16	P	GEDKFM/ISSP
2	W	28	613	2	P 2		G	150	2,334	3.2	4.6	2.2	2.7	0.0187	1.11	AP	GEDKFM/ISSP
2	W	29	613	2	P 3		G	150	4,416	6.1	1.5	3.1	3.8	0.0140	1.12	P	GEVSPT/GEFM
2	W	30	613	1	L 2		G	95	2,280	3.2	4	9.2	10.8	0.0803	1.45	P	FWLC/GESMPT
2	W	31	613	1	L 23		G	95	5,016	7.0	4	17.9	23.9	0.0710	0.75	AP	GECULC/FWPT
2	W	32	613	1	I 23		L	95	5,016	7.0	4.9	11	17.9	0.0440	0.40	P	FWCUCOLC/FWARVSPT?
2	W	33	613	1	L 2		I	95	2,280	3.2	4					P	"A" data on gas part
2	W	34	613	1	L 2		I	95	2,280	3.2	4					P	"A" data on gas part
2	W	35	613	1	L 2		I	95	2,280	3.2	4					P	"A" data on gas part
2	W	36	613	1	I 2		L	95	2,280	3.2	4.9	8.4	9.9	0.0730	1.41	P	GESMLCPT/ARCUCO
2	W	37	613	1	I 34		I	95	6,408	8.9	4.9					P	
2	W	38	613	4	Y 1		I	95	2,499	3.5	0.04					P	
2	W	39	613	3	S 4		G	95	1,517	2.1	1.6	3.2	4.2	0.0420	0.81	P	GEDKSPPT/ARLSLC
2	W	40	613	3	S 3		G	95	860	1.2	1.6	3.1	4	0.0710	0.87	P	ARCUCO/GESMSP
2	W	41	613	3	S 4		G	95	1,517	2.1	1.6	2.8	3.5	0.0366	1.01	P	GEDKSPSMPT
2	W	42	613	4	W 1		G	95	2,499	3.5	0.041	7.2	9	0.0569	1.01	P	ARLCPTSP
2	W	44	613	4	Y 1		L	95	2,499	3.5	0.04	19.9	25.9	0.1572	0.84	P	GESMPTLCSP?/ARCUCO
2	W	45	613	4	Y 1		L	95	2,499	3.5	0.04	21	27.6	0.1659	0.80	P	GESMPTLC/ARCUCO
2	W	46	613	4	Y 1		I	95	2,499	3.5	0.04					P	
2	W	47	613	1	I 34		L	95	6,408	8.9	4.9	19.9	27.3	0.0612	0.68	P	ISLC/ARVSPT
2	W	48	613	4	W 1		G	95	2,499	3.5	0.041	6.4	8.1	0.0506	0.95	P	GEFM/GESMSPPT/FWLC
2	W	49	613	2	P 45		G	150	4,007	5.6	1.5	3	3.7	0.0148	1.08	P	CL/FWVSD*SPPT
2	W	50	613	3	S 3		G	95	860	1.2	1.6	4	5.2	0.0920	0.84	P	ARSPCUCO
2	W	51	613	2	P 45		G	150	4,007	5.6	1.5	3.1	3.9	0.0153	0.98	P	CL/ISSMSPPT
2	W	53	613	2	E 5		G	150	1,515	2.1	0.31	1.2	1.4	0.0157	1.51	P	CL/FMSP
2	W	54	613	2	E 5		G	150	1,515	2.1	0.31	1.3	1.4	0.0170	3.27	P	CL/FWSMSPPT
2	W	55	613	2	P 45		G	150	4,007	5.6	1.5	3.1	3.9	0.0153	0.98	P	CL/FWLTSP
2	W	56	613	1	I 4		L	95	3,672	5.1	4.9	30.7	37.4	0.1653	1.15	P	ARCUCO/GERU/GEFM
2	W	57	613	1	L 34		G	95	6,408	8.9	4	42.5	65.3	0.1311	0.47	P	ARLC/GEVSPTSP
2	W	58	613	3	S 3		G	95	860	1.2	1.6	3.1	4.1	0.0710	0.78	P	ARPTLCCUCO
2	W	59	613	2	E 5		G	150	1,515	2.1	0.31	1.6	1.8	0.0209	2.01	P	GEVSSP
2	W	60	613	4	Y 1		L	95	2,499	3.5	0.04	20.5	27.1	0.1621	0.78	P	ARCUCO/GESM/OPPTSP?
2	W	61	613	3	S 4		G	95	1,517	2.1	1.6	3.7	4.7	0.0482	0.93	P	GEFM/GESMLC
2	W	62	613	4	W 1		G	95	2,499	3.5	0.041	5.4	6.8	0.0428	0.97	P	GESMSPPT/FWLC/GEFM
2	W	63	613	4	Y 1		I	95	2,499	3.5	0.04					P	
2	W	64	613	1	L 4		G	95	3,672	5.1	4	20.6	26.2	0.1107	0.93	P	ISLC/GESMPT
2	W	65	613	3	SS 12		G	95	2,927	4.1	2	8.5	11.1	0.0570	0.82	P	GEFLPTLC
2	W	66	613	3	SS 12		G	95	2,927	4.1	2	9.8	12.4	0.0660	0.95	P	GEFLPTLC ARCUCO
2	W	67	613	3	SS 12		G	95	2,927	4.1	2	8.5	11.4	0.0600	0.90	P	GEFLPTLC ARCUCO

TABLE A-5

CDA 715 DATA BASE

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (hr)	Time (mpy)	Flux (xE-5)	Wt Loss (mg)	Film Wt (mg)	Corr Rt (mils/yr)	M/D	Anal.	Visual Examination
3	B	1	715	1	F	1234	G	95	9,406	13.1	1.3					P	GESMPT/ISLC
3	B	2	715	2	BB	12345	G	150	11,593	16.1	2					P	GESMD&SPDD/PTC
3	B	3	715	1	F	1	G	95	720	1.0	1.3						GESMPT
3	B	4	715	2	BB	12345	G	150	11,593	16.1	2						GESMD&SP/CUFM
3	B	5	715	2	BB	1234	G	150	10,078	14.0	2.1						ARSMPT/CL
3	B	6	715	2	J	3	G	150	4,416	6.1	1.2						GELTSP
3	B	7	715	2	J	1	G	150	836	1.2	3.1						CL/ARLTSP
3	B	8	715	1	A	1	L	95	720	1.0	2.6					D	ARLTSP/ISLC
3	B	9	715	2	J	1	G	150	836	1.2	3.1					D	CLNF
3	B	10	715	1	A	1	L	95	720	1.0	2.6						AR/SPT/&FM
3	B	11	715	2	J	345	G	150	8,423	11.7	1.2						GED&CUFM/ARSMSP
3	B	12	715	2	J	3	G	150	4,416	6.1	1.2						GELTSP
3	B	13	715	2	J	1	G	150	836	1.2	3.1						CLNF
3	B	14	715	1	F	1	G	95	720	1.0	1.3					ADP	GESMPT
3	B	15	715	1	A	1234	L	95	9,406	13.1	2.6						GED&FM/FWLC/ARRU
3	B	16	715	2	J	2	G	150	2,334	3.2	3.1						GED&FM/GEVSLTSP
3	B	17	715	2	J	2	G	150	2,334	3.2	3.1						CL/GED&CUFM
3	B	18	715	2	J	2	G	150	2,334	3.2	3.1					D	GESMLTSP/ISLC
3	B	19	715	1	A	2	L	95	2,280	3.2	2.6					D	ISCULC/GED&FM
3	B	20	715	1	A	23	L	95	5,016	7.0	2.6						GEARRU/FWLC
3	B	21	715	1	F	2	G	95	2,280	3.2	1.3					DP	ISLGLC/ARMDPT
3	B	22	715	4	X	1	L	95	2,499	3.5	0.027						ARD&FM/CL
3	B	23	715	1	F	23	G	95	5,016	7.0	1.3						ARPT/ARRULTCO
3	B	25	715	4	V	1	G	95	2,499	3.5	0.019						CL/ISPT
3	B	26	715	2	J	45	G	150	4,007	5.6	1.2						GED&FM/FWSMPT
3	B	28	715	2	J	45	G	150	4,007	5.6	1.2						GED&FM/CL
3	B	29	715	1	F	34	G	95	6,408	8.9	1.3						GELCRU
3	B	30	715	4	V	1	G	95	2,499	3.5	0.019						CL/FWMDLTSP
3	B	31	715	1	A	34	L	95	6,408	8.9	2.6						GEXLRUSP/FWLC/D&FM
3	B	32	715	3	T	12	G	95	2,927	4.1	4.6						GEXLLC
3	B	33	715	2	B	5	G	150	1,515	2.1	1.5						GED&FM/CL
3	B	34	715	3	R	2	G	95	2,183	3.0	3.1						GEXLLC
3	B	35	715	4	X	1	L	95	2,499	3.5	0.027						ARLTCO
3	B	36	715	1	A	4	L	95	3,672	5.1	2.6						GED&FMLTCO
3	B	37	715	3	*					0.0							Non-data;Spacer;GELCPT/ARCUCO Ru
3	B	38	715	1	F	4	G	95	3,672	5.1	1.3						GEMDLC/ARRU
3	B	39	715	3	T	1234	G	95	5,304	7.4	4.6						PP Spacer;GELCPT/ARCUCO Ru
3	B	40	715	1	F	34	G	95	6,408	8.9	1.3						GELGLC/D&CO
3	B	41	715	4	V	1	G	95	2,499	3.5	0.019						CLNF
3	B	42	715	1	A	34	L	95	6,408	8.9	2.6					P	GELGLC/D&CO
3	B	43	715	4	X	1	L	95	2,499	3.5	0.027						CLNF

TABLE A-5

CDA 715 DATA BASE (Cont.)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (xE-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/D	Analy	Visual Examination
3	C	3	715	1	D	1	L	95	720	1.0	4.1					AxP	GEVSPTIM/CLNF
3	C	4	715	2	H	3	G	150	4,416	6.1	0.75					P	GEVSPTIM/CLNF
3	C	5	715	1	D	1	L	95	720	1.0	4.1					P	GESMPTLC2M
3	C	6	715	2	N	1	G	150	836	1.2	1.6					AxP	CLNF/DKFM
3	C	7	715	2	GG	1234	G	150	10,078	14.0	0.42					P	CLNF/DKFM
3	C	8	715	1	KO	123	G	95	5,736	8.0	2.5					P	CL/DKFMISLC1M
3	C	10	715	2	P	1	G	150	836	1.2	4.6					P	ISLC/CLNF
3	C	11	715	2	CC	12345	G	150	11,593	16.1	2.5					P	CLNF
3	C	12	715	2	P	3	G	150	4,416	6.1	1.5					P	CLNF
3	C	13	715	1	I	123	L	95	5,736	8.0	4.9					P	ARVSPTIM/CLNF
3	C	14	715	2	CC	12345	G	150	11,593	16.1	2.5					P	FWLGDKSP/GEDKFM
3	C	15	715	1	K	1	G	95	720	1.0	2.5					AxP	FWLGLC/GEDKFM
3	C	16	715	2	H	2	G	150	2,334	3.2	1.6					AxP	GEDKFM/CLNF
3	C	17	715	2	P	2	G	150	2,334	3.2	4.6					P	CLNF
3	C	18	715	1	D	2	L	95	2,280	3.2	4.1					AxP	GESMMDLTSP/ARVSPTIM
3	C	21	715	1	O	2	G	95	2,280	3.2	2.5					AxP	CLNF
3	C	23	715	1	D	2	L	95	2,280	3.2	4.1					P	GEVSPTIM
3	C	24	715	1	O	34	G	95	6,408	8.9	2.5					P	ARLCFL5M/GEDKFM
3	C	25	715	1	D	34	L	95	6,408	8.9	4.1					P	GEVSPT2M/ARSMPTGE
3	C	26	715	3	U	1234	G	95	5,304	7.4	0.67					P	ARPTLC/ARDKFM
3	C	27	715	3	U	1234	G	95	5,304	7.4	0.67					P	ARLCFL
3	C	28	715	4	E	1	G	95	2,499	3.5	0.033					P	ISLC/CLNF
3	C	29	715	2	H	45	G	150	4,007	5.6	0.75					P	CLNF
3	C	30	715	1	O	4	G	95	3,672	5.1	2.5					P	FWFL5M
3	C	31	715	2	P	45	G	150	4,007	5.6	1.5					P	CLNF
3	C	32	715	1	D	4	L	95	3,672	5.1	4.1					P	GEVSPTIM
3	C	33	715	4	M	1	L	95	2,499	3.5	0.037					P	GEVSPTIM
3	C	34	715	2	E	5	G	150	1,515	2.1	0.31					P	CLNF
3	C	35	715	4	M	1	L	95	2,499	3.5	0.037					P	ARVSPTIM
3	C	37	715	4	E	1	G	95	2,499	3.5	0.033					P	FWXLLC1M/GEDKFM
3	W	1	715	1	L	1	G	95	720	1.0	4	19.2	26.7	0.4700	0.64	P	GELC/RUAR/SMPT/ARRU
3	W	2	715	2	GG	1234	G	150	10,078	14.0	0.42	27.6	34.8	0.0480	0.97	P	CL/GERU
3	W	3	715	2	P	1	G	150	836	1.2	4.6	10	12.1	0.2110	1.20	P	CL/ISVSPT/RU
3	W	4	715	1	L	1	G	95	720	1.0	4					AP	
3	W	5	715	2	NHH	12345	G	150	11,593	16.1	0.98	10.8	13.9	0.0164	0.88	P	GEDKFM
3	W	6	715	2	P	3	G	150	4,416	6.1	1.5	10.5	13.1	0.0420	1.02	AP	ARBRFM/ARLTSP
3	W	7	715	2	P	3	G	150	4,416	6.1	1.5	7.6	8.9	0.0310	1.47	P	GESMLTSP
3	W	8	715	1	I	34	I	95	6,408	8.9	4.9					P	
3	W	9	715	1	I	1	L	95	720	1.0	4.9	3.4	4.5	0.0830	0.78	P	ISLC/CL
3	W	10	715	1	L	1	I	95	720	1.0	4					P	"A" data on gas part
3	W	11	715	1	I	1	L	95	720	1.0	4.9	4.8	5.5	0.1180	1.73	P	GESMLTSP
3	W	12	715	2	GG	1234	G	150	10,078	14.0	0.42	23.3	29	0.0410	1.03	P	CL/GERU
3	W	14	715	2	P	1	G	150	836	1.2	4.6					AxP	
3	W	16	715	1	L	1	I	95	720	1.0	4					P	"A" data on gas part
3	W	18	715	1	L	1	I	95	720	1.0	4					AP	"A" data on liquid part
3	W	19	715	2	P	1	G	150	836	1.2	4.6	7	8.9	0.1480	0.93	P	CL/ISVSPT

TABLE A-5

CDA 715 DATA BASE (Cont.)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flow (XE-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/O	Analy	Visual Examination
3	W	20	715	1	L	1234	G	95	9,408	13.1	4	54.8	76.4	0.1033	0.64	P	GELCMP/ISXLLC
3	W	21	715	1	I	34	I	95	6,408	8.9	4.9					P	
3	W	22	715	1	I	1234	L	95	9,408	13.1	4.9	5.3	9.6	0.0099	0.31	P	GESMLC/ISXLLC/ARRU
3	W	23	715	2	NHH	12345	G	150	11,593	16.1	0.98	11.5	14.6	0.0175	0.93	P	GECUDKFM
3	W	24	715	2	NHH	12345	G	150	11,593	16.1	0.98	10.6	13.7	0.0161	0.86	P	GECUDKFM
3	W	25	715	2	GG	1234	G	150	10,078	14.0	0.42	18	22.6	0.0320	0.99	P	CL/GERU
3	W	26	715	2	P	2	G	150	2,334	3.2	4.6	8.4	11.2	0.0630	0.76	P	GEVSLTSP/FWPT/ARRU
3	W	27	715	2	P	2	G	150	2,334	3.2	4.6	10.4	13.6	0.0780	0.82	P	GEVSLTSP/FWPT/ARRU
3	W	28	715	2	P	2	G	150	2,334	3.2	4.6	11.7	14.3	0.0876	1.13	P	GEVSLTSP/FWPT/ARRU
3	W	29	715	1	L	23	G	95	5,016	7.0	4	64.3	87.6	0.2240	0.69	AP	GEMP/GEMDPTDD/FWLC
3	W	30	715	1	I	23	L	95	5,016	7.0	4.9	25.7	35	0.0900	0.70	AP	ARRU/ARLC/ARLTSP
3	W	31	715	1	I	34	I	95	6,408	8.9	4.9					P	
3	W	32	715	1	I	2	L	95	2,280	3.2	4.9	17.7	21.6	0.1400	1.14	AP	GEDKFM/FWLC
3	W	33	715	1	L	2	G	95	2,280	3.2	4	70.6	87	0.5400	1.08	AP	GEMP/GEPTDD/FWLC
3	W	34	715	1	L	2	I	95	2,280	3.2	4					P	"A" data on gas part
3	W	35	715	1	L	2	I	95	2,280	3.2	4					P	"A" data on gas part
3	W	36	715	2	P	3	G	150	4,416	6.1	1.5	9	11.1	0.0360	1.08	P	GELTSP/FWSMPT
3	W	37	715	1	L	2	I	95	2,280	3.2	4					P	DATA ON GAS PART
3	W	38	715	3	S	4	G	95	1,517	2.1	1.6	5.9	7.6	0.0684	0.87	P	GEXLLCLTSPDKFM
3	W	39	715	4	Y	1	I	95	2,499	3.5	0.04					P	
3	W	41	715	4	Y	1	L	95	2,499	3.5	0.04	8.3	10.7	0.0586	0.87	P	GEDKFM/GEVSLTSPPT
3	W	42	715	4	Y	1	I	95	2,499	3.5	0.04					P	
3	W	43	715	4	W	1	G	95	2,499	3.5	0.041	2.3	3	0.0162	0.83	P	FWXLLC/GEFLLC
3	W	44	715	3	S	4	G	95	1,517	2.1	1.6	6.9	9	0.0803	0.83	P	FWXLLC/GEDKFM/GEMPLTSP
3	W	45	715	2	E	5	G	150	1,515	2.1	0.31	7.7	9.4	0.0897	1.14	P	CLNF
3	W	46	715	3	S	3	G	95	860	1.2	1.6	3	3.8	0.0620	0.94	P	ARLC/GEXLLTSPLTLC
3	W	47	715	1	I	34	L	95	6,408	8.9	4.9	26.7	33.2	0.0735	1.03	P	FWXLLC/GEFMRSGEMDSP
3	W	48	715	2	E	5	G	150	1,515	2.1	0.31	4.4	5.4	0.0511	1.11	P	CL/GEDKCO
3	W	49	715	4	Y	1	L	95	2,499	3.5	0.04	8	10.4	0.0562	0.84	P	GEDKFM/GEVSLTSPPT
3	W	50	715	3	S	3	G	95	860	1.2	1.6	4	5.2	0.0820	0.84	P	GESPMPLCPT
3	W	51	715	3	S	3	G	95	860	1.2	1.6	3.2	4.2	0.0660	0.81	P	GESPLCPT
3	W	52	715	3	S	4	G	95	1,517	2.1	1.6	6.8	8.8	0.0790	0.86	P	GELTSP/ISXLLC
3	W	53	715	3	SS	12	G	95	2,927	4.1	2	9.4	12.8	0.0570	0.70	P	GEXLSPLCCUPT
3	W	54	715	2	P	45	G	150	4,007	5.6	1.5	4.4	5.8	0.0193	0.79	P	GEDKFM/GEVSLTSP
3	W	55	715	4	W	1	G	95	2,499	3.5	0.041	3.8	4.7	0.0267	1.06	P	GEFLLGLC
3	W	56	715	4	Y	1	L	95	2,499	3.5	0.04	7.8	10.2	0.0550	0.82	P	GEVSPTLCDD/GEDKFM
3	W	57	715	1	L	34	G	95	6,408	8.9	4	75.5	105.3	0.2078	0.64	P	GERUMPLC
3	W	58	715	1	L	4	G	95	3,672	5.1	4	69.1	97.1	0.3322	0.62	P	GERUMPLC
3	W	59	715	2	E	5	G	150	1,515	2.1	0.31	7.8	9.5	0.0907	1.16	P	CLNF
3	W	60	715	4	W	1	G	95	2,499	3.5	0.041	4.4	5.7	0.0310	0.85	P	GELCPT
3	W	61	715	2	P	45	G	150	4,007	5.6	1.5	4	5.3	0.0176	0.77	P	GEDKFM
3	W	62	715	3	SS	12	G	95	2,927	4.1	2	9.7	13.3	0.0580	0.68	P	GEXLCULCSP
3	W	63	715	4	Y	1	I	95	2,499	3.5	0.04					P	
3	W	65	715	3	SS	12	G	95	2,927	4.1	2	9.9	13.2	0.0590	0.76	P	GEXLLTSPLCCU
3	W	66	715	1	I	4	L	95	3,672	5.1	4.9	20.7	22.9	0.0991	2.37	P	GEMPLC/ISXLLC
3	W	67	715	2	P	45	G	150	4,007	5.6	1.5	5.1	6.7	0.0225	0.80	P	GEDKFM

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A P P E N D I X B

SUBGROUPS OF SPECIMENS SORTED BY ALLOY AND SPECIFIC CORROSION FEATURES/CONDITIONS

Note: Explanation of columns and codes are in Tables A1 and A2 of Appendix A.

TABLE B-1A

SPECIMENS SHOWING EVIDENCE OF PITS
(Crevice and Interface Specimens Not Included)

Alloy	Type	Spec No.	CDH	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (E-5)	Wt Loss (mg)	Film Wt (mg)	Corr Rt (mil/yr)	M-G	Analy	Visual Examination
1	B	11	101	1	F	1	G	95	720	1.0	1.3					AD	ARSMPT/FWPT
1	W	41	101	3	S	3	G	95	860	1.2	1.6	2.7	3.1	0.055	1.79		GEMDDKSPPT?
1	W	65	101	3	S	3	G	95	860	1.2	1.6	3.5	4	0.072	1.76		GEDKSPLCPT
1	W	49	101	3	S	3	G	95	860	1.2	1.6	2.7	3	0.055	2.27		ARDKSPLCPT?/CL/FWSP
1	W	64	101	3	S	4	G	95	1,517	2.1	1.6	3.3	3.5	0.0383	4.15		CL/ARVSSPPT?
1	W	52	101	3	S	4	G	95	1,517	2.1	1.6	2.6	2.9	0.03	2.18		GESMPT?DKSP
1	B	43	101	3	T	2	G	95	2,183	3.0	4.6						GESMDKSPPT?
1	B	20	101	1	F	2	G	95	2,280	3.2	1.3					D	ISPT/CL
1	B	26	101	4	V	1	G	95	2,499	3.5	0.019						FWMDDKLTSP/PT?
1	W	44	101	3	SS	12	G	95	2,927	4.1	2	8.7	10.1	0.052	1.56		GEDKRSSPLCPT
1	W	46	101	3	SS	12	G	95	2,927	4.1	2	6.8	7.9	0.041	1.56		GEDKRSSPLCPT?
1	W	42	101	3	SS	12	G	95	2,927	4.1	2	8.3	9.6	0.05	1.61		GEDKSPLCPT?
1	B	40	101	1	F	4	G	95	3,672	5.1	1.3						GEMPDKLTSP/PT?
1	B	19	101	1	F	23	G	95	5,016	7.0	1.3						GEMDDKSPPT?
1	B	38	101	3	T	1234	G	95	5,304	7.4	4.6						PP Spacer;GELCPT/GEDKSP
1	B	29	101	3	T	1234	G	95	5,304	7.4	4.6						PP Spacer;GESMPT/ARDKSP
1	W	62	101	1	L	34	G	95	6,408	8.9	4	218.5	257.2	0.6002	1.42		ARDKRS/GEXLLCPT?
1	B	7	101	1	F	1234	G	95	9,408	13.1	1.3						GEXLBKSP/PT
1	B	5	101	1	A	1	L	95	720	1.0	2.6						GESMPT
1	B	2	101	1	A	1	L	95	720	1.0	2.6					D	CL/FWDKSPPT?
1	B	32	101	4	X	1	L	95	2,499	3.5	0.027						ARSMSP/PT?
1	W	34	101	1	I	23	L	95	5,016	7.0	4.9	23	32.3	0.08	0.62		GERU/ARVSPT
1	B	39	101	1	A	34	L	95	6,408	8.9	2.6						GEMPLTSP/ARDKSPPT?
1	B	10	101	1	A	1234	L	95	9,408	13.1	2.6						GESMLTDKSP/ARVSPT
1	B	16	101	2	J	2	G	150	2,334	3.2	3.1					D	ISPT
1	W	27	101	2	P	2	G	150	2,334	3.2	4.6	4.6	5.2	0.035	1.93		CL/FWSP/ISPT
1	W	2	101	2	GG	1234	G	150	10,078	14.0	0.42	21.6	24.9	0.038	1.65		GEPTLC/ARDKSP
1	W	24	101	2	GG	1234	G	150	10,078	14.0	0.42	10.2	11.7	0.018	1.71		GEPTLC/ARDKSP
1	B	14	101	2	BB	1234	G	150	10,078	14.0	2.1						FWDKSPPT/FWLC
1	W	23	101	2	GG	1234	G	150	10,078	14.0	0.42	9.6	10.9	0.017	1.86		ARPTLC/ARDKSP
1	B	3	101	2	BB	12345	G	150	11,593	16.1	2						ARBKSPPT
1	B	4	101	2	BB	12345	G	150	11,593	16.1	2						ARDKSPPT

TABLE B-1B

SPECIMENS SHOWING LOCAL CORROSION
(Crevice and Interface Specimens Not Included)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (XE-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/D	Analy	Visual Examination
1	W	17	101	1	L	1	G	95	720	1.0	4	10.5	12.1	0.26	1.65		ARDkRSLC
1	W	65	101	3	S	3	G	95	860	1.2	1.6	3.5	4	0.072	1.76		GEDKSPLCPT
1	W	49	101	3	S	3	G	95	860	1.2	1.6	2.7	3	0.055	2.27		ARDKSPLCPT?/CL/FWSP
1	W	44	101	3	SS	12	G	95	2,927	4.1	2	8.7	10.1	0.052	1.56		GEDkRSSPLCPT
1	W	46	101	3	SS	12	G	95	2,927	4.1	2	6.8	7.9	0.041	1.56		GEDkRSSPLCPT?
1	W	42	101	3	SS	12	G	95	2,927	4.1	2	8.3	9.6	0.05	1.61		GEDKSPLCPT?
1	B	38	101	3	T	1234	G	95	5,304	7.4	4.6						PP Spacer;GELCPT/GEDKSP
1	W	62	101	1	L	34	G	95	6,408	8.9	4	218.5	257.2	0.6002	1.42		ARDkRS/GEXLLCPT?
1	W	12	101	1	I	1	L	95	720	1.0	4.9	6.6	7.5	0.162	1.80		CL/FWLC
1	W	54	101	1	I	34	L	95	6,408	8.9	4.9	15	20.8	0.0411	0.65		GEXLDKSPLC
1	W	2	101	2	GG	1234	G	150	10,078	14.0	0.42	21.6	24.9	0.038	1.65		GEPTLC/ARDKSP
1	W	24	101	2	GG	1234	G	150	10,078	14.0	0.42	10.2	11.7	0.018	1.71		GEPTLC/ARDKSP
1	B	14	101	2	BB	1234	G	150	10,078	14.0	2.1						FWDKSPPT/FWLC
1	W	23	101	2	GG	1234	G	150	10,078	14.0	0.42	9.6	10.9	0.017	1.86		ARPTLC/ARDKSP

TABLE B-1C

SPECIMENS HAVING A CLEAR SURFACE OR NO CORROSION FEATURES
(Crevice and Interface Specimens Not Included)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (XE-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/O	Anal.	Visual Examination
1	B	13	101	1	F	1	G	95	720	1.0	1.3						CL/FWSP
1	W	49	101	3	S	3	G	95	860	1.2	1.6	2.7	3	0.055	2.27		ARD*SPLCPT?/CL/FWSP
1	W	64	101	3	S	4	G	95	1,517	2.1	1.6	3.3	3.5	0.0383	4.15		CL/ARVSSPPT?
1	B	20	101	1	F	2	G	95	2,280	3.2	1.3					D	ISPT/CL
1	W	66	101	4	W	1	G	95	2,499	3.5	0.041	3	3.4	0.0211	1.89		CL
1	W	51	101	4	W	1	G	95	2,499	3.5	0.041	3.4	4	0.0239	1.43		CL
1	W	47	101	4	W	1	G	95	2,499	3.5	0.041	2.7	3.1	0.019	1.70		CL
1	W	25	101	1	I	1	L	95	720	1.0	4.9	4.4	5.1	0.108	1.58		RU/ISD*SP/CL
1	W	12	101	1	I	1	L	95	720	1.0	4.9	6.6	7.5	0.162	1.80		CL/FWLC
1	B	2	101	1	A	1	L	95	720	1.0	2.6					D	CL/FWD*SPPT?
1	B	22	101	1	A	2	L	95	2,280	3.2	2.6					DP	CL/ARB*SP
1	W	37	101	1	I	2	L	95	2,280	3.2	4.9	10.9	13.9	0.084	0.91		CL
1	W	63	101	4	Y	1	L	95	2,499	3.5	0.04	8.7	11.3	0.0613	0.84		CL
1	W	55	101	4	Y	1	L	95	2,499	3.5	0.04	9	11.6	0.0636	0.87		CL/GELISP
1	W	58	101	4	Y	1	L	95	2,499	3.5	0.04	9	11.6	0.0636	0.87		CL
1	B	6	101	2	J	1	G	150	836	1.2	3.1					D	CL/FWD*SP
1	B	8	101	2	J	1	G	150	836	1.2	3.1						CL/FWROWD
1	B	9	101	2	J	1	G	150	836	1.2	3.1						CL
1	W	53	101	2	E	5	G	150	1,515	2.1	0.31	3.4	3.8	0.0394	2.14		CL
1	B	28	101	2	B	5	G	150	1,515	2.1	1.5						CLNF
1	W	68	101	2	E	5	G	150	1,515	2.1	0.31	2.8	3.1	0.0326	2.35		CL
1	W	56	101	2	E	5	G	150	1,515	2.1	0.31	3.2	3.5	0.0373	2.69		CL
1	W	27	101	2	P	2	G	150	2,334	3.2	4.6	4.6	5.2	0.035	1.93		CL/FWSP/ISPT
1	W	28	101	2	P	2	G	150	2,334	3.2	4.6	4.3	4.8	0.032	2.17		CL
1	B	17	101	2	J	2	G	150	2,334	3.2	3.1						CL
1	B	21	101	2	J	2	G	150	2,334	3.2	3.1						CL
1	W	60	101	2	P	45	G	150	4,007	5.6	1.5	11	12.3	0.0483	2.13		CL
1	B	37	101	2	J	45	G	150	4,007	5.6	1.2						CLNF
1	W	45	101	2	P	45	G	150	4,007	5.6	1.5	10.2	11.6	0.0449	1.83		CL
1	W	59	101	2	P	45	G	150	4,007	5.6	1.5	9.6	11	0.0422	1.73		CL
1	B	35	101	2	J	45	G	150	4,007	5.6	1.2						CLNF
1	W	31	101	2	P	3	G	150	4,416	6.1	1.5	7.8	8.7	0.031	2.18		CLNF
1	W	4	101	2	P	3	G	150	4,416	6.1	1.5	7.8	8.8	0.031	1.96		CLNF
1	B	15	101	2	J	3	G	150	4,416	6.1	1.2						CL/ISMDSP
1	W	16	101	2	P	3	G	150	4,416	6.1	1.5	7.8	8.8	0.031	1.96		CLNF
1	B	12	101	2	J	345	G	150	8,423	11.7	1.2						CLNF
1	W	14	101	2	NHH	12345	G	150	11,593	16.1	0.98	15.9	18.1	0.0243	1.82		CL
1	W	11	101	2	NHH	12345	G	150	11,593	16.1	0.98	14.3	16.2	0.0218	1.90		CL
1	W	22	101	2	NHH	12345	G	150	11,593	16.1	0.98	15.8	18	0.0241	1.81		CL

TABLE B-1D

SPECIMENS SHOWING FILIFORM-LIKE LOCAL CORROSION
(There were no pure copper specimens showing these features.)

TABLE B-1E

LOW FLUX SPECIMENS

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (hr)	Time (mon)	Flux (1E-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/O	Analy	Visual Examination
1	B	30	101	3	#			95		0.0							# Non-data;PP Spacer;GEDKSPPT
1	C	41	101	4	E	1	G	95	2,499	3.5	0.033						NFLC
1	W	66	101	4	W	1	G	95	2,499	3.5	0.041	3	3.4	0.0211	1.89		CL
1	W	51	101	4	W	1	G	95	2,499	3.5	0.041	3.4	4	0.0239	1.43		CL
1	W	47	101	4	W	1	G	95	2,499	3.5	0.041	2.7	3.1	0.019	1.70		CL
1	B	42	101	4	V	1	G	95	2,499	3.5	0.019						ARXLDKSP
1	B	26	101	4	V	1	G	95	2,499	3.5	0.019						FWMDDKLTSP/PT?
1	C	32	101	4	E	1	G	95	2,499	3.5	0.033						NFCL
1	B	27	101	4	V	1	G	95	2,499	3.5	0.019						FWLGDKSP
1	W	67	101	4	Y	1	I	95	2,499	3.5	0.04						
1	W	61	101	4	Y	1	I	95	2,499	3.5	0.04						
1	W	40	101	4	Y	1	I	95	2,499	3.5	0.04						
1	W	63	101	4	Y	1	L	95	2,499	3.5	0.04	8.7	11.3	0.0613	0.84		CL
1	B	24	101	4	X	1	L	95	2,499	3.5	0.027						GELTMP/FWMDDKSP
1	W	55	101	4	Y	1	L	95	2,499	3.5	0.04	9	11.6	0.0636	0.87		CL/GELTSP
1	B	32	101	4	X	1	L	95	2,499	3.5	0.027						ARSMSP/PT?
1	C	43	101	4	M	1	L	95	2,499	3.5	0.037						ARLC1M
1	B	18	101	4	X	1	L	95	2,499	3.5	0.027						FWLGDKSP
1	C	40	101	4	M	1	L	95	2,499	3.5	0.037						ARLC1M
1	W	58	101	4	Y	1	L	95	2,499	3.5	0.04	9	11.6	0.0636	0.87		CL

TABLE B-2A

SPECIMENS SHOWING EVIDENCE OF PITS
(Crevice and Interface Specimens Not Included)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (XE-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/D	Analy	Visual Examination
2	B	7	613	1	F	1	G	95	720	1.0	1.3					AD	FWFL/FWXLLC/ARSMPT
2	B	12	613	1	F	1	G	95	720	1.0	1.3						ARCUCO/FWPT
2	W	20	613	1	L	1	G	95	720	1.0	4	7.9	9.6	0.217	1.17	A	ARCUCO/ISPT
2	W	58	613	3	S	3	G	95	860	1.2	1.6	3.1	4.1	0.071	0.78		ARPTLCCUCO
2	W	39	613	3	S	4	G	95	1,517	2.1	1.6	3.2	4.2	0.042	0.81		GEDKSPPT/ARLGLC
2	W	41	613	3	S	4	G	95	1,517	2.1	1.6	2.8	3.5	0.0366	1.01		GEDKSPSMPT
2	B	19	613	1	F	2	G	95	2,280	3.2	1.3					D	GEFL/ARPT/ROPT
2	W	30	613	1	L	2	G	95	2,280	3.2	4	9.2	10.8	0.0803	1.45		FWLC/GESMPT
2	W	48	613	4	W	1	G	95	2,499	3.5	0.041	6.4	8.1	0.0506	0.95		GEFM/GESMSPPT/FWLC
2	W	42	613	4	W	1	G	95	2,499	3.5	0.041	7.2	9	0.0569	1.01		ARLCPTSP
2	W	62	613	4	W	1	G	95	2,499	3.5	0.041	5.4	6.8	0.0428	0.97		GESMSPPT/FWLC/GEFM
2	W	67	613	3	SS	12	G	95	2,927	4.1	2	8.9	11.4	0.06	0.90		GEFLPTLC/ARCUCO
2	W	65	613	3	SS	12	G	95	2,927	4.1	2	8.5	11.1	0.057	0.82		GEFLPTLC
2	W	66	613	3	SS	12	G	95	2,927	4.1	2	9.8	12.4	0.066	0.95		GEFLPTLC/ARCUCO
2	W	64	613	1	L	4	G	95	3,672	5.1	4	20.6	26.2	0.1107	0.93		ISLC/GESMPT
2	W	31	613	1	L	23	G	95	5,016	7.0	4	17.9	23.9	0.071	0.75	A	GECULC/FWPT
2	W	57	613	1	L	34	G	95	6,408	8.9	4	42.5	65.3	0.1311	0.47		ARLC/GEVSPTSP
2	B	38	613	1	F	34	G	95	6,408	8.9	1.3						GELGPT
2	B	8	613	1	F	1234	G	95	9,408	13.1	1.3	3.4	4.2	0.015	1.07		GEFLPT/ROPTWD
2	W	21	613	1	I	1	L	95	720	1.0	4.9	3.2	4.5	0.088	0.62		GEVSSPPT
2	B	6	613	1	A	1	L	95	720	1.0	2.6						GEXLLTSPVSDKPT
2	W	16	613	1	I	1	L	95	720	1.0	4.9	2.7	3.8	0.074	0.62		GEVSSPPT/ARDKFM
2	B	14	613	1	A	1	L	95	720	1.0	2.6					AD	GELTMDSPSMPT/ROPTWD
2	W	36	613	1	I	2	L	95	2,280	3.2	4.9	8.4	9.9	0.073	1.41		GESMLCPT/ARCUCO
2	B	23	613	1	A	2	L	95	2,280	3.2	2.6					D	ARCUCO/GESMPT/ROPT
2	B	33	613	4	X	1	L	95	2,499	3.5	0.027						GESMSPPT?
2	W	44	613	4	Y	1	L	95	2,499	3.5	0.04	19.9	25.9	0.1572	0.84		GESMPTLCSP?/ARCUCO
2	W	60	613	4	Y	1	L	95	2,499	3.5	0.04	20.5	27.1	0.1621	0.78		ARCUCO/GESM/OPPTSP?
2	W	45	613	4	Y	1	L	95	2,499	3.5	0.04	21	27.6	0.1659	0.80		GESMPTLC/ARCUCO
2	B	34	613	4	X	1	L	95	2,499	3.5	0.027						GESMSPPT/FWLGPT
2	B	29	613	1	A	4	L	95	3,672	5.1	2.6						ISPT/CUCO/CL
2	B	22	613	1	A	23	L	95	5,016	7.0	2.6						ARCUCO/GEVSSPPT
2	W	32	613	1	I	23	L	95	5,016	7.0	4.9	11	17.9	0.044	0.40		FWCUCOLC/FWARVSPT?
2	W	47	613	1	I	34	L	95	6,408	8.9	4.9	19.9	27.3	0.0612	0.68		ISLC/ARVSPT
2	B	24	613	1	A	34	L	95	6,408	8.9	2.6						GESMPT/ISLC
2	B	36	613	1	A	34	L	95	6,408	8.9	2.6						GEVSPT/FWXLFL
2	B	15	613	1	A	1234	L	95	9,408	13.1	2.6						GEVSPT/ARCUCO
2	W	11	613	2	P	1	G	150	836	1.2	4.6	1.1	1.4	0.026	0.92		FWVSSPPT
2	W	22	613	2	P	1	G	150	836	1.2	4.6	1.7	2.1	0.04	1.07		FWVSSPPT
2	B	3	613	2	J	1	G	150	836	1.2	3.1					D	FWVSSPPT/ROCUCO
2	B	32	613	2	B	5	G	150	1,515	2.1	1.5						ARSMPT/GEDKFM
2	W	54	613	2	E	5	G	150	1,515	2.1	0.31	1.3	1.4	0.017	3.27		CL/FWSMSPPT
2	B	17	613	2	J	2	G	150	2,334	3.2	3.1					D	ROPT/GEDKFM/ISSP
2	W	49	613	2	P	45	G	150	4,007	5.6	1.5	3	3.7	0.0148	1.08		CL/FWVSDKSPPT

TABLE B-2A (Cont'd)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (hr)	Time (mon)	Flux (xE-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil yr)	M/O	Anal.	Visual Examination
																	CL/ROPTWD/ARDKFM/FWPT
2	B	43	613	2	J	45	G	150	4,007	5.6	1.2						CL/ISSMSPPT
2	W	51	613	2	P	45	G	150	4,007	5.6	1.5	3.1	3.9	0.0153	0.98		GEVSPT/GEFM
2	W	29	613	2	P	3	G	150	4,416	6.1	1.5	3.1	3.8	0.014	1.12		GEVSPT/ARDKFM
2	W	8	613	2	P	3	G	150	4,416	6.1	1.5	3.4	4.2	0.015	1.07		ROPT/CLNF
2	B	4	613	2	J	3	G	150	4,416	6.1	1.2						GEDKFM/GEVSPTSP
2	W	6	613	2	NHH	12345	G	150	11,593	16.1	0.98	5.2	6.6	0.0089	0.94		ARDKFM/GESMPTSP
2	W	18	613	2	NHH	12345	G	150	11,593	16.1	0.98	6.9	8.7	0.0118	0.97		ARDKFM/ARVSSPPT
2	B	5	613	2	BB	12345	G	150	11,593	16.1	2						GEVSPTDKSP/ARDKFM
2	W	2	613	2	NHH	12345	G	150	11,593	16.1	0.98	6.9	8.7	0.0118	0.97		

TABLE B-2B

SPECIMENS SHOWING LOCAL CORROSION
(Crevice and Interface Specimens Not Included)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (XE-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	h/D	Analy	Visual Examination
2	B	7	613	1	F	1	G	95	720	1.0	1.3					AD	FWFL/FWXLLC/ARSMPT
2	W	58	613	3	S	3	G	95	860	1.2	1.6	3.1	4.1	0.071	0.78		ARPTLCCUCO
2	W	61	613	3	S	4	G	95	1,517	2.1	1.6	3.7	4.7	0.0482	0.93		GEFM/GESMLC
2	W	39	613	3	S	4	G	95	1,517	2.1	1.6	3.2	4.2	0.042	0.81		GEDKSPPT/ARLGLC
2	W	30	613	1	L	2	G	95	2,280	3.2	4	9.2	10.8	0.0803	1.45		FWLC/GESMPT
2	W	48	613	4	W	1	G	95	2,499	3.5	0.041	6.4	8.1	0.0506	0.95		GEFM/GESMSPPT/FWLC
2	W	42	613	4	W	1	G	95	2,499	3.5	0.041	7.2	9	0.0569	1.01		ARLCPTSP
2	W	62	613	4	W	1	G	95	2,499	3.5	0.041	5.4	6.8	0.0428	0.97		GESMSPPT/FWLC/GEFM
2	W	67	613	3	SS	12	G	95	2,927	4.1	2	8.9	11.4	0.06	0.90		GEFLPTLC/ARCUCO
2	W	65	613	3	SS	12	G	95	2,927	4.1	2	8.5	11.1	0.057	0.82		GEFLPTLC
2	W	66	613	3	SS	12	G	95	2,927	4.1	2	9.8	12.4	0.066	0.95		GEFLPTLC/ARCUCO
2	W	64	613	1	L	4	G	95	3,672	5.1	4	20.6	26.2	0.1107	0.93		ISLC/GESMPT
2	W	31	613	1	L	23	G	95	5,016	7.0	4	17.9	23.9	0.071	0.75	A	GECULC/FWPT
2	B	41	613	3	T	1234	G	95	5,304	7.4	4.6						PP Spacer;GEXLPLLC
2	B	40	613	3	T	1234	G	95	5,304	7.4	4.6						PP Spacer;GEXLPLLC
2	W	57	613	1	L	34	G	95	6,408	8.9	4	42.5	65.3	0.1311	0.47		ARLC/GEVSPTSP
2	W	13	613	1	L	1234	G	95	9,408	13.1	4	44.9	54.5	0.0951	1.18	A	GERU/FWXLLC
2	W	36	613	1	I	2	L	95	2,280	3.2	4.9	8.4	9.9	0.073	1.41		GESMLCPT/ARCUCO
2	W	44	613	4	Y	1	L	95	2,499	3.5	0.04	19.9	25.9	0.1572	0.84		GESMPTLCSP?/ARCUCO
2	W	45	613	4	Y	1	L	95	2,499	3.5	0.04	21	27.6	0.1659	0.80		GESMPTLC/ARCUCO
2	W	32	613	1	I	23	L	95	5,016	7.0	4.9	11	17.9	0.044	0.40		FWCUCOLC/FWARVSPT?
2	W	47	613	1	I	34	L	95	6,408	8.9	4.9	19.9	27.3	0.0612	0.68		ISLC/ARVSPT
2	B	24	613	1	A	34	L	95	6,408	8.9	2.6						GESMPT/ISLC
2	W	19	613	1	I	1234	L	95	9,408	13.1	4.9	4.7	13	0.0099	0.14		ISLC/GELTFM/GESMLTSP
2	W	24	613	2	GG	1234	G	150	10,078	14.0	0.42	3.6	4.8	0.0071	0.76		GEDKFM/FWLCLTSP
2	W	4	613	2	GG	1234	G	150	10,078	14.0	0.42	5.3	7	0.01	0.78		GEDKFM/ARCULC
2	W	5	613	2	GG	1234	G	150	10,078	14.0	0.42	3.8	5.1	0.0075	0.74		GEDKFM/ARCULC

TABLE B-2C

SPECIMENS HAVING A CLEAR SURFACE OR NO CORROSION FEATURES
(Crevice and Interface Specimens Not Included)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (XE-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/O	Analy	Visual Examination
2	B	29	613	1	A	4	L	95	3,672	5.1	2.6						ISPT/CUCO/CL
2	W	53	613	2	E	5	G	150	1,515	2.1	0.31	1.2	1.4	0.0157	1.51		CL/FMSF
2	W	54	613	2	E	5	G	150	1,515	2.1	0.31	1.3	1.4	0.017	3.27		CL/FWSMSPPT
2	B	16	613	2	J	2	G	150	2,334	3.2	3.1						GEDKFM/CL
2	B	18	613	2	J	2	G	150	2,334	3.2	3.1						GEDKFM/CL
2	W	55	613	2	P	45	G	150	4,007	5.6	1.5	3.1	3.9	0.0153	0.98		CL/FWLTSP
2	W	49	613	2	P	45	G	150	4,007	5.6	1.5	3	3.7	0.0148	1.08		CL/FWVSDKSPPT
2	B	43	613	2	J	45	G	150	4,007	5.6	1.2						CL/ROPTWD/ARDKFM/FWPT
2	W	51	613	2	P	45	G	150	4,007	5.6	1.5	3.1	3.9	0.0153	0.98		CL/ISSMSPPT
2	W	7	613	2	P	3	G	150	4,416	6.1	1.5	2.6	3.3	0.012	0.94		GEDKFM/CL
2	B	4	613	2	J	3	G	150	4,416	6.1	1.2						ROPT/CLNF
2	B	10	613	2	J	345	G	150	8,423	11.7	1.2						LTCUCO/CL
2	W	24	613	2	GG	1234	G	150	10,078	14.0	0.42	3.6	4.8	0.0071	0.76		GEDKFM/FWLCLTSP

TABLE B-2D

SPECIMENS SHOWING FILIFORM-LIKE LOCAL CORROSION
(Crevice and Interface Specimens Not Included)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (XE-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/D	Analy	Visual Examination
2	B	7	613	1	F	1	G	95	720	1.0	1.3						
2	B	19	613	1	F	2	G	95	2,280	3.2	1.3					AD	FWFL/FWXLLC/ARSMPT
2	W	67	613	3	SS	12	G	95	2,927	4.1	2	8.9	11.4	0.06	0.90	D	GEFL/ARPT/ROPT
2	W	65	613	3	SS	12	G	95	2,927	4.1	2	8.5	11.1	0.057	0.82		GEFLPTLC/ARCUCO
2	W	66	613	3	SS	12	G	95	2,927	4.1	2	9.8	12.4	0.066	0.95		GEFLPTLC
2	B	37	613	1	F	4	G	95	3,672	5.1	1.3						GEFLPTLC/ARCUCO
2	B	20	613	1	F	23	G	95	5,016	7.0	1.3						ARCUCO/FWFL
2	B	41	613	3	I	1234	G	95	5,304	7.4	4.6						GEFL
2	B	40	613	3	I	1234	G	95	5,304	7.4	4.6						PP Spacer;GEXLFLLC
2	B	28	613	1	F	34	G	95	6,408	8.9	1.3						PP Spacer;GEXLFLLC
2	B	8	613	1	F	1234	G	95	9,408	13.1	1.3	3.4	4.2	0.015	1.07		GEFL/GELISP
2	B	36	613	1	A	34	L	95	6,408	8.9	2.6						GEFLPT/ROPTWB
																	GEVSPT/FWXLFL

TABLE B-2E

LOW FLUX SPECIMENS

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (hr)	Time (mon)	Flux (XE-5)	Wt Loss (mg)	Film wt (mg)	Cor Rt (mil/yr)	M/O	Analy	Visual Examination
2	B	42	613	3	#					0.0							PP Spacer;CL/ISLC/CUWD
2	B	39	613	3	#					0.0							# Non-data;PP Spacer;GEXLFLLC
2	B	35	613	4	V	1	G	95	2,499	3.5	0.019						ARDKFM/GELIDKSP
2	C	35	614	4	E	1	G	95	2,499	3.5	0.033						GELCFLPT
2	B	30	613	4	V	1	G	95	2,499	3.5	0.019						GEDKFM
2	W	48	613	4	W	1	G	95	2,499	3.5	0.041	6.4	8.1	0.0506	0.95		GEFM/GESMSPPT/FWLC
2	L	36	614	4	E	1	G	95	2,499	3.5	0.033						GELCPT
2	B	26	613	4	V	1	G	95	2,499	3.5	0.019						GEDKFM/ARVSSP
2	W	42	613	4	W	1	G	95	2,499	3.5	0.041	7.2	9	0.0569	1.01		ARLCPTSP
2	W	62	613	4	W	1	G	95	2,499	3.5	0.041	5.4	6.8	0.0428	0.97		GESMSPPT/FWLL/GEFM
2	W	38	613	4	Y	1	I	95	2,499	3.5	0.04						
2	W	63	613	4	Y	1	I	95	2,499	3.5	0.04						
2	W	46	613	4	Y	1	I	95	2,499	3.5	0.04						
2	B	33	613	4	X	1	L	95	2,499	3.5	0.027						GESMSPPT?
2	C	25	614	4	M	1	L	95	2,499	3.5	0.037						ARLCIM/CUFM
2	C	27	614	4	M	1	L	95	2,499	3.5	0.037						ARPILCIM/CUFM
2	B	27	613	4	X	1	L	95	2,499	3.5	0.027						CUCOSPWD/ARCUCO/GEVSSP
2	W	44	613	4	Y	1	L	95	2,499	3.5	0.04	19.9	25.9	0.1572	0.84		GESMPILCSP?/ARCUCO
2	W	60	613	4	Y	1	L	95	2,499	3.5	0.04	20.5	27.1	0.1621	0.78		ARCUCO/GESM/DPPTSP?
2	W	45	613	4	Y	1	L	95	2,499	3.5	0.04	21	27.6	0.1659	0.80		GESMPILC/ARCUCO
2	B	34	613	4	X	1	L	95	2,499	3.5	0.027						GESMSPPT/FWLGPT

TABLE B-3A

SPECIMENS SHOWING EVIDENCE OF PITS
(Crevice and Interface Specimens Not Included)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (XE-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/D	Analy	Visual Examination
3	B	1	715	1	F	1234	G	95	9,408	13.1	1.3						GESMPT/ISLC
3	B	2	715	2	BB	12345	G	150	11,593	16.1	2						GESMDKSPDD/PT?
3	B	3	715	1	F	1	G	95	720	1.0	1.3						GESMPT
3	B	5	715	2	BB	1234	G	150	10,078	14.0	2.1						ARSMPT/CL
3	B	10	715	1	A	1	L	95	720	1.0	2.6						ARVSPT/DKFM
3	B	14	715	1	F	1	G	95	720	1.0	1.3					AD	GESMPT
3	B	21	715	1	F	2	G	95	2,280	3.2	1.3					D	ISLGLC/ARMDPT
3	B	23	715	1	F	23	G	95	5,016	7.0	1.3						ARPT/ARRULTCO
3	B	25	715	4	V	1	G	95	2,499	3.5	0.019						CL/ISPT
3	B	26	715	2	J	45	G	150	4,007	5.6	1.2						GEDKFM/FWSMPT
3	B	37	715	3	#					0.0							# Non-data;PP Spacer;GELCPT/ARCULO/RU
3	B	39	715	3	T	1234	G	95	5,304	7.4	4.6						PP Spacer;GELCPT/ARCUCO/RU
3	W	1	715	1	L	1	G	95	720	1.0	4	19.2	26.7	0.47	0.64		GELC/RUAR SMPT/ARRU
3	W	3	715	2	P	1	G	150	836	1.2	4.6	10	12.1	0.211	1.20		CL/ISVSPT/RU
3	W	19	715	2	P	1	G	150	836	1.2	4.6	7	8.9	0.148	0.93		CL/ISVSPT
3	W	26	715	2	P	2	G	150	2,334	3.2	4.6	8.4	11.2	0.063	0.76		GEVSLTSP/FWPT/ARRU
3	W	27	715	2	P	2	G	150	2,334	3.2	4.6	10.4	13.6	0.078	0.82		GEVSLTSP/FWPT/ARRU
3	W	28	715	2	P	2	G	150	2,334	3.2	4.6	11.7	14.3	0.0876	1.13		GEVSLTSP/FWPT/ARRU
3	W	29	715	1	L	23	G	95	5,016	7.0	4	64.3	87.6	0.224	0.69	A	GEMP/GEMDPTDD/FWLC
3	W	33	715	1	L	2	G	95	2,280	3.2	4	70.6	87	0.54	1.08	A	GEMP/GEPTDD/FWLC
3	W	36	715	2	P	3	G	150	4,416	6.1	1.5	9	11.1	0.036	1.08		GELTSP/FWSMPT
3	W	41	715	4	Y	1	L	95	2,499	3.5	0.04	8.3	10.7	0.0586	0.87		GEDKFM/GEVSLTSPPT
3	W	49	715	4	Y	1	L	95	2,499	3.5	0.04	8	10.4	0.0562	0.84		GEDKFM/GEVSLTSPPT
3	W	50	715	3	S	3	G	95	860	1.2	1.6	4	5.2	0.082	0.84		GESPMPLCPT
3	W	51	715	3	S	3	G	95	860	1.2	1.6	3.2	4.2	0.066	0.81		GESPLCPT
3	W	53	715	3	SS	12	G	95	2,927	4.1	2	9.4	12.8	0.057	0.70		GEXLSPLCCUPT
3	W	56	715	4	Y	1	L	95	2,499	3.5	0.04	7.8	10.2	0.055	0.82		GEVSPTLCDD/GEDKFM
3	W	60	715	4	W	1	G	95	2,499	3.5	0.041	4.4	5.7	0.031	0.85		GELCPT

TABLE B-3B

SPECIMENS SHOWING LOCAL CORROSION
(Crevice and Interface Specimens Not Included)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (XE-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/U	Analy	Visual Examination
3	B	1	715	1	F	1234	G	95	9,408	13.1	1.3						GESMPT/ISLC
3	B	8	715	1	A	1	L	95	720	1.0	2.6					D	ARLTSP/ISLC
3	B	15	715	1	A	1234	L	95	9,408	13.1	2.6						GEDKFM-FWLC/ARRU
3	B	18	715	2	J	2	G	150	2,334	3.2	3.1					D	GESMLTSP/ISLC
3	B	19	715	1	A	2	L	95	2,280	3.2	2.6					D	ISCULC/GEDKFM
3	B	20	715	1	A	23	L	95	5,016	7.0	2.6						GEARRU/FWLC
3	B	21	715	1	F	2	G	95	2,280	3.2	1.3					D	ISLGLC/ARMDPT
3	B	29	715	1	F	34	G	95	6,408	8.9	1.3						GELCRU
3	B	31	715	1	A	34	L	95	6,408	8.9	2.6						GEXLRUSP/FWLC/DKFM
3	B	32	715	3	T	12	G	95	2,927	4.1	4.6						GEXLLC
3	B	34	715	3	R	2	G	95	2,183	3.0	3.1						GEXLLC
3	B	37	715	3	#					0.0							# Non-data;PP Spacer;GELCPT/ARCUCO/RU
3	B	38	715	1	F	4	G	95	3,672	5.1	1.3						GEMDLC/ARRU
3	B	39	715	3	T	1234	G	95	5,304	7.4	4.6						PP Spacer;GELCPT/ARCUCO/RU
3	B	40	715	1	F	34	G	95	6,408	8.9	1.3						GELGLC/DKCO
3	B	42	715	1	A	34	L	95	6,408	8.9	2.6						GELGLC/DKCO
3	W	1	715	1	L	1	G	95	720	1.0	4	19.2	26.7	0.47	0.64		GELC/RUAR/SMPT/ARRU
3	W	9	715	1	I	1	L	95	720	1.0	4.9	3.4	4.5	0.083	0.78		ISLC/CL
3	W	20	715	1	L	1234	G	95	9,408	13.1	4	54.8	76.4	0.1033	0.64		GELCMP/ISXLLC
3	W	22	715	1	I	1234	L	95	9,408	13.1	4.9	5.3	9.6	0.0099	0.31		GESMLC/ISXLLC/ARRU
3	W	29	715	1	L	23	G	95	5,016	7.0	4	64.3	87.6	0.224	0.69	A	GEMP/GEMPTDD/FWLC
3	W	30	715	1	I	23	L	95	5,016	7.0	4.9	25.7	35	0.09	0.70	A	ARRU/ARLC/ARLTSP
3	W	32	715	1	I	2	L	95	2,280	3.2	4.9	17.7	21.6	0.14	1.14	A	GEDKFM/FWLC
3	W	33	715	1	L	2	G	95	2,280	3.2	4	70.6	87	0.54	1.08	A	GEMP/GEPTDD/FWLC
3	W	38	715	3	S	4	G	95	1,517	2.1	1.6	5.9	7.6	0.0684	0.87		GEXLLCLTSPDKFM
3	W	43	715	4	W	1	G	95	2,499	3.5	0.041	2.3	3	0.0162	0.83		FWXLLC/GEFLLC
3	W	44	715	3	S	4	G	95	1,517	2.1	1.6	6.9	9	0.0803	0.83		FWXLLC/GEDKFM/GEMPLTSP
3	W	46	715	3	S	3	G	95	860	1.2	1.6	3	3.8	0.062	0.94		ARLC/GEXLLTSPLTLC
3	W	47	715	1	I	34	L	95	6,408	8.9	4.9	26.7	33.2	0.0735	1.03		FWXLLC/GEFMRSGEMDSP
3	W	50	715	3	S	3	G	95	860	1.2	1.6	4	5.2	0.082	0.84		GESPMPLCPT
3	W	51	715	3	S	3	G	95	860	1.2	1.6	3.2	4.2	0.066	0.81		GESPLCPT
3	W	52	715	3	S	4	G	95	1,517	2.1	1.6	6.8	8.8	0.079	0.86		GELTSP/ISXLLC
3	W	53	715	3	SS	12	G	95	2,927	4.1	2	9.4	12.8	0.057	0.70		GEXLSPLCCUPT
3	W	55	715	4	W	1	G	95	2,499	3.5	0.041	3.8	4.7	0.0267	1.06		GEFLLGLC
3	W	56	715	4	Y	1	L	95	2,499	3.5	0.04	7.8	10.2	0.055	0.82		GEVSPTLCDD/GEDKFM
3	W	57	715	1	L	34	G	95	6,408	8.9	4	75.5	105.3	0.2078	0.64		GERUMPLC
3	W	58	715	1	L	4	G	95	3,672	5.1	4	69.1	97.1	0.3322	0.62		GERUMPLC
3	W	60	715	4	W	1	G	95	2,499	3.5	0.041	4.4	5.7	0.031	0.85		GELCPT
3	W	62	715	3	SS	12	G	95	2,927	4.1	2	9.7	13.3	0.058	0.68		GEXLCULCSP
3	W	65	715	3	SS	12	G	95	2,927	4.1	2	9.9	13.2	0.059	0.76		GEXLLTSPLCCU
3	W	66	715	1	I	4	L	95	3,672	5.1	4.9	20.7	22.9	0.0991	2.37		GEMPLC/ISXLLC

TABLE B-3C

SPECIMENS HAVING A CLEAR SURFACE OR NO CORROSION FEATURES
(Crevice and Interface Specimens Not Included)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (XE-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/O	Analy	Visual Examination
3	B	5	715	2	BB	1234	G	150	10,078	14.0	2.1						
3	B	7	715	2	J	1	G	150	836	1.2	3.1						ARSMPT/CL
3	B	9	715	2	J	1	G	150	836	1.2	3.1						CL/ARLTSP
3	B	13	715	2	J	1	G	150	836	1.2	3.1					D	CLNF
3	B	17	715	2	J	2	G	150	2,334	3.2	3.1						CLNF
3	B	22	715	4	X	1	L	95	2,499	3.5	0.027						CL/GEDKCUFM
3	B	25	715	4	V	1	G	95	2,499	3.5	0.019						ARDKFM/CL
3	B	28	715	2	J	45	G	150	4,007	5.6	1.2						CL/ISPT
3	B	30	715	4	V	1	G	95	2,499	3.5	0.019						GEDKFM/CL
3	B	33	715	2	B	5	G	150	1,515	2.1	1.5						CL/FWMDLTSP
3	B	41	715	4	V	1	G	95	2,499	3.5	0.019						GEDKFM/CL
3	B	43	715	4	X	1	L	95	2,499	3.5	0.027						CLNF
3	W	2	715	2	GG	1234	G	150	10,078	14.0	0.42	27.6	34.8	0.048	0.97		CLNF
3	W	3	715	2	P	1	G	150	836	1.2	4.6	10	12.1	0.211	1.20		CL/GERU
3	W	9	715	1	I	1	L	95	720	1.0	4.9	3.4	4.5	0.083	0.78		CL/ISVSPT/RU
3	W	12	715	2	GG	1234	G	150	10,078	14.0	0.42	23.3	29	0.041	1.03		ISLC/CL
3	W	19	715	2	P	1	G	150	836	1.2	4.6	7	8.9	0.148	0.93		CL/GERU
3	W	25	715	2	GG	1234	G	150	10,078	14.0	0.42	18	22.6	0.032	0.99		CL/ISVSPT
3	W	45	715	2	E	5	G	150	1,515	2.1	0.31	7.7	9.4	0.0897	1.14		CL/GERU
3	W	48	715	2	E	5	G	150	1,515	2.1	0.31	4.4	5.4	0.0511	1.11		CLNF
3	W	59	715	2	E	5	G	150	1,515	2.1	0.31	7.8	9.5	0.0907	1.16		CL/GEDKCO
																	CLNF

TABLE B-3D

SPECIMENS SHOWING FILIFORM-LIKE LOCAL CORROSION
(Crevice and Interface Specimens Not Included)

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (xE-5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/U	Analy	Visual Examination
3	W	43	715	4	W	1	G	95	2,499	3.5	0.041	2.3	3	0.0162	0.83		FWXLLC/GEFLLC
3	W	55	715	4	W	1	G	95	2,499	3.5	0.041	3.8	4.7	0.0267	1.06		GEFLLGLC

TABLE B-3E

LOW FLUX SPECIMENS

Alloy	Type	Ser No.	CDA	Vessel No.	Cage No.	Runs	Phase	Temp (C)	Time (h)	Time (mon)	Flux (xE 5)	Wt Loss (mg)	Film Wt (mg)	Cor Rt (mil/yr)	M/D	Analy	Visual Examination
3	B	22	715	4	X	1	L	95	2,499	3.5	0.027						ARDKFM/CL
3	B	25	715	4	V	1	G	95	2,499	3.5	0.019						CL/ISPT
3	B	30	715	4	V	1	G	95	2,499	3.5	0.019						CL/FWMDLTSP
3	B	35	715	4	X	1	L	95	2,499	3.5	0.027						ARLTCO
3	B	37	715	3	#					0.0							# Non-data;PP Spacer:GELCPT/ARCUCO/RU
3	B	41	715	4	V	1	G	95	2,499	3.5	0.019						CLNF
3	B	43	715	4	X	1	L	95	2,499	3.5	0.027						CLNF
3	C	28	715	4	E	1	G	95	2,499	3.5	0.033						ISLC/CLNF
3	C	33	715	4	M	1	L	95	2,499	3.5	0.037						GEVSPTIM
3	C	35	715	4	M	1	L	95	2,499	3.5	0.037						ARVSPTIM
3	C	37	715	4	E	1	G	95	2,499	3.5	0.033						FWXLLCIM/GEDKFM
3	W	39	715	4	Y	1	I	95	2,499	3.5	0.04						
3	W	41	715	4	Y	1	L	95	2,499	3.5	0.04	8.3	10.7	0.0586	0.87		GEDKFM/GEVSLTSPPT
3	W	42	715	4	Y	1	I	95	2,499	3.5	0.04						
3	W	43	715	4	W	1	G	95	2,499	3.5	0.041	2.3	3	0.0162	0.83		FWXLLC/GEFLLC
3	W	49	715	4	Y	1	L	95	2,499	3.5	0.04	8	10.4	0.0562	0.84		GEDKFM/GEVSLTSPPT
3	W	55	715	4	W	1	G	95	2,499	3.5	0.041	3.8	4.7	0.0267	1.06		GEFLLGLC
3	W	56	715	4	Y	1	L	95	2,499	3.5	0.04	7.8	10.2	0.055	0.82		GEVSPTLCDD/GEDKFM
3	W	60	715	4	W	1	G	95	2,499	3.5	0.041	4.4	5.7	0.031	0.85		GELCPT
3	W	63	715	4	Y	1	I	95	2,499	3.5	0.04						

END

DATE FILMED

11 / 08 / 90