FABRICATION AND LOADING OF LONG-TERM STRESS CORROSION CRACKING SURVEILLANCE SPECIMENS FOR THE DRESDEN 1 DECONTAMINATION PROGRAM

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ABSTRACT

Stress-corrosion cracking test specimens were prepared for Dow Nuclear Services for insertion in the Dresden 1 reactor during the chemical decontamination of the primary system, and for subsequent exposure under operating conditions when the station returns to service. The specimens consist of pressurized tubes fabricated from Type-304 and -304L stainless steel, Inconel 600, Incoloy 800, and Zircaloy 2. In addition, constant radius bent-beam specimens of 3/4 hard Type-410 stainless steel were also included. All specimens were stressed to, or slightly above, their respective 0.2% offset yield strengths at the temperatures of interest.

1. INTRODUCTION

A large laboratory corrosion test program has been conducted in association with the proposed chemical cleaning of the Dresden 1 nuclear power plant primary system, and the results of this work have been reported in several documents.¹⁻⁴ None of the results obtained in the previous studies have indicated that the use of the proprietary Dow Chemical Company solvent (NS-1) developed for this cleaning operation would represent significant problems from a stress-corrosion cracking (SCC) standpoint either during the cleaning operation itself, or in subsequent service after completion of the cleaning. Although a large number of tests were performed by the Dow Chemical Company (Dow) and the General Electric Nuclear Technology Department (GE), these tests were limited in duration and were virtually all conducted under laboratory conditions. It was considered prudent to perform tests of longer duration, utilizing specimens which were exposed to NS-1 during the actual reactor cleaning operation itself and then exposed to the actual operating environment of the Dresden 1 plant in subsequent service. The information related to the fabrication and stressing of the SCC specimens in the program will be presented in this report. Dow has also inserted general corrosion rate specimens in the long-term surveillance program; however, the details of these specimens will be the subject of a Dow report.

The materials of primary concern included in this program were Type-304 stainless steel (304 SS), Type-304L stainless steel (304L SS), Inconel 600, and hardened Type-410 stainless steel (410 SS). Zircaloy 2 was included to evaluate the effects of NS-1 on that alloy for future reference purposes, since the Dresden 1 fuel will be removed from the vessel during the chemical cleaning operation. Incoloy 800 was included to provide information if the Dow NS-1 solvent is used on plants with that alloy present as heat exchanger tubing.

The specimens consist of pressurized tubes and constant radius bent beams in three general groups to evaluate the effects of the cleaning cycle NS-1 exposure only (one group) and the evaluation of the effects of the cleaning cycle plus subsequent service exposure (two groups: one exposed to NS-1 and a control group). The initial exposure of all specimens to NS-1 will be made in the Dresden 1 reactor pressure vessel (RPV) during the actual plant cleaning operation. If the "B" secondary steam generator test loop is available after the cleaning operation, half of the long-term surveillance specimens will be transferred to that location to permit relatively easy access for more frequent examinations and evaluations. If the loop should not be operative, all specimens will be exposed to subsequent service environment in the RPV turning vane location.

The specimens and holders were fabricated by GE, and the specimens were stressed by GE. The loaded specimens and holders were then shipped to Dow Nuclear Services, Midland, Michigan, for the addition of general corrosion rate specimens by Dow. The final set of specimens was inserted in the Dresden 1 RPV turning vane to await the primary system cleaning operation scheduled for early 1980. This report documents the fabrication, treatment, stressing, and locations of the specimens prepared by GE. The future conduct of the long-term surveillance program is the responsibility of Dow Nuclear Services.

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2. SUMMARY

Pressurized tube specimens were fabricated from single heats of Type-304 and -304L SS, Inconel 600, Incoloy 800, and Zircaloy 2. In addition, pressurized tubes were initially fabricated from 410 SS; however, the heat-treated strength of this alloy was such that the required pressure could not be obtained from the available equipment, and the handling of the specimens at the required pressure would have represented a significant safety hazard. For these reasons, the 410 SS specimens were exposed as fixed deflection constant radius bent beams. All long-term service specimens were stressed to the 288°C (550°C) 0.2% offset yield strength (YS), and specimens for evaluation of the cleaning cycle only were stressed to the ambient temperature 0.2% offset YS. Single heats of material were used for each alloy. The 0.2% offset YS was chosen as the test stress level, rather than a higher more conservative value, to assure that differences between the stress corrosion cracking behavior of the control and test specimens would be observable if they existed. At higher stresses, a significant fraction of the control specimens might fail during the first operating cycle and this would greatly reduce the sensitivity of the test to detect effects of the NS-1 exposure.

The 304 SS and 304L SS and the Inconel 600 specimens were exposed in two different conditions: severely sensitized by heat-treating at 620°C (1150°F) for 40 hours with a furnace cool, and in the as-welded condition. The Incoloy 800 specimens were exposed in the as-welded-condition; the Zircaloy-2 specimens were exposed in the as-received condition, and the 410 SS specimens were exposed in the 3/4 hard condition. Three general groups of specimens were prepared: one to be removed after the NS-1 cleaning operation for destructive examination; one to be exposed to NS-1 during the cleaning operation and then to subsequent BWR service; and a third group which had seen no exposure to NS-1 and which acted as the control group for the subsequent service exposures. Multiple specimens of each alloy and condition were included in each group, with a nominal number of six in each set. The specimens were inserted in the Dresden 1 reactor vessel in December of 1978.

Details of the fabrication, heat-treatment, stressing, and loading of the long-term SCC surveillance specimens are presented in this report.

3. MATERIALS

3.1 PRODUCT FORM AND COMPOSITION

The purchased product form and mill certification analysis for each alloy is shown in Table 3-1. Copies of mill certifications of test materials are presented in Appendix A. While the carbon content of the heat of 304 SS is less than that typically encountered in BWR's, the heat was the most susceptible to IGSCC in the furnace sensitized condition of the seven heats characterized at the time of the start of the program; six of which had higher carbon contents than the chosen heat.⁵

Table 3-1
PRODUCT FORM AND MILL CERTIFICATION ANALYSIS OF MATERIALS
IN THE STRESS-CORROSION CRACKING
SURVEILLANCE PROGRAM

Alloy	Product Form	C	Mn	P	S	Si	Mo	Cr	Ni	Cu	Sn
304 SS	6 in. Schedule 80 Pipe	0.045 (Balance Fe)	1.63	0.019	0.013	0.53	—	19.05	9.00	—	—
304L SS	3/4 in. Plate	0.028 (Balance Fe)	1.48	0.025	0.016	0.48	0.20	18.95	9.10	0.30	—
Inconel 600	8 in. o.d. 5 in. i.d. Pipe	0.07 (Balance Fe)	0.17	—	0.007	0.23	—	15.33	75.61	0.19	—
Incoloy 800	1/2 in. Plate	0.07 (Al — 0.41, Ti — 0.43. Balance Fe)	0.89	—	0.002	0.43	—	20.33	32.55	0.55	—
410 SS	1/16 in. Sheet	0.14 (Al — 0.025, N — 0.043, Balance Fe)	0.48	0.010	0.002	0.40	0.06	11.89	0.20	0.05	0.001
Zr-2	1/2 in. Bar	0.011 (Al — 0.004, N — 0.002, Fe — 0.16, Balance Zr)	0.002	—	—	0.007	—	0.10	0.06	0.002	1.52

3.2 MECHANICAL PROPERTIES

Room temperature mechanical properties were obtained from the mill certifications, except for the 410 SS which was tested in the heat-treated condition. Mechanical properties tests were performed on all materials at 288°C (550°F) in the as-received condition, except for the 410 SS which was tested in the heat-treated condition. The results are shown in Table 3-2.

3.3 MATERIALS PREPARATION AND HEAT-TREATMENT

The materials represented in this program were tested in a variety of conditions. The 304 SS, 304L SS, and Inconel 600 alloys were tested in both the as-welded condition and the severely sensitized condition. The severely sensitized condition is representative of material which would be subjected to a post-weld heat-treatment with the RPV, and consisted of a heat-treatment of 40 hours at 620°C (1250°F) followed by a slow furnace cool. The Incoloy 800 material was tested in the as-welded condition only. The Zircaloy 2 was tested in the as-received condition, and the 410 SS was tested in the 3/4 hard condition.

Table 3-2
MECHANICAL PROPERTIES OF SURVEILLANCE PROGRAM MATERIALS

Room Temperature

Alloy	Heat No.	0.2% YS	UTS^a	% E^a	% RA^a
304 SS	78500	235 mPa (34.1 ksi)	549 mPa (79.6 ksi)	75	—
304L SS	V58077	236 mPa (34.3 ksi)	581 mPa (84.2 ksi)	60	—
Inconel 600	NX2715	241 mPa (35.0 ksi)	607 mPa (88.0 ksi)	43	56
Incoloy 800	HH7077A	238 mPa (34.5 ksi)	607 mPa (88.0 ksi)	44	61
410 SS ^b	8644145	931 mPa (135 ksi)	1055 mPa (153 ksi)	7	59
Zr-2	397208Q	375 mPa (54.0 ksi)	555 mPa (80.6 ksi)	24	—

288°C (550°F)

304L SS	78500	136 mPa (19.7 ksi)	426 mPa (61.8 ksi)	51	75
304L SS	V58077	142 mPa (20.6 ksi)	439 mPa (63.7 ksi)	44	67
Inconel 600	NX2715	181 mPa (26.3 ksi)	590 mPa (85.5 ksi)	44	56
Incoloy 800	HH7077A	145 mPa (21.1 ksi)	481 mPa (69.8 ksi)	40	58
410 SS ^b	8644145	820 mPa (119 ksi)	917 mPa (133 ksi)	4	55
Zr-2	397208Q	155 mPa (22.5 ksi)	271 mPa (39.3 ksi)	26	68

The fabrication of the test specimens, with the exception of those of 410 SS, involved welding to produce the pressurized tube configuration. However, the welds involve only simple fusion of thin-wall sections and do not represent the structural welds of interest, except in the case of Zircaloy 2 fuel cladding. To reproduce a reasonable facsimile of a structural weld, full thickness welds were made in the other materials, except for the Inconel 600, in their as-received thicknesses; the tubular test sections of the specimens (to be described in the next section) were machined from these welds with the centerline of the weld in the approximate center of the tubular specimen. Material thicknesses were such that both the root and crown sides of the original weld were reasonably represented on the finished specimens, as shown in Figure 3-1.

Originally, tubular specimens were prepared from 410 SS and heat treated in accordance with current General Electric Nuclear Technology Department specifications. However, a subsequent check of the heat-treatment used for this alloy in the construction of the Dresden 1 plant revealed that a significantly harder material condition was used. It was not possible to pressurize the tubes to the required stress level with existing equipment and, had it been possible, the handling of thin-walled tubes under those pressures would have represented a significant safety hazard. For these reasons, fixed deflection bent beams were chosen as the test specimen configuration for the 410 SS. The primary purpose of the pressurized tube specimen is to compensate for stress relaxation at service temperature in materials such as the austenitic stainless steels. Since no significant relaxation would be anticipated in the hardened 410 SS, the use of the bent-beam configuration was considered acceptable.

^a UTS = Ultimate Tensile Strength

E = Elongation

RA = Reduction in Area

^b Heat treated 1 hr at 982°C (1800°F) and oil quenched, then tempered for 1 hr at 566°C (1050°F) and air cooled.

Figure 3-1. Sketch Showing Nominal Location of Capsule Bodies in As-Welded Test Materials

4. SPECIMEN FABRICATION

4.1 SPECIMEN CONFIGURATIONS

The pressurized tube specimen is shown in Figure 4-1. The capsule body was fabricated from the heat of material being tested and the end seal plugs were fabricated from the same alloy, but not necessarily the same heat of material. Internal mandrels were used in all specimens to reduce the kinetic energy released in the event of a tube rupture, and all mandrels were fabricated from 304 SS. The capsule bodies were welded to the end plugs by single pass fusion welds using the tungsten-inert gas process. All welding was performed in an inert gas-filled chamber.

The bent beam specimen used for the 410 SS is shown in Figure 4-2, and the constant radius block used for stressing the specimens is shown in Figure 4-3. The radius blocks were fabricated from 304 SS, and 304 SS Allen screws were used for mounting the specimens.

4.2 MATERIALS PREPARATION

4.2.1. 304 SS

A standard 30-degree bevel, extended land, weld preparation was made on the pipe for consumable insert welding. The welding procedure used duplicated a conventional pipe field weld, with an inert gas-tungsten arc root fusion pass of the consumable insert, a single layer of inert gas-tungsten arc weld with filler metal, and completion of the weld with the shielded metal arc process. Filler metal for all layers was 308 SS. Longitudinal sections were cut through the completed weld for fabrication into capsule bodies, with the centerline of the weld in the approximate center of the final machined capsule body.

The non-welded specimens were prepared from longitudinal sections cut from the as-received pipe.

4.2.2 304L SS

The configuration of the 304L SS material (plate) prohibited duplicating a pipe weld. However, the weld preparation was identical and a length of 308 SS welding rod was used to simulate a consumable insert. Welding processes and parameters were as nearly identical to those used on the 304 SS pipe weld as was practical, and the edges of the plates were tacked to a strongback to prevent serious bowing of the plate and to provide restraint comparable to that which would be encountered in a pipe weld. Weld filler metal used was 308 SS. The rolling direction of the plate was perpendicular to the welding direction to provide a final specimen orientation identical to that of the 304 SS. Longitudinal sections were cut through the completed weld for fabrication into capsule bodies, with the centerline of the weld in the approximate center of the final machined capsule body.

The non-welded specimens were prepared from sections cut parallel to the rolling direction of the plate.

4.2.3 Inconel 600

The heavy-walled Inconel 600 pipe was machined on both the inside diameter (i.d.) and the outside diameter (o.d.) to produce a wall thickness equivalent to that of a 6 in. Schedule 80 pipe (approximately 0.432 in.) and was then prepared for welding in the same manner as the 304 SS pipe. An inert gas-tungsten arc root fusion pass was made with a consumable insert, and a second layer was deposited by inert gas-tungsten arc weld with filler metal. The remainder of the weld was completed using the shielded metal arc process. Weld filler metal used was Inconel 82 and 182. Longitudinal sections were cut through the completed weld for fabrication into capsule bodies with the weld centerline in the approximate center of the final machined capsule body.

The non-welded specimens were prepared from longitudinal sections cut from the machined pipe.

4.2.4 Incoloy 800

The preparation of the welded Incoloy 800 specimens was identical to that of the 304L SS specimens. A consumable insert weld prep was machined on the plate edges and the welding procedure duplicated that of a pipe weld insofar as was practical. The rolling direction of the plate was perpendicular to the direction of welding, and the plate was restrained during the welding process. Weld filler metal used was Inconel 82 and 182. Longitudinal sections were cut through the completed weld for fabrication into capsule bodies with the centerline of the weld in the approximate center of the final machined capsule body. Incoloy 800 was tested in the as-welded condition only.

4.2.5 410 SS

As stated previously, the original intent was to test 410 SS as pressurized tubes but the pressures required to achieve the desired stress level were prohibitive, both from an equipment and a personnel safety standpoint. The original material purchased was discarded and 16-gage sheet material was ordered. Bent-beam specimens were machined from the sheet stock oriented parallel to the rolling direction. The 410 SS was tested in the heat-treated condition only.

4.2.6 Zircaloy 2

Zircaloy 2 was tested in the as-received condition on the main portion of the capsule body. The areas immediately adjacent to the end plug closure welds can be considered to represent the as-welded condition because the wall thickness is similar to that of fuel cladding. However, the stresses will be lower than those calculated for the main capsule body. Capsule bodies were simply machined from the 1/2 in. diameter round bar in the as-received condition.

4.3 MATERIAL HEAT TREATMENTS

4.3.1 304 SS, 304L SS, Inconel 600

The two austenitic stainless steels and the nickel-base austenitic alloy were tested in two conditions: as-welded and severely sensitized. The sensitizing heat-treatment simulated that which a component attached to the RPV might be expected to experience during post-weld heat-treatment of the vessel and consisted of 40 hours at 620°C (1150°F) followed by a furnace cool. This heat-treatment was performed in an inert gas atmosphere after the completion of all specimen fabrication operations.

4.3.2 410 SS

It was considered desirable to test the 410 SS in the same heat-treat condition as that present in the Dresden 1 plant. However, a search of the available records did not provide definitive information as to the actual condition of that alloy.

Conversations with two GE engineers who were involved with materials and fabrication of the Dresden 1 vessel indicated that the material was used in the "3/4 Hard" condition and that the hardness in the heat-treated condition was "in the middle Rockwell C30's." A series of tests indicated that these two criteria were met by a heat-treatment consisting of austenitizing at 982°C (1800°F) for 1 hour with an oil quench, followed by tempering at 566°C (1050°F) for 1 hour with an air cool. These heat-treatments were performed in an inert gas atmosphere and the material exhibited 0.2% YS and UTS of 931 mPa (135 ksi) and 1055 mPa (153 ksi), respectively, and a hardness of Rockwell C34.

4.3.3 Incoloy 800 and Zircaloy-2

As stated previously, no specific heat-treatments were performed upon specimens fabricated from either of these alloys.

4.4 SPECIMEN DIMENSIONS

Two groups of specimens were fabricated: one for exposure during the cleaning cycle only at 121°C (250°F), and the other for exposure to the cleaning cycle and then to the operating plant environment at 288°C (550°F). Because of limits on the capability of the pressurizing equipment, and the difference in expansion of the fill gas at the two temperatures, the wall thickness of the capsule body of specimens for the cleaning cycle set was thinner than that of specimens intended for subsequent service exposure. In addition, weld shrinkage effects and weld deposit irregularities on the welded 304 SS and Inconel 600 materials required that a somewhat smaller capsule body be used to assure that all specimens could be machined from the welded pipes. The nominal critical capsule body dimensions (i.d. and wall thickness) for each group of specimens are shown in Table 4-1.

Since the dimensions of the bent-beam specimens fabricated from 410 SS were independent of temperature, pressure, and intended exposure, all specimens from this alloy were identical. The dimensions of these specimens are shown in Figure 4-2; the dimensions of the constant radius loading block are shown in Figure 4-3.

Finished dimensional variance of the capsule bodies was checked by measuring the finished bodies of 20 specimens, representing 5 specimens each from the as-received and as-welded 304 SS and Inconel 600 sets. The mean wall thickness for the 20 capsule bodies was 0.0455 in., with a mean standard deviation of 0.0003 in. The mean i.d. of the as-welded capsule bodies was 0.2807 in., and the mean i.d. of the as-received capsule bodies was 0.3111 in. Since all of the specimens were machined in the same shop, and the four sets from which the samples were taken were machined at different points in time, the results indicated excellent consistency on the part of the fabricator.

4.5 NUMBER OF SPECIMENS PREPARED

The test matrix, described in Section 6, required 30 specimens for each material/condition combination tested. A total of 35 specimens were prepared for each material/condition to provide spares in the event that faulty tubes were encountered during the pressurizing operation. Only 30 bent-beam specimens were prepared from the 410 SS because no defects would be encountered in such specimens.

Table 4-1
NOMINAL CRITICAL CAPSULE BODY DIMENSIONS OF PRESSURIZED
TUBE SPECIMENS

Material	Condition	Specimen Group	Nominal Dimensions	
			Capsule Body i.d. (in.)	Capsule Body Wall Thickness (in.)
304 SS	As-Welded	Cleaning Cycle	0.280	0.025
304 SS	Sensitized	Cleaning Cycle	0.312	0.025
304 SS	As-Welded	BWR Service	0.280	0.044
304 SS	Sensitized	BWR Service	0.312	0.044
304L SS	As-Welded	Cleaning Cycle	0.312	0.025
304L SS	Sensitized	Cleaning Cycle	0.312	0.025
304L SS	As-Welded	BWR Service	0.312	0.044
304L SS	Sensitized	BWR Service	0.312	0.044
Inconel 600	As-Welded	Cleaning Cycle	0.280	0.025
Inconel 600	Sensitized	Cleaning Cycle	0.312	0.025
Inconel 600	As-Welded	BWR Service	0.280	0.044
Inconel 600	Sensitized	BWR Service	0.312	0.044
Incoloy 800	As-Welded	Cleaning Cycle	0.312	0.025
Incoloy 800	As-Welded	BWR Service	0.312	0.044
Zircaloy 2	As-Received	Cleaning Cycle	0.312	0.025
Zircaloy 2	As-Received	BWR Service	0.312	0.044

PRESSURIZED TUBE SPECIMEN

ALL DIMENSIONS IN INCHES

NOTE: THREADS AND CONE SEAT MUST BE MADE DURING SAME CHUCKING OPERATION TO INSURE PERFECT CONCENTRICITY.

UPPER END PLUG DETAIL

NOTE: THREADS AND CONE TIP MUST BE MADE DURING SAME CHUCKING OPERATION TO INSURE PERFECT CONCENTRICITY.

SEAL PLUG DETAIL

Figure 4-1. Pressurized Tube Specimen Sketch, and Detailed Drawings of Upper End Plug and Seal Plug

Figure 4-2. Type-410 SS Bent-Beam Specimen

Figure 4-3. Constant Radius Block for Loading of the Type-410 SS Specimens

5. STRESS-CORROSION CRACKING TEST MATRIX

5.1 GENERAL MATRIX

The general matrix consists of five groups of specimens described as (1) Cleaning Cycle, (2) RPV Control, (3) RPV Cleaning, (4) B-Loop Control, and (5) B-Loop Cleaning. The specific definitions of these groups are as follows.

5.1.1 Cleaning Cycle Specimens

These specimens were stressed to the ambient temperature 0.2% offset YS of the individual heats of material tested. The specimens will be exposed during the actual plant cleaning operation and then removed for examination. Examinations performed may include destructive metallography. None of these specimens will be returned to the reactor for subsequent exposure to the operating environment when the plant returns to service.

5.1.2 RPV Control Specimens

These specimens will act as controls and will not be inserted in the RPV until after the completion of the chemical cleaning, and will see no exposure to the cleaning solvent. The pressurized tube specimens were filled to a pressure which would result in a nominal stress of the 288°C (550°F) 0.2% offset YS of the individual heats of material at the operating temperature of the plant when it returns to service. The 410 SS bent-beam specimens were stressed over constant radius blocks to give a strain equal to that of the 288°C (550°F) 0.2% YS.

5.1.3 RPV Cleaning Specimens

These specimens will be exposed to the cleaning solvent during the actual plant cleaning operation, and will then be returned to the RPV turning vane for subsequent service exposure to the normal operating environment. Like the RPV Controls, these specimens were pressurized such that they would be stressed to the 288°C (550°F) 0.2% offset YS during normal plant operation. This means that during the actual cleaning operation these specimens will be stressed to approximately two-thirds of that value, because of the lower temperature of the cleaning solution, i.e., 121°C (250°F).

5.1.4 B-Loop Control Specimens

These specimens are identical to the RPV Controls, but will be exposed to subsequent plant operation in the B secondary steam generator test loop if that facility is operative following the cleaning operation. Should the facility not be operative, these specimens will be exposed in the RPV turning vane with the RPV Controls. The purpose of both groups of B-loop specimens is to provide for more frequent examinations of the surveillance specimens than would be provided by the normal plant refueling outages, without interruption of plant operation.

5.1.5 B-Loop Cleaning Specimens

These specimens are identical to the RPV Cleaning specimens, and will be exposed to the actual plant cleaning cycle in the RPV and then will be transferred to the B secondary steam generator test loop, if that facility is operative, for subsequent plant operational exposure. The purpose is to provide for more frequent examinations without interruption of normal plant operation. Should the B-loop facility not be available, these specimens will be exposed to subsequent plant operation in the RPV turning vane area along with the RPV Cleaning specimens.

5.2 SPECIFIC TEST MATRIX

The specific test matrix for the SCC is shown in Table 5-1. Each material/condition combination is represented in each of the five groups as a set of six (nominally) specimens. In a few instances, less than six specimens are present because of original material fabrication weld defects which did not permit repair and repressurization of the specimens. The total number of specimens represented by the nominal test matrix is 270.

Table 5-1
NOMINAL MATRIX FOR LONG-TERM STRESS-CORROSION
CRACKING SURVEILLANCE PROGRAM SPECIMENS

Alloy/Condition	Cleaning Cycle	RPV Control	RPV Cleaning	B-Loop Control	B-Loop Cleaning
304 SS					
As-Welded	X	X	X	X	X
Sensitized ^a	X	X	X	X	X
304L SS					
As-Welded	X	X	X	X	X
Sensitized ^a	X	X	X	X	X
Inconel 600					
As-Welded	X	X	X	X	X
Sensitized ^a	X	X	X	X	X
Incoloy 800					
As-Welded	X	X	X	X	X
410 SS					
3/4 Hard ^b	X	X	X	X	X
Zircaloy 2					
As-Received	X	X	X	X	X

^a 40 hrs at 620°C (1150°F), furnace cool.

^b 982°C (1800°F) austenitizing, 556°C (1050°F) temper.

6. SPECIMEN HOLDER FABRICATION

6.1 RACK CARRIER

The rack carrier, usually referred to as the "saddlebag," is designed to fit over the turning vane and to act as a container for one or more specimen containers. The carrier is identical to those used previously by GE in other in-reactor test programs at the Dresden 1 plant and was fabricated from 304 SS in accordance with the "G-1" designation of GE drawing 135C5380, a reduced copy of which is shown in Figure 6-1. The carrier was designated as No. 20, using the binary code on the carrier handle, to remove it numerically from the number sequence of GE carriers which may be returned to the reactor vessel after completion of the plant cleaning operation. Additional drainage holes, not shown on the drawing, were added by Dow after their receipt of the specimens by agreement with Dresden 1 Station personnel.

6.2 RACK CONTAINERS

The rack container is designed to fit within the compartments of the carrier and to contain individual specimen racks in a vertical array. The container is identical to those used previously in other GE programs at the Dresden 1 plant and was fabricated from 304 SS in accordance with the "G-2" designation of GE drawing 13C5373, a reduced copy of which is shown in Figure 6-2. The containers were numbered 1 through 6 using a left-justified binary code of punched holes near the handle of the carrier, as shown in Figure 6-3. However, there was a misinterpretation of the binary code when the containers were received by Dow and the Arabic numerals which were metal stamped on the container handles at that time do not correspond to the binary designations. The metal stamped Dow numbers corresponding to the binary container numbers are also shown in Figure 6-3. To clearly distinguish the Dow surveillance program containers and racks from those of GE programs, the Dow binary place markers were punched as diamonds rather than the circular holes used in the GE programs.

6.3 SPECIMEN RACKS

The specimen rack is designed to hold the pressurized tube specimens securely in place, while permitting easy rotation and removal of specimens as necessary during examinations. The racks are identical to those used previously in other GE programs at the Dresden 1 plant and were fabricated from 304 SS in accordance with GE drawing 706E738, a reduced copy of which is shown in Figure 6-4. Drainage holes were punched in the back of the racks to facilitate draining of the solvent and rinsing during the plant cleaning operation. The racks were numbered 1 through 25 using the left-justified binary code previously described, and Arabic numerals corresponding to the binary number were metal stamped on each rack at the time of manufacture.

Each rack is designed to hold 13 pressurized tube specimens. However, in this investigation only 12 specimens were loaded in each rack, with the seventh space left empty to separate 2 sets of 6 specimens each. This system permits ready identification of particular specimens within a set. In the case of the 410 SS bent-beam specimens, the 304 SS loading block was tack-welded to the back of the rack, with the specimens oriented parallel to the long direction of the rack. A detailed listing of the individual specimen locations will be presented in Section 8 of this report.

Figure 6-1. Dresden 1 Turning Vane Rack Carrier

Figure 6-2. Pressurized Tube Rack Container

Figure 6-3. Dow In-Reactor Long-Term Surveillance Program Rack Container Identification Numbers

NEDC-24644

7. SPECIMEN STRESSING

7.1 PRESSURIZED TUBES

As stated previously, the nominal stress selected for pressurized tube specimens was the 0.2% offset YS at 121°C (250°F) for the cleaning cycle specimens, and 288°C (550°F) for the long-term surveillance specimens. The values used for the cleaning cycle specimens were the reported room temperature yield strengths from the mill certification sheets, with the expectation that the change in strength at the higher temperature would be small and in the conservative direction; i.e., if a change occurred over the moderate temperature increase, it would represent a reduction in the true yield strength, and the specimens would be slightly overstressed. The values used for the long-term specimens were those obtained from mechanical properties tests performed on the alloys at 288°C (550°F).

7.1.1 Calculations

The formula used to calculate stresses was for thick-walled tubes given by Shigley.⁶ The internal pressure required was calculated to give the desired stress on the outer fibers of the tube, corrected for thermal expansion of the pressurizing gas and external pressures at the cleaning and operating temperatures. The general form of the equation is shown below.

$$S = \frac{P_i \times A^2}{B^2 - A^2} \left(\frac{B^2}{R^2} + 1 \right)$$

Where:

S = Hoop Stress

P_i = Internal Pressure

A = Tube Inside Radius

B = Tube Outside Radius

R = Radius of the element of interest

For the o.d. fibers, the outside radius and the radius of interest are the same and the equation reduces to:

$$S = \frac{P_i \times A^2}{B^2 - A^2} \times 2$$

Rearranging to solve for P_i, and correcting for the external pressure, the equation becomes:

$$P_i = \frac{S (B^2 - A^2)}{2 A^2} + P_o$$

Where:

P_o = External pressure

Assuming that the pressurizing gas obeys the ideal gas law, a correction factor is then inserted to give the correct fill pressure at ambient temperature and the equation becomes:

$$P_f = \frac{S (B^2 - A^2)}{2 A^2 C_t} + P_o$$

Where:

P_f = Ambient temperature fill pressure

C_t = Correction Factor for Temperature

C_t = 1.331 at 121°C (250°F)

C_t = 1.895 at 288°C (550°F)

P_o = 15 psi at 121°C (250°F)

P_o = 1030 psi at 288°C (550°F)

Fill pressures for each set of specimens were then calculated, as shown in Table 7-1.

7.1.2 Tube Pressurizing

The technician performing the pressurizing operation was instructed to pressurize the specimens to the next highest scale division on the gage, rather than attempting to interpolate exact pressures between scale divisions in 0.07 Pa (10 psi) increments. Individual specimens were placed in the pressurizing chamber with the seal plug partially threaded into the upper end plug. The chamber and the capsule were pressurized to the desired value and the threaded seal plug was turned until it was tightly seated through a sealed rotating fitting. Argon gas was used as the pressurizing fluid, and each specimen was leak checked after pressurizing by submerging in acetone; with the observance of bubble formation indicating a leak.

7.1.3 "True" Pressurized Tube Specimen Stresses

The fill pressures calculated and shown in Table 7-1 were inadvertently obtained using the specified nominal specimen dimensions. This error was not noted until after the specimens had been shipped to Dow, and there was not sufficient time for their return and repressurization because of the schedule for closure of the Dresden 1 RPV. The "true" stresses for the given fill pressures were recalculated for those sets of specimens from which direct dimensional measurements had been made, and the results are shown in Table 7-2. It would appear that the long-term surveillance specimens are actually stressed to a value of 105 to 110% of the 288°C (550°F) 0.2% offset YS.

Similar calculations could not be made for the cleaning cycle specimens because true specimen dimensional checks were not made on any sets from this group. However, because of the consistency exhibited by the specimen fabricator in those sets which were checked, one would expect a similar situation to exist in the cleaning cycle specimens; i.e., the specimens are stressed slightly above the 121°C (250°F) 0.2% offset YS.

The 304L SS pressurized tube specimens were subject to significantly higher stresses than originally intended because of a records error. The value used for the 288°C (550°F) 0.2% YS was obtained from previous studies utilizing this heat of material and was quoted as 163 mPa (23.6 ksi); the required fill pressures were calculated on that basis. During the preparation of this report, design record confirmation of this value was attempted, and no record of the performance of elevated temperature mechanical properties tests on this heat of material could be located. Specimens were prepared and

tested to generate record data, and the 288°C 0.2% YS value obtained as a mean of three specimens was 142 mPa (20.6 ksi). If this mean is used as the true value of the 288°C YS, then the 304L SS specimens were stressed to ~ 115% of the intended value. This error in true stress level would not affect the conclusions of the program regarding the effects of exposure to NS-1 solvent of subsequent service performance.

7.2 410 SS BENT-BEAM SPECIMENS

These specimens were stressed as fixed deflection constant radius bent beams over 304 SS radius blocks. Mechanical properties tests were made on the heat-treated material, and the total strain at the 0.2% offset YS was determined at 21°C (70°F) and 288°C (550°F). The difference between these two values was not large, and a single value corresponding to that at 288°C was selected for stressing of all 410 SS specimens (0.70% strain). The formula used for calculating the strain in the bent beams was as follows:

$$E = \frac{T}{2R + T}$$

Where:

E = Strain in outer fibers, cm/cm (in./in.)

T = Specimen thickness

R = Radius of curvature of loading block

The product form of the 410 SS used was 16-gage sheet stock, which gave a loading block radius of 11.4 cm (4.5 in.).

The cleaning cycle specimens and the long-term control specimens were loaded on the constant radius blocks prior to shipment of the specimens to Dow, and the blocks were tack welded into the specimen racks. The long-term cleaning specimens were not loaded on the blocks at this time, but were simply wired into the specimen holders. This procedure was followed based on observations in Dow investigations of increasing general corrosion rates of 3/4 hard 410 SS in the NS-1 solvent at 121°C (250°F) as a function of the stress level. Since loss of specimen thickness would result in lower stresses on the bent-beam specimens, it was decided to minimize that loss on the long-term specimens by exposing them in the unstressed condition and then stressing them prior to the subsequent operating plant exposures.

Table 7-1
NOMINAL HOOP STRESSES AND FILL PRESSURES OF
PRESSURIZED TUBE STRESS-CORROSION CRACKING SURVEILLANCE SPECIMENS

Alloy/Condition	Cleaning Cycle ^a		Long-Term Surveillance ^b	
	Hoop Stress	Fill Pressure	Hoop Stress	Fill Pressure
304 SS				
As-Welded ^c	235 mPa (34.1 ksi)	34.5 mPa (5.0 ksi)	136 mPa (19.7 ksi)	29.6 mPa (4.3 ksi)
Sensitized ^d	235 mPa (34.1 ksi)	30.3 mPa (4.4 ksi)	136 mPa (19.7 ksi)	26.9 mPa (3.9 ksi)
304L SS				
As-Welded	276 mPa (40.1 ksi)	37.2 mPa (5.4 ksi)	163 mPa (23.6 ksi)	31.0 mPa (4.5 ksi)
Sensitized ^d	276 mPa (40.1 ksi)	37.2 mPa (5.4 ksi)	163 mPa (23.6 ksi)	31.0 mPa (4.5 ksi)
Inconel 600				
As-Welded ^c	241 mPa (35.0 ksi)	35.2 mPa (5.1 ksi)	181 mPa (26.3 ksi)	38.6 mPa (5.6 ksi)
Sensitized ^d	241 mPa (35.0 ksi)	31.0 mPa (4.5 ksi)	181 mPa (26.3 ksi)	34.5 mPa (5.0 ksi)
Incoloy 800				
As-Welded	238 mPa (34.5 ksi)	31.0 mPa (4.5 ksi)	145 mPa (21.1 ksi)	28.3 mPa (4.1 ksi)
Zircaloy 2				
As-Received	375 mPa (54.4 ksi)	49.0 mPa (7.1 ksi)	155 mPa (22.5 ksi)	30.3 mPa (4.4 ksi)

^a 121°C (250°F), 0.1 mPa (15 psi)

^b 288°C (550°F), 7.1 mPa (1030 psi)

^c As-Welded specimens are smaller in diameter than sensitized specimens

^d 40 hr 620°C (1150°F), furnace cool

Table 7-2
"TRUE" STRESS ON PRESSURIZED TUBE SPECIMENS USING
MEAN MEASURED DIMENSIONAL VALUES

Material/Condition	Fill Pressure	"True" Stress^a	Variance from Nominal Stress
304 SS			
As-Welded	29.9 mPa (4337 psi)	145 mPa (21.0 ksi)	+6%
Sensitized ^b	26.8 mPa (3890 psi)	149 mPa (21.6 ksi)	+10%
Inconel 600			
As-Welded	38.7 mPa (5607 psi)	192 mPa (27.8 ksi)	+6%
Sensitized ^b	34.6 mPa (5011 psi)	196 mPa (28.4 ksi)	+8%

^a Based on mean measured i.d. and o.d. of five tubes from each group

^b 40 hr 620°C (1150°F), furnace cool

8. SPECIMEN LOCATIONS

8.1 RACK NUMBERING

As stated in subsection 6.3, the specimen racks were numbered 1 through 25 using a left-justified binary code and were metal stamped with Arabic numerals corresponding to that code. The rack numbers for the different specimen sets are shown in Table 8-1, and examples of the binary code are shown in Figure 8-1.

8.2 SPECIMEN NUMBERING

The SCC specimens were numbered sequentially through each alloy and condition with a given alloy. The numbering system used was Arabic, and the specimen numbers were Vibra-Tooled on the bottom capsule plug of the pressurized tubes prior to pressurizing and were metal-stamped on the 410 SS bent beams prior to loading. The specimen numbers were preceded by "D1" to identify the individual specimens as part of the Dresden 1 chemical cleaning program. The numbers assigned to the individual specimens are shown in Table 8-2.

8.3 SPECIMEN LOCATIONS

The specimen sets were loaded sequentially in the racks beginning with the position nearest the rack handle; when the rack contained two sets of specimens they were separated by an empty space, as shown in Figure 8-1. With the exception of the Incoloy 800, and one set of severely sensitized 304 SS, full sets of specimens were loaded for all alloys and conditions.

Considerable difficulty was encountered in the sealing and pressurizing of the Incoloy 800 specimens. The production of sound closure welds was difficult and a number of specimens had to be re-welded. In addition, the original plate weld exhibited a large number of defects, and the re-welding of capsule bodies to correct this condition was not possible. While the closure weld problem was eventually solved, there were insufficient spare specimens to account for those lost because of original weld defects, and the Incoloy 800 specimen set is incomplete. Two specimens (Nos. 185 and 186) are missing from rack No. 16, one specimen (No. 194) is missing from rack No. 18, and two specimens (Nos. 205 and 207) are missing from rack No. 20. A single specimen (No. 36) of severely sensitized 304 SS is missing from rack No. 1.

Sketches showing the locations of specimens in each individual rack are presented as Appendix B. In addition, the fill pressure recorded by the technician for each tube is shown as a parenthesized value in each specimen location, expressed as pounds per square inch.

Table 8-1
STRESS-CORROSION CRACKING SURVEILLANCE PROGRAM
SPECIMEN RACK NUMBERS

Alloy/Condition	Cleaning Cycle	RPV Control	RPV Cleaning	B-Loop Control	B-Loop Cleaning
304 SS					
As-Welded	1	2	3	4	5
Sensitized	1	2	3	4	5
304L SS					
As-Welded	6	7	8	9	10
Sensitized	6	7	8	9	10
Inconel 600					
As-Welded	11	12	13	14	15
Sensitized	11	12	13	14	15
Incoloy 800					
As-Welded	16	17	18	19	20
410 SS					
3/4 Hard	16	17	18	19	20
Zircaloy 2					
As-Received	21	22	23	24	25

Table 8-2
STRESS-CORROSION CRACKING SURVEILLANCE PROGRAM
SPECIMEN NUMBERS

Alloy/Condition	Cleaning Cycle	RPV Control	RPV Cleaning	B-Loop Control	B-Loop Cleaning
304 SS					
As-Welded	1-6	7-12	13-18	19-24	25-30
Sensitized	31-36	37-42	43-48	49-54	55-60
304L SS					
As-Welded	61-66	67-72	73-78	79-84	85-90
Sensitized	91-96	97-102	103-108	109-114	115-120
Inconel 600					
As-Welded	121-126	127-132	133-138	139-144	145-150
Sensitized	151-156	157-162	163-168	169-174	175-180
Incoloy 800					
As-Welded	181-186	187-192	193-198	199-204	205-210
410 SS					
3/4 Hard	211-216	217-222	223-228	229-234	235-240
Zircaloy 2					
As-Received	241-246	247-252	253-258	259-264	265-270

Example: Specimen D1-45 is a furnace sensitized 304 specimen in the set subjected to the cleaning cycle, followed by service exposure, in the reactor. It would be located in Rack No. 3 from Table 8-1.

Figure 8-1. Sketches of Specimen Racks 3 and 18 Showing Specific Specimen Sequences and Arrangements

9. REFERENCES

1. *Technical Study for the Chemical Cleaning of Dresden 1*, Dow Nuclear Services, Vols. II, IV, V, VI, VIII, June 1977 (DNS-D1-016).
2. *The Chemical Cleaning of the Corrosion Fatigue Loop at Dresden 1*, Dow Nuclear Services, Vol. 1, August 1978 (DNS-D1-019).
3. W. L. Walker, *Dresden 1 Radiation Level Reduction Program: Intergranular Corrosion Tests of Sensitized Type 304 Stainless Steel in Dow NS-1, and Stress Corrosion Cracking Tests of Type 304 Stainless Steel and Carbon and Low Alloy Steels in Dow Copper Rinse Solution*, General Electric Co., September 1978 (NEDC-24143).
4. W. L. Walker, *Dresden 1 Radiation Level Reduction Program: Long Term Evaluation of the Effects of Exposure to Dow NS-1 Solvent on the Stress Corrosion Cracking of Sensitized Type 304 Stainless Steel in Simulated BWR Environment*, General Electric Co., November 1978 (NEDC-24159).
5. W. L. Walker, *Correlation Analyses of Mechanical Properties, General Intergranular Corrosion, and Intergranular Stress Corrosion Cracking Data from Multiple Heats of Type 304 Stainless Steel*, General Electric Co., July 1973 (NEDM-13347).
6. J. E. Shigley, *Machine Design*, McGraw-Hill, New York, 1956, p. 462-466.

APPENDIX A
MILL CERTIFICATION OF TEST MATERIALS

NO 30 SEPT 13-71 SF TO LA ATTN JOE

TUESALES.

SHEET NUMBER

GENERAL ELECTRIC CO
NUCLEAR ENERGY DIV
175 CENTER AVE
SAN JOSE CA

51

215378

SHOULD BE SENT AS SHOWN UNLESS OTHERWISE INDICATED

NAME - VALLECITOS NUCLEAR CENTER
VALLECITOS RD
PLEASANTON CA

QUANTITY ORDERED		LENGTH	SIZE	PRICE CFT	DISCOUNT	QUANTITY SHIPPED
SMLS 304		54312				
1	60 FT	RL	6 SCH 80	3		
1 AT 27333			5X6.625 X .432	.432		
2	20 FT	RL	6 SCH 80	3		
1 AT 73500			6.625 X .432			

CERTIFICATE

OF

TEST

21' 5" 314
28' 8" 314

CERTIFICATE OF TESTS		OD 6" WALL 80		TENSILE PSI		YIELD PSI		ELONG IN 2"		GRAIN		HARDNESS	
SMLS 304		6-5/8"		82,490		35,556		73.3				27388	
CHEM ANALYSIS		C	MN	P	S	SI	NI	CR	MO	TI	CU	HARDENABILITY	
		.045	1.59	.023	.005	.60	8.84	18.75					
TESTS PERFORMED		CECAB	MAG	CORR	EMB	HYDRO	FLARE	FLAT	CRUSH	FLANG	R. FLAT	SURFACE	BEND
				X		X		X					

DESCRIPTION & REMARKS:

SMLS 304 PIPE ASTM A-312 C/T TO MIL-P-1144B

CERTIFICATE OF TESTS		OD 6" WALL 80		TENSILE PSI		YIELD PSI		ELONG IN 2"		GRAIN		HARDNESS	
MECH PROPERTIES		6-5/8"		79,640		34,135		74.8				73500	
CHEM ANALYSIS		C	MN	P	S	SI	NI	CR	MO	TI	CU	HARDENABILITY	
		.045	1.63	.019	.013	.53	9.00	19.05					
TESTS PERFORMED		CECAB	MAG	CORR	EMB	HYDRO	FLARE	FLAT	CRUSH	FLANG	R. FLAT	SURFACE	BEND
				X		X		X					

DESCRIPTION & REMARKS:

SMLS 304 PIPE ASTM A-312 C/T TO MIL-P-1144B

RON HOLLOWAY

TUESALES.

TESTED BY: 48

6615

BALTIMORE, MARYLAND 21203

DATE 5-25-66

1580
3/4 + 1

SHIP TO:

SOLD TO:

AFFILIATED METALS

3301 E. MEDFORD

LOS ANGELES, CAL

GENERAL ELECTRIC CO.
175 CARTNER AVE
SAN JOSE, CALIF.

ATTN: PURCH.

205-3W107

41053

5-11-70

MILL ORDER NO.		CUSTOMER ORDER NO.			SHIPPED VIA	
58-2390		2404			PER-SSW-SP	
ITEM	M.P.O. NO.	HEAT NO.	GAUGE	SIZE	TYPE	
19	97090	P 58072	5000	96 x 245	TYPE 316L-F1	
9	98054	P 58132	2500	96 x 244		
10	97211	X 63041	2500	96 x 250	TYPE 321SW-F1	
9	97478	P 58132	2500	96 x 274	TYPE 316L-F1	
26	97210	K 68117	1.000	96 x 250	TYPE 316-F1	
15	97240	X 68034	3750	96 x 230	TYPE 321SW-F1	
5	97477	X 68023	1875	96 x 312		
24	97403	V 58077	7500	96 x 264	TYPE 304L-F1	
27	97305	V 58077	1.000	96 x 255		

1		1681
1		1723
1		1888
1		6990
1		2894
1		1612
1		5457
1		7026
9		32549

HEAT	TYPE	C	MN	P	S	SI	CR	NI	CU	TI	CL	MO	W	AI	V	B	SN	N	CO	TA	SC	OTHER
x68084	321	056	140	021	014	61	1724	980	20	69		24										
x68023	321	045	149	020	020	70	1721	957	28	55		22										
V58077	304L	028	148	025	016	48	1895	910	30			20										

WE CERTIFY THAT THE CHEMICAL ANALYSIS AND MECHANICAL TEST RESULTS APPLYING ON THE ABOVE NUMBER ARE CORRECT, AND TO THE BEST OF OUR KNOWLEDGE AND BELIEF.

DATE: 5-27-66
METALLURGICAL DEPT.

TRANSVERSE OR FRONT						LONGITUDINAL BACK OR AGED						REMARKS					
HEAT	MPO	TENSILE	YIELD	ELONG.	HARDNESS	TENSILE	YIELD	ELONG.	HARDNESS	TENSILE	YIELD	ELONG.	REMARKS	REMARKS	REMARKS	REMARKS	REMARKS
x68084	97240	855	417	50	BN170												
x68023	97477	860	467	50	BN170												
V58077	97403	860	459	57	BN170												
V58077	97305	813	343	60	BN167												

JUNE 26, 1966
SIGNED AND SUBSCRIBED TO

RECEIVED

AUG 16 1972

W. L. WALSH

CHARGE ORDER NO.

83070-1-D

DATE: 11-07-71 PAGE 1 OF 1

MARK ORDER NO.

884-CC328

PREPARED PRIOR TO ☐ AFTER ☒ SHIPMENT

CERTIFICATE OF:

☐ CHEMICAL ANALYSIS ☐ COMPLIANCE ☐ WELD DEP. ☒ TEST

EXPLANATION OF NOTES

(1) UNLESS OTHERWISE SHOWN OR INDICATED, A SMALL AMOUNT OF COBAL
(2) UNLESS THE MATERIAL IS SHIPPED WITH THE FINAL HEAT TREATED CONDITION, THE PROPERTIES SHOWN
RESULTED FROM HEAT TREATING THE TEST SPECIMEN AS REQUIRED BY THE SPECIFICATION OR
(3) SYMBOLS IN PLACES OF LIFE COLUMN OF STRESS RUPTURE TEST INDICATE THE FOLLOWING CONDITIONS:
(a) TEST ACCEPTED WITHOUT FRACTURE
(b) COMBINATION NOTCH AND SMOOTH BAR SPECIMEN FRACTURED IN SMOOTH GAGE
(c) STRESS WAS INCREASED PER SPECIFICATION OPTION TO INDUCE EARLY FRACTURE
(4) MATERIAL AS SHIPPED FROM HUNTINGTON PLANT FREE FROM CONTAMINATION
BY MG. RA. AND ALPHA SOURCE.

THIS IS TO CERTIFY THAT ALL REQUIRED INSPECTIONS AND TESTS HAVE BEEN COMPLETED
IN ACCORDANCE WITH THE ORDER REQUIREMENTS AND THAT THE VALUES SHOWN
ARE CORRECT AND TRUE, BASED ON THESE TESTS. THE MATERIAL COMPLIED WITH
THE ORDER REQUIREMENTS.

H. U. Wilson
QUALITY CONTROL DEPARTMENT

PACIFIC METALS DIV

A H CASTLE & CO

1000 10TH ST

SAN FRANCISCO CAL 94107

GENERAL ELECTRIC CO.

VALLEJO RD.

FLORISSANT CAL.

CO ORDER NUMBER 884-CC328

ASME SB-167

ITEM	QUANTITY	DESCRIPTION OF MATERIAL SHIPPED
5334	8.000" OD X 5.125" ID X 60.000" INCONEL 600 EXT AVG WA TUBE PKL ANH	

HEAT NO. (4)	C	MN	FE	S	SI	CU	NI (1)	CR	AL	TI	MG	CO	MO	CB + TA	EL	EL	EL
112715	0 07	00 17	08 37	007	00 23	00 19	75 61	15 33									

ITEM	QUANTITY	HEAT NO.	PIECE NUMBERS	TENSILE RESULTS - AS SHIPPED - ROOM TEMP				TENSILE RESULTS - ROOM TEMP (2)				TENSILE RESULTS - HIGH TEMP (2)				STRESS RUPTURE RESULTS (2)			
				HARDNESS	ASTM GRAIN SIZE	YIELD STRENGTH 2% OFFSET	TENSILE STRENGTH P.S. X1000	HARDNESS	ASTM GRAIN SIZE	YIELD STRENGTH 2% OFFSET P.S. X1000	TENSILE STRENGTH P.S. X1000	HARDNESS	TEMP. F	YIELD STRENGTH 2% OFFSET P.S. X1000	TENSILE STRENGTH P.S. X1000	HARDNESS	TEMP. F	STRESS P.S. X1000	RUPTURE LIFE IN HOURS (1)
1 PC		112715		53076		0350	0880	4358											

C.P. REV.	DATE OF C.P.	ULTRASONIC TESTING						INSTRUMENT	COUPLANT	DYE PEN. TEST	METAL DENSITY	HYDRO PRESSURE TEST PSI	BODY JOINT	WT. LOSS	MACRO ETCH	FLARE TEST	BEND TEST
		WAVE MODE	ACCEPTANCE STANDARD	TYPE	SIZE (INCHES)	FREQ (MHZ)											
												1000					

Duplicate Copies 4/3/72

TEST REPORT

A. M. CASTLE & CO.

SOLD TO:

GENERAL ELECTRIC CO APED
175 CURTNER AVENUE
SAN JOSE, CALIFORNIA 95125

SHIPPED TO:

VALLECITOS ROAD
PLEASANTON, CALIFORNIA

CUST. ORDER NO.

529 V3/ 18

Castle-Pacific

Order No. 45645

SPECIFICATION NO.

ASTM-B-409

ITEM NO.

MATERIAL

2 PCS INCOLOY 800 HR PLATE DESCALED ANNEALED 1/2" x 48" x 8"

MILL: HUNTINGTON

PHYSICALS

ITEM	HEAT NO.	YIELD POINT P.S.I.	TENSILE STRENGTH P.S.I.	% ELONG 2"	% RED. AREA	BRINELL	ROCK- WELL	BEND TEST	MACRO	EMBRI- MENT	IZOD IMPACT	ENH GRAI SIZE
	HH7077A	34,500	88000	44	61	LOT PC-0014-2						

CHEMICALS

ITEM	HEAT NO	% C	% MN	% P	% S	% SI	% NI	% CR	% CU	% AL	% TI	% MG	% MO	% CO
	HH7077A	.07	.89		.002	.43	32.55	20.33	.55	.41	.43			

SUBSCRIBED AND SWORN TO BEFORE ME THIS

DAY OF 19

NOTARY PUBLIC

MY COMMISSION EXPIRES

IN AND FOR THE COUNTY OF

STATE OF

I CERTIFY THAT THESE ARE CORRECT
COPIES OF REPORTS NOW ON FILE AT

A. M. CASTLE & CO

A-6

BY *David Zapanta*
SAN FRANCISCO LOS ANGELES SALT LAKE CITY

EARLE M. JORGENSEN CO.

STEEL

CERTIFIED MATERIAL TEST REPORT

GENERAL ELEC
NUCLEAR ENERGY DIV
175 CURTNER AV MC 116
SAN JOSE CA 95114

DATE	10/27/78	YOUR ORDER NUMBER	529 F J 035	OUR INVOICE NUMBER	20999 0
------	----------	----------------------	-------------	-----------------------	---------

	DESCRIPTION & SPECIFICATIONS	QUANTITY & SIZE
1	410 ANN 2D FIN SHEET ASTM A 240 77	16 GA
2		
3		

CHEMICAL ANALYSIS														G/S	F	S
HEAT NO.	C	MN	PHOS	SUL	SIL	NI	CR	CU	MO	CO	N	AL	SN			
8644145	.14	.48	.010	.002	.40	.20	11.89	.05	.06		.043	.025	.001	8		

MECHANICAL PROPERTIES												HARDENABILITY				
YIELD THOUSAND LBS/SQ IN	TENSILE STRENGTH THOUSAND LBS/SQ IN	ELONG % IN 2 IN	RED OF AREA %	BRINELL	ROCK- WELL	B E N D	E M B	M A C R O	M I C R O	D E C A R B						
55.6	81.3	29			B 85							DEV RC 41				

We hereby certify that the material covered by this report has been inspected in accordance with, and has been found to meet, the requirements described herein, including any specifications forming a part of the description, and test results are on file subject to examination.

SUBSCRIBED AND SWORN TO BEFORE ME

THIS _____ DAY OF _____ 19____

NOTARY PUBLIC

MY COMMISSION EXPIRES _____

CERTIFIED MATERIAL TEST REPORT

EARLE M. JORGENSEN CO.

BY _____
STOCK RECORDS SUPERVISOR

TO
ADDRESSGeneral Electric Company
Vallecitos Nuclear Center
Vallecitos Road
Pleasanton, CA 94566TELEDYNE
WAH CHANG ALBANYP. O. BOX 460
ALBANY, OREGON 97321
(503) 926-4211 TWX (510) 595-0973

ATTENTION OF: Fernando Velez

IN REGARD TO YOUR PURCHASE ORDER NO 529-V3A20

ITEM NO 1

*DESCRIPTION Zr 2 Rod
DIMENSIONS 1/2" min. dia. x 4 to 5 ft. R/L
SPECIFICATIONS ASTM B 351-67 & P.O.

THE TEST REPORT FOLLOWS:

*Hot worked, cold finished & annealed.

DATE July 16, 1976
DATE SHIPPED Ref. P.L. # /
QUANTITY SHIPPED 2 pcs. 6.4 lbs.
PRODUCTION ORDER NO 2232
HEAT NO 397208Q Zr2
Macs No. 48601
Anneal Run No. 7835INGOT ANALYSIS
COMPOSITION IN PERCENT

	Spec.	Top	Bottom
Sn	1.20-1.70	1.50	1.53
Fe	0.07-0.20	0.15	0.17
Cr	0.05-0.15	0.10	0.11
Ni	0.03-0.08	0.05	0.06
Fe+Cr-Ni	0.18-0.38	0.30	0.34
Zr		BALANCE	

IMPURITIES IN PPM

AL	75	41	42
B	0.5	0.3	0.3
Cd	0.5	<0.2	<0.2
C	270	120	100
Co	20	<10	<10
Cu	50	13	22
Hf	200	67	67
H	25	<5	7
Mn	50	<25	<25
N	80	40	32
Si	200	64	75
Ti	50	<25	<25
W	100	<25	<25
V	3.5	<25	<25

PRODUCT CHEMISTRY, PPM

Element	Spec. Max:	1	2	3
N	80	33R, 39R	36	33
H	25	13	18	15

TENSILE TEST RESULTS @ ROOM TEMP.

	Tensile STR Psi	Yield strength (0.2% offset) Psi	Elong. in %
Spec. Min:	60,000	35,000	14
Sample			
Long. #1	80,500	54,200	24
Long. #2	80,600	54,500	24

RECEIVED

AUG 16

W. L. WALKER

A-8

al ANALYSIS
CERTIFIED BY

 Charles Kappler
 Quality Assurance Dept.

APPENDIX B
DETAILED SKETCHES OF INDIVIDUAL RACK CONTENTS

SPECIMEN RACK NO. 1

(BINARY CODE NUMBER PLACE MARKERS)

RACK NO. (BINARY) → ●

1

		ALLOY	CONDITION	REMARKS
SPECIMEN NUMBERS	D1-1	304 SS	AS-WELDED	
				(5,000)
	D1-2			
				(5,000)
	D1-3			
				(5,000)
	D1-4			
		(5,000)		
	D1-5			
		(5,000)		
	D1-6			
		(5,000)		
	EMPTY			
	D1-31	304 SS	FURNACE SENSITIZED	
				(4,440)
D1-32				
	(4,440)			
D1-33				
	(4,438)			
D1-34				
	(4,438)			
D1-35				
	(4,400)			
X				

SPECIMEN NO. D1-36
COULD NOT BE
REPAIRED AND
PRESSURIZED

**RACK NO.
(BINARY)**

SPECIMEN RACK NO. 2

2

(BINARY CODE NUMBER PLACE MARKERS)

	ALLOY	CONDITION	REMARKS
D1-7	304 SS	AS-WELDED	(4,340)
D1-8			(4,340)
D1-9			(4,340)
D1-10			(4,340)
D1-11			(4,340)
D1-12			(4,340)
EMPTY			
D1-37	304 SS	FURNACE SENSITIZED	(3,890)
D1-38			(3,900)
D1-39			(3,900)
D1-40			(3,900)
D1-41			(3,900)
D1-42			(3,900)

SPECIMEN NUMBERS

SPECIMEN RACK NO. 3

RACK NO.
(BINARY)

→ ● ●

← ◇ ◇ ◇ ◇ ◇ ◇ ◇

(BINARY CODE NUMBER PLACE MARKERS)

3

	SPECIMEN NUMBERS	ALLOY	CONDITION	REMARKS
	D1-13	304 SS	AS-WELDED	
	(4,340)			
	D1-14			
	(4,340)			
	D1-15			
	(4,340)			
	D1-16			
	(4,340)			
	D1-17			
	(4,340)			
	D1-18			
	(4,340)			
	EMPTY			
	D1-43	304 SS	FURNACE SENSITIZED	
	(3,900)			
	D1-44			
	(3,900)			
	D1-45			
	(3,900)			
	D1-46			
	(3,900)			
	D1-47			
	(3,900)			
	D1-48			
	(3,900)			

SPECIMEN RACK NO. 4

(BINARY CODE NUMBER PLACE MARKERS)

RACK NO. (BINARY) → **4**

SPECIMEN NUMBERS

	ALLOY	CONDITION	REMARKS
D1-19	304 SS	AS-WELDED	(4,340)
D1-20			(4,340)
D1-21			(4,340)
D1-22			(4,340)
D1-23			(4,340)
D1-24			(4,340)
EMPTY			
D1-49	304 SS	FURNACE SENSITIZED	(3,900)
D1-50			(3,900)
D1-51			(3,900)
D1-52			(3,900)
D1-53			(3,900)
D1-54			(3,900)

SPECIMEN RACK NO. 5

(BINARY CODE NUMBER PLACE MARKERS)

RACK NO. (BINARY) →

5

SPECIMEN NUMBERS

D1-25	(4,340)	304 SS	AS-WELDED	
D1-26	(4,340)			
D1-27	(4,340)			
D1-28	(4,340)			
D1-29	(4,340)			
D1-30	(4,340)			
EMPTY				
D1-55	(3,900)	304 SS	FURNACE SENSITIZED	
D1-56	(3,900)			
D1-57	(3,900)			
D1-58	(3,900)			
D1-59	(3,900)			
D1-60	(3,900)			

SPECIMEN RACK NO. 6

RACK NO.
(BINARY)

(BINARY CODE NUMBER PLACE MARKERS)

		ALLOY	CONDITION	REMARKS
SPECIMEN NUMBERS	D1-61	304L SS	AS-WELDED	
				(5,420)
	D1-62			
				(5,420)
	D1-63			
				(5,420)
	D1-64			
		(5,420)		
	D1-65			
		(5,420)		
D1-66				
	(5,420)			
	EMPTY			
	D1-91	304L SS	FURNACE SENSITIZED	
				(5,420)
	D1-92			
				(5,420)
	D1-93			
				(5,420)
	D1-94			
		(5,420)		
	D1-95			
		(5,420)		
	D1-96			
		(5,420)		

SPECIMEN RACK NO. 7

(BINARY CODE NUMBER PLACE MARKERS)

RACK NO. (BINARY) →

7

SPECIMEN NUMBERS

	ALLOY	CONDITION	REMARKS
D1-67	304L SS	AS-WELDED	
(4,560)			
D1-68			
(4,560)			
D1-69			
(4,560)			
D1-70			
(4,560)			
D1-71			
(4,560)			
D1-72			
(4,560)			
EMPTY			
D1-97	304L SS	FURNACE SENSITIZED	
(4,560)			
D1-98			
(4,560)			
D1-99			
(4,560)			
D1-100			
(4,560)			
D1-101			
(4,560)			
D1-102			
(4,560)			

SPECIMEN RACK NO. 8

(BINARY CODE NUMBER PLACE MARKERS)

RACK NO. (BINARY) → **8**

SPECIMEN NUMBERS

	ALLOY	CONDITION	REMARKS
D1-73 (4,560)	304L SS	AS-WELDED	
D1-74 (4,560)			
D1-75 (4,560)			
D1-76 (4,560)			
D1-77 (4,560)			
D1-78 (4,560)			
EMPTY			
D1-103 (4,560)	304L SS	FURNACE SENSITIZED	
D1-104 (4,560)			
D1-105 (4,560)			
D1-106 (4,560)			
D1-107 (4,560)			
D1-108 (4,560)			

SPECIMEN RACK NO. 9

(BINARY CODE NUMBER PLACE MARKERS)

RACK NO. (BINARY) → **9**

SPECIMEN NUMBERS

	ALLOY	CONDITION	REMARKS
D1-79	304L SS	AS-WELDED	
(4,560)			
D1-80			
(4,560)			
D1-81			
(4,560)			
D1-82			
(4,560)			
D1-83			
(4,560)			
D1-84			
(4,560)			
EMPTY			
D1-109	304L SS	FURNACE SENSITIZED	
(4,560)			
D1-110			
(4,560)			
D1-111			
(4,560)			
D1-112			
(4,560)			
D1-113			
(4,560)			
D1-114			
(4,560)			

SPECIMEN RACK NO. 10

(BINARY CODE NUMBER PLACE MARKERS)

RACK NO.
(BINARY)

10

	SPECIMEN NUMBERS	ALLOY	CONDITION	REMARKS
	D1-85	304L SS	AS-WELDED	
	D1-86			
	D1-87			
	D1-88			
	D1-89			
	D1-90			
	EMPTY			
	D1-115	304L SS	FURNACE SENSITIZED	
	D1-116			
	D1-117			
	D1-118			
	D1-119			
	D1-120			

SPECIMEN RACK NO. 11

(BINARY CODE NUMBER PLACE MARKERS)

RACK NO. (BINARY) → **11**

SPECIMEN NUMBERS

	ALLOY	CONDITION	REMARKS
D1-121	INCONEL 600	AS-WELDED	(5,130)
D1-122			(5,130)
D1-123			(5,130)
D1-124			(5,130)
D1-125			(5,130)
D1-126			(5,130)
EMPTY			
D1-151	INCONEL 600	FURNACE SENSITIZED	(4,560)
D1-152			(4,560)
D1-153			(4,560)
D1-154			(4,560)
D1-155			(4,560)
D1-156			(4,560)

SPECIMEN RACK NO. 12

(BINARY CODE NUMBER PLACE MARKERS)

RACK NO. (BINARY) → **12**

SPECIMEN NUMBERS

	ALLOY	CONDITION	REMARKS
D1-127 (5,610)	INCONEL 600	AS-WELDED	
D1-128 (5,610)			
D1-129 (5,610)			
D1-130 (5,610)			
D1-131 (5,610)			
D1-132 (5,610)			
EMPTY			
D1-157 (5,020)	INCONEL 600	FURNACE SENSITIZED	
D1-158 (5,020)			
D1-159 (5,020)			
D1-160 (5,020)			
D1-161 (5,020)			
D1-162 (5,020)			

SPECIMEN RACK NO. 13

(BINARY CODE NUMBER PLACE MARKERS)

RACK NO. (BINARY) → 13

SPECIMEN NUMBERS

	ALLOY	CONDITION	REMARKS
D1-133	INCONEL 600	AS-WELDED	(5,610)
D1-134			(5,610)
D1-135			(5,610)
D1-136			(5,610)
D1-137			(5,610)
D1-138			(5,610)
EMPTY			
D1-163	INCONEL 600	FURNACE SENSITIZED	(5,020)
D1-164			(5,020)
D1-165			(5,020)
D1-166			(5,020)
D1-167			(5,020)
D1-168			(5,020)

SPECIMEN RACK NO. 14

(BINARY CODE NUMBER PLACE MARKERS)

RACK NO. (BINARY) → **14**

SPECIMEN NUMBERS

	ALLOY	CONDITION	REMARKS
D1-139	INCONEL 600	AS-WELDED	
			(5,610)
D1-140			
			(5,610)
D1-141			
			(5,610)
D1-142			
	(5,610)		
D1-143	INCONEL 600	FURNACE SENSITIZED	
			(5,610)
D1-144			
			(5,610)
EMPTY			
D1-169			
			(5,020)
D1-170			
			(5,020)
D1-171			
	(5,020)		
D1-172			
	(5,020)		
D1-173			
	(5,020)		
D1-174			
	(5,020)		

SPECIMEN RACK NO. 16

RACK NO. (BINARY) → **16** (BINARY CODE NUMBER PLACE MARKERS)

SPECIMEN NUMBERS		ALLOY	CONDITION	REMARKS
D1-181	(5,130)	INCOLOY 800	AS-WELDED	
D1-182	(5,130)			
D1-183	(5,130)			
D1-184	(5,130)			
EMPTY				
D1-211		410 SS	3/4 HARD	BENT BEAMS 0.7% TOTAL STRAIN (0.2% YIELD STRENGTH) DURING CLEANING CYCLE.
D1-212				
D1-213				
D1-214				
D1-215				
D1-216				

SPECIMEN NOS. D1-185 AND D1-186 COULD NOT BE REPAIRED AND PRESSURIZED.

SPECIMEN RACK NO. 17

RACK NO. (BINARY)		SPECIMEN RACK NO. 17						(BINARY CODE NUMBER PLACE MARKERS)		
		17						ALLOY	CONDITION	REMARKS
SPECIMEN NUMBERS	D1-187	(4,130)						INCOLOY 800	AS-WELDED	
	D1-188	(4,130)								
	D1-189	(4,130)								
	D1-190	(4,130)								
	D1-191	(4,130)								
	D1-192	(4,130)								
	EMPTY							410 SS	3/4 HARD	BENT BEAMS 0.7% TOTAL STRAIN (0.2% YIELD STRENGTH)
	D1-217	D1-218	D1-219	D1-220	D1-221	D1-222				

SPECIMEN RACK NO. 18

RACK NO. (BINARY)		(BINARY CODE NUMBER PLACE MARKERS)						18	ALLOY	CONDITION	REMARKS
SPECIMEN NUMBERS	D1-193								INCOLOY 800	AS-WELDED	SPECIMEN NO. D1-194 COULD NOT BE REPAIRED AND PRESSURIZED.
	D1-195										
	D1-196										
D1-197											
D1-198											
	EMPTY										
	D1-223	D1-224	D1-225	D1-226	D1-227	D1-228		410 SS	3/4 HARD	BENT BEAMS UNSTRESSED DURING CLEANING CYCLE. STRAINED 0.7% (0.2% YIELD STRENGTH) AFTER CLEANING.	

SPECIMEN RACK NO. 19

RACK NO. (BINARY) →

(BINARY CODE NUMBER PLACE MARKERS)

19

SPECIMEN NUMBERS

	ALLOY	CONDITION	REMARKS	
D1-199	INCOLOY 800	AS-WELDED		
(4,130)				
D1-200				
(4,130)				
D1-201				
(4,130)				
D1-202	410 SS	3/4 HARD		
(4,130)				
D1-203				
(4,130)				
D1-204				
(4,130)				
EMPTY				
D1-229	410 SS	3/4 HARD	BENT BEAMS 0.7% TOTAL STRAIN (0.2% YIELD STRENGTH)	
D1-230				
D1-231				
D1-232				
D1-233				
D1-234				

SPECIMEN RACK NO. 20

(BINARY CODE NUMBER PLACE MARKERS)

RACK NO. (BINARY) → 20

SPECIMEN NUMBERS

	ALLOY	CONDITION	REMARKS
D1-206	INCOLOY 800	AS-WELDED	SPECIMEN NOS. D1-205 AND D1-207 COULD NOT BE REPAIRED AND PRESSURIZED.
(4,130)			
D1-208	INCOLOY 800	AS-WELDED	SPECIMEN NOS. D1-205 AND D1-207 COULD NOT BE REPAIRED AND PRESSURIZED.
(4,130)			
D1-209	INCOLOY 800	AS-WELDED	SPECIMEN NOS. D1-205 AND D1-207 COULD NOT BE REPAIRED AND PRESSURIZED.
(4,130)			
D1-210	INCOLOY 800	AS-WELDED	SPECIMEN NOS. D1-205 AND D1-207 COULD NOT BE REPAIRED AND PRESSURIZED.
(4,130)			
EMPTY			
D1-235	410 SS	3/4 HARD	BENT BEAMS UNSTRESSED DURING CLEANING CYCLE. STRAINED 0.7% (0.2% YIELD STRENGTH) AFTER CLEANING.
D1-236	410 SS	3/4 HARD	BENT BEAMS UNSTRESSED DURING CLEANING CYCLE. STRAINED 0.7% (0.2% YIELD STRENGTH) AFTER CLEANING.
D1-237	410 SS	3/4 HARD	BENT BEAMS UNSTRESSED DURING CLEANING CYCLE. STRAINED 0.7% (0.2% YIELD STRENGTH) AFTER CLEANING.
D1-238	410 SS	3/4 HARD	BENT BEAMS UNSTRESSED DURING CLEANING CYCLE. STRAINED 0.7% (0.2% YIELD STRENGTH) AFTER CLEANING.
D1-239	410 SS	3/4 HARD	BENT BEAMS UNSTRESSED DURING CLEANING CYCLE. STRAINED 0.7% (0.2% YIELD STRENGTH) AFTER CLEANING.
D1-240	410 SS	3/4 HARD	BENT BEAMS UNSTRESSED DURING CLEANING CYCLE. STRAINED 0.7% (0.2% YIELD STRENGTH) AFTER CLEANING.

SPECIMEN RACK NO. 22

RACK NO.
(BINARY)

22

(BINARY CODE NUMBER PLACE MARKERS)

	SPECIMEN NUMBERS	ALLOY	CONDITION	REMARKS
	D1-247	Zr-2	AS-RECEIVED	
	D1-248			
	D1-249			
	D1-250			
	D1-251			
	D1-252			
	EMPTY			

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↓

EMPTY

↓

SPECIMEN RACK NO. 23

RACK NO.
(BINARY)

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SPECIMEN NUMBERS

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23

(BINARY CODE NUMBER PLACE MARKERS)

SPECIMEN NUMBERS	ALLOY	CONDITION	REMARKS
D1-253	Zr-2	AS-RECEIVED	
(4,370)			
D1-254			
(4,370)			
D1-255			
(4,370)			
D1-256			
(4,370)			
D1-257			
(4,370)			
D1-258			
(4,370)			
EMPTY			

↓

EMPTY

↓

SPECIMEN RACK NO. 24

(BINARY CODE NUMBER PLACE MARKERS)

RACK NO. (BINARY) →

24

	ALLOY	CONDITION	REMARKS
D1-259	Zr-2	AS-RECEIVED	
			(4,370)
D1-260			(4,370)
D1-261			(4,370)
D1-262			(4,370)
D1-263			(4,370)
D1-264			(4,370)
EMPTY			

EMPTY

EMPTY

SPECIMEN RACK NO. 25

(BINARY CODE NUMBER PLACE MARKERS)

RACK NO.
(BINARY)

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SPECIMEN NUMBERS

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	ALLOY	CONDITION	REMARKS
D1-265	Zr-2	AS-RECEIVED	
(4,370)			
D1-266			
(4,370)			
D1-267			
(4,370)			
D1-268	↓	↓	
(4,370)			
D1-269			
(4,370)			
D1-270			
(4,370)			
EMPTY			
	↓		