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MASTER

INVESTIGATION OF PITTING CORROSION

on the

MALCOMIZED STAINLESS STEEL CONTROL ROD PUSH RODS

in the

LA CROSSE BOILING WATER REACTOR

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July 1970

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SUMMARY AND CONCLUSION

During the repair of the LACBWR control rod drive mechanical seals in January 1967 it was observed on extending the push rods that there was evidence of minor rusting and pitting on the malcomized surfaces. All of the push rods were subsequently examined and the degree of pitting recorded as reported in Sec. A, LACBWR CRD Push Rod Corrosion Discovery. An immediate cause was not identifiable. Allis-Chalmers subsequently carried out a static corrosion test program on malcomized stainless steel 304 as outlined in the January 31, 1967 letter from W. S. Farmer to W. Albert, which appears in Appendix A.

In addition, Allis-Chalmers started a push rod surveillance program. Detailed visual and photographic examinations of the surface of the malcomized push rod from CRD No. 27 (which was selected as the control) over the interval from April 1967 to September 1967 showed no further pitting or additional corrosion beyond that present when first discovered in January 1967. During this period the push rod had been continuously exposed to additional normal reactor coolant at room temperature. Pictures of the push rod examination are contained in Appendix B and discussed further in Sec. B, Monitoring of a CRD Push Rod. In March of 1969 CRD No. 4 was disassembled due to failure of a lug on the roller nut guide. While CRD No. 4 was apart the push rod was examined and pictures taken. The push rod from CRD No. 4 was found in the January 1967 examination to have been pitted to about the same extent as that of the control CRD No. 27. The push rod was found in March of 1969 to have a uniform silvery oxide coating typical of a nitrided surface exposed to water for a period of time. No significant change in the degree of pitting from that present in January 1967 was observed. The small microscopic protrusions (believed to be formed by iron oxide particles imbedded in the surface which, when they break away, form pits) previously observed were now well "burnished" as one would expect from the many times the push rod had been cycled through the stellite bushing. Pictures taken of the CRD No. 4 push rod at this time are contained in Appendix D. During the period from January 1967 to March of 1969, the push rods had been exposed to reactor coolant for a period of approximately 18 months. This included exposure at room temperature, full operating temperature (540 F) and also cycling back and forth between room and operating temperature. The control rods had been scrambled many times in this period. It was concluded that the pitting corrosion of the push rods was not progressing and its original occurrence was probably attributable to that period of CRD history during the first six months after their installation in July 1966.

A static corrosion test was conducted on specimens of 304 stainless steel which were malcomized and machined in an identical manner to the 30 CRD push rods. No correlation could be found between various methods of machining the push rod slots and pitting corrosion. No positive cause for the pitting could be determined from the tests other than the fact that the largest number of pits on the exposed malcomized stainless steel surfaces occurred when iron rust was present in the water in copious quantities.

It is known that the General Electric Company is malcomizing the index tube of the control rod drives on their large boiling water reactors. This, it is understood, has been the standard practice with all their boiling water nuclear plants beginning with Oyster Creek Unit No. 1. Nitrided type-304 stainless steel was used for the index to replace 17-4 PH (H-1100) steel because of its superior resistance to galling. To our knowledge GE has never reported any material problems with the malcomized 304 stainless steel even though they have been exposed to reactor coolant over a range of temperatures for some time now.

The General Electric Company conducted a very extensive corrosion program in the early 60's to evaluate malcomized stainless steel prior to its use above. It was found to show excellent corrosion and wear resistance. It was observed that corrosion resistance was much poorer at room temperature than at elevated temperature (350 F to 550 F) with a new unoxidized malcomized stainless steel surface. Once the oxide film was formed it was equally corrosion resistant at all temperatures. They did find that contact corrosion with pitting occurred when large amounts of rust accumulated in the water. This was also consistent with observations of minor pitting of nitrided stainless steel as reported in the Corrosion and Wear Handbook for Water Cooled Reactors.

During the first six months the LACBWR push rods were installed (July 1966 to January 1967), they were exposed to stagnant demineralized water. The reactor had been only recently filled after acid cleaning and flushing in April 1966. Hence, there was a fairly high iron corrosion product input to the reactor water from the fresh surface in the low alloy steel forced circulation loop. The water in the drives was largely stagnant. Thus, water conditions appear to have been optimum for pitting corrosion, i.e., stagnant water, room temperature, large amounts of rust present. The pits are believed to have arisen as a result of rust accumulation on the push rod surface with small particles of iron oxide being possibly imbedded in the push rod surface galvanically or by the action of the push rod passing through the stellite bushing. Whenever these small iron oxide protuberances break away they could leave a pit or crater behind. Another source of iron oxide particles could have been contamination from the aluminum oxide abrasive removal of the outer malcomized skin of the push rods. At this time, it is not possible to identify positively the specific source of the iron oxide particles which are believed to have caused the pitting.

The CRD push rod pitting corrosion appears to no longer be a problem. The extent to which it has occurred in the past in no way inhibits the present functioning of the control rod drives or affects their future mechanical and structural integrity. It would probably be advisable to periodically remove a push rod if a convenient occasion arises and check the condition of the malcomized surface. However, a plant shutdown for scheduled removal for this purpose does not appear warranted. It would be advisable in order to minimize corrosion problems in the future to keep the drives flushed and free of iron crud as much as possible at all times.

A. LACBWR CRD PUSH ROD CORROSION DISCOVERY

During the repair of the LACBWR CRD mechanical seal assembly in January 1967, it was observed that pitting corrosion had occurred on the exposed upper end of some of the push rods. It was decided to inspect the upper portion of each of the push rods in order to determine the extent of the pitting. This inspection showed that pitting corrosion had occurred in each of the push rods except the prototype. The prototype was not installed in the reactor at this time and hence had only been exposed to a water environment at Royal Industries in the testing program. The extent of the pitting on the 29 production run models varied with each push rod with these general observations:

1. The number of pits varied significantly with each push rod.
2. The pits varied in size (cross-sectional area).
3. The pits on most push rods were randomly spaced, both along the length and around the circumference of the push rods.
4. Corrosion was evident primarily at areas where a cutting or machining operation was performed, such as at the slots and at the juncture of the push rod and latch assembly.
5. The push rods which had the most pits were not located in a particular pattern with respect to the control rod drive array.
6. An average pit appeared to be on the order of 5 mils deep (measurements could not be made to verify this) and 10 mils in diameter.
7. The pits had a reddish brown color typical of iron oxide.
8. The bare (not malcomized) stainless steel slots of the push rods were rusted.

At the same time as the inspection of the push rods was being performed the other control rod drive internals were also examined. This was done by removing the brake, bearing and mechanical seal from each drive and observing the inside of the mechanisms under illumination. There was no evidence of corrosion attack in any location in the control rod drives with the exception of the push rods. All 30 control rod drives were examined.

The following specific observations were noted for each of the 30 control rod drive push rods during the inspection in January 1967:

- CRD No. 1 (Serial No. A-C 21) Amount of pitting was almost negligible. The pits that were present were widely scattered and were not oriented in a particular pattern.
- CRD No. 2 (Serial No. A-C 12) Numerous pits were evident on this rod. The pits were not oriented in a particular pattern.
- CRD No. 3 (Serial No. A-C 30) Very few pits observed on this rod. The majority of the pits were on the upper 3 in. of the rod. The pits were not oriented in a particular pattern.
- CRD No. 4 (Serial No. A-C 2) Numerous pits were evident. One 60° longitudinal sector, however, seemed to be free of any attack.
- CRD No. 5 (Serial No. A-C 15) Medium number of pits which were primarily in two 30° longitudinal sectors at 180° to each other.
- CRD No. 6 (Serial No. A-C 23) Medium amount of pitting. The pits were scattered and were not oriented in a particular pattern.
- CRD No. 7 (Serial No. A-C 8) Medium amount of pitting with indications scattered and not oriented in a particular pattern.
- CRD No. 8 (Serial No. A-C 20) Medium pitting but the pits were larger than usual. Pits were randomly located.
- CRD No. 9 (Serial No. A-C 5) Medium pitting with larger than average pits. Indications were not oriented in a particular pattern.
- CRD No. 10 (Serial No. A-C 22) Medium pitting. Pits were randomly spaced over the observed portion of the rod.
- CRD No. 11 (Serial No. A-C 10) Medium amount of pitting with the pits randomly spaced.
- CRD No. 12 (Serial No. A-C 18) Very light pitting. The pits were widely scattered and were not oriented in a particular pattern.
- CRD No. 13 (Serial No. A-C 13) Medium pitting with pits larger in size than usual. Pits were randomly spaced over the observed length.
- CRD No. 14 (Serial No. A-C 7) Very light pitting with pits widely scattered. Pits were randomly oriented.

- CRD No. 15 (Serial No. A-C 25) Numerous pits were evident particularly in the upper 3 in. The size of the pits was larger than usual and the pits were randomly oriented.
- CRD No. 16 (Serial No. A-C 27) Numerous pits were evident. The size of the pits was larger than usual. The pits were scattered and were not oriented in a particular pattern.
- CRD No. 17 (Serial No. A-C 26) Very light pitting. Most of the pits are confined to a 90° longitudinal sector. Size of pits is larger than usual.
- CRD No. 18 (Serial No. A-C 11) Medium pitting. Most of the pits were in a 180° longitudinal sector with the other half of the rod almost unmarked.
- CRD No. 19 (Serial No. A-C 3) Very light pitting. Indications were random and widely scattered.
- CRD No. 20 (Serial No. A-C 29) Numerous pits were evident, especially at the top. Elsewhere, the pits were randomly oriented.
- CRD No. 21 (Serial No. A-C 6) Very light pitting with the majority of the pits located near the top. Pits were randomly oriented and widely scattered.
- CRD No. 22 (Serial No. A-C 19) Amount of pitting was almost negligible. Pits that were present were widely scattered and were not oriented in a particular pattern.
- CRD No. 23 (Serial No. A-C 20) Medium pitting with larger pits than usual. Pits were randomly oriented.
- CRD No. 24 (Serial No. A-C 4) Medium pitting. The pits were randomly located and were not oriented in a particular pattern.
- CRD No. 25 (Serial No. A-C 24) Very light pitting. Pits are randomly oriented and widely scattered.
- CRD No. 26 (Serial No. A-C 28) Almost no indications in the portion observed. Indications were small and widely scattered.
- CRD No. 27 (Serial No. A-C 9) Numerous pits were evident in this rod, particularly in one 90° longitudinal sector. Pits were randomly spaced.

- CRD No. 28 (Serial No. A-C 16) Medium pitting. The pits were randomly oriented throughout the area observed.
- CRD No. 29 (Serial No. A-C 14) Very light pitting. Pits were widely scattered and randomly oriented.
- Prototype (Serial No. A-C 1) This rod was observed down to the first row of slots. There was no evidence of any type of rust on the outer surfaces or in the slots.

The following table classifies each drive according to the amount of pitting observed:

<u>Extensive Pitting</u>	<u>Moderate Pitting</u>	<u>Negligible Pitting</u>
CRD No. 2	CRD No. 5	CRD No. 1
CRD No. 4	CRD No. 6	CRD No. 3
CRD No. 15	CRD No. 7	CRD No. 12
CRD No. 16	CRD No. 8	CRD No. 14
CRD No. 20	CRD No. 9	CRD No. 17
CRD No. 27	CRD No. 10	CRD No. 19
	CRD No. 11	CRD No. 21
	CRD No. 13	CRD No. 22
	CRD No. 18	CRD No. 25
	CRD No. 23	CRD No. 26
	CRD No. 24	CRD No. 29
	CRD No. 28	Prototype

On January 31, 1967, a letter explaining the above observations and a course of action was submitted by W. S. Farmer, of Allis-Chalmers, Bethesda, Maryland, to W. G. Albert, of the AEC-COO. The primary course of action as stated in the above letter was to monitor one of the CRD push rods to determine if the pitting corrosion was continuing. A second parallel course of action outlined in this letter was to conduct a static corrosion test program using samples malcomized by the same process as the push rods. The third course of action was to conduct a literature search in an attempt to determine what would cause the type of corrosion observed on the push rods.

B. MONITORING OF A CRD PUSH ROD

1. Discussion

The primary purpose of this phase of the program was to determine if the corrosion of the push rods was continuing with time. By monitoring one of the push rods with extensive pitting, it should be possible to determine if the corrosion has stopped. If it was continuing, it would give some idea of the rate that pitting and corrosion was increasing. For this phase of the program, CRD No. 27 (A-C 9) push rod was chosen as the rod to be monitored. CRD No. 27 push rod had numerous pits and was felt to be representative of the push rods which were most affected as determined by the inspection in January 1967 (see Sec. A). It was selected over the others in its category of "extensive pitting" because of its outside position in the CRD array, thereby making it less of a problem to later remove for visual examination and photographing.

It was decided to extend the push rod and photograph the areas of interest so that they could be compared to photographs of the same areas taken at a later date. (The specific area photographed was indexed as stated in Appendix B.) In this manner, it was reasoned that the number and size of the pits could be permanently recorded at this point in time and could be compared to the same area at any future date. In addition, a visual examination would be used to determine if the depth of the pits had increased.

2. Results

The first set of photographs of CRD No. 27 push rod was taken in April 1967. The photographs and description are included in Appendix B of this report. A second set of photographs was taken in September 1967, and they are also included along with a description in Appendix B.

The photographs when compared showed no increase in the number of pits in the areas photographed. Secondly, by comparing the photographs it can be seen that the size (cross-sectional area) of the pits had not increased. Finally, it was observed (although it was impractical to verify by actual measurements) that the depth of the pits was still not significant and by best estimates had not changed in the five months following April 1967.

The photographs taken in April 1967 were at a time in the life of the control rod drives when the drives had not been subjected to a significant number of scram or shim cycles at LACBWR. In the subsequent five months, or up until the time the second set of photographs was taken, the drives were operated frequently during preoperational testing and the low power test program. This additional operation probably contributed in part to the fact that the push rod appeared to be much cleaner in September than in April (see photographs in Appendix A). The passage of the push rod through the upper bushing produces a wiping action thus tending to remove any rust or other particles from the push rod external surface.

3. Conclusions

On the basis of the photographs taken and the visual observations made of CRD No. 27 push rod, it was concluded that corrosion of this push rod was not continuing. It was felt that the five months between the first and second sets of photographs represented sufficient time to have anticipated seeing some indication that additional corrosion had occurred.

Despite the fact that no additional corrosion had occurred in five months, it was still not obvious what had caused the initial pitting or even when it had occurred.

Water quality and circulation in the control rod drive upper housing was maintained under closer control during the period April 1967 to September 1967 than had been the case during July 1966 to January 1967. This, plus the wiping action of the stellite bushing on the moving push rod, minimized iron crud formation on the push rod surface during the April to September 1967 period.

C. LITERATURE SEARCH

1. Discussion

A literature search was initiated for data on the corrosion behavior of nitrided (malcomized) stainless steel in reactor water. Phone discussions were also held with Lindberg Steel Treating Company, Los Angeles, California, who performed the malcomizing operation for the Royal Industries LACBWR push rods. An effort was made to locate published corrosion test data. The history of the push rod fabrication at Royal Industries was also reviewed.

2. Results

In telephone conversations with representatives of Lindberg Steel Treating Company, an effort was made to obtain information on possible causes for the type of pitting corrosion shown on the CRD push rods. When the Lindberg representatives were told that there was free iron or iron oxide suspended in the water they expressed the opinion that this condition could possibly have caused the pits but that it was unlikely that suspended iron oxide by itself was the cause. They expressed the opinion that if carbon steel particles had become imbedded in the outer surface of the push rods subsequent to malcomizing, either during abrasive removal of the "skin" or during handling, they would probably result in pitting.

Extensive testing of malcomized stainless steel has been performed by General Electric Company in connection with its use in the index tubes of their control rod drives. The purpose of their testing was to determine whether the wear and corrosion resistance of malcomized 304 stainless steel was adequate for nuclear service.

Over 500 test specimens were corrosion tested for a 3000-hr period to evaluate the effects of various surface treatments, the effects of applied stress, contact corrosion, and the effects of exposure temperature. In addition, wear tests were also performed on a large number of specimens. The following conclusions were reported as a result of these tests:

a. Type-304 malcomized stainless steel (0.005-in. case) showed outstanding wear resistance. It was found to be at least 20 times as resistant to wear as bare 17-4 PH (H-1100) steel.

b. Impact loads can cause chipping of the malcomized case if the loads are high enough to deform the base metal.

c. Liquid honing and pre-oxidation are recommended as surface treatments for all malcomized parts used in boiling water reactors. These surface treatments provide the maximum protection against both general and contact corrosion. The corrosion

resistance of liquid honed and pre-oxidized test pieces is quite adequate for nuclear reactor service. A corrosion rate of 0.0001 in./yr was the maximum measured even in low temperature water which results in the highest corrosion rate.

d. It was found that the most severe corrosion occurred in low temperature (room temperature and 190 F) water. Exposure at 350 F and 550 F produced a protective oxide film which inhibited corrosion.

e. The effects of the various surface treatments on general corrosion were:

- (1) Liquid honing and pre-oxidation were beneficial.
- (2) Diffusion of the malcomized case was detrimental.
- (3) Surface roughness and sodium dichromate passivation had no effect.

f. Stress corrosion cracking of test specimens stressed over their elastic limit did not appear to be a problem.

g. The surface treatments which were beneficial for general corrosion resistance also provided the most resistance to contact corrosion. Contact corrosion did not occur on liquid honed and pre-oxidized specimens at any test temperature when they were exposed in refreshed, high purity water. Contact corrosion did occur in static "bucket" tests where large amounts of rust and crud accumulated in the water and on the test specimens. The most severe contact corrosion occurred in 350-F water. Pitting was also observed in these tests.

The function of the liquid honing operation is to remove approximately 0.2 mil of the gray surface layer ("skin") of the "as-malcomized" piece. This operation was performed on the LACBWR CRD push rods with aluminum oxide paper.

The pre-oxidation operation is performed by exposing the malcomized stainless steel to high temperature (500 - 550 F) water which produces a protective black silvery oxide surface. Almost no further corrosion occurs at this temperature. The oxide film confers some corrosion resistance to the malcomized part at low temperature (room temperature to say 200 F) for some undetermined period. The LACBWR CRD push rods were not pre-oxidized.

A search was made of other available technical literature. No information could be found in the literature which would suggest that malcomized 304 stainless steel was not satisfactory for the LACBWR environment. In addition, the literature search failed to uncover any evidence that malcomized 304 stainless steel had incurred significant corrosion attack in any operating reactors. Some of the early corrosion test work is reported in TID-7006, Corrosion and Wear Handbook for Water Cooled Reactors, by DePaul.

The history of the prototype push rod was reviewed to determine if there was any evidence of corrosion during the prototype test program. The results from the inspection of the prototype push rod at the completion of testing are described in Amendment 12 to the Application of the Allis-Chalmers Manufacturing Company for Construction Authorization of the La Crosse Boiling Water Reactor, Docket 115-5 (ACNP-65611), RS-8623-R-113, Rev. A, page 7. It states there that there was no evidence of corrosion, chipping or cracking and that the wear was well within acceptable limits.

The history of the prototype push rod is reviewed below. It was modified, due to problems encountered during development. Because of spalling of the nickel plate and delayed scram times the push rod was changed from a nonslotted electroless nickel plated tube to a slotted malcomized tube. The push rod OD operating clearances were increased to make them less wear-particle sensitive. The prototype push rod was chemically stripped of its nickel plate and then passivated before it was malcomized. This process was a nitric acid passivation followed by a thorough washing with distilled or de-ionized water. The push rod was then malcomized and hard polished with aluminum oxide paper to remove the "skin." Following this, the push rod was slotted by grinding and then cleaned with acetone and distilled or de-ionized water. The final design of the push rod is shown in Allis-Chalmers Dwg. No. 41-503-256, which is attached.

The fabrication history of the production push rods was identical to that of the prototype push rod above with only one exception, the method of making the slots. The slots were made by a process called electrical discharge machining. In this process, a water-free and very low sulfur content oil, continuously filtered to 4 microns particle size, floods the work and removes the electrically eroded "chips." Following this operation, the oil was removed by vapor degreasing.

3. Conclusions

There is no available data indicating that malcomized 304 stainless steel is susceptible to extensive corrosion attack in a water cooled nuclear reactor environment such as at LACBWR. The available literature shows nitrided stainless steel to possess good corrosion resistance. There are a few cases reported where nitrided stainless steel has shown a susceptibility to pitting in contact corrosion tests when foreign iron oxide has been present on the malcomized surface.

D. STATIC CORROSION TEST PROGRAM

1. Discussion

In order to try to evaluate the basic cause of the pitting corrosion observed on the LACBWR push rods, Allis-Chalmers decided to set up a static corrosion test program. In general, two basic factors were assumed to be related to the causes of the corrosion. One factor was the condition of the push rod surface material and the second was the specific water environment to which the LACBWR push rods had been exposed.

In order to determine if the cause of the push rod corrosion was related to the quality of the LACBWR reactor water, it was decided to test specimens in solutions of LACBWR water containing suspected contaminants known to have been present in the water at one time or another in the period from July 1966 to January 1967. Rust was one of the suspected contaminants, so rust products which had accumulated on the LACBWR core plugs were obtained from the LACBWR site to be used in the tests. Another possible source was demineralizer resins (there had been a minor accidental release of resins to the primary coolant during this period), so a small quantity of the resins was also procured. In addition, demineralized water actually used in the LACBWR reactor was obtained for use in the tests.

It was desired also to factor into the tests the condition of the push rod material surface. As mentioned before, the prototype push rod had experienced no pitting corrosion while all of the production push rods had experienced pitting to various degrees. On this basis, all fabrications operations which were performed on the production push rods and which were also performed on the prototype push rod were not considered to be probable causes of the pitting. The only operation performed on the prototype push rod and not performed on the production models was the method of slotting. The slots in the prototype push rod were made by grinding and showed no evidence of corrosion. The production push rods were slotted by a process called electrical discharge machining. In this process, a water-free and very low sulfur content oil, continuously filtered to 4 microns particle size, floods the work and removes the electrically eroded "chips." The oil is removed by vapor degreasing when slotting is completed. Rusting was evident in the push rod slots that were made by electrical discharge machining; therefore, it was decided to slot part of the samples by each of the two methods.

Identical material, annealed 304 stainless steel tubing, was obtained and used in all tests. The cross section of the tubing was 2-in. OD by 0.25-in. wall, which closely approximated the actual push rod dimensions. The tube was cut into pieces, each 4 in. long, and all of the individual tubes were sent to Lindberg Steel Treating Company to be malcomized in accordance with the same procedure used to malcomize the original push rods. After malcomizing was completed, a portion of the samples was sent to Electronic Machining Company, 2210 East Walnut Street, Pasadena, California 91107, for slotting by electrical discharge machining. The above company was chosen

because it had performed the slotting of the LACBWR CRD push rods. Cleaning was performed with acetone followed by a demineralized water rinse and drying. The samples were then sent to Wilks Precision Instrument Company, Rockville, Maryland, for abrasive removal of the outer "skin" which is formed in malcomizing. Removal of the outer "skin" was performed with aluminum oxide paper, as was done at Royal Industries on both the prototype and production push rods. Another portion of the tubes, after malcomizing, was sent to Wilks Precision Instrument Company for grinding of the slots and abrasive removal of the outer "skin." Out of this lot, three tubes were not slotted, but had only the outer "skin" abrasively removed.

At Lindberg Steel Treating Company, the samples were annealed for 20 min at 1950 F and water quenched. They were then malcomized for a sufficient time to obtain a case depth of 0.006 in. The final inspection indicated a resultant hardness as shown in the table below.

MICRO-HARDNESS TEST RESULTS

<u>Depth, in.</u>	<u>Filars</u>	<u>Knoop</u>	<u>Rockwell C</u>
0.001	55.0	940.8	68.9
0.002	56.5	891.2	66.8
0.003	60.0	790.4	62.6
0.004	57.5	860.8	65.5
0.005	57.5	860.8	65.5
0.006	55.0	940.8	68.9
0.007	87.5	371.6	37.1
Core	119.0	201.0	R/B 90

On August 31, 1967, 27 of the malcomized stainless steel samples were placed in solution in glass containers. The following is a summary of the type of samples and solutions used:

- Sample No. 1 Malcomized 304 stainless steel sample slotted by electrical discharge machining and tested in LACBWR demineralized water.
- Sample No. 2 Same as sample No. 1.
- Sample No. 3 Same as sample No. 1.
- Sample No. 4 Malcomized 304 stainless steel sample slotted by grinding and tested in LACBWR demineralized water.
- Sample No. 5 Same as sample No. 4.
- Sample No. 6 Same as sample No. 4.

- Sample No. 7 Malcomized 304 stainless steel sample slotted by electrical discharge machining and tested in LACBWR demineralized water containing rust.
- Sample No. 8 Same as sample No. 7.
- Sample No. 9 Same as sample No. 7.
- Sample No. 10 Malcomized 304 stainless steel sample slotted by grinding and tested in LACBWR demineralized water containing rust.
- Sample No. 11 Same as sample No. 10.
- Sample No. 12 Same as sample No. 10.
- Sample No. 13 Malcomized 304 stainless steel sample slotted by electrical discharge machining and tested in LACBWR demineralized water containing cation bed resin beads.
- Sample No. 14 Same as sample No. 13.
- Sample No. 15 Same as sample No. 13.
- Sample No. 16 Malcomized 304 stainless steel sample slotted by grinding and tested in LACBWR demineralized water containing cation bed resin beads.
- Sample No. 17 Same as sample No. 16.
- Sample No. 18 Same as sample No. 16.
- Sample No. 19 Malcomized 304 stainless steel sample slotted by electrical discharge machining and tested in LACBWR demineralized water containing mixed bed resin beads.
- Sample No. 20 Same as sample No. 19.
- Sample No. 21 Same as sample No. 19.
- Sample No. 22 Malcomized 304 stainless steel sample slotted by grinding and tested in LACBWR demineralized water containing mixed bed resin beads.
- Sample No. 23 Same as sample No. 22.
- Sample No. 24 Same as sample No. 22.

- Sample No. 25 Unslotted malcomized 304 stainless steel sample tested in LACBWR demineralized water.
- Sample No. 26 Unslotted malcomized 304 stainless steel sample tested in LACBWR demineralized water containing rust.
- Sample No. 27 Unslotted malcomized 304 stainless steel sample tested in LACBWR demineralized water containing cation bed and mixed bed resin beads.

The samples were monitored periodically to determine if there were any significant changes occurring. The samples remained in their glass test containers up until January 31, 1968 for an elapsed exposure time of five months.

(All samples were turned over to DPC during plant turnover in November 1969.)

2. Results

On September 1, 1967, one day after the test was initiated, minor rusting was noted on practically all of the samples. The rust, however, was forming at the periphery of the slots and at the bottom and top edges of the samples. It was suspected that these areas had carbon steel contamination from cutting the tube into specimens. Five of the samples showed no evidence of corrosion. These were samples 4, 5, 10, 11, and 12.

At various times during the month of September it was noted that the amount of surface rust formation was still increasing. On September 29, 1967, approximately one month after the test was initiated, no significant increase in the amount of rust was apparent. On November 14, 1967, the samples were rechecked and it was apparent that the rust formation on the surfaces had not increased. On January 24, 1968, a complete recheck was made of all samples and again showed no further increase in rust formation. It was therefore decided to conclude the testing on the basis that the samples had undergone as much exposure as the push rods prior to the discovery of the pitting and that there appeared to be no further increase in corrosion with time.

The following is a general description of the appearance of each of the samples after they were removed from their glass containers at the end of the test:

- Sample No. 1 Slot rusted, top and bottom surfaces rusted, surfaces silvery in color, and no evidence of pitting.
- Sample No. 2 Slot rusted, top and bottom surfaces rusted, surfaces silvery in color, and no evidence of pitting.
- Sample No. 3 Slot rusted, top and bottom surfaces rusted, surfaces silvery in color, and no evidence of pitting.

- Sample No. 4 Slot and top surface not rusted, bottom surface rusted, surfaces silvery in color, and no evidence of pitting.
- Sample No. 5 Slot and top surface not rusted, bottom surface rusted, surfaces silvery in color, and no evidence of pitting.
- *Sample No. 6 Slot and top surface not rusted, bottom surface rusted, and one pit is present.
- Sample No. 7 Slot rusted, top and bottom surfaces rusted, surfaces black and rusty in color, and no evidence of pitting.
- Sample No. 8 Slot rusted, top and bottom surfaces rusted, surfaces silvery in color, and no evidence of pitting.
- Sample No. 9 Slot rusted, top and bottom surfaces rusted, surfaces black and rusty in color, and no evidence of pitting.
- *Sample No. 10 Slot rusted, top and bottom surfaces rusted, surfaces over the lower third black and rusty in color, and over the top two-thirds are silvery in color, and one pit is present.
- Sample No. 11 Slot rusted, top and bottom surfaces are rusted, surfaces are silvery in color and no evidence of pits.
- Sample No. 12 Slot rusted, top and bottom surfaces are rusted, the surfaces are black in color, and there is no evidence of pits.
- Sample No. 13 Slot rusted, top and bottom surfaces are rusted, and the surfaces are black and rusty in color, and there is no evidence of pitting.
- Sample No. 14 Slot rusted, top and bottom surfaces rusted, surfaces black and rusty in color, and no evidence of pitting.
- *Sample No. 15 Slot rusted, top and bottom surfaces rusted, surfaces are black and rusty in color, and there is one pit.
- *Sample No. 16 Slot rusted, top and bottom surfaces rusted, 80 percent of the surface area is black and rusty, 20 percent is silvery in color, and there is one pit.
- Sample No. 17 Slot rusted, top and bottom surfaces rusted, 80 percent of the surface area is black and rusted, 20 percent is silvery in color, and there is no evidence of pitting.

*Denotes samples in which pitting occurred.

- *Sample No. 18 Slot is rusted, top and bottom surfaces are rusty, the surfaces are black and rusty in color, and there is one pit.

- Sample No. 19 Slot is rusty, top and bottom surfaces are not rusted, 5 percent of the surface area is black, and 95 percent is silvery in color, and there is no evidence of pits.

- Sample No. 20 Slot is rusted, top and bottom surfaces are not rusted, surface area is silvery in color, and there is no evidence of pitting.

- Sample No. 21 Slot is rusted, top and bottom surfaces are not rusted, 5 percent of the surface area is black, and the other 95 percent is silvery in color, with no evidence of pitting.

- Sample No. 22 Slot is not rusted, top and bottom surfaces are rusted, 5 percent of the surface area is black, and 95 percent is silvery in color, and there is no evidence of pitting.

- *Sample No. 23 Slot is not rusted, top and bottom surfaces are not rusted, 5 percent of surface area is black, and other 95 percent is silvery in color, with one pit.

- *Sample No. 24 Slot is not rusted, top and bottom surfaces are not rusted, 5 percent of surface area is black, and other 95 percent is silvery in color, with one pit.

- Sample No. 25 Top and bottom surfaces are rusted, surfaces are silvery in color, with no evidence of pitting.

- *Sample No. 26 Top and bottom surfaces are rusted, bottom third of surface area is black and rusty and top two-thirds is silvery in color, with a total of five pits.

- Sample No. 27 Top and bottom surfaces are rusted, 20 percent of surface area is black and the other 80 percent is silvery in color, with no evidence of pitting.

*Denotes samples in which pitting occurred.

The following are general observations which are evident from the data:

a. In all 12 cases where samples were slotted by electrical discharge machining, there is evidence of rusting at the unmalcomized slots.

b. In all but five of the 27 samples, there was evidence of rusting at either the top or bottom surfaces where a cutting operation was performed.

c. In 27 samples, seven had one pit each and one had five pits. The pitting could not be attributed to any particular preparation of the sample. The largest number of pits (five) was on the surface of the sample exposed to water "salted" with rust (Sample No. 26).

d. In all six cases where the medium included cation bed resins, the surfaces were both black and rusted.

e. In all six cases where mixed bed resins were in the water, the surfaces were partially black with no evidence of rust.

f. In all seven cases where the medium was demineralized water only, there was no evidence of the black surface.

g. In five of the seven cases where rust was in the water, the surfaces became black and rusty in color. As noted above, the sample with the largest number of pits was in this category.

h. The sample which had the five pits was the one used to recheck the hardness to verify the malcomized surface. The pit marks are believed to have occurred at areas where indentations were made to check the hardness and may have been due to carbon steel contamination. The pits on the other samples could not be identified with a specific cause.

i. Generally, the samples which were slotted by grinding exhibited less rusting than the samples slotted by electrical discharge machining.

After the corrosion samples were removed from their glass containers, they were photographed after sitting a sufficient period to permit the samples to dry. The samples were then cleaned with demineralized water and clean rags (no cleaning fluids were used) to remove any rust or dirt clinging to their external surfaces. The samples were then photographed again in the "cleaned" condition. The photographs and their description are included in Appendix C of this report.

3. Conclusions

The most striking observation from the testing was the relatively higher rusting in the slots of the samples slotted by electrical discharge machining compared to those slotted

by grinding. It would appear that the electrical discharge machining process deposits corrodents at the slots which cannot be readily removed by cleaning the area with acetone followed by a demineralized water rinse. This may explain the similar behavior observed at the slots in the photographs of CRD No. 27 push rod shown in Appendix A. This is best seen in the photographs taken in April 1967.

Another significant observation is the behavior of the samples tested in plain demineralized water. The corrosion resistance of these samples was very good. It would appear from these tests that uncontaminated demineralized water can be eliminated as a cause of the pitting corrosion. The performance of the samples in demineralized water containing mixed bed resins was also very good. There was no formation of rust occurring on these samples but the black oxide was beginning to form on most samples to varying degrees. The mixed bed resins present in the water at the time therefore were not considered to be detrimental to the corrosion resistance of the malcomized stainless steel.

The solutions containing rust and cation bed resins however provided a more severe corrosive environment. On five of the seven samples in the rust solution and all six of the samples in the cation bed resins solution there was rust and black oxide formations on the surfaces. After cleaning was performed on these samples, it became obvious that the rust formation was not necessarily detrimental other than from the standpoint of crud formation. On all samples it was a very easy matter to remove the rust by wiping the sample with clean rags and demineralized water. On removal of the rust there is a black oxide formation remaining and this coating apparently inhibits further corrosion. It was concluded that in actual operation of the drives where there is a continuous flow of water past the push rod there would be little chance of rust being built up on the push rod surfaces. It was recognized however that contamination of the water with rust and/or resins was to be avoided if at all possible even though their presence could not be positively identified as the cause of the pitting corrosion experienced on the push rods.

As for the cause of the pitting, it was not possible from the static corrosion testing to state that any of the variables factored into the program is absolutely responsible. Out of the 27 samples tested, a total of eight samples experienced at least one pit, neglecting the immediate area around the periphery of the slots and the top and bottom edges of the sample. Seven of the eight samples had only one pit while one sample (No. 26) had five pits. The pits on No. 26 however can be noted to have occurred in the same locations where hardness checks were made and may be the result of carbon steel contamination. The hardness was checked on this sample previous to corrosion testing in order to verify the existence of the malcomized case. The pits on the other samples could not be laid to a specific cause. The following table illustrates this:

Variable	<u>Samples Pitted</u>	<u>Samples Not Pitted</u>
Electric Discharge Machining of Slots	1	11
Grinding of Slots	6	6
Not Slotted	1	2
Demineralized Water Solution	1	6
Demineralized Water and Rust Solution	2	5
Demineralized Water and Cation Bed Resin Solution	3	4
Demineralized Water and Mixed Bed Resin Solution	2	5

On the basis of these results, it does not seem likely that the pitting can be associated with the method of slotting the sample. It seems more likely that the pitting is the result of contamination occurring during the abrasive removal of the "skin" or is introduced by exposure to rusty water. The amount of pitting experienced in the corrosion test was small compared to the actual push rod corrosion.

E. OBSERVATIONS

As a result of the corrosion program described in Secs. B and D of this report, it is possible to tabulate a number of observations as to the probable cause of the push rod pitting. In this section of the report, these observations are stated along with related information from other sections of the report. The observations are as follows:

1. It is concluded that malcomized 304 stainless steel is reasonably corrosion resistant to demineralized water at room temperature when good water quality control is maintained.

a. The prototype push rod was inspected after prototype testing in demineralized water was completed. (See Amendment 12 to the Application of the Allis-Chalmers Manufacturing Company for Construction Authorization of the La Crosse Boiling Water Reactor, Docket 115-5.) There was no evidence that any rusting or pitting had occurred. The prototype push rod was again inspected in January 1967 at the LACBWR site to reconfirm this condition and again there was no evidence of pitting or other types of corrosion.

b. CRD No. 27 push rod was photographed in April 1967, and again in September 1967. There was no evidence that additional pitting or corrosion had occurred in this span of time (see Appendix B) during which water quality was maintained.

c. A literature search disclosed no information which would refute the conclusion that malcomized 304 stainless steel is corrosion resistant in a demineralized water environment with proper water quality control.

d. The static corrosion test program conducted by Allis-Chalmers produced results indicating that the static corrosion resistance of the malcomized 304 stainless steel was very good in plain demineralized water. The only significant area of rusting in these tests was in the immediate area of those slots made by electrical discharge machining.

2. It is concluded that demineralized water containing rust and/or resins can cause malcomized 304 stainless steel to rust slightly in room temperature water. It is also concluded that the amount of corrosion will not be sufficient to preclude the use of malcomized 304 stainless steel in such an environment.

a. Lindberg Steel Treating Company, who performed the push rod malcomizing, indicated that rust might possibly be the cause of the pitting corrosion observed on the push rods.

b. Corrosion testing results indicate that rusting of the malcomized surfaces can occur when the water to which it is exposed is contaminated with rust

and/or cation bed resins. The rust is easily removed by water and the resulting surface, in general, is found to be covered with a black oxide film. Mixed bed resins had no detrimental effect, and produced a partial black oxide surface on the samples.

3. It is concluded that electrical discharge machining of the slots makes the surface susceptible to rusting at the periphery of the slots. It is also concluded that the degree of rusting is not detrimental to the corrosion resistance in areas remote from the slots.

a. The prototype push rod had slots which were made by grinding and showed no evidence of rusting. All 29 production push rods had slots made by electrical discharge machining and they all experienced rusting to varying degrees.

b. It is apparent from the static corrosion tests performed that a significant amount of rusting occurs at the periphery of the slots made by electrical discharge machining. It is not apparent however from the corrosion tests that the bare stainless steel in the slots has rusted. As for pitting, in the corrosion tests, six out of the seven samples which were pitted had slots made by grinding.

c. The photographs in Appendix B also show a significant amount of rusting, both in and at the periphery of CRD No. 27 slots. The photographs also show that pitting is occurring at points remote (3 ft) from the slots.

4. It is believed that the factor most probably causing the pitting is the presence of iron oxide that may have been deposited on the push rods prior to their installation in the control rod drive mechanism or iron oxide particle deposition during the push rod exposure to stagnant rusty water early in their history at LACBWR (1966).

a. Observation of CRD No. 27 push rod indicates that there was no continuation of the pitting occurring after April 1967. Better water quality was maintained during the period of exposure after April 1967. Frequent use of the control rods would have wiped crud off the push rod during the period of observation from April to September 1967.

b. During the period July 1966 to January 1967, following control rod installation, both the seal injection system and forced circulation pumps were used very intermittently and then only for short periods. Hence, iron oxide from accelerated oxidation of the fresh surfaces of the alloy steel forced circulation piping could be circulated to the reactor vessel. Without the seal injection system operating, microscopic rust particles could settle into the stagnant water in the control rod upper drive units. Although the main purification system was operating at this time, the restricted passages between the

control rod drives and the reactor vessel would minimize cleanup of the water in the "dead-leg" in the drives.

c. The pits observed on all push rods were randomly distributed.

d. Using all available suspected contaminants thought to have been present in the reactor, it was not possible during static corrosion testing to duplicate the extent of pitting on the push rods.

e. The flocculent nature of the rust formation on the push rods could possibly act as a trap for microscopic floating iron oxide particles. Subsequent movement through the stellite bushing could imbed the particles in the surfaces.

f. During the cleaning operation in January 1967, at the time the push rod corrosion was initially discovered, a visual examination of the other control rod drive internals was made. On the basis of this examination, it was concluded that no corrosion was occurring on these other components, the major portion of which were fabricated of type-304 stainless steel. In general, the various corrosive media which attack malcomized stainless steel will also attack plain stainless steel. The exceptions to this rule, as published in Lindberg Steel Treating Company literature, are concentrated solutions of acetic, nitric, or sulphuric acids. It seems likely therefore that had the drives been subjected to a corrosive solution at LACBWR then the plain 304 stainless steel would also have experienced some corrosion. Hence, hideaway of cleaning solution was discounted.

g. During the initial inspection of the push rods it was observed that rusting had occurred in the longitudinal slots as well as at the periphery. Since the slots were made subsequent to the malcomizing operation, their surfaces are bare stainless steel.

h. General Electric, in their tests of nitrided or malcomized stainless steel, found that surfaces exposed to stagnant water at 190 F began rusting almost immediately. After a week, they were covered with red rust. The rust though disappeared as the test continued leaving behind an oxidized protective surface. On the other hand, specimens exposed to refreshed or moving water tests didn't exhibit rusting at any time. Pitting problems were not observed in the GE static tests of malcomized stainless steel unless the specimens were given an added diffusion treatment. Contact corrosion with pitting was observed in the presence of large amounts of rust.

i. The control rod push rods were not withdrawn for examination after production testing at Royal Industries in Pasadena, California, or prior to installation at the LACBWR site. However, since both the prototype and 29 production models were exposed to the same malcomizing preparation and water

environment at Royal Industries, one would believe that pitting had not occurred prior to installation at the LACBWR site.

j. The malcomized skin was abrasively removed from both the prototype and production models in the same manner. The method used was a hard polishing using aluminum oxide paper. The method and material employed were both acceptable and the process was consistent for both the prototype and production push rods. Any deviation from the process which could have introduced carbon steel contaminants to the push rod surface during this operation could have produced a situation capable of causing the pitting observed on the push rods.

APPENDIX A

PROGRAM LETTER, W. S. FARMER TO W. ALBERT, JANUARY 31, 1967

Letter from W. S. Farmer to W. Albert on January 31, 1967, setting forth the Allis-Chalmers plans for investigating the pitting observed on the LACBWR control rod push rods.

COPY

January 31, 1967

Mr. W. G. Albert
Chicago Operations Office
U. S. Atomic Energy Commission
9800 South Cass Avenue
Argonne, Illinois

In reply refer to:
LAC-3639

Dear Mr. Albert:

This will confirm the information given to you verbally on Monday, January 30, in response to your questions about Allis-Chalmers' observations and plans concerning the LACBWR control rod drive push rods.

On Monday, January 23, while at the site, several drives were brought down to the lower level of the turbine building and the push rods were extended from within the housing so that I could observe the surface condition of the rods that had been in the reactor for various periods during the past year. Scattered about on the surface of the two rods examined (A-C Nos. 27 and 29) were numerous pits. The pits appeared to be of the order of 5 mils deep and approximately 10 mils in diameter. No physical measurements were made so that these dimensions represent my best estimate from visual observations. Along with the pits, there were numerous little corrosion protrusions which were obviously the formation points which ultimately became pits on detachment. The pits and protrusions were scattered around on the surface in an irregular fashion approximately 1/2 inch apart. They were not uniformly distributed in all cases but occasionally appeared on only one side of the rod or in one location. The protrusions had a reddish-brown color and appeared to be iron oxide. Whether the iron oxide protrusions represent particulate matter that had been in solution in the reactor and had deposited on the surface of the push rod and had been subsequently ground in by the bearing sleeve or were actually created by local corrosion could not be determined. It is obvious that the pits were created by these particles or corrosion spots breaking away from the surface. In addition, there was some iron oxide corrosion at the intersection of the end of the push rod and the longitudinal surface. There was no apparent evidence of cracking, nor did the corrosion appear to be deep enough to lead to early failure of the push rod.

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Mr. W. G. Albert

-2-

January 31, 1967

In addition to looking at the push rods on control rods A-C Nos. 27 and 29, which had been in the reactor during the past year, we also examined the push rod on the prototype A-C No. 1. The prototype exhibited no evidence of corrosion of any kind, in spite of its having been exposed to demineralized water at Royal Industries for a lengthy period of time during prototype testing. This led us to believe that we might be observing a deposition of iron from solution, rather than direct corrosion.

It was our conclusion that the corrosion, although a matter of concern, was not sufficient to endanger the functional operation or safety of the control rod drive. We therefore have proceeded to reinstall the control rod drives on the reactor vessel nozzles. However, we believe that the presence of corrosion products or deposits warrants further actions both to monitor whether it is progressive and to try to determine and understand the cause. We therefore would propose that sometime before the end of this year, most probably in the fall, that one of the drives be removed from the reactor and that the push rod on that drive be examined to study whether the corrosion is becoming progressively greater and more extensive. We are also in the process of negotiating with Royal Industries to procure samples of stainless steel which have been malcomized by the same procedures as the push rod. We contemplate setting up a static corrosion test program in the immediate future in order to try and see whether we can duplicate the type of corrosion observed on the push rod. We also contemplate investigating further the literature and available industrial information pertaining to the corrosion behavior of malcomized surfaces in demineralized water. As soon as our plans for a corrosion test program have become more firm, we will be glad to forward them to you.

In response to your question regarding the time that would be required should it be found necessary to replace the push rods at some future date, I will reconfirm my very approximate estimates of time as given to you on the phone. It would appear that the corrosion test program would take at least three months to set up and obtain meaningful data. Should it then be desired to initiate procurement of new push rods, I would estimate approximately six months for design, selection of materials, procurement and manufacture. It would take approximately two months to take down all of the drives, disassemble them, install new push rods and replace them. To this, of course, would have to be added the preoperational test time and also any bench testing time should that be required.

At this time, I believe Allis-Chalmers is taking the proper steps to adequately study the problem and feel that the observed corrosion or deposition does not represent an immediate safety problem. We feel that the above-recommended actions in setting up a corrosion program and subsequent examination of the push rods at a future time will provide ample opportunity to become aware of any serious problems before they become serious.

Very truly yours,

/s/ W. S. Farmer

W. S. Farmer
LACBWR Project Manager

WSF:slk

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APPENDIX B

CRD NO. 27 PUSH ROD PICTURES

This appendix contains photographs taken of CRD No. 27 push rod as described in Sec. B of this report. One set of photographs was taken in April 1967 of selected areas of the push rod to show the pits described in Sec. A of this report. Another set of photographs was taken in September 1967 to show these same areas after five months' exposure to reactor water. A description of these photographs follows:

Photograph No. 1	Area between first and second slots from the bottom of the push rod at the 12 o'clock position (April 1967).
Photograph No. 2	Same area as in photograph No. 1 after cleaning the area with acetone (April 1967).
Photograph No. 3	Area between second and third slots from bottom of push rod at 12 o'clock position (April 1967).
Photograph No. 4	Same area as in photograph No. 3 after cleaning the area with acetone (April 1967).
Photograph No. 5	Area between third and fourth slots from the bottom of the push rod at 12 o'clock position (April 1967).
Photograph No. 6	Same area as in photograph No. 5 after cleaning the area with acetone (April 1967).
Photograph No. 7	Area between third and fourth slots from the bottom of the push rod at 6 o'clock position (April 1967).
Photograph No. 8	Same area as in photograph No. 7 after cleaning the area with acetone (April 1967).
Photograph No. 9	Area at the top of the uppermost slot at the 12 o'clock position (April 1967).
Photograph No. 10	Same area as in photograph No. 9 after cleaning the area with acetone (April 1967).
Photograph No. 11	Interface of latch assembly and push rod showing slight deposits of rust in crevice (April 1967).
Photograph No. 12	Latch assembly at 10 o'clock (April 1967).
Photograph No. 13	Same area as in photograph No. 1 (September 1967).
Photograph No. 14	Same area as in photograph No. 1 after cleaning the area with acetone (September 1967).

Photograph No . 15	Same area as in photograph No . 3 (September 1967).
Photograph No . 16	Same area as in photograph No . 3 after cleaning the area with acetone (September 1967).
Photograph No . 17	Same area as in photograph No . 5 (September 1967).
Photograph No . 18	Same area as photograph No . 5 after cleaning the area with acetone (September 1967).
Photograph No . 19	Same area as in photograph No . 7 (September 1967).
Photograph No . 20	Same area as in photograph No . 7 after cleaning the area with acetone (September 1967).
Photograph No . 21	Same area as in photograph No . 9 (September 1967).
Photograph No . 22	Same area as in photograph No . 9 after cleaning the area with acetone (September 1967).
Photograph No . 23	Same area as in photograph No . 11 (September 1967).
Photograph No . 24	Same area as in photograph No . 12 (September 1967).

NOTE: The 12 o'clock position corresponds to the location of the seal-welded cap screws located along the length of the pressure housing as viewed from the upper flange end of the pressure housing .

Photograph No . 1

Photograph No . 2

Photograph No . 3

Photograph No . 4

Photograph No . 5

Photograph No . 6

Photograph No . 7

Photograph No . 8

Photograph No. 9

Photograph No. 10

Photograph No. 11

Photograph No. 12

Photograph No. 13

Photograph No. 14

Photograph No. 15

Photograph No. 16

Photograph No. 17

Photograph No. 18

Photograph No. 19

Photograph No. 20

Photograph No. 21

Photograph No. 22

Photograph No. 23

Photograph No. 24

APPENDIX C

STATIC CORROSION TEST SPECIMEN PICTURES

The photographs shown in this appendix are of the corrosion samples from the Allis-Chalmers static corrosion test program described in Sec. D of this report. A description of the photographs follows:

Photograph No. 1	Typical malcomized 304 stainless steel sample (slotted by electrical discharge machining), prior to corrosion testing.
Photograph No. 2	Typical malcomized 304 stainless steel sample (slotted by grinding), prior to corrosion testing.
Photograph No. 3	Typical malcomized 304 stainless steel sample (not slotted), prior to corrosion testing.
Photograph No. 4	Malcomized 304 stainless steel sample slotted by electrical discharge machining and tested in LACBWR demineralized water (sample No. 1).
Photograph No. 5	Sample No. 1 after cleaning.
Photograph No. 6	Sample No. 2 whose preparation and testing was identical to sample No. 1.
Photograph No. 7	Sample No. 2 after cleaning.
Photograph No. 8	Sample No. 3 whose preparation and testing was identical to sample No. 1.
Photograph No. 9	Sample No. 3 after cleaning.
Photograph No. 10	Malcomized 304 stainless steel sample slotted by grinding and tested in LACBWR demineralized water (sample No. 4).
Photograph No. 11	Sample No. 4 after cleaning.
Photograph No. 12	Sample No. 5 whose preparation and testing was identical to sample No. 4.
Photograph No. 13	Sample No. 5 after cleaning.
Photograph No. 14	Sample No. 6 whose preparation and testing was identical to sample No. 4.
Photograph No. 15	Sample No. 6 after cleaning.
Photograph No. 16	Malcomized 304 stainless steel sample slotted by electrical discharge machining and tested in LACBWR demineralized water containing rust (sample No. 7).

Photograph No . 17	Sample No . 7 after cleaning .
Photograph No . 18	Sample No . 8 whose preparation and testing was identical to sample No . 7 .
Photograph No . 19	Sample No . 8 after cleaning .
Photograph No . 20	Sample No . 9 whose preparation and testing was identical to sample No . 7 .
Photograph No . 21	Sample No . 9 after cleaning .
Photograph No . 22	Malcomized 304 stainless steel sample slotted by grinding and tested in LACBWR demineralized water containing rust (sample No . 10) .
Photograph No . 23	Sample No . 10 after cleaning .
Photograph No . 24	Sample No . 11 whose preparation and testing was identical to sample No . 10 .
Photograph No . 25	Sample No . 11 after cleaning .
Photograph No . 26	Sample No . 12 whose preparation and testing was identical to sample No . 10 .
Photograph No . 27	Sample No . 12 after cleaning .
Photograph No . 28	Malcomized 304 stainless steel sample slotted by electrical discharge machining and tested in LACBWR demineralized water containing cation resin beads (sample No . 13) .
Photograph No . 29	Sample No . 13 after cleaning .
Photograph No . 30	Sample No . 14 whose preparation and testing was identical to sample No . 13 .
Photograph No . 31	Sample No . 14 after cleaning .
Photograph No . 32	Sample No . 15 whose preparation and testing was identical to sample No . 13 .
Photograph No . 33	Sample No . 15 after cleaning .
Photograph No . 34	Malcomized 304 stainless steel sample slotted by grinding and tested in LACBWR demineralized water containing cation bed resin beads (sample No . 16) .

Photograph No . 35	Sample No . 16 after cleaning .
Photograph No . 36	Sample No . 17 whose preparation and testing was identical to sample No . 16 .
Photograph No . 37	Sample No . 17 after cleaning .
Photograph No . 38	Sample No . 18 whose preparation and testing was identical to sample No . 16 .
Photograph No . 39	Sample No . 18 after cleaning .
Photograph No . 40	Malcomized 304 stainless steel sample slotted by electrical discharge machining and tested in LACBWR demineralized water containing mixed bed resin beads (sample No . 19) .
Photograph No . 41	Sample No . 19 after cleaning .
Photograph No . 42	Sample No . 20 whose preparation and testing was identical to sample No . 19 .
Photograph No . 43	Sample No . 20 after cleaning .
Photograph No . 44	Sample No . 21 whose preparation and testing was identical to sample No . 19 .
Photograph No . 45	Sample No . 21 after cleaning .
Photograph No . 46	Malcomized 304 stainless steel sample slotted by grinding and tested in LACBWR demineralized water containing mixed bed resin beads (sample No . 22) .
Photograph No . 47	Sample No . 22 after cleaning .
Photograph No . 48	Sample No . 23 whose preparation and testing was identical to sample No . 22 .
Photograph No . 49	Sample No . 23 after cleaning .
Photograph No . 50	Sample No . 24 whose preparation and testing was identical to sample No . 22 .
Photograph No . 51	Sample No . 24 after cleaning .
Photograph No . 52	Unslotted malcomized 304 stainless steel sample tested in LACBWR demineralized water (sample No . 25) .

Photograph No . 53	Sample No . 25 after cleaning .
Photograph No . 54	Unslotted malcomized 304 stainless steel sample tested in LACBWR demineralized water containing rust (sample No . 26) .
Photograph No . 55	Sample No . 26 after cleaning .
Photograph No . 56	Unslotted malcomized 304 stainless steel sample tested in LACBWR demineralized water containing both cation bed and mixed bed resin beads (sample No . 27) .
Photograph No . 57	Sample No . 27 after cleaning .
Photograph No . 58	Sample No . 6 oriented to show a pit .
Photograph No . 59	Sample No . 6 after cleaning .
Photograph No . 60	Sample No . 10 oriented to show a pit .
Photograph No . 61	Sample No . 10 after cleaning .
Photograph No . 62	Sample No . 13 oriented to show a pitted area .
Photograph No . 63	Sample No . 13 after cleaning .
Photograph No . 64	Sample No . 18 oriented to show a pit .
Photograph No . 65	Sample No . 18 after cleaning .
Photograph No . 66	Sample No . 24 oriented to show a pit .
Photograph No . 67	Sample No . 24 after cleaning .

NOTE:

1. Photographs 1, 2, and 3 are representative of typical types of samples used in the test. Samples used in test were not photographed in the pretested condition since there was no basic visible differences between their respective conditions except for the type of slots.
2. Photographs 4 through 51 were taken specifically to show the area at the slots.
3. Photographs 52 through 57 were taken of specific areas which were most corroded on the unslotted samples.
4. Photographs 58 through 67 were taken specifically of pits in various samples.

Photograph No. 1

Photograph No. 2

Photograph No. 3

Photograph No. 4

Photograph No. 6

Photograph No. 8

Photograph No. 10

Photograph No. 12

Photograph No. 14

Photograph No. 16

Photograph No. 18

Photograph No. 20

Photograph No. 22

Photograph No. 24

Photograph No. 26

Photograph No. 28

Photograph No. 30

Photograph No. 32

Photograph No. 34

Photograph No. 36

Photograph No. 38

Photograph No. 40

Photograph No. 42

Photograph No. 44

Photograph No. 46

Photograph No. 48

Photograph No. 50

Photograph No. 52

Photograph No. 54

Photograph No. 56

Photograph No. 58

Photograph No. 60

Photograph No. 62

Photograph No. 64

Photograph No. 66

Photograph No. 5

Photograph No. 7

Photograph No. 9

Photograph No. 11

Photograph No. 13

Photograph No. 15

Photograph No. 17

Photograph No. 19

Photograph No . 21

Photograph No . 23

Photograph No . 25

Photograph No . 27

Photograph No. 29

Photograph No. 31

Photograph No. 33

Photograph No. 35

Photograph No. 37

Photograph No. 39

Photograph No. 41

Photograph No. 43

Photograph No . 45

Photograph No . 47

Photograph No . 49

Photograph No . 51

Photograph No. 53

Photograph No. 55

Photograph No. 57

Photograph No. 59

Photograph No. 61

Photograph No. 63

Photograph No. 65

Photograph No. 67

Photograph No. 4

Photograph No. 5

Photograph No. 6

Photograph No. 7

Photograph No. 8

Photograph No. 9

Photograph No. 10

Photograph No. 11

APPENDIX D

PHOTOGRAPHS OF CRD NO. 4 PUSH ROD IN MARCH 1969

The photographs shown in this appendix were taken in March 1969 of the push rod from Control Rod Drive No. 4. This push rod was observed to have extensive pitting similar to that of CRD No. 27 in the examination in January 1967. There did not appear to be any new pitting or rusting on the surfaces of the push rod. Where protuberances had existed before they were now well burnished. A silvery black oxide coating was apparent over the entire surface. The pits previously present are believed to be still present but unchanged in size.