



# OAK RIDGE NATIONAL LABORATORY

operated by

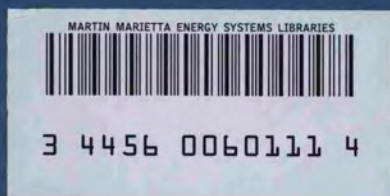
UNION CARBIDE CORPORATION

for the

U.S. ATOMIC ENERGY COMMISSION



ORNL-TM-14



61

N. S. SAVANNAH  
Nuclear Merchant Ship

INVESTIGATION OF THE EFFECTS OF WET,  
CHLORIDE-BEARING, THERMAL INSULATION  
ON AUSTENITIC STEEL PIPE

L. D. Schoffer  
Oak Ridge National Laboratory  
and

J. A. Klapper  
EBASCO Services Incorporated

CENTRAL RESEARCH LIBRARY  
DOCUMENT COLLECTION  
**LIBRARY LOAN COPY**  
**DO NOT TRANSFER TO ANOTHER PERSON**  
If you wish someone else to see this  
document, send in name with document  
and the library will arrange a loan.

## NOTICE

This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report. The information is not to be abstracted, reprinted or otherwise given public dissemination without the approval of the ORNL patent branch, Legal and Information Control Department.



LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

ORNL-TM-14

Report No. ESI-25(a)-1

N. S. SAVANNAH  
Nuclear Merchant Ship

INVESTIGATION OF THE EFFECTS OF WET, CHLORIDE-BEARING, THERMAL INSULATION  
ON AUSTENITIC STEEL PIPE

Prepared by

L. D. Schaffer  
Oak Ridge National Laboratory

and

J. A. Klapper  
EBASCO Services Incorporated

DATE ISSUED

**NOV - 1 1961**

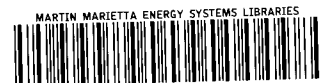
OAK RIDGE NATIONAL LABORATORY  
Oak Ridge, Tennessee  
Operated by  
UNION CARBIDE CORPORATION  
for the  
U. S. ATOMIC ENERGY COMMISSION

Prepared under U. S. Atomic Energy Commission Contract No. W-7405-eng-26  
Submitted to the U. S. Atomic Energy Commission

and

EBASCO SERVICES INCORPORATED  
Two Rector Street  
New York 6, New York

Prepared under States Marine Lines Contract Dated April 1, 1960  
Submitted to SML, General Agent to the U. S. Maritime Administration



3 4456 0060111 4

## ACKNOWLEDGMENT

The authors would like to acknowledge the cooperation and contributions of the following people in the study of this problem:

J. E. Cunningham	ORNL Metallurgy Division
R. S. Crouse	ORNL Metallurgy Division
J. L. English	ORNL Reactor Chemistry Division
F. M. Hill	ORNL Analytical Chemistry Division
V. O. Haynes	ORNL Reactor Division
H. C. McCurdy	ORNL Reactor Division
J. C. Dedrick	ORNL Inspection Engineering Department
B. J. Ward	ORNL Inspection Engineering Department
E. C. Miller	ORNL Inspection Engineering Department
E. H. Thalmann	Ebasco Corrosion Group
H. Heffan	Ebasco Metallurgy
R. Plottel	Ebasco Metallurgy
R. O. Mehann	States Marine Lines
W. Beckwith	AEC-MARAD Inspection

## ABSTRACT

In the latter phases of construction of the nuclear-powered merchant ship, the N. S. SAVANNAH, pressurization tests of the primary system were begun. After the primary system was hydrostatically tested, the piping was insulated so that the temperature of the system could be raised for the hot-flushing operation. Since the system was still under inspection for leak tightness, all joints and areas of potential leaks were left uninsulated. Because the insulating operation was not complete, the insulation had not been waterproofed. In the course of the hot-flushing operation, several leaks developed in the primary system, including a valve gasket failure. As a result of these events, the insulation was wet with high-purity water in several locations within the reactor containment compartment.

Since it was known that the thermal insulation applied to the primary system piping contained chlorides and that the primary system had been thermally cycled several times after the insulation had been wet, an investigation was initiated to determine whether the system had been damaged. It was found that the proper conditions existed for chloride stress-corrosion cracking of the austenitic stainless steel in the primary system. Laboratory investigation of a sample of pipe removed from the primary system indicated that chloride stress-corrosion cracking had begun but that the reaction had been interrupted before serious damage occurred. Therefore, the insulation on the N. S. SAVANNAH primary system was removed and the underlying piping surfaces were inspected. Indications

of surface defects which were considered significant were removed by grinding, and the piping surfaces were cleaned and reinsulated with an asbestos-type insulation containing 20 per cent  $\text{Na}_2\text{SiO}_3$ .

In addition to the laboratory investigation, the literature pertinent to this problem was surveyed and industrial investigators in this field were contacted. Based on the information accumulated, specifications for the insulation of austenitic stainless steel piping were prepared. Stress-corrosion protection concepts are identified and discussed in relation to the development of solutions to the insulation problem in future nuclear marine systems.

## CONTENTS

	<u>Page</u>
ACKNOWLEDGMENT . . . . .	ii
ABSTRACT . . . . .	iii
I. INTRODUCTION . . . . .	1
II. CONCLUSIONS . . . . .	5
III. RECOMMENDATIONS FOR CLEANING, INSPECTING, AND REINSULATING	
AUSTENITIC STAINLESS STEEL PIPE ON THE N. S. SAVANNAH . .	8
IV. DEVELOPMENT OF PROBLEM AND RESOLUTION . . . . .	10
Field Inspections. . . . .	11
Field Inspection I . . . . .	11
Field Inspection II . . . . .	14
Laboratory Investigations . . . . .	15
Metallurgy Investigation of Defects. . . . .	16
Stress-Corrosion Susceptibility Tests. . . . .	44
Cathodic Protection Tests. . . . .	53
Chemical Analyses. . . . .	54
ORNL Insulation Analysis . . . . .	55
Ebasco Insulation Analysis . . . . .	56
Cleaning Agent Study . . . . .	57
Spectrographic Analysis of Pipe Surface Deposit. . . .	58
Discussion of Corrective Measures . . . . .	61
V. LITERATURE AND INDUSTRIAL SURVEY . . . . .	65

	<u>Page</u>
Introduction . . . . .	65
Review Information . . . . .	67
Insulation Sealers and Thermal Insulation . . . . .	68
Pipe Coatings. . . . .	68
Chlorides in Insulation . . . . .	69
Cathodic Protection . . . . .	70
Inhibitors . . . . .	72
Conclusions from Survey. . . . .	73
VI. INSULATION IN FUTURE MARINE APPLICATIONS . . . . .	75
N. S. SAVANNAH Experience. . . . .	75
Proposed Standards . . . . .	78
Operating System . . . . .	79
System under Construction. . . . .	79
Considerations for the Future . . . . .	80
Preoperational and Initial Operation Period of the	
N. S. SAVANNAH . . . . .	82
Initial Major Overhaul Period of the N. S. SAVANNAH. . .	83
Subsequent Generations of the N. S. SAVANNAH . . . . .	85
Concepts Requiring Development . . . . .	88
Dry Containment. . . . .	89
Chloride-Free Insulation . . . . .	89
Stress-Corrosion Inhibitors. . . . .	89
Cathodic Protection . . . . .	90
Waterproof Sealers and Insulation. . . . .	90



	<u>Page</u>
Water-Permeation Indicators. . . . .	90
Coatings . . . . .	90
Insulation Joint Designs . . . . .	91
System Piping Designs . . . . .	91
Wet Containment. . . . .	91
Insulation Cladding. . . . .	91
Insulation Providing Cathodic Protection . . . . .	91
Stress-Corrosion Inhibitor in Containment Water. . . . .	92
Coatings . . . . .	92
Stress-Corrosion Resistant Materials for the Primary System . . . . .	92
VII. REFERENCES . . . . .	94
VIII. BIBLIOGRAPHY . . . . .	97
IX. APPENDICES . . . . .	99
A. Task Assignment and Program Relations. . . . .	100
B. Report on Pipe Cleaning, Inspection, and Reinsulating Program . . . . .	103
C. Tentative Specification for Austenitic Stainless Steel Piping Insulation, Cleaning, and Inspection in Marine Nuclear Service. . . . .	115
D. Letter to Maritime Administration Requesting Removal of Stainless Steel Pipe Section . . . . .	127
E. Investigation of Sacrificial Anode Protection. . . . .	128

	<u>Page</u>
F. Comparisons of Solutions of Nitric Acid and Alconox Detergent to Remove Chlorides from Austenitic Stainless Steel Piping. . . . .	152
G. Summary of the ORNL Nondestructive Inspection Procedures Employed on the Piping Samples Taken from the Primary System of the N. S. SAVANNAH and the New York Shipbuilding Corporation As-Received Storage. . . . .	156
H. ORNL Analysis for Chloride in Thermobestos Insula- tion, January 17, 1961 . . . . .	157
I. Ebasco Procedure for Determination of Chlorides in Thermobestos Insulation . . . . .	164
J. Case Histories--Failure of Austenitic Stainless Steel Associated with Thermal Insulation . . . . .	166
DISTRIBUTION. . . . .	172

## LIST OF FIGURES

<u>Fig.</u>		<u>Page</u>
1	Indications Found December 22 and 27, 1960, in PP-IV Line Preceding Letdown Coolers . . . . .	13
2	In-Place Section of PP-IV Line after Cleaning at ORNL . . . .	17
3	Indications Revealed by Ultraviolet Light Inspection . . . .	18
4	Indications Revealed by Ultraviolet Light Inspection-- Section 4 . . . . .	19
5	Indications Revealed by Ultraviolet Light Inspection . . . .	20
6	Indications Revealed by Ultraviolet Light Inspection-- Section 5 . . . . .	21
7	Indications Revealed by Ultraviolet Light Inspection-- Section 3 . . . . .	22
8	Indications Revealed by Ultraviolet Light Inspection-- Section 6 . . . . .	23
9	Photomicrograph of Section 5, Fig. 6, Showing Penetration Normal to Surface, as Polished, X-250 . . . . .	25
10	Photomicrograph of Section 5, Fig. 6, Showing Penetration Normal to Surface, Etched with Modified Aqua Regia, X-250 .	26
11	Photomicrograph of Section 5, Fig. 6, Showing Penetration Normal to Surface, Etched with Modified Aqua Regia, X-750 .	27
12	Photomicrograph of Section 6, Fig. 8, Showing Penetration Normal to Surface, as Polished, X-250 . . . . .	28

<u>Fig.</u>		<u>Page</u>
13	Photomicrograph of Section 4, Fig. 8, Showing Penetration Normal to Surface, Etched with Modified Aqua Regia, X-250 .	29
14	Photomicrograph of Section 6, Fig. 8, Showing Penetration Normal to Surface, Etched with Modified Aqua Regia, X-750 .	30
15	Section through "v"-Shaped Indication, Fig. 7, Etched with Modified Aqua Regia, X-250 . . . . .	31
16	Another View of Sample Cut from PP-IV . . . . .	32
17	Indications Revealed by Ultraviolet Light Inspection from Fig. 16 . . . . .	33
18	Typical Defect Area Shown on Figs. 16 and 17, Modified Aqua Regia Etch, X-250 . . . . .	34
19	Typical Defect Area Shown on Figs. 16 and 17 (Different Location from Fig. 18), Modified Aqua Regia Etch, X-250 . .	35
20	Lap in Surface from Area Shown in Figs. 16 and 17, as Polished, X-250 . . . . .	36
21	Typical Ultraviolet Light Indication from as-Received Stock at New York Shipbuilding Corporation . . . . .	38
22	Crack or Slag Inclusion in as-Received Pipe, as Polished, X-250 . . . . .	39
23	Crack or Slag Inclusion in as-Received Pipe, Modified Aqua Regia Etch, X-250 . . . . .	40
24	Other Typical Defects in as-Received Pipe, as Polished, X-250 . . . . .	41

<u>Fig.</u>		<u>Page</u>
25	Other Typical Defects in as-Received Pipe, Modified Aqua Regia Etch, X-250 . . . . .	42
26	Pretest Appearance of 2-in., Type 304 Stainless Steel Pipe Specimen, X-1.68 (Test AN-32) . . . . .	45
27	Condition of Type 304 Stainless Steel Test Specimen after 100 hr at 250°C in Water Containing 100 ppm of Chloride, X-1.6 . . . . .	47
28	Condition of Type 304 Stainless Steel Test Specimens after 200 hr at 250°C in Water Containing 50 ppm Chloride, X-1.6 (Test AN-40). . . . .	49
29	Crack on OD of Type 304 Stainless Steel Pipe Specimen after 200 hr at 250°C in Water Containing 50 ppm Chloride, Etched in Glyceria Regia. . . . .	50
30	Cracks on OD of Type 304 Stainless Steel Pipe Specimen after 200 hr at 250°C in Water Containing 50 ppm Chloride, Etched in Glyceria Regia, X-100 . . . . .	51
31	Crack on ID of Type 304 Stainless Steel Pipe Specimen after 200 hr at 250°C in Water Containing 50 ppm Chloride, Etched in Glyceria Regia, X-250 . . . . .	52
1E	Water Discoloration of Aluminum in Contact with Wet Insula- tion . . . . .	135
2E	Components Making up the Aluminum-Stainless Steel Couple-- Type 304 Stainless Steel Tubing, Fiberglass Mat, Aluminum Foil Alloy 1145 . . . . .	137

<u>Fig.</u>		<u>Page</u>
3E	Completed Aluminum-Stainless Steel Couple Showing Glass Fiber between the Tube and Foil and Method of Maintain- ing Electrical Contact. . . . .	138
4E	Experimental Set-Up . . . . .	141



# INVESTIGATION OF THE EFFECTS OF WET, CHLORIDE-BEARING, THERMAL INSULATION ON AUSTENITIC STEEL PIPE

L. D. Schaffer and J. A. Klapper

## I. INTRODUCTION

In the course of construction of the N. S. SAVANNAH at New York Shipbuilding Corporation, the hydrostatic test and the hot-flushing operation were performed on the primary system within the reactor containment vessel. Numerous leaks occurred in the austenitic stainless steel piping at valves and at pumps as would be expected during such operations. AEC-MARAD decided that an investigation of the possibility of chloride stress-corrosion cracking of the austenitic stainless steel piping would be required. This decision was based on the above-stated circumstances and the following facts:

1. The N. S. SAVANNAH primary system had been insulated but not waterproofed prior to the hot-flushing operation.<sup>1</sup>
2. The thermal insulation was wet as a result of the leaks which developed in these testing operations.<sup>2</sup>
3. After the insulation was applied, the primary system was operated at 150°F and 100 psi for three days followed by a two- to three-day shutdown. The primary system was then taken to 120°F and 100 psig. The following day the system reached a temperature of 150°F and a pressure of 150 psig. At this point, the gasket in valve PP-1V failed. The system was

held at 100 psig at 150°F for 13 days, after which the temperature was raised to 510°F and the pressure to 1750 psia. This condition was held for four days, and the system was then shut down.<sup>1</sup>

4. Attention had been called to the chloride content in the insulation and the possible consequences of wetting the insulation in letters from ORNL to AEC-MARAD, the first of which was dated September 9, 1958, and by Ebasco Services Incorporated in their Task Assignment No. 17 dated June 14, 1960.

AEC-MARAD requested that Ebasco remove representative areas of the insulation on the primary system that had been wet and inspect the underlying stainless steel piping surface with dye-penetrant (Appendix A). The inspection showed numerous indications of defects, most of which were oriented parallel to the longitudinal axis of the pipe. Light grinding was performed on these indications, but most were not removed in this operation.

ORNL was asked by AEC-MARAD to perform a metallographic examination of a section of pipe from the primary letdown system that had been field inspected by Ebasco. This pipe was 2-in., sched.-160, type 304 stainless steel. A 6-in. length of this piping with a forged 90-deg elbow welded in place was removed and delivered to ORNL. In addition, ORNL requested samples of as-received, 2-in., sched.-160, type 304 stainless steel piping from the same lot as the in-place section under investigation.

Samples of the in-place insulation and of the insulating mud were also sent to ORNL and Ebasco for chemical analysis.

ORNL and Ebasco performed the investigations which resulted in specific recommendations for corrective measures and a proposed procedure for implementing these measures (Appendix B). The investigations included:

1. Field inspections to locate wet insulation areas and to inspect underlying pipe surfaces for chloride stress-corrosion cracking;
2. Nondestructive tests of stainless steel samples to locate imperfections for further analysis;
3. Metallography on stainless steel pipe samples to determine the nature of the imperfections noted;
4. Tests to determine the susceptibility of the austenitic stainless steel samples to chloride stress-corrosion cracking and to explore means, such as cathodic protection, for minimizing this susceptibility;
5. Chemical analyses of the in-place insulation and mud to determine both the amount of leachable water-soluble chlorides originally present and the amount that actually had been leached out;
6. Tests to determine the effectiveness of cleaning solutions for removal of chloride contaminants from stainless steel piping surfaces in order to find a satisfactory method that would

assure removal of any chlorides from the N. S. SAVANNAH primary system before reinsulation;

7. A field and literature survey of stress-corrosion phenomena to aid in solution of the immediate problem and to determine what might be done to avoid such problems in the future.

As a result of the investigation, AEC-MARAD directed that the insulation on the N. S. SAVANNAH primary piping be removed. By February 14, 1961, all the insulation had been removed; and the austenitic stainless steel piping within the containment vessel had been inspected and reinsulated. Indications had been removed to the satisfaction of Government inspectors; and the piping had been thoroughly cleaned, covered with a sodium silicate-bearing insulation (Unibestos), waterproofed, and fire-proofed.

This report covers the details of the investigation of the possible consequences to the primary system of the N. S. SAVANNAH due to the thermal insulation being wet and describes the corrective action that was taken. In addition, proposed standards are presented for future construction and maintenance of nuclear marine systems; and protection concepts requiring further development are identified.

## II. CONCLUSIONS

On the basis of the metallurgical and chemical analyses, field and laboratory inspections, and literature <sup>3,4,5</sup> and field surveys concerning chloride-induced stress-corrosion cracking of austenitic stainless steel associated with chloride-bearing insulations, <sup>6,7,8</sup> the following conclusions were reached:

1. The majority of indications found on the 2-in., sched.-160 pipe removed from letdown cooler line PP-1V were not attributable to chloride stress-corrosion cracking.
2. The penetrations shown in Figs 11 and 14 are believed to be chloride stress-corrosion cracks in the incipient state. The conditions under which the piping operated during the testing program support this view.
3. It appears that most of the defects found in the examined pipe cannot be attributed to handling during installation. Further, these defects are potential sites for concentration of chlorides and as such could serve as origins for stress-corrosion cracking.
4. Almost all commercially available insulation has sufficient soluble chloride <sup>3,4,6,7,8</sup> to cause chloride stress-corrosion cracking of stressed austenitic stainless steel at elevated temperatures if these chlorides are leached out and contact the stainless steel surface in the presence of water. The only exceptions found were metal insulations.

5. There is some experimental evidence that sodium silicate ( $\text{Na}_2\text{SiO}_3$ ) in the insulation or on the piping protects the austenitic stainless steel from chloride stress-corrosion cracking.<sup>6,9,10,11,12</sup> The mechanism of protection is uncertain, but some investigators believe it to be associated with the fact that sodium silicate is water soluble and raises the pH of chloride-containing solutions.
6. Coatings such as silicones can protect the metal surfaces by sealing them from chloride solutions. Dependability of such coatings for this application is uncertain.<sup>6</sup>
7. Utilization of less noble metals such as aluminum appears attractive as a sacrificial anode in the form of foil or wire wrapped around the austenitic stainless steel piping before the insulation is applied.<sup>13,14</sup> This approach looks more practical than coatings because the piping can be easily stripped for surface inspection. In addition, complete surface coverage is not absolutely necessary since this method involves electrochemical protection, whereas the coatings in general must remain continuous and impermeable to be effective.
8. Some glass insulations appear to be lower in soluble chlorides than most of the other insulating materials.<sup>6</sup>
9. Some glass insulations are to be preferred over many of the other insulations because they have a low permeability



to water and can vent water vapor easily.<sup>6</sup>

10. A resilient insulation covering such as asbestos cloth with a Mylar finish may give the best long-term waterproofing of insulation.<sup>12,15</sup>
11. Pipe or equipment joints that are expected to be opened during the life of the system should have a special insulation design so that, when the insulation over the joint is removed, the adjacent pipe insulation will remain sealed, thus preventing water from soaking into the pipe insulation when the joint is broken.<sup>12</sup>
12. Although the dangers of chloride stress-corrosion cracking of austenitic stainless steel are recognized widely, it is noted that often due to the distractions and pressure of everyday activity, the constructor and sometimes even the designer loses sight of this danger in his work. Where systems exist that are susceptible to this danger, physical protection must be provided. Where this is not possible, administrative control must be exercised. Such protective considerations for future marine systems are discussed in section VI of this report.

### III. RECOMMENDATIONS FOR CLEANING, INSPECTING, AND REINSULATING AUSTENITIC STAINLESS STEEL PIPE ON THE N. S. SAVANNAH

These recommendations were directed at solving the immediate problem concerned with construction of the N. S. SAVANNAH. The recommendations were as follows:

1. All of the existing thermal insulation must be removed.
2. The austenitic stainless steel pipelines in the containment compartment shall be mechanically cleaned in preparation for fluorescent-penetrant inspection.
3. Fluorescent-penetrant inspection should be performed on all piping surface areas known to have been wet and areas that could have been wet, such as areas near or under flanged or packed components.
4. In addition, spot-check inspection should be performed on a minimum of 2 per cent of the primary piping surfaces selected randomly from those areas not inspected by recommendation No. 3 above.
5. Defects found in the piping that exceed the specified limits as stated in Appendix B shall be removed by grinding.
6. After inspection, the pipelines must be thoroughly cleaned using a 3 to 5 per cent nitric acid ( $\text{HNO}_3$ ) cleaning solution followed by water rinses to remove all surface contaminants.
7. A sacrificial anode such as aluminum foil should be wrapped on the piping surfaces prior to the application of the thermal insulation.

8. New thermal insulation containing sodium silicate ( $\text{Na}_2\text{SiO}_3$ ) should be installed, fully waterproofed and fireproofed.
9. During the remainder of construction and during operation, all attempts must be made to keep the insulation dry.

(The procedure that was written from these recommendations is included in this report as Appendix B.)

The procedure actually employed in correcting this problem included all the above recommendations except two. The exceptions were:

1. An alternate cleaning solution was employed. Instead of using a nitric acid solution, a commercial detergent, Alconox, was used.
2. No anodic material was applied with the insulation to the austenitic stainless steel piping.

#### IV. DEVELOPMENT OF PROBLEM AND RESOLUTION

On October 27, 1960, the hydrotesting operation of the N. S. SAVANNAH reactor plant began at the New York Shipbuilding Corporation shipyards. On October 28, 1960, the primary system temperature measurements ranged from 146°F to 150°F; and these temperatures were maintained during the 3000-psi hydrotest.<sup>1</sup> Various leaks were observed during this test.<sup>2</sup>

Following the hydrotest, the primary system temperature was maintained above 150°F until cool-down on November 1, 1960. Insulation of the primary piping began on November 4, 1960, and continued until November 14, 1960.<sup>1</sup> The insulation was applied to most of the system, but joints and areas where leaks were more likely to occur were left uninsulated until the hot-flushing operation was finished. Since the insulation job was not complete, no waterproof sealing was applied to the asbestos insulation.

On November 15, 1960, the primary system reached 200°F and 100 psig and was maintained at these conditions until November 17, 1960, when the system was shut down for dye checking of some welds. On November 21, 1960, the system was heated to 120°F and 100 psig, reaching 150°F and 1500 psig by the next day. At this point the PP-1V valve gasket failed. The resulting leak wet portions of the insulation.<sup>1</sup> Prior to the rupture of this gasket but after the insulation was applied to the primary piping, other leaks were also observed in the system. These leaks were noted in the forward end of the containment in the area of the pressurizer in the stem packing of a valve and in the after end of the containment in the packed glands of the coolers.

After the rupture of the gasket of PP-1V valve, the system was taken down to 100 psig at 150°F until December 5, 1960. Then the temperature was raised to 510°F, and the pressure reached 1750 psia. Finally, the plant was shut down December 9, 1960,<sup>1</sup> due to a plugged filter.

AEC-MARAD was informed of the above condition on December 20, 1960. On the same day AEC-MARAD telephoned Ebasco about this problem. At this time Ebasco stated that, if the pipelines were at 500°F at the time of the leakage, there probably would be nothing to be concerned about as vaporization in the insulation would not permit washing down and concentration of chlorides on the pipe surfaces. However, it was reported to AEC-MARAD that the system had been cycled between approximately 150°F and 500°F and that the insulation was water soaked. In view of these circumstances, Ebasco requested permission to inspect primary piping in the vicinity of PP-1V valve.

#### A. Field Inspections

Ebasco performed two field inspections prior to the decision to remove a section of the primary system piping for laboratory study. During these inspections it was found that no personnel could positively identify all areas of insulation that had been wet, although it was apparent that there were many such areas within the containment vessel.

##### 1. Field Inspection I

Ebasco carried out the first fluorescent-penetrant inspection of the PP-1V line on December 22, 1960. At this time the insulation was removed from the valve as well as a 5-in. length of insulation from the

horizontal 2-in., sched.-160, type 304 stainless steel pipe. This insulation was set aside for chloride analysis. The valve and pipe were cleaned with a stainless steel wire brush and 80-grit emery paper in order to remove a heavy brown deposit. The deposit was tightly adherent and required considerable effort to remove. The deposit appeared to be the baked remains of the protective shipping tape which was on the pipe and fittings when received at the shipyards. Scrapings of the deposit were collected for analysis. The inspection revealed indications as shown on Fig. 1. The indications varied in length from  $1/16$  in. to  $3/4$  in. The inspection procedure followed is given in Appendix B. Upon finding these indications, Ebasco requested that AEC-MARAD inform the N. S. SAVANNAH constructor (New York Shipbuilding Corporation) and the N. S. SAVANNAH designer (The Babcock & Wilcox Company) of the results of this operation.

One indication (indication 1, Fig. 1) when first observed was only  $1/4$  in. long. The indication was abraded with 80-grit emery paper four times for 5 min each time. After each abrading operation, the indication grew in length in a jagged pattern (as observed under the fluorescent penetrant) until it reached a length of  $3/4$  in. Unfortunately, during the cutting of the pipe on December 29, 1960, indication 1 was completely obliterated by the grinding. The area in which indication 1 was located was ground to a depth of greater than  $3/32$  in. during the removal operation. Thus, it cannot be established if this indication was removed at the  $3/32$ -in. depth or at a depth considerably less than  $3/32$  in.



ORNL-LR-DWG. 56235  
UNCLASSIFIED

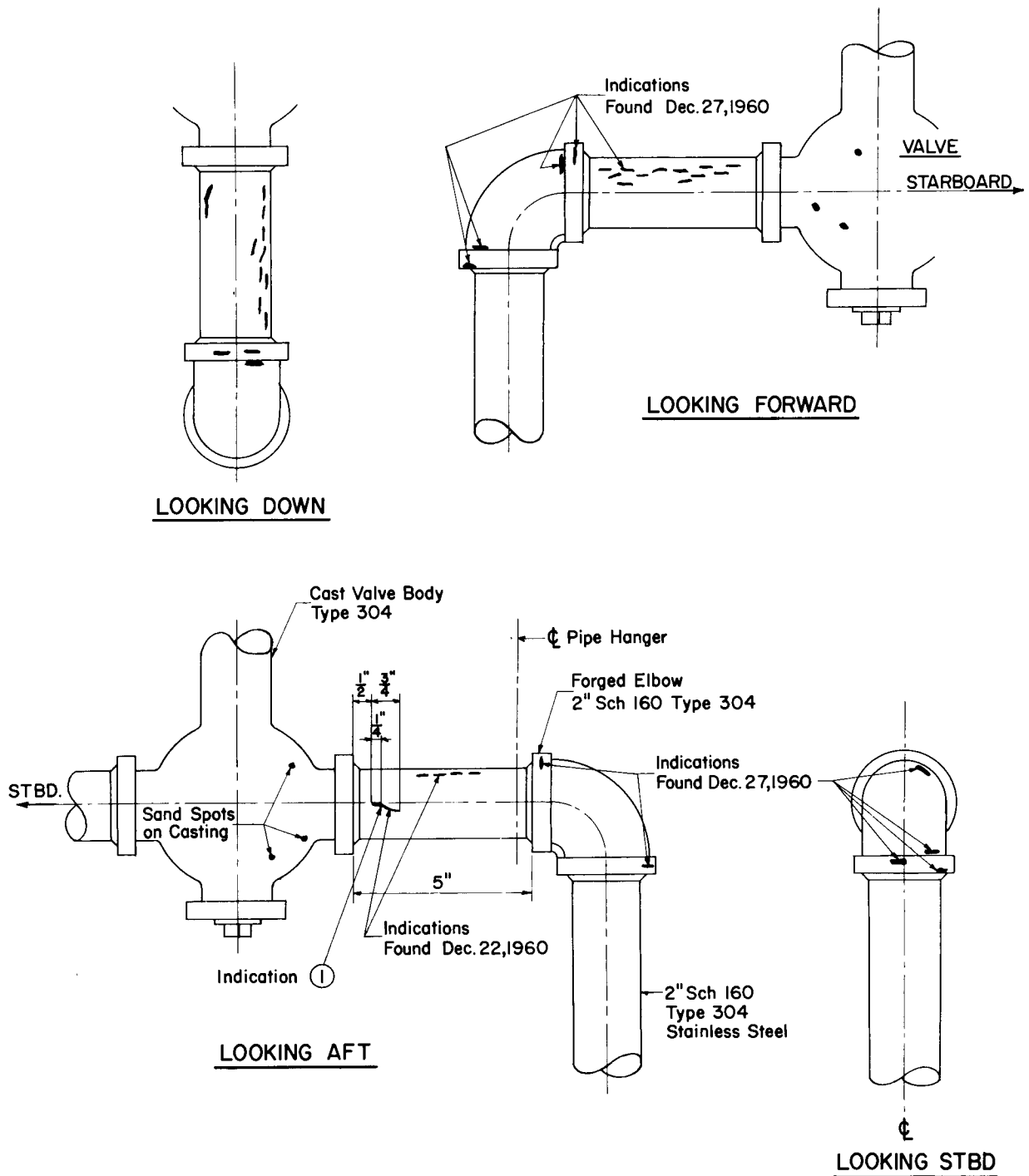


Fig. 1. Indications Found December 22, and 27, 1960, in PP-1V Line preceding Letdown Coolers.

## 2. Field Inspection II

On December 27, 1960, Ebasco carried out the second fluorescent-penetrant inspection in the presence of metallurgists from The Babcock & Wilcox Company. At this time the pipe hanger, as well as the insulation around the elbow, was removed. The indications found on December 22, 1960, were noted. Additional indications in excess of 20 were found during this inspection in the aft section of the pipe as well as on the forged elbow (see Fig. 1). The indications were mainly aligned with the longitudinal axis of the pipe, although some indications were irregular and traversed the pipe axis. These indications varied in length from 1/16 to 3/4 in. The indications on the forged elbow occurred mainly at changes in section and were from 1/4 to 1 in. long. It was decided that an attempt should be made to remove some of the indications so that an idea could be obtained as to their magnitude. A small air-driven grinder with a 1-in.-dia, rubber-bonded tip was used in the attempt to remove indications on the top of the pipe and on the elbow. The grinding operation was carefully performed so that gouging or scorching would not occur. The indications were ground for approximately 15 min with moderate pressure at a wheel speed of approximately 24,000 rpm. At the end of this time the indications remained. Ebasco recommended that the 6-in. section of pipe with the elbow be removed for laboratory analysis. This was agreed to by The Babcock & Wilcox Company representatives. A letter was sent immediately to the Maritime Administration in this regard (see Appendix D).

## B. Laboratory Investigations

On December 29, 1960, AEC-MARAD requested that the Oak Ridge National Laboratory perform nondestructive tests and metallographic analyses on the section of piping that had been inspected by Ebasco. In addition, ORNL requested samples of this same piping material in the as-received condition and samples of the in-place insulation known to have been wet, of insulation that had not been wet, and of the insulation mud.

The in-place section of piping was cut from the N. S. SAVANNAH primary system, and samples of the insulation were removed. These materials were delivered by an AEC-MARAD representative to ORNL December 30, 1960; and work on these materials was initiated immediately. Two 3-ft-long sections of the as-received piping were withdrawn from the New York Shipbuilding as-received storage and delivered by an ORNL inspector to the Laboratory on January 1, 1961. Work on this material began January 3, 1961.

The nondestructive testing and metallographic investigations were performed by ORNL. Representatives of B&W and Ebasco as well as several members of ORNL staff examined the metallographic specimens removed from the samples. In addition, ORNL performed tests on the chloride stress-corrosion cracking susceptibility of the in-place piping in order to evaluate the residual stress level.

A previous 2000-hr test by ORNL had demonstrated the effectiveness of aluminum wire as a stress-corrosion inhibitor for stainless steel.<sup>13</sup> In order to determine whether or not this means could be used to protect the austenitic stainless steel piping in the N. S. SAVANNAH from chloride

stress-corrosion cracking in the event the piping insulation became wet and chlorides reached the pipe surface, Ebasco performed an experiment using aluminum foil.

The chemistry studies performed in the course of this investigation included analyses of the chloride content of the thermal insulation samples, determination of the effectiveness of various cleaning agents to remove chlorides from austenitic stainless steel pipe surfaces, and analyses of the chemical composition of the surface film of various areas of the in-place piping where the insulation had been water soaked. Ebasco and ORNL performed parallel studies on analyzing the thermal insulation. Ebasco performed the cleaning solution study and the surface film analysis.

#### 1. Metallurgical Investigation of Defects

When the pipe section which had been removed from the N. S. SAVANNAH primary system was received at ORNL, it was untaped (the tape was applied for shipping) and vapor degreased (see Fig. 2). Then it was dye-penetrant inspected with ZL-22 (see ORNL Nondestructive Test Procedure, Appendix G).

Although the pipe was badly battered from the cutting operation at the shipyard, many areas of definite longitudinal cracklike indications were noted in the fluorescent-penetrant inspection. Some of these areas were photographed under ultraviolet light and are shown in Figs. 3-8. Figure 3 shows the area ground by the Ebasco inspectors. Figures 4-7 exhibit miscellaneous indications. Figure 8 shows the strongest



Fig. 2. In-Place Section of PP-1V Line after Cleaning at ORNL.

Y-38704

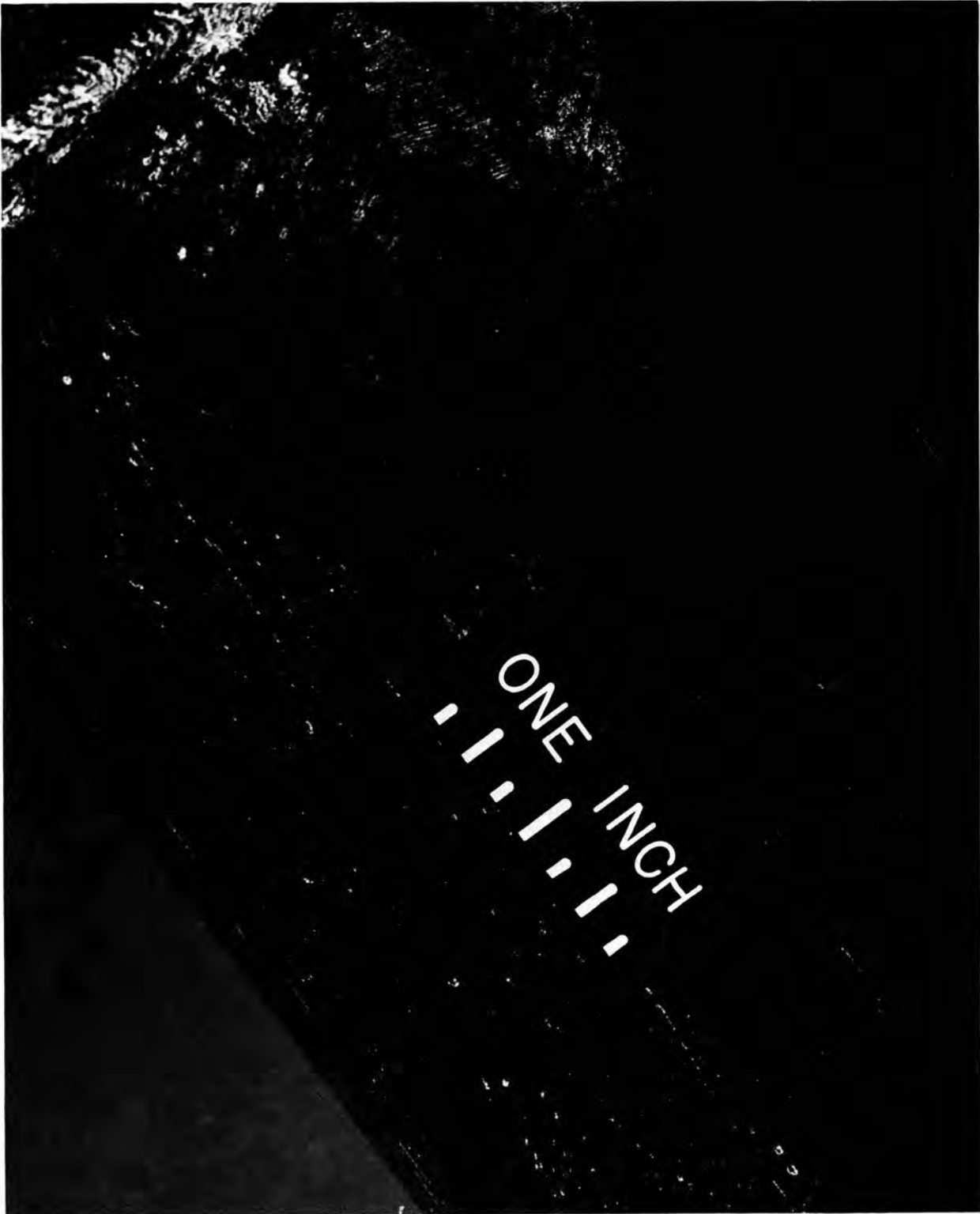


Fig. 3. Indications Revealed by Ultraviolet Light Inspection.

Y-38708

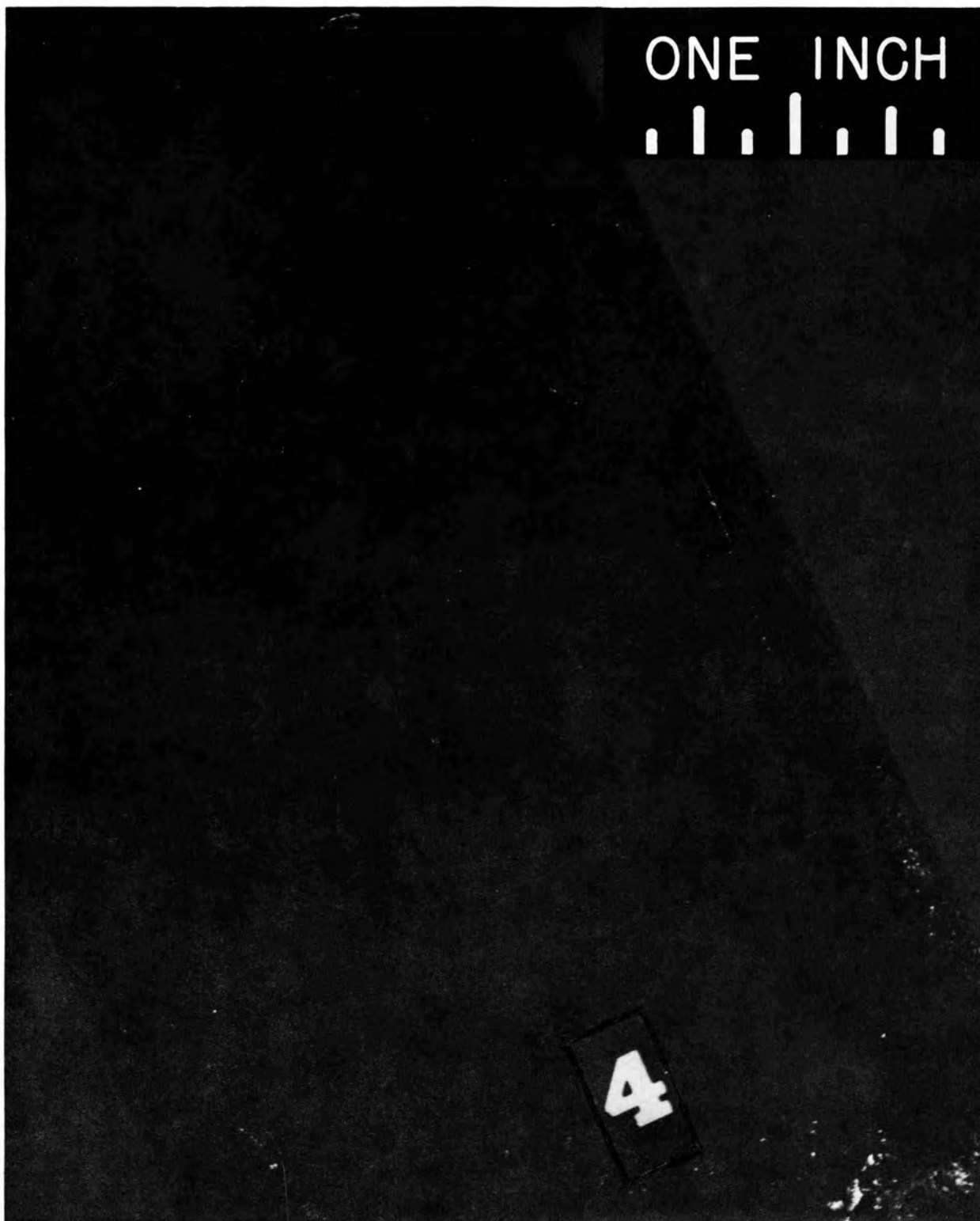


Fig. 4. Indications Revealed by Ultraviolet Light Inspection--Section 4.



Fig. 5. Indications Revealed by Ultraviolet Light Inspection.





Fig. 6. Indications Revealed by Ultraviolet Light Inspection--Section 5.



Fig. 7. Indications Revealed by Ultraviolet Light Inspection--Section 3.

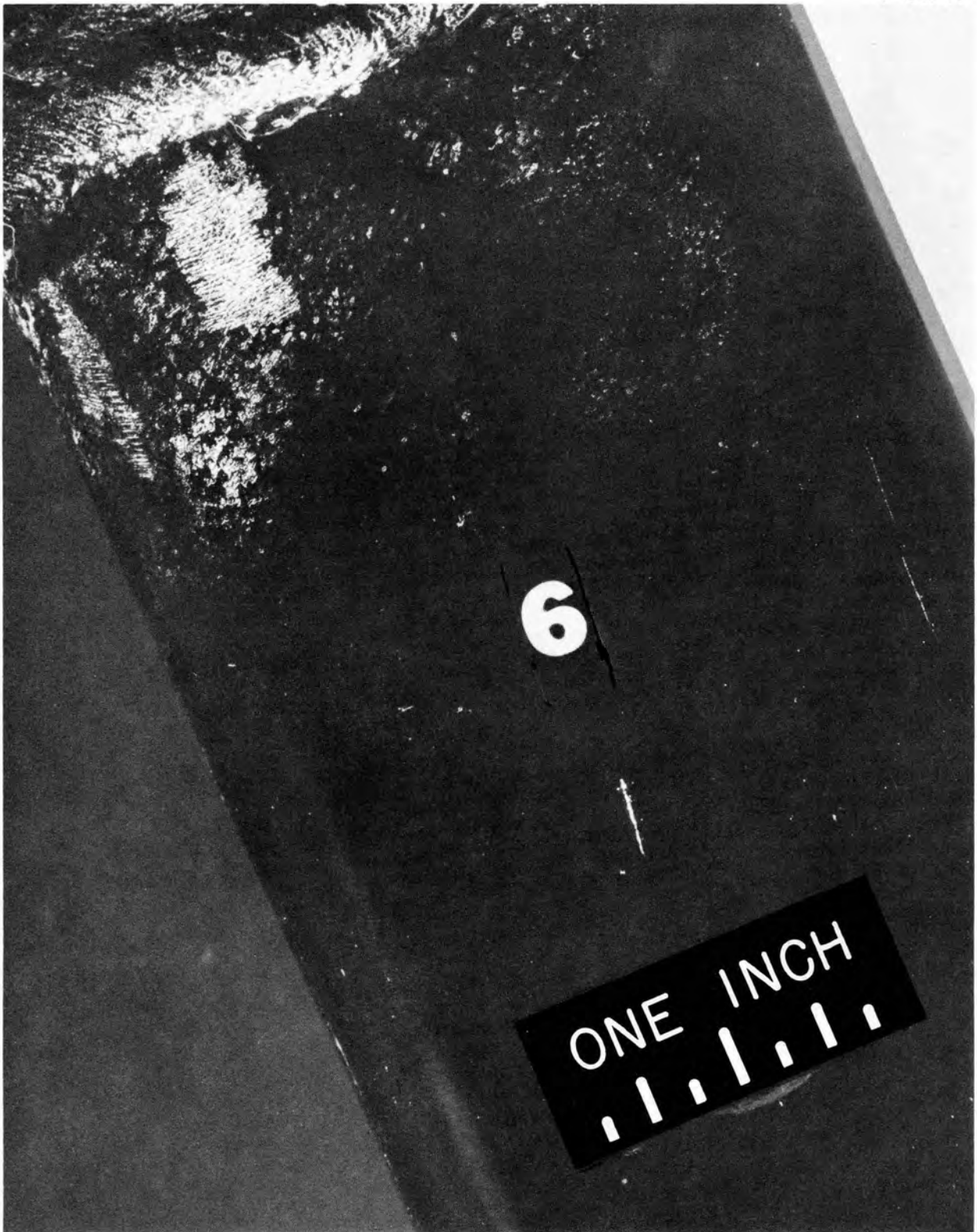


Fig. 8. Indications Revealed by Ultraviolet Light Inspection--Section 6.

indications seen on the pipe. Metallographic specimens were taken through section 5, Fig. 6; the "v"-shaped indication, Fig. 7; and section 6, Fig. 8.

Examinations of these specimens revealed at least two points of definite penetration of the pipe surface to a maximum depth of 3 to 5 mils (see Figs. 9 through 14).

Under the microscope these penetrations appeared to contain a dark nonmetallic material that was not resolvable on the photomicrographs. Note the strain lines associated with the penetrations.

One area of considerable interest is shown in Fig. 7 as it appeared under ultraviolet light. It was noted in the shipyard inspection as having a "v"-shaped configuration. A metallographic section revealed this to be either a lap in the surface or an elongated inclusion encountering the surface at a low angle (see Fig. 15).

Metallographic specimens taken at other indications of the in-place pipe section (see Figs. 16 and 17) showed only shallow grooves (these grooves appear as surface pits on photomicrographs) and folds in the surface. Figures 18 through 20 are typical of these indications. None of these grooves exhibited the character of those in Figs. 9 through 15.

In an attempt to confirm the nature of the flaws, the two sections of as-received pipe were examined. An obvious difference in appearance was noted between the as-received pipe and the in-service pipe. The as-received pipe had been surface ground, and the in-service pipe apparently had not.

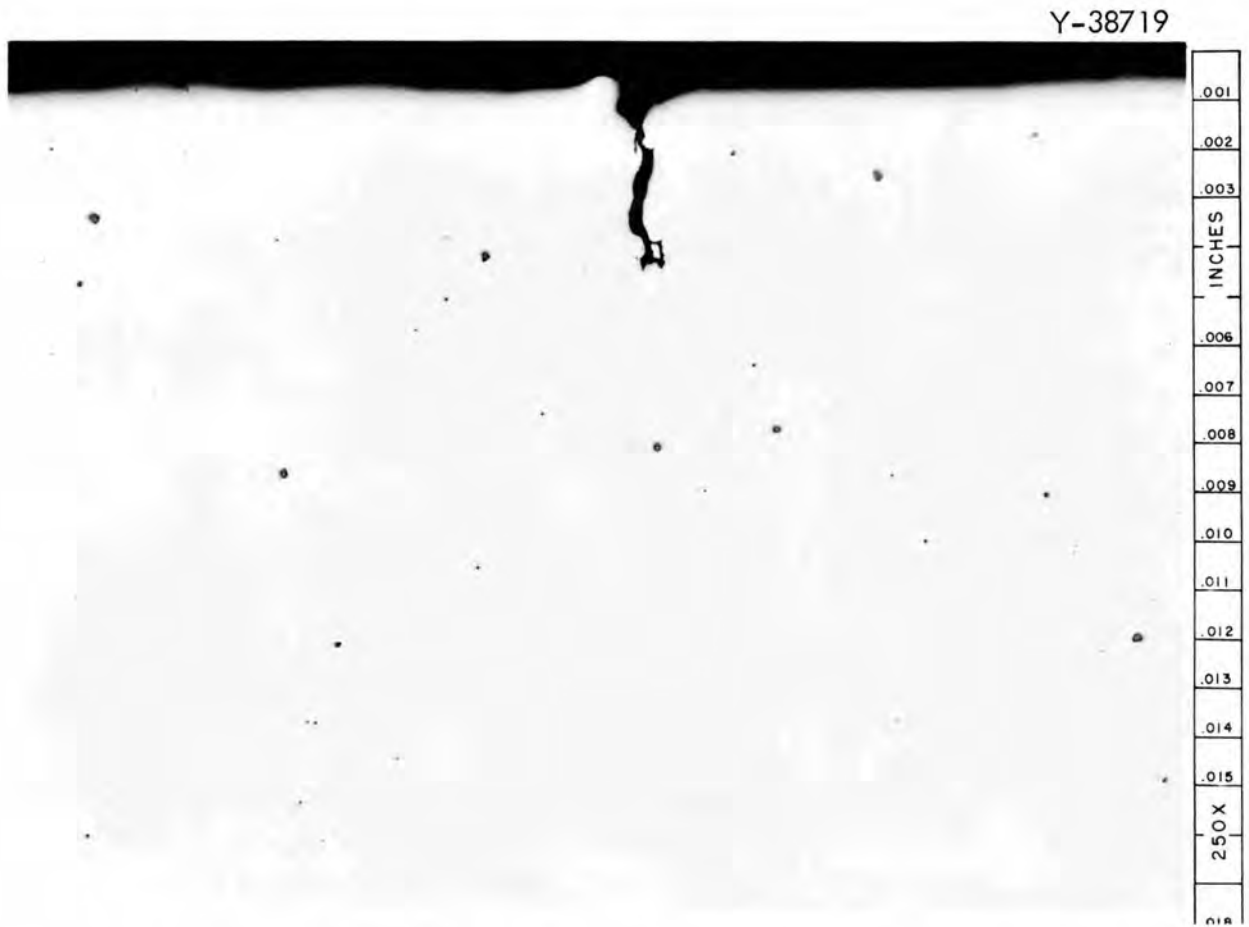


Fig. 9. Photomicrograph of Section 5, Fig. 6, Showing Penetration Normal to Surface, as Polished, X-250.

Y-38718

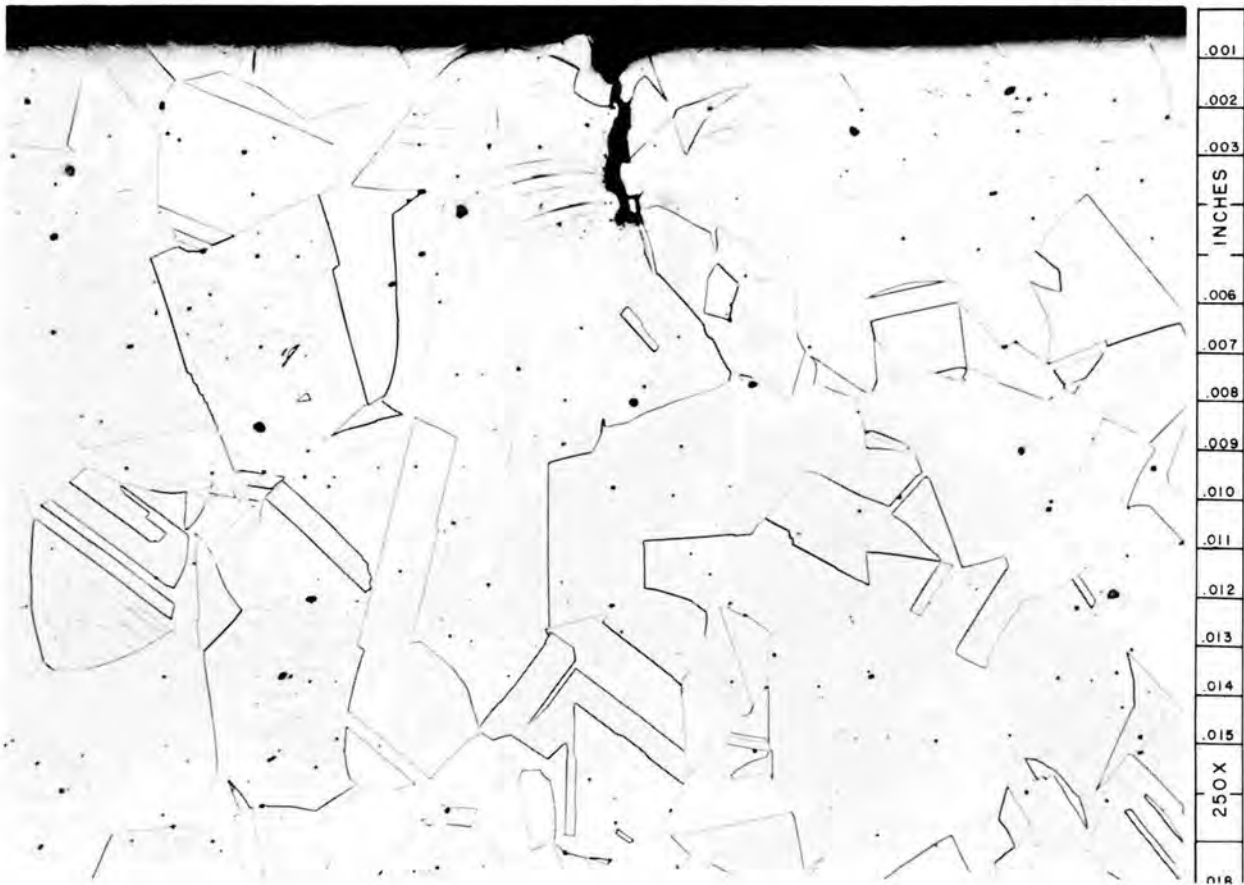


Fig. 10. Photomicrograph of Section 5, Fig. 6, Showing Penetration Normal to Surface, Etched with Modified Aqua Regia, X-250.

Y-39217

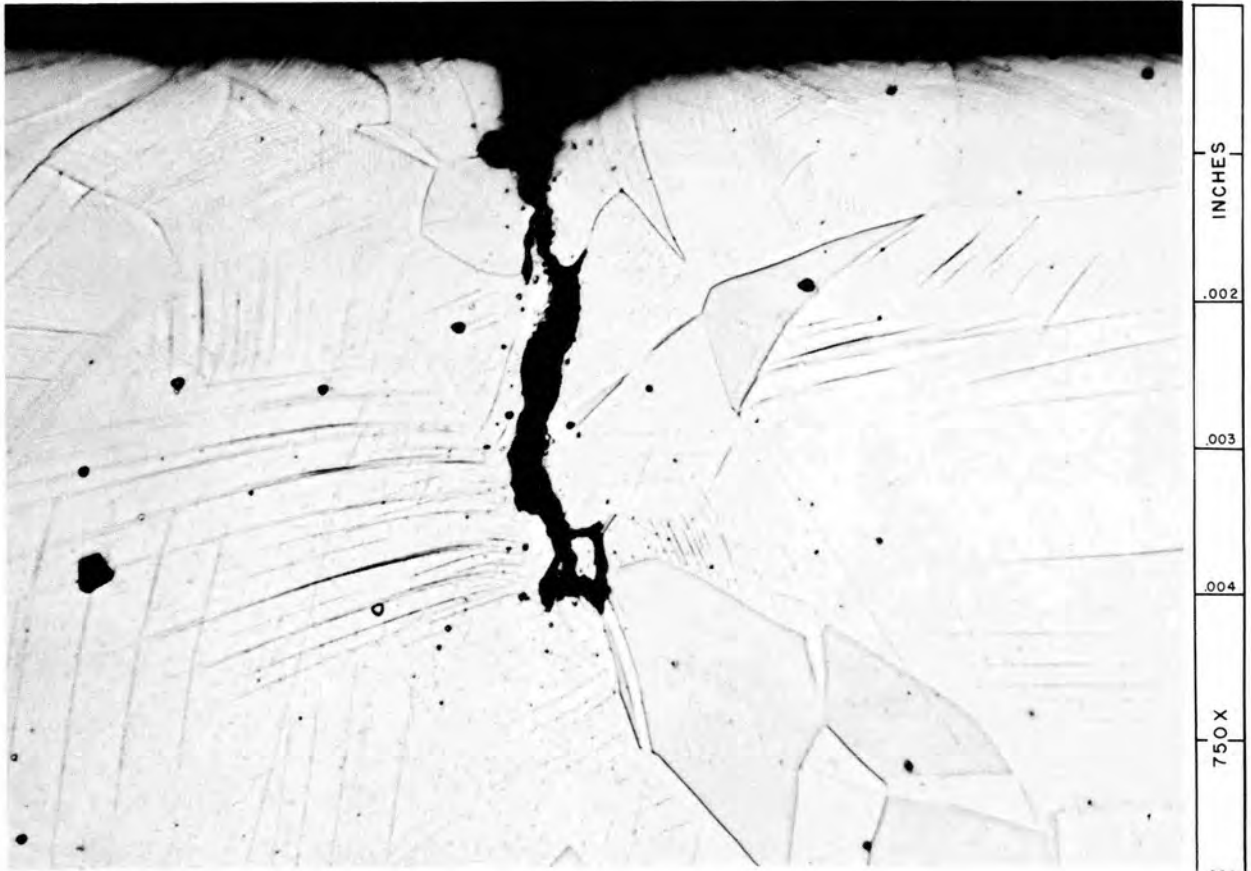


Fig. 11. Photomicrograph of Section 5, Fig. 6, Showing Penetration Normal to Surface, as Polished, X-750.



Fig. 12. Photomicrograph of Section 6, Fig. 8, Showing Penetration Normal to Surface, as Polished, X-250.



Y-38720

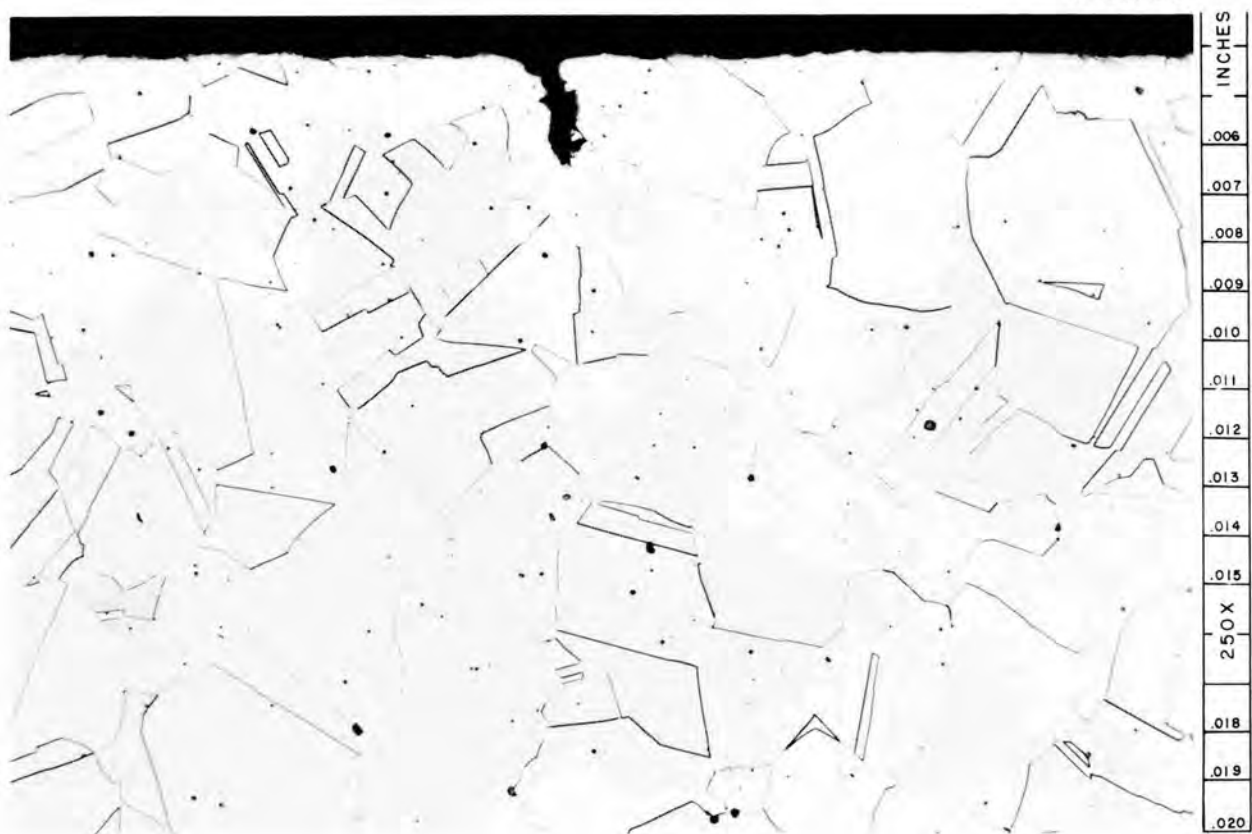


Fig. 13. Photomicrograph of Section 4, Fig. 8, Showing Penetration Normal to Surface, Etched with Modified Aqua Regia, X-250.

Y-39216



Fig. 14. Photomicrograph of Section 6, Fig. 8, Showing Penetration Normal to Surface, Etched with Modified Aqua Regia, X-750.

Y-38722

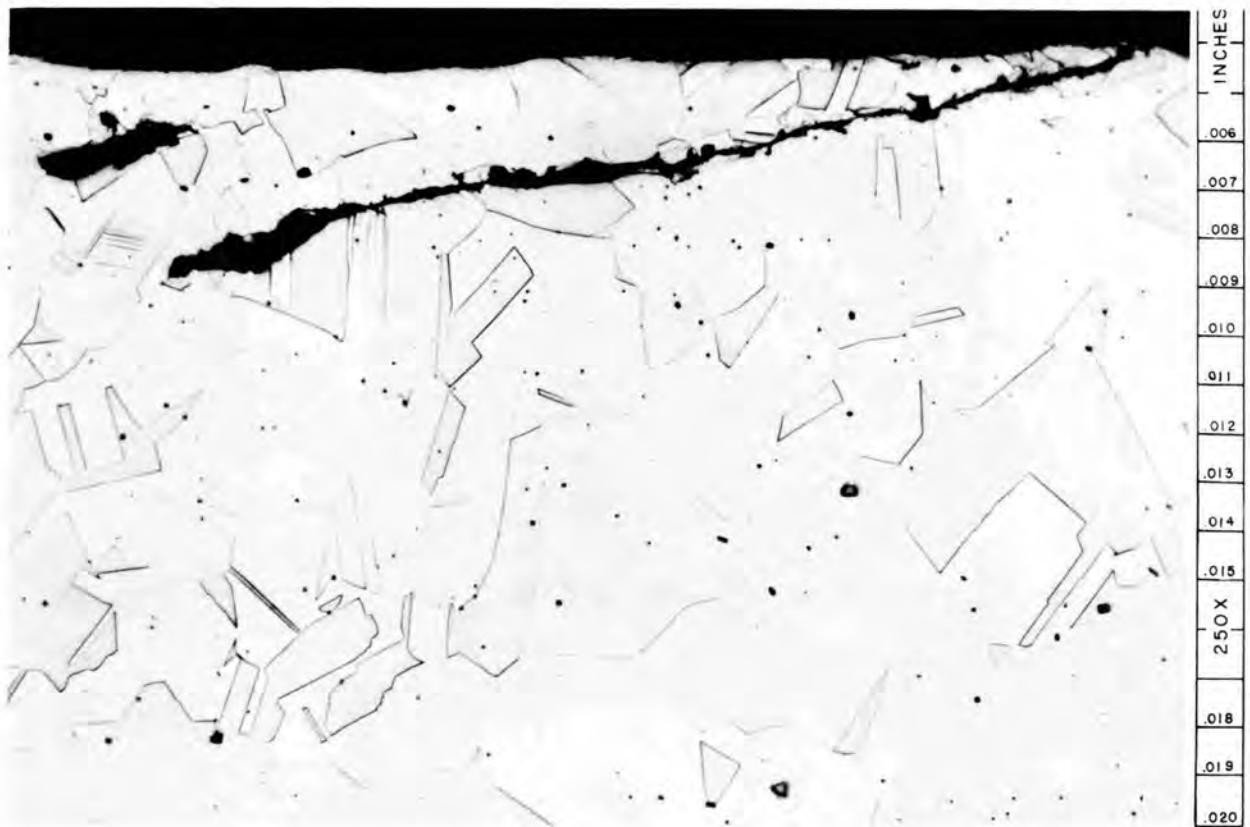


Fig. 15. Section through "v"-Shaped Indication, Fig. 7, Etched with Modified Aqua Regia, X-250.

Y-38711



ONE INCH

A scale bar with markings for one inch.

Fig. 16. Another View of Sample Cut from PP-1V.

Y-38712



Fig. 17. Indications Revealed by Ultraviolet Light Inspection from Fig. 16.

Y-38731

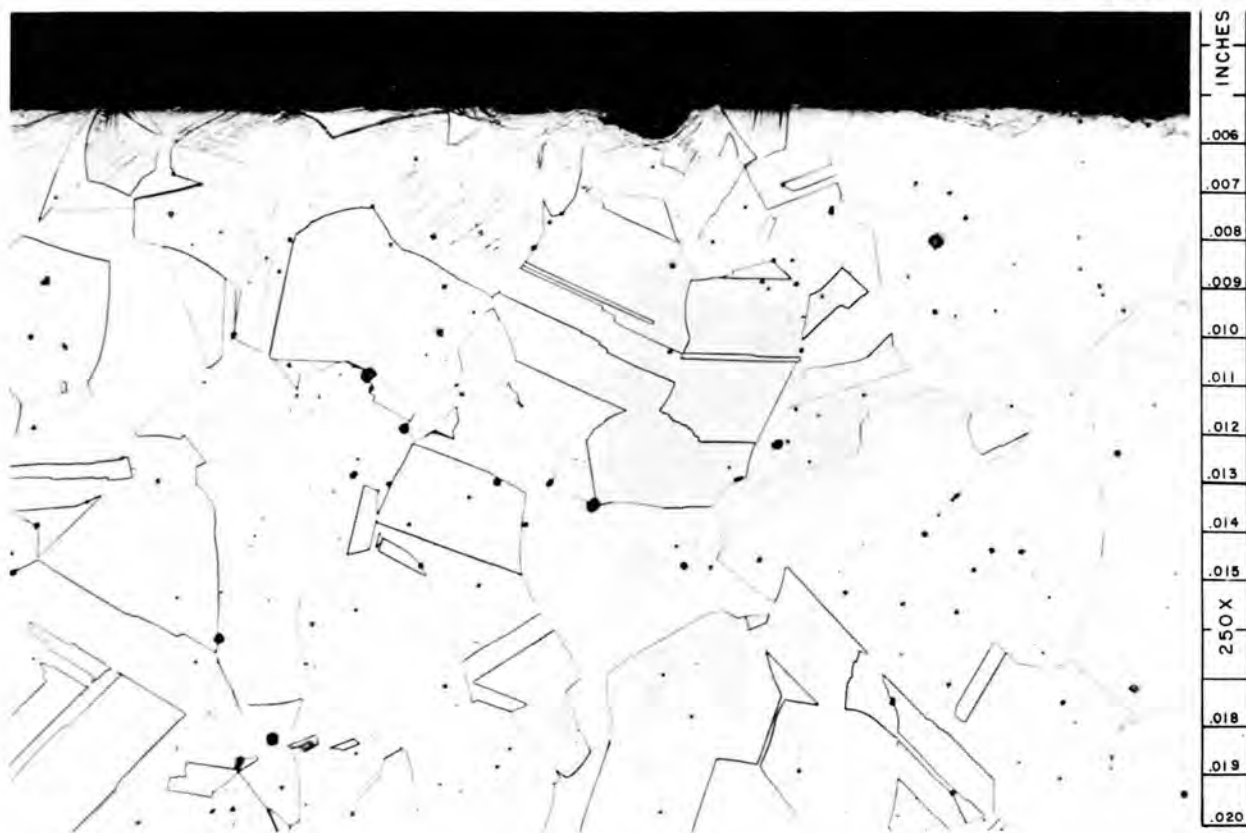


Fig. 18. Typical Defect Area Shown on Figs. 16 and 17, Modified Aqua Regia Etch, X-250.

Y-38732

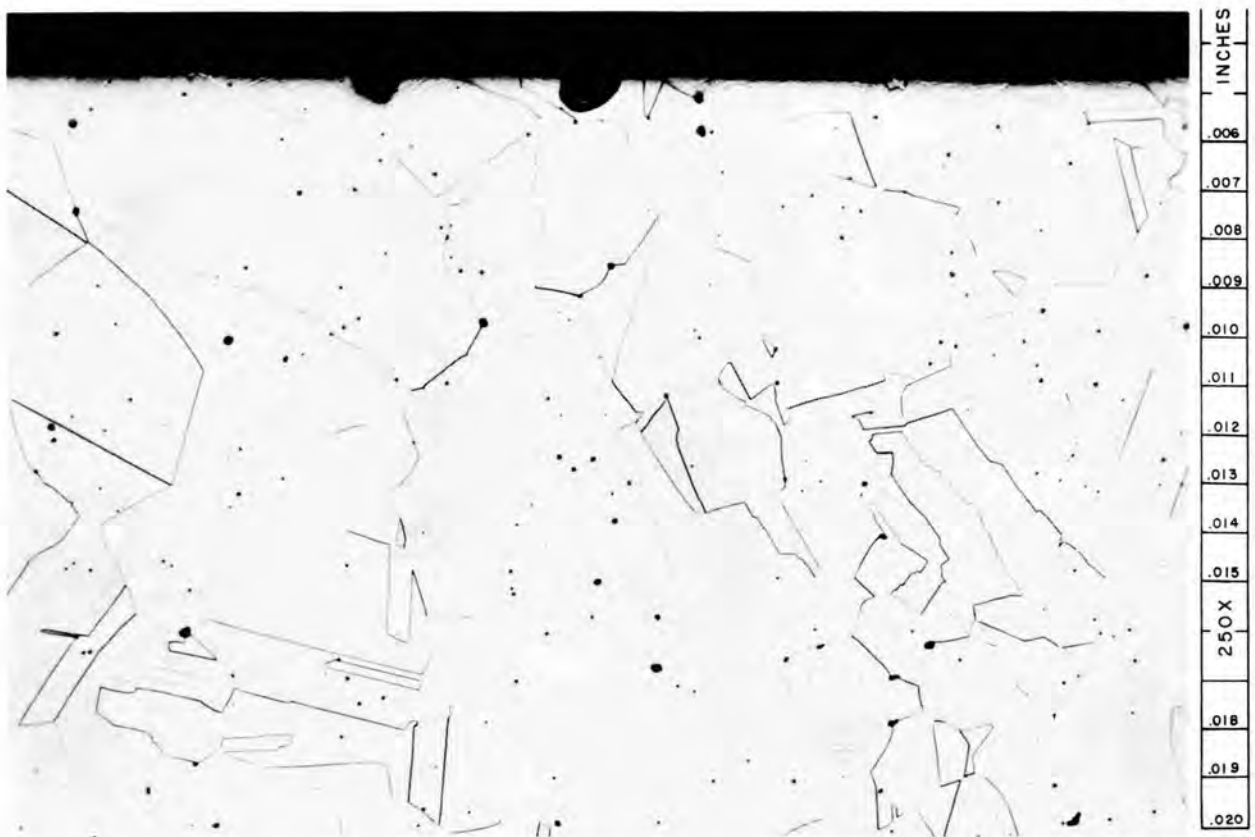


Fig. 19. Typical Defect Area Shown on Figs. 16 and 17 (Different from Fig. 18), Modified Aqua Regia Etch, X-250.

Y-38730



Fig. 20. Lap in Surface from Area Shown in Figs. 16 and 17, as Polished, X-250.



Both sections of as-received pipe were ultrasonically and dye-penetrant inspected. Each section of the as-received pipe was found to have numerous longitudinal fluorescent-penetrant indications. One section had approximately three times as many indications as the other. Figure 21 is a typical picture of indications seen on these pipe sections.

Figures 22 through 25 are photomicrographs of the typical flaw found in the as-received pipe. They appear to be slag inclusions that connect with the surface.

Numerous surface indications were noted on both the in-place and as-received sections of pipe. Most of these indications were parallel to the longitudinal axis of the piping. The section removed from the N. S. SAVANNAH showed a greater number of indications, several of which were much more apparent than those noted on the as-received sections.

From the orientation of the indications as well as the cross-sectional shape of the indications examined metallographically, it appears that most of the indications seen on the in-place pipe were manufacturing defects. These defects provide ideal sites for concentration of chloride and could serve as origins for chloride stress-corrosion cracking.

A total of six metallographic sections were made through the prominent as well as the typical indications in the in-place section of piping, and two metallographic sections were made through the typical indications seen on the as-received piping. The results are summarized as follows:

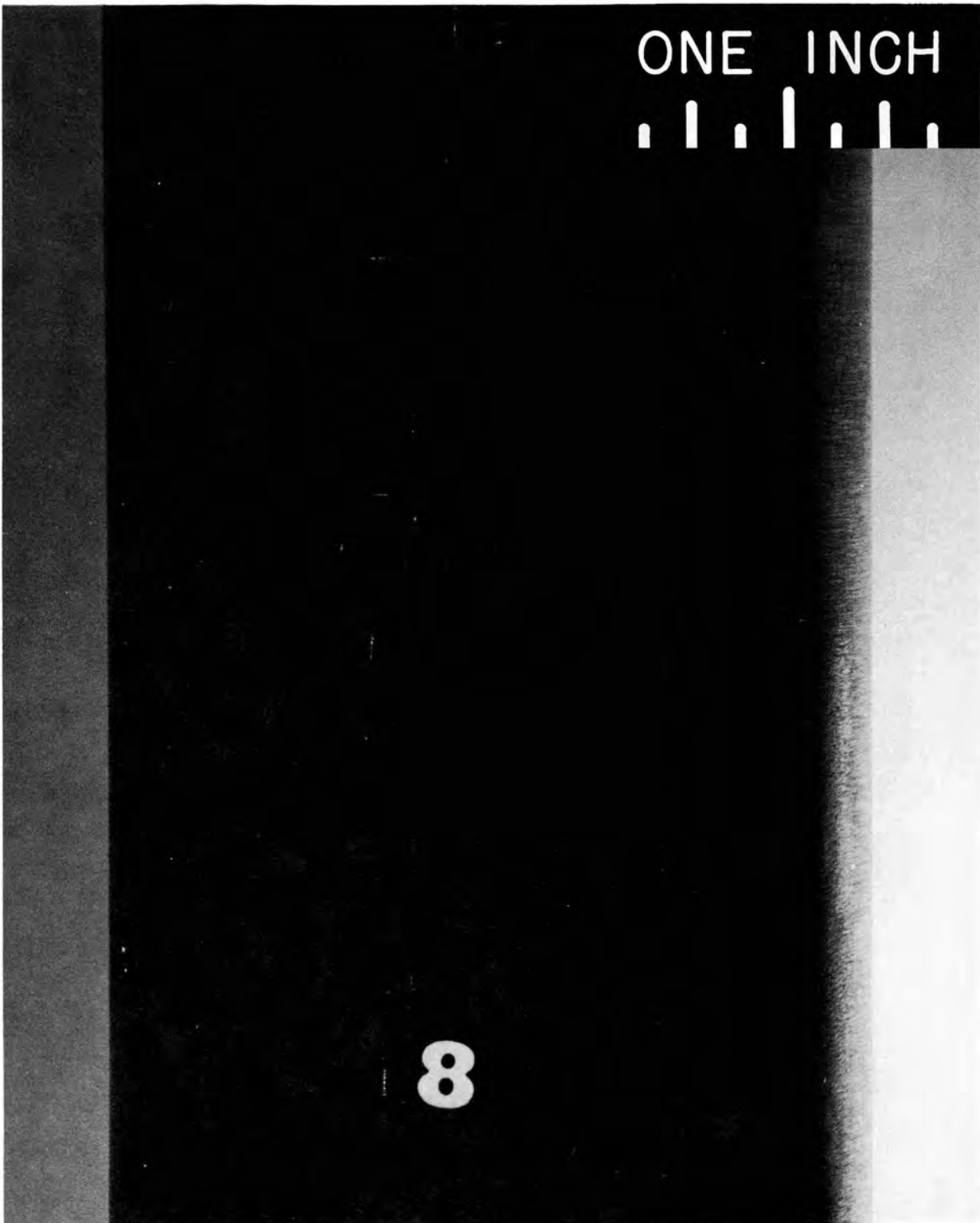


Fig. 21. Typical Ultraviolet Light Indication from as-Received Stock at New York Shipbuilding Corporation.



Fig. 22. Crack or Slag Inclusion in as-Received Pipe, as Polished, X-250.

Y-38726

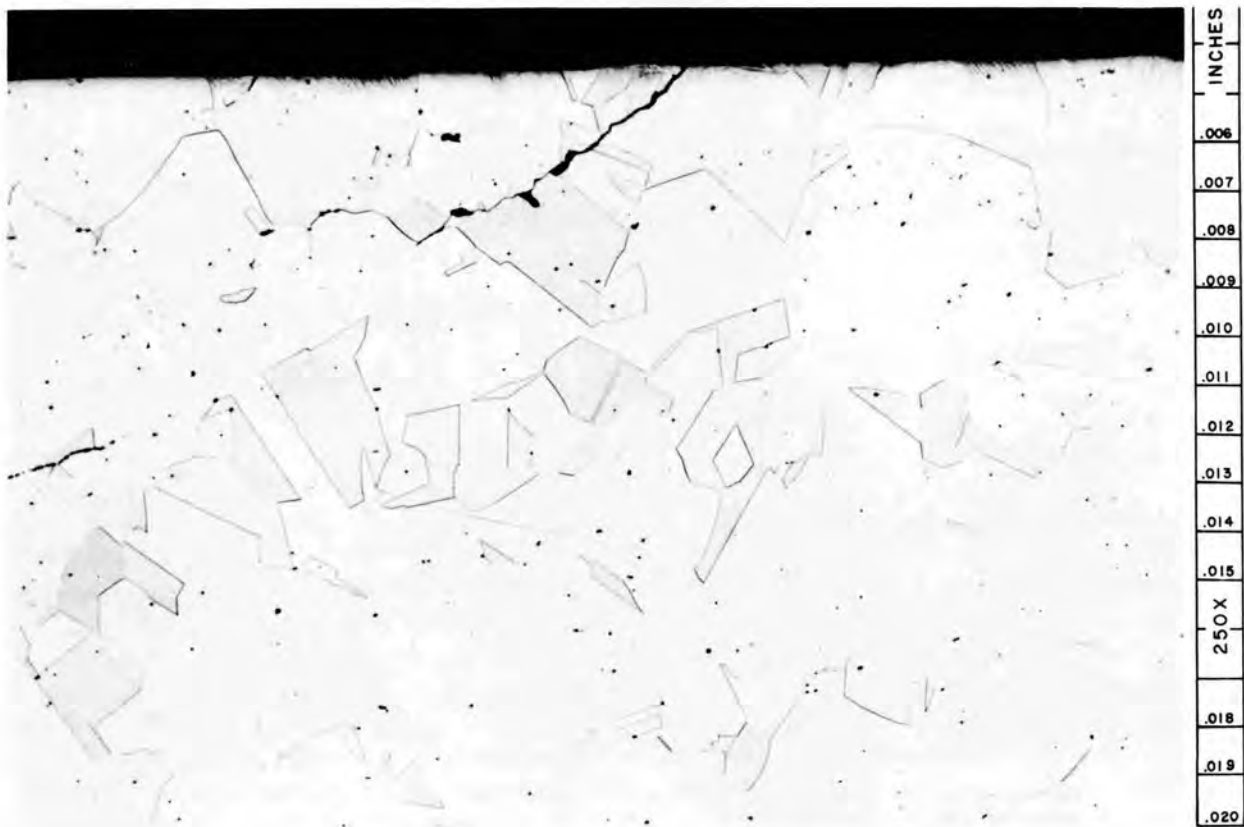


Fig. 23. Crack or Slag Inclusion in as-Received Pipe, Modified Aqua Regia Etch, X-250.

Y-38725



Fig. 24. Other Typical Defects in as-Received Pipe, as Polished, X-250.

Y-38724



Fig. 25. Other Typical Defects in as-Received Pipe, Modified Aqua Regia Etch, X-250.

In-Place Pipe Section

2 sections--lap or inclusion, 1 to 5 mils normal-to-surface depth;  
 2 sections--shallow grooves, < 1 mil depth;  
 2 sections--intergranular and intragranular defects, 3 to 4 mils  
 normal-to-surface depth.

As-Received Pipe Sections

2 sections--lap or inclusion, 3 to 4 mils normal-to-surface depth.

The surface indications of the in-place piping showed only one irregular line which, when sectioned, turned out to be a lap. The two defects normal to the surface that were both intergranular and intragranular were in sections made through indications that were straight and parallel to the longitudinal axis of the pipe. These defects appear to be chloride stress-corrosion cracks. Note the transgranular nature of the defects and the several extensions of each defect at the root<sup>14</sup> (see Figs. 11 and 14). This type of defect was not noted on the as-received piping; however, insufficient sectioning was performed to be able to make a general comparison between the in-place and the as-received material, and it cannot be unequivocally stated that chloride stress-corrosion cracking had taken place. It is likely that chloride stress-corrosion cracking was beginning, particularly in light of the condition under which the piping had operated; and it is very likely that chloride stress-corrosion cracking is responsible for the two suspicious defects which could have extended from initially shallow fabrication defects (like those seen in the two sections noted as shallow grooves) to deeper intergranular and intragranular defects.

## 2. Stress-Corrosion Susceptibility Tests<sup>17</sup>

The purpose of the laboratory tests was to establish whether in a chloride-containing environment the magnitude of fabrication stresses in the 0.343-in.-thick-wall pipe was sufficient to induce cracking. The initial laboratory test was made at 250°C in deionized water containing 100 ppm of chloride (added as potassium chloride) since considerable laboratory experience has been accumulated with this environment in stainless steel stress-corrosion cracking studies. The starting water pH was 5.6. Prior to test a 1/2-in.-long piece of pipe was cut from the length of 2-in., sched.-160, type 304 stainless steel pipe removed from part of the letdown cooler system of the N. S. SAVANNAH. Both cross-sectional faces of the test specimen were carefully abraded on 120-grit paper. A pretest view of the pipe specimen is shown in Fig. 26. The small surface irregularities are a result of the cutting operation.

After degreasing and weighing, the specimen and the test medium were placed in a titanium autoclave which was pressurized with 150 psi of oxygen at room temperature. The autoclave was run at 250°C for 100 hours at which time the test was stopped. A considerable quantity of red-brown corrosion product was observed on the bottom of the autoclave; the final water pH was 7.0. A heavy, nonuniform, varicolored scale was present on the specimen; and low-power microscopic examination disclosed numerous pits. No cracks were found. A small amount of the scale was removed by mechanical scraping and placed in a magnetic field; a good portion of the fine particles were magnetic which indicated the presence



UNCLASSIFIED  
PHOTO 55694



Fig. 26. Pretest Appearance of 2-in., Type 304 Stainless Steel Pipe Specimen, X-1.68 (Test AN-32).

of magnetite,  $\text{Fe}_3\text{O}_4$ . The existence of magnetite was unexpected since calculations based upon the amount of metal corroded and the amount of oxygen added to the autoclave initially showed that only approximately 5 per cent of the added oxygen was consumed in the corrosion process. It is conceivable, however, in view of the thickness of the scale on areas of the specimen, that little or no oxygen diffused into the innermost oxide layers so that in these regions the major corrosion product was magnetite. A photograph showing the condition of the specimen after test appears in Fig. 27.

The specimen was descaled cathodically in inhibited 5 per cent  $\text{H}_2\text{SO}_4$  solution; the observed weight loss indicated a corrosion rate of 62 mpy for the 100-hr period. Careful microscopic examination of the cleaned surfaces again failed to reveal any cracks. The specimen was badly pitted; measurements made on 19 of the deepest-appearing pits indicated a pit-depth range between 2 and 11 mils.

The 62 mpy corrosion rate was considered excessive as compared with observed rates on other grades of austenitic steel exposed in a similar environment for the same time interval. As a check on the chemical and metallurgical soundness of the type 304 stainless steel, as-received specimens from another section of the 2-in. pipe were subjected to the boiling 65 per cent  $\text{HNO}_3$  test (ASTM:262-55T). The performance of the material was entirely satisfactory; duplicate specimens each exhibited an average penetration rate of 7.2 mpy for five 48-hr periods.

In an attempt to reduce the excessive corrosion encountered in the preceding test, the chloride concentration was lowered to 50 ppm; the

UNCLASSIFIED  
PHOTO 55695



Fig. 27. Condition of Type 304 Stainless Steel Test Specimen after 100 hr at 250°C in Water Containing 100 ppm of Chloride, X-1.6.

solution pH was 5.5. The specimen was repolished on 120-grit paper and exposed for two consecutive 100-hr periods under identical conditions described for the initial run in the titanium autoclave. Also included in the test was an unstressed control specimen from another heat of type 304 stainless steel. Upon completion of the first 100 hr in the 50-ppm chloride solution, it was evident by visual examination that attack on the specimens was appreciably less severe than was experienced in the 100-ppm chloride solution. Both specimens showed mild accumulations of dark brown-and-black colored corrosion product randomly distributed. In other areas a thin semilustrous, tan-colored film covered the surface. Pitting was in evidence on both the pipe and the control specimens. Microscopic examination showed several suspect areas which appeared to contain fine cracks. The two specimens were exposed for a second 100-hr run using fresh solution. Additional scaling and corrosion occurred; Fig. 28 shows the as-removed appearance after 200 hr.

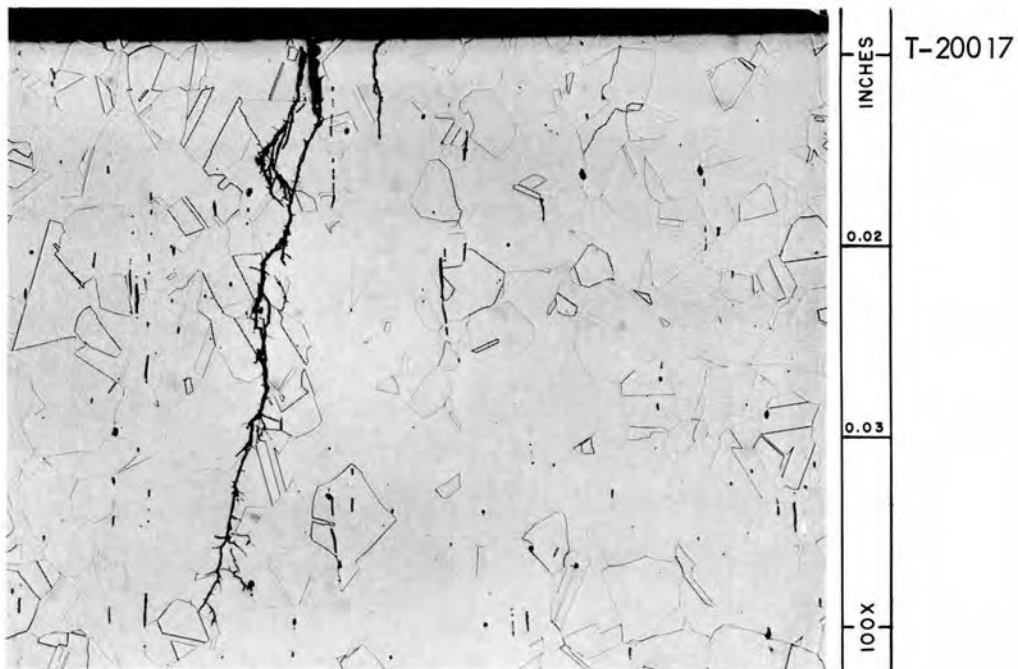
The defilmed corrosion rates for the two specimens were nearly identical, 4.0 mpy for the pipe specimen and 4.7 mpy for the control specimen. Both specimens were badly pitted; pit depths ranged up to 10 mils. Fairly numerous hairline cracks were noted on the pipe specimen which was submitted for metallographic examination. No cracks were found on the control specimen.

Figures 29, 30, and 31 are photomicrographs of a number of the cracks found in the pipe specimen. In all cases the cracks were transgranular and penetrated to depths up to 35 mils. Cracks were present on both the outer and inner surfaces of the pipe.

UNCLASSIFIED  
PHOTO 55696



Fig. 28. Condition of Type 304 Stainless Steel Test Specimens after 200 hr at 250°C in Water Containing 50 ppm Chloride, X-1.6 (Test AN-40).



View of Complete Crack, X-100.

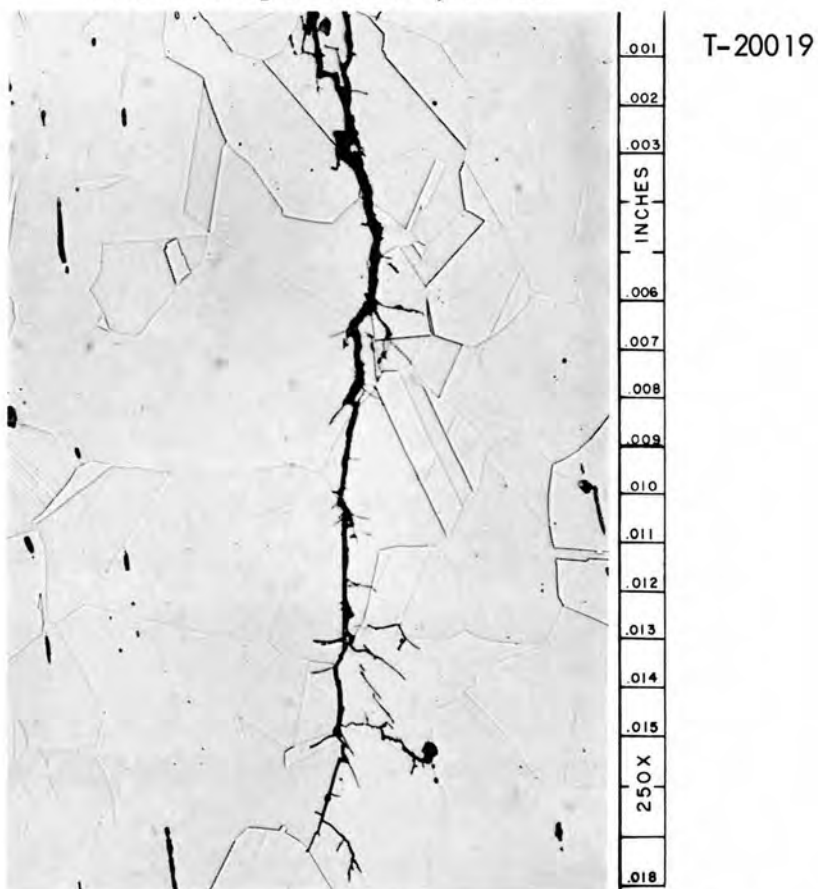


Fig. 29. Crack on OD of Type 304 Stainless Steel Pipe Specimen after 200 hr at 250°C in Water Containing 50 ppm Chloride, Etched in Glyceria Regia.

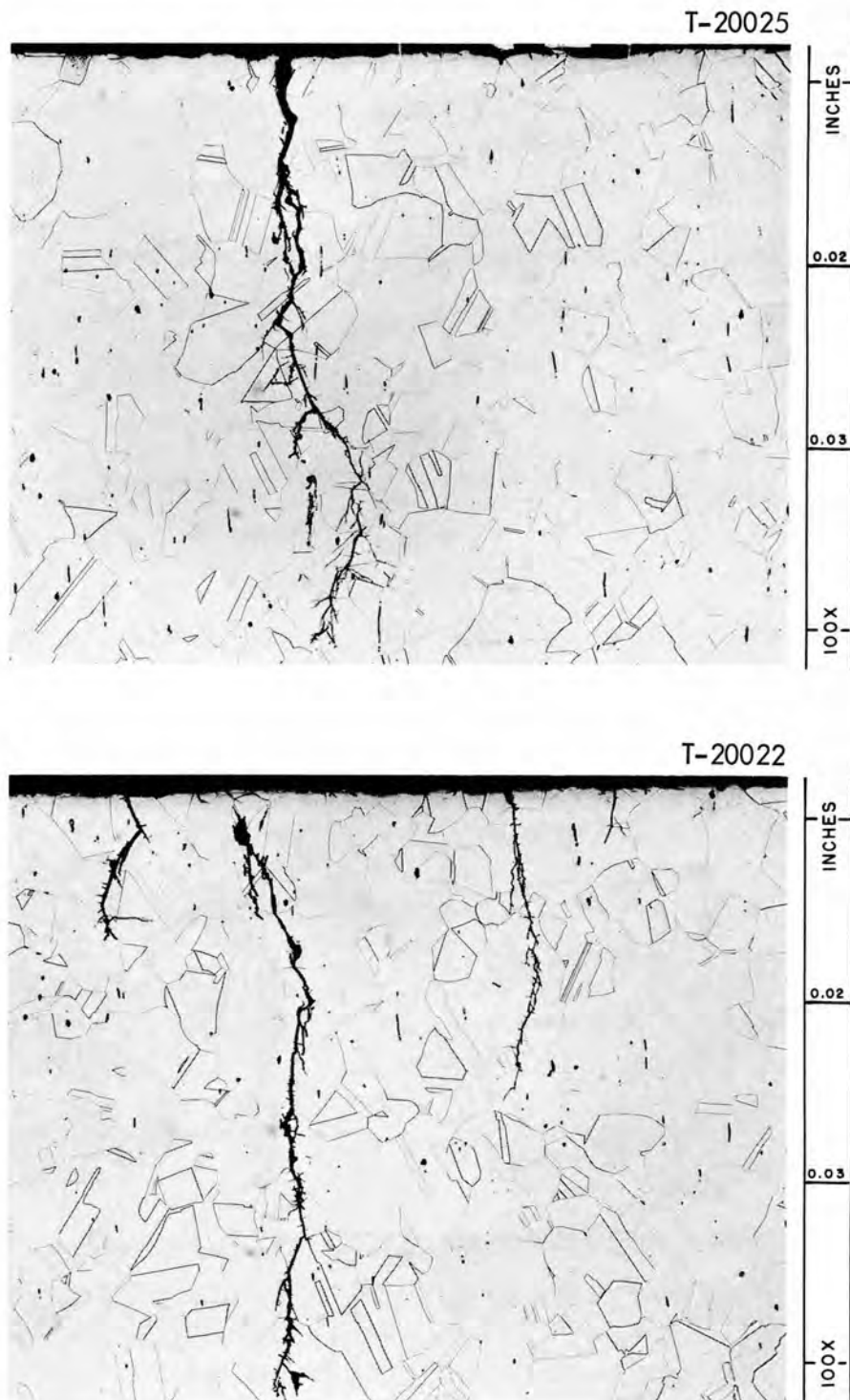


Fig. 30. Cracks on OD of Type 304 Stainless Steel Pipe Specimen after 200 hr at 250°C in Water Containing 50 ppm Chloride, Etched in Glyceria Regia, X-100.



Fig. 31. Crack on ID of Type 304 Stainless Steel Pipe Specimen after 200 hr at 250°C in Water Containing 50 ppm Chloride, Etched in Glycemia Regia, X-250.



It is concluded that the stress levels resulting from fabrication of the 2-in., sched.-160, type 304 stainless steel pipe removed from the primary cooling system of the N. S. SAVANNAH were of sufficient magnitude that in chloride-containing water at elevated temperature the combined effects of stress and corrosion produced severe cracking in a relatively short period of time.

### 3. Cathodic Protection Tests

Inasmuch as stress-corrosion can be controlled by cathodic protection, design tests were started by Ebasco to ascertain the desirable current density for the stainless steel in an environment of warm, crushed-block insulation and demineralized water (see Appendix E). Tests conducted during the course of this investigation indicated that aluminum acted as a sacrificial anode when coupled to type 304 stainless steel in an electrolyte obtained from an extract leached from Johns-Manville Thermobestos insulation and type 301 cement. In this investigation four cycles of complete wetting and drying were experienced without substantial increase in cell resistance. This was confirmed by tests with the calcium-silicate insulation used for insulating the austenitic stainless steel pipelines on the N. S. SAVANNAH. It is likely that additional wetting and drying cycles can be tolerated and that the galvanic protection cells will continue to operate. However, additional tests would be required to establish this.

It was found that the aluminum wrapping under the thermal insulation did not deteriorate as a result of moist contact with the calcium-

silicate type of insulation. In addition, the New Kensington Laboratories of the Aluminum Company of America have tested Johns-Manville Thermobestos insulation in a humidity cabinet for 6-month periods and found that aluminum foil in contact with this insulation did not deteriorate.<sup>16</sup>

It is believed that, with the information presently available, the aluminum foil would not introduce any additional problems and would act as a protective medium.<sup>13,14</sup>

The advantages of using aluminum foil around pipelines are as follows:

1. Cathodic protection against chloride stress-corrosion cracking is available in the event the insulation becomes water soaked.
2. In the event the insulation had to be removed, the operation would be facilitated since the aluminum foil would prevent the insulation from adhering to the pipe during high temperature operation.

#### 4. Chemical Analyses

It was of interest to this problem to determine the water-soluble chloride content of the in-place insulation and to see if there was a significant difference between the chloride level in the insulation known to have been wet and the insulation that was thought to have remained dry during the testing. ORNL and Ebasco carried out parallel efforts in this investigation.

There was also considerable interest in developing an adequate cleaning procedure for removing chloride that had been leached from the

insulation and deposited on stainless steel surfaces, particularly because of the many surface imperfections found in the piping. Ebasco performed a laboratory investigation on this problem.

In an effort to gain additional information, Ebasco scraped the external surfaces of the stainless steel piping fittings at several locations to obtain samples of deposits and performed qualitative spectrographic analyses on these samples.

(a) ORNL Insulation Analysis. The following samples were requested and received from AEC-MARAD:

1. Block insulation that had been applied to the piping and had remained dry throughout the testing and cleaning operations.
2. Block insulation that had been applied to the system and had been wet.
3. As-applied insulation cement (mud).

These samples were analyzed for chlorides. The average values of the chloride content of the insulation as determined by the amount leached during 1 hour in boiling 9 N  $\text{H}_2\text{SO}_4$  were:

Dry insulation block	83 ppm $\text{Cl}^-$
Wet insulation block	47 ppm $\text{Cl}^-$
Insulation cement	157 ppm $\text{Cl}^-$

Leaching studies were performed on the various samples in water and  $\text{H}_2\text{SO}_4$  until the leached chloride measurements leveled off. The chloride contents were:

<u>Sample</u>	<u>Leach Solution</u>	<u>Leach Time (hr)</u>	<u>Cl<sup>-</sup> (ppm)</u>
Dry	Cold H <sub>2</sub> O	47	85
Dry	Boiling H <sub>2</sub> O	45	215
Dry	Boiling 9 N H <sub>2</sub> SO <sub>4</sub>	44	275
Wet	Boiling H <sub>2</sub> O	84	185
Wet	Boiling 9 N H <sub>2</sub> SO <sub>4</sub>	84	190

These analyses are believed to be within  $\pm 5$  ppm Cl<sup>-</sup>. For the detailed procedure, see Appendix H.

It can be noted that in a period of two days, even with cold water and no agitation, sufficient chlorides could be leached from the insulation to promote chloride stress-corrosion cracking of stressed austenitic stainless steel piping, particularly when the piping was being thermal cycled between room temperature and 500°F.

(b) Ebasco Insulation Analysis. The chloride content of the block and mud insulation reported to have been soaked during the hot-flushing operation was determined (see Appendix I).

Samples of the block and mud insulation were submitted for analysis on December 23, 1960. The block insulation was analyzed from crushed samples taken from a cross-sectional segment. The mud was analyzed from pieces taken at random and crushed. Each sample was leached in demineralized water at room temperature (75°F) for 243 hr. The liquor was then filtered and diluted to 500 ml with the following results:

<u>Insulation and Location</u>	<u>Chloride Content (ppm)</u>
Cement Insulation (Mud) around Valve (239 g)	168
Block Insulation at Valve End (68.5 g)	68
Block Insulation at Elbow End (74.5 g)	91

(c) Cleaning Agent Study. ORNL had successful experience in removing chlorides from stainless steel surfaces with 3 to 5 per cent  $\text{HNO}_3$  solutions.<sup>18</sup> The Atomics International and The Babcock & Wilcox Company are reported to have used a commercial product called Alconox to clean stainless steel fuel elements prior to placing them in service. Alconox is a sulfonated hydrocarbon containing complex phosphates. The manufacturer, Alconox, Incorporated, reports that Alconox is very low in chlorides--in the range of a few parts per million. This was confirmed by an analysis at ORNL .

Since The Babcock & Wilcox Company and the New York Shipbuilding Corporation suggested the use of Alconox rather than a nitric acid solution, Ebasco performed a study to determine if Alconox was as effective in removing chlorides from stainless steel surfaces as was the dilute  $\text{HNO}_3$  wash (Appendix F). If found satisfactory in this regard, it would be preferable to use Alconox rather than nitric acid in such a cleaning operation since the corrosive nature of dilute  $\text{HNO}_3$  on copper and carbon steel would require careful use of the wash solution.

A type 304 stainless steel tube 2-in.-o.d. x 1/16-in. wall containing a highly porous weld produced with a tungsten electrode and

stainless steel filler metal in air was sectioned in four segments 1 1/2 in. long, each segment containing one-quarter of the weld.

The segments were placed in a boiling solution of magnesium chloride and demineralized water for 3 hr. The solution contained 28.5 g of MgCl per 100 cc demineralized water. After 3 hr the samples were removed and permitted to air dry.

The following table lists the results of cleaning these samples with various agents.

It was concluded, based on these tests, that the Alconox solution appears to have the ability to remove chlorides as effectively as the 5 per cent  $\text{HNO}_3$ .

(d) Spectrographic Analysis of Pipe Surface Deposits. Deposits were scraped from the 2-in., sched.-160, type 304 stainless steel pipe and valve body at two locations by Ebasco inspectors. Samples of these deposits found on the PP-1V line were submitted for qualitative analysis on December 28, 1961. Each sample was analyzed spectrographically and found to contain the following:

<u>Element</u>	Deposit	Deposit
	<u>On Valve Body And Horizontal Pipe (Percent Estimate)</u>	<u>On Vertical Pipe (Percent Estimate)</u>
Silicon	> 5	0.1 to 0.9
Magnesium	> 5	0.01 to 0.09
Aluminum	> 5	0.01 to 0.09
Iron	> 5	0.01 to 0.09
Calcium	> 5	0.1 to 0.9

<u>Sample</u>	<u>First Wash</u>		<u>Second Wash</u>		<u>Third Wash</u>	
	<u>Solution</u>	<u>ppm Cl<sup>-</sup></u>	<u>Solution</u>	<u>ppm Cl<sup>-</sup></u>	<u>Solution</u>	<u>ppm Cl<sup>-</sup></u>
1	Demineralized Water	Not Made	Demineralized Water	< 1 ppm	5% HNO <sub>3</sub>	17.5
2	1% Alconox	Phosphates Shielded Chlorides	Demineralized Water	< 1 ppm	5% HNO <sub>3</sub>	5
3	5% HNO <sub>3</sub>	Not Made	Demineralized Water	< 1 ppm	5% HNO <sub>3</sub>	Not Made
4	5% HNO <sub>3</sub>	Not Made	Demineralized Water	< 1 ppm	5% HNO <sub>3</sub>	8

For details of the investigation, see Appendix K.

<u>Element</u>	<u>Deposit On Valve Body And Horizontal Pipe (Percent Estimate)</u>	<u>Deposit On Vertical Pipe (Percent Estimate)</u>
Titanium	1 to 5	0.001 to 0.009
Zinc	1 to 5	1 to 5
Sodium	0.1 to 0.9	0.001 to 0.009
Potassium	0.1 to 0.9	0.001 to 0.009
Lead	0.1 to 0.9	0.001 to 0.005
Manganese	0.1 to 0.9	0.0001 to 0.0009
Copper	0.01 to 0.09	0.001 to 0.009
Chromium	0.01 to 0.09	Not Found
Nickel	0.01 to 0.09	Not Found

The following elements were checked but not found: tin, molybdenum, vanadium, cobalt, tungsten, bismuth, arsenic, cadmium, indium, antimony, barium, strontium, lithium.

The spectrographic analyses of the surface deposits sampled from these two areas appear to be completely different, although the deposits looked the same--as if the adhesive tape had been baked on the surface. It is possible that the valve body and horizontal pipe deposit contains elements from the Thermobestos and mud insulations. These elements could have adhered to the material on the pipe surface at the time the system was coming up to temperature. The composition of the deposit on the vertical pipe is not understood. No conclusions could be drawn from these data.



### C. Discussion of Corrective Measures

On January 5, 1961, Ebasco and ORNL met to review the investigatory work that had been performed up to that time by both organizations. A second purpose of the meeting was to ascertain what corrective action should be recommended for the primary piping system. AEC-MARAD requested that ORNL and Ebasco keep in mind the urgency of the situation in that delays due to the corrective measures should be kept to a minimum so that the reactor testing operation could proceed as quickly as possible.

The problem of determining which sections of insulation had been wet was difficult to resolve. The insulation that had been wet did not show any distinguishing characteristics that would allow identification. Without positive identification of wet areas and knowing that several leaks had occurred in the containment vessel, it was decided that all insulation on the primary system would have to be considered as having been wet; and, therefore, it must all be removed. It was also decided that a pipe inspection and cleaning program should be recommended because of the possible surface contamination as well as the indications (flaws and defects) found in the in-place pipe and the tenacious baked-on deposits found on the pipe surfaces.

On January 6, 1961, a meeting was held at New York Shipbuilding Corporation in Camden, New Jersey, for the purpose of discussing the Ebasco-ORNL recommended corrective measures. The meeting was attended by representatives of AEC-MARAD, New York Shipbuilding Corporation, The Babcock & Wilcox Company, ORNL, and Ebasco.

Ebasco and ORNL presented their opinions of results of the investigation performed up to January 5, 1961, as follows:

It appears that the majority of the indications found on the 2-in., sched.-160, type 304 stainless steel pipe and elbow removed from the N. S. SAVANNAH are manufacturing defects such as scores and laps. However, two defects were observed which were not of the same nature as the scores and laps. These two defects are normal to the outside pipe surface and display branching characteristics that are transgranular in nature.

It is believed that these two particular defects are chloride stress-corrosion cracks in the incipient state. This observation is supported by the following considerations:

1. The unsealed chloride-bearing thermal insulation on the N. S. SAVANNAH was wet during precritical operational testing.
2. The temperature during test ranged from approximately 150°F to 500°F, thereby permitting washing down of chlorides to the pipe at the lower temperature and concentration of chlorides at the higher temperature.
3. The system was under applied and fabrication stress during the operating test pressure of 1750 psig.
4. The defects that existed in the austenitic stainless steel pipe surfaces were ideal sites for collection of chlorides.
5. Many case histories exist of austenitic stainless steel systems (other than the N. S. SAVANNAH) which experienced stress-corrosion cracking or failure due to stress-corrosion under wet chloride-bearing thermal insulation. (See Appendix J.)

As a result of the above, it is believed that measures must be taken to correct the present condition and to initiate action to prevent the possibility of future problems with chloride stress-corrosion cracking of austenitic stainless steel systems covered with chloride-bearing thermal insulation.

The ORNL-Ebasco recommendations for corrective action also were presented at this meeting (see Section III).

Subsequent to this meeting, a rough draft procedure was written so that the work of removing insulation and inspection could proceed

immediately. The procedure (Appendix B, Section 3) was written and submitted for review to AEC-MARAD, New York Shipbuilding Corporation, and The Babcock & Wilcox Company on January 18, 1961.

At a second meeting in Washington, D. C., on January 18, 1961, AEC-MARAD, Hazards Evaluation Branch of the AEC, The Babcock & Wilcox Company, ORNL, and Ebasco reviewed the Ebasco-ORNL recommendations.

In a subsequent meeting held in Washington, D. C., on January 24, 1961, with the same representation as above except for the addition of New York Shipbuilding Corporation representatives, it was brought out that B&W and NYS objected to the use of a 3 to 5 per cent  $\text{HNO}_3$  cleaning solution and suggested the use of Alconox, a commercial detergent. The use of Alconox was considered. Tests were performed at Ebasco and ORNL to determine the relative effectiveness of Alconox and 3 to 5 per cent  $\text{HNO}_3$  to remove chlorides from pipe surfaces (Section 4C). Alconox proved to be a satisfactory cleaning agent; and, therefore, it was employed as cleaning agent on the N. S. SAVANNAH primary system.

The New York Shipbuilding Corporation initiated and completed removal of the Thermobestos insulation on January 18, 1961. All stainless steel pipe surfaces were mechanically cleaned as the insulation was removed to remove the baked-on tape and other foreign matter. This task was finished January 19, 1961. The fluorescent-penetrant inspection including removal of defects commenced on January 19, 1961, and was completed on January 28, 1961 (see Appendix B). Solution cleaning of all pipeline surfaces with Alconox was started on February 3, 1961, and completed February 5, 1961. Installing and sealing of Unibestos insulation

was started on February 8, 1961, and completed February 14, 1961. The time that elapsed from the removal of the Thermobestos insulation to the completion of the reinsulation with Unibestos was 28 calendar days.

The Unibestos insulation complied with military specification MIL-I-2781B. It contained approximately 330 ppm chloride and was impregnated with 20 wt per cent sodium silicate.<sup>19</sup>

The pump volutes and valve bodies were insulated with layers of amosite felt cemented together by a fibrous adhesive. The adhesive contained sodium silicate. The final layer of insulation on the valve and pump volutes consists of rockwool cement, fibrous adhesive, and demineralized water. The insulation surface was sealed with Benjamin Foster Sealer No. 30-72. The sealer will be painted with a vinyl paint under the trade name Polyclad No. 933-1 before the N. S. SAVANNAH leaves the shipyard.<sup>19</sup>

## V. LITERATURE AND INDUSTRIAL SURVEY

### A. Introduction

Several possible solutions to the problem of chloride stress-corrosion cracking of insulated austenitic stainless steel became evident when the factors involved in this corrosion mechanism and the metal-insulation design were reviewed. If the thermal insulation contains water-soluble chlorides in an air environment and if water as a vapor or liquid can penetrate into the insulation, chlorides may be leached from the insulation. If the operating temperature of the piping is low enough or if the operating temperature is cycled to lower values periodically so that the chloride-bearing solution reaches the pipe surface, evaporation will cause the chlorides to be concentrated on the metal surface. If, in addition to a suitable environment, the austenitic stainless steel surface is under stress, the development of stress-corrosion cracking is highly probable. This corrosion mechanism is associated with the combination of either residual or applied stress in the metal component, an oxidizing chloride environment that will support an electrochemical reaction, and a reasonable temperature that will permit the proper environment to persist.

From these factors, one may be selected which can most conveniently be eliminated in order to prevent the mechanism from operating. Some solutions that might be considered are as follows:

1. Preventing water from reaching the metal surface would eliminate an environmental requirement for the electrochemical reaction. Assuming no water leaks in the pipe,

this could be accomplished by providing a reliable waterproof seal on the insulation or on the piping or by utilizing an insulation that is itself waterproof. In addition, if the piping temperature were operated well beyond the boiling point of the water and maintained at this temperature for the life of the system, water would not be able to get to the surface of the metal even if it were able to get into the insulation.

2. If the above approach is not practical and assuming that it was known that the water that could permeate the insulation during operation had a very low chloride level, the next approach could be to eliminate all water-soluble chlorides in the insulation, thereby removing an alternate essential to this corrosion mechanism.
3. If there is still a possibility that water might get into the insulation and if this water could have a high chloride level, e.g., sea water, then the remaining primary contributors to stress-corrosion mechanism which might be eliminated are the stress in the metal component and/or the oxygen in the environment. These approaches are dismissed as unpractical in this application.
4. In considering other ways that the environment at the metal-insulation interface might be altered to prevent the electro-chemical reaction, it appears feasible to divert the corrosion

reaction from the austenitic stainless steel member to a less noble material such as aluminum by placing such a material in contact with the steel. Alternately, the prevention of the reaction of the stainless steel with chloride-oxygen environment might be effected by chemical inhibitors associated with the insulation or coating.

In addition to the above list, there probably exist other ways of stopping or retarding the stress-corrosion on the austenitic stainless steel. An absolute solution would be substitution of a structural material that is not susceptible to stress-corrosion cracking.

#### B. Review Information

In order to determine which of these approaches have been developed, a number of people<sup>6,7,8,12,14,16</sup> in the thermal insulation and/or metal corrosion fields were contacted; and the literature in these areas was consulted (see references and bibliography). The specific information sought from these sources was answers to the following questions:

1. Are there any thermal insulations commercially available which contain no water-soluble chlorides?
2. What ways presently exist to protect the outer surface of thermally insulated austenitic stainless steel pipes from stress-corrosion cracking?

The commercial methods most widely used at the present time to protect thermally insulated austenitic stainless steel from stress-corrosion cracking are: pipe coatings, waterproof sealers, and water-resistant

insulations. Cathodic protection and use of inhibitors have been investigated and are beginning to be used.

### 1. Insulation Sealers and Thermal Insulation

Waterproof insulation sealers that have high durability and water-resistant insulations that can vent water vapor but resist soaking by liquids are being developed and used to reduce the possibility of stress-corrosion. One way to increase the durability of a sealer is to make it of metal or to provide a metal covering as a run-off shield. Another approach is to employ an asbestos cloth covered with a film of plastic and metal such as is being used on the U. S. Army Nuclear Reactor Power Plant, PM-2A.<sup>12,15</sup> The PM-2A Plant uses an asbestos cloth covered with a Mylar and aluminum film produced by U. S. Rubber.

Insulations which are either waterproof or resistant to water are being developed, and some are available at present. These, in general, are in the glass-type insulation category. Some of the glass insulations are also attractive because of their relatively low water soluble chloride content.<sup>4</sup>

### 2. Pipe Coatings

Ashbaugh<sup>20</sup> in writing about chloride stress-corrosion cracking of austenitic stainless steel in chemical plants and marine atmospheres feels that applying a protective paint film or barrier to the stainless steel surface is the most practical solution. He considers a silicon base material to be the most likely choice for service above 200°C.

McGoff, Glacier, and King<sup>9</sup> tested numerous coatings for their protective character against stress-corrosion cracking of austenitic



stainless steel and concluded that, while some protective coatings are better than others, no coating will provide complete protection for the environment of their tests. All of the coatings tested detached from the metal surface after thermal cycling in the emersion apparatus. The best coating found was a synthetic resin containing manganese.

One area of uncertainty that exists in the use of coatings is the effect of gamma radiation of the coating. This uncertainty is borne out by McGoff, et al., in data gathered from questionnaires received from coating manufacturers.

In general, it appears that certain coatings on the metal surfaces help provide protection against chloride stress-corrosion cracking but that the protection is not absolute.

In addition to these points, it appears that, if chloride stress-corrosion cracking threatens the integrity of a high-pressure system, periodic inspection of some of the piping surfaces is necessary. Further, when insulation is known to have been wet, inspection of the underlying piping should be undertaken as soon as possible. The prospect of having to remove a tenacious surface coating would certainly discourage periodic inspection; and, where inspection was felt to be mandatory, the removal of the coating might possibly mask the surface indications that are of concern.

### 3. Chlorides in Insulation

Dana<sup>6</sup> in his study of stress-corrosion cracking of insulated austenitic stainless steel noted that the three types of insulation which

were studied, 85 per cent magnesia, calcium silicate, and glass fiber, all contained water-soluble chlorides. In addition, there was considerable variation in the water-soluble chloride levels between the types of insulation, between the different samples of one type insulation from a given manufacturer, and between manufacturers of each type of insulation material. This appears to be the situation that exists at the present time. Almost all suitable thermal insulations except possibly experimental samples of metal insulations contain water-soluble chloride.<sup>4,5</sup> Although the chloride level of the insulation can be minimized, contamination of the insulation with water-soluble chloride during manufacture is apparently difficult to avoid. Presumably with careful control, possibly with postmanufacturing leaching of the insulation, a material could be provided that is free of water-soluble chloride.

It is also of interest to note that McGoff, Glaser, and King<sup>9</sup> received three affirmative answers out of 11 from insulation manufacturers who were asked if it would be possible to manufacture a chloride-free thermal insulation. Apparently this problem is not considered beyond solution, but at the present time it appears that it has not been solved on a commercial scale.

#### 4. Cathodic Protection

Another way to reduce or prevent chloride stress-corrosion cracking is by cathodic protection. This has been demonstrated by Hoar and Hines.<sup>21</sup> They report that they were able to stop cracking in stainless steel by an applied cathodic current indefinitely after the crack propagation had begun.

The solution corrosion group at Oak Ridge National Laboratory found that they could cathodically protect one-half of cold-formed type 347 stainless steel pipe bend specimens. The pipe bends operated for 2000 hr with steam at 150°C, 60 psig flowing through the pipes which were cooled on the outside with 3 to 7 ppm chloride content water. The half-sections of the pipe bends that had been wrapped with aluminum wire showed no sign of cracking at the completion of the test, but the unprotected portions cracked between 1000 and 2000 hr.<sup>13</sup>

Aluminum was used as a reflective-type insulation on the Homogeneous Reactor Test in-cell piping system, and aluminum is also being used similarly on most of the primary piping on the Consolidated Edison Reactor at Indian Point, New York, and on the Commonwealth Edison Reactor at Dresden, Illinois.<sup>8,14</sup> In addition to serving as thermal insulation, the less noble metal on the austenitic stainless steel systems in these applications provides cathodic protection of the stainless steel.

It appears that a less noble metal acting as a sacrificial anode could be used in association with the thermal insulation and austenitic stainless steel piping and would be able to divert the corrosive action from the stainless steel to the aluminum. If the piping surface temperature is too high, the aluminum might possibly be applied to the external surface of the thermal insulation assuming a suitable means of electrically coupling the aluminum and stainless steel could be devised.

The New Kensington Laboratories of the Aluminum Company of America have been experimenting with various thermal insulations in contact with

aluminum. After several months in humidity cabinets, it was found that the foil in contact with these insulations had not deteriorated.<sup>16</sup>

## 5. Inhibitors

Probably the most closely related effort to the general problem of this report is the work of McGoff on sodium silicate as an inhibitor of chloride stress-corrosion cracking in austenitic stainless steel.<sup>9-11</sup> McGoff performed his work on austenitic stainless steel with Unibestos pipe insulation manufactured by Union Asbestos and Rubber Company. This particular insulation contains approximately 20 wt per cent sodium silicate which is used as a binder for the amosite (a particular type of asbestos) fibers. Additional quantities of sodium silicate were applied to the Unibestos by various means--coating insulation surfaces, mixing with ground insulation, and soaking bulk insulation. McGoff concluded from his tests that the stainless steel was protected by the sodium silicate and that this protection appeared to be a function of the quantity of sodium silicate that was placed in the insulation.

McGoff found that sodium silicate applied directly to the pipe surface did not offer much protection as the coating tended to crack and deteriorate. When the sodium silicate was contained in the insulation, however, it was effective in reducing chloride stress-corrosion cracking.

Although the mechanism of this protection does not seem to be well understood, McGoff and others seem to feel that the protection is related to pH control.<sup>4</sup> McGoff reports<sup>11</sup> that, if the sodium silicate becomes insoluble so that it would not be leached out by the water that had

permeated the insulation, it would offer no protection. Ashbaugh reports<sup>20</sup> that pH is a factor in the stress-corrosion mechanism and that a pH of less than seven accelerates the rate of cracking. Therefore, the sodium silicate protection might involve what corrosion specialists refer to as alkaline protection.

McGoff<sup>11</sup> points out that the main limitation of using sodium silicate is that the inhibitor can be depleted by leaching if the insulation is permeated by sufficient water in relation to the amount of contained sodium silicate. He seems to favor allowing the insulation to absorb a dilute sodium silicate solution as the best means of introducing sodium silicate into the insulation. However, he points out that this is done at the expense of increasing the insulation density. He suggests further that other chemicals should be investigated to develop a more effective agent for obtaining the required pH control.

In addition, experience with sodium silicate in insulation muds has been reported as favorable for inhibiting chloride stress-corrosion cracking.<sup>4</sup> This was confirmed by McGoff's experiments.

### C. Conclusions from Survey

From this survey it appears that the means and methods developed to date to reduce chloride stress-corrosion cracking in thermally insulated austenitic stainless steel show considerable promise; however, none of them at this state of development appear absolute. If the protection used is subject to depletion (as appears to be the case with inhibitors and possibly to a lesser degree with cathodic protection), the

designer would be required to estimate how long the protection provided would remain effective. Bases for such estimates are essentially nonexistent; therefore, one can rely only on periodic inspection to note whether or not the protection provided remains adequate.

The methods that presently appear most attractive and which can be used separately or in combination to prevent stress-corrosion cracking of insulated austenitic stainless steel are:

1. Insulation sealers that are waterproof and durable (if the thermal design permits, the use of water-resistant insulations may be considered),
2. Thermal insulations that are low in water-soluble chlorides,
3. Cathodic protection,
4. Chemical inhibitors in bulk and mud insulations.

## VI. INSULATION IN FUTURE MARINE APPLICATIONS

In an investigation such as this, an attempt should be made to review what has been learned and to consider what can be done to avoid such problems in the future. The review should disclose rules and standards of practice that, if followed, could prevent such problems from occurring again. However, such planning is not always clear-cut. There are uncertainties that often lead to a conservative approach in formulating standards, but the same uncertainties may be used to justify an optimistic approach if the practical problem has to be faced anew. Therefore, in planning an ultimate solution it is desirable to eliminate as many areas of uncertainty as possible so that a realistic solution can be developed. In this section a summarization will be made of what has been learned, how this problem might be handled in the future, and what additional work appears to be required for a long-term solution to the stress-corrosion cracking problem of thermally insulated austenitic stainless steel.

### A. N. S. SAVANNAH Experience

A review of the insulation problem on the N. S. SAVANNAH shows that the thermal insulation containing water-soluble chlorides had been partially applied after the hydrostatic test on the primary system was performed. This was done in order to permit heat-up of the primary system for the precritical hot-flushing operation. While the system was being raised in temperature and pressure, leaks developed in the system

and the water soaked into the insulation in several locations. Although the insulation had been applied to most of the system, joints, flanges, and other potential areas for leaks were left exposed for inspection. The sealing operation was being reserved until the insulating job could be completed, presumably after the leak testing. (The details concerning temperature, pressures, and cyclic conditions are to be found in Section IV of this report.)

It was feared that the high-purity water which leaked onto the unsealed insulation would leach out some of the chlorides and deposit them on the pipes. This situation was further aggravated in that the stainless steel pipelines of the primary system were hot enough to evaporate the water on its surfaces, thereby concentrating any chlorides in the water; but they were not hot enough to keep the surfaces free of water which was percolating in through the insulation from exterior leaks. This condition was then followed by a slow temperature increase of the system further worsening the situation until all the fluid was driven from the pipe surfaces.

The foregoing conditions brought about the subject investigation. The investigation confirmed that proper conditions existed for chloride stress-corrosion cracking of the austenitic stainless steel piping system. The piping section removed from the primary system showed many defects which were presumed to be manufacturing defects and some other defects which were ascribed to chloride stress-corrosion cracking.

As a result of the findings, the insulation on the primary system of the N. S. SAVANNAH was removed so that the piping surface could be



inspected to determine the extent of possible damage and so that the piping could be cleaned. The piping was ground where significant defects were found without reducing the piping thickness beyond tolerance.

A cleaning operation was performed to eliminate any surface contamination on the piping which conceivably could contain chlorides. This operation was performed so that the situation would not be aggravated by having a supply of chlorides available at the surface ready to contribute to the stress-corrosion reaction should the insulation again be wet.

The system was reinsulated with thermal insulation containing 20 per cent by weight sodium silicate. This type of insulation was selected because sodium silicate has been shown to inhibit chloride stress-corrosion cracking (see Section VI-B-5 of this report).

In addition to the above means of protecting the system, it was recommended that aluminum foil be wrapped around the piping prior to re-insulation<sup>4</sup> to provide additional protection against stress-corrosion cracking. This recommendation was not acted upon because the construction contractors questioned the effectiveness of the method. AEC-MARAD reserved consideration of protection by cathodic means until further laboratory verification could be obtained.

A great deal has been learned from this experience which provides knowledge on how to handle a similar situation in the future. Specifically:

1. A greater awareness and appreciation of the hazards of stress-corrosion cracking of insulated stainless steel needs to be developed and consistently reflected in the system design,

the construction methods, and all maintenance efforts on the N. S. SAVANNAH and on all subsequent systems containing materials susceptible to stress-corrosion cracking.

2. Definite administrative plans are required to protect such systems against stress-corrosion. A development program must be initiated to find ways and means to best furnish the required protection. Until such protection is available, a general philosophy on what action is required when insulation becomes wet must be formulated in light of the particular design.
3. Those provisions which are considered necessary for adequate protection against stress-corrosion on the N. S. SAVANNAH and subsequent systems must be carefully outlined in a specification which should be kept current with technical developments. Such provisions should be carefully controlled by Maritime inspection.

#### B. Proposed Standards

This section is concerned with the provisions that are presently considered necessary for protection of nuclear marine propulsion systems. From the experience derived from this investigation, a tentative specification for inspecting, cleaning, and insulating austenitic stainless steel piping in marine service has been prepared and is recommended for use in future nuclear power marine systems (see Appendix C). This specification incorporates the procedure employed in inspecting, cleaning, and

reinsulating the N. S. SAVANNAH along with alternate procedures for cleaning and reinsulating. In addition, the specification includes designations indicating which statements of the specification apply to a new reactor system, i.e., a marine power plant under construction or in initial operation, and which apply to a reactor system that has operated for some time.

The standards involved in this recommended specification are summarized as follows:

1. Operating System

If the applied thermal insulation has lost its integrity and it is known that water leaked within the reactor compartment, all insulation shall be removed unless it is determined that the insulation has not been wet. After removing the insulation, the underlying austenitic stainless steel surfaces shall be inspected. Any significant surface imperfections that are found shall be removed, the surfaces shall be cleaned to remove all surface contaminants, and the system surfaces shall be reinsulated and sealed.

2. System under Construction

- (a) Hydrostatic testing shall be performed prior to insulation.
- (b) The reactor system shall not be subsequently hydrostatically tested or flushed unless the thermal insulation has been thoroughly waterproofed. In addition, it shall be required that the waterproofing shall be sealed to the pipe whenever exposed sections of insulation exist.

- (c) A high degree of cleanliness shall be maintained not only internally but externally during the construction of the primary system of the nuclear power plant.
- (d) The external surfaces of the austenitic stainless steel system shall be free of all chlorides and all significant material imperfections before being insulated.
- (e) The insulation and sealer as well as any other materials used to protect and insulate the system shall be of high quality. The chloride content of these materials and the extent of the water solubility of contained chlorides shall be determined. Only zero chloride content materials or materials with water-soluble chloride contents as low as is commercially feasible at the time of purchase shall be used.
- (f) All insulation other than metal that is known to have been or suspected of having been wet shall be removed. The underlying surfaces shall be inspected for damage, repaired or replaced if necessary, cleaned and reinsulated. If aluminum insulation is used, water soaking shall be allowed without removal of the insulation so long as the water can be proven not to be sea water or high in chlorides and the insulation is in place against the piping.

#### C. Considerations for the Future

This section of the report reviews some of the possible ways of solving the stress-corrosion problems associated with marine nuclear

propulsion in the next ten years. Three time phases are used to classify these considerations which include certain ideas for development. As a result of such development and additional study, other ideas will undoubtedly be forthcoming. It is hoped that this brief look into the future will help formulate future work on insulation for this application and that, as developments from this effort are tested and proven, a specification such as is given in Appendix C for marine application will be maintained and continually revised to reflect improvements until a satisfactory solution is found for the various system designs in use or under consideration.

The three time phases used for this discussion are: (1) the immediate application time period, i.e., within the next year or two; (2) the next three to five years, which would be the approximate time for a major overhaul or maintenance effort on the N. S. SAVANNAH; and (3) a period of possibly five to ten years when subsequent generation nuclear-powered ships are constructed or present systems are converted to more advanced systems.

In discussing the various stress-corrosion protective concepts in this section, two types of reactor containment will be mentioned. The first type, referred to as dry containment, is the more conventional type used on the N. S. SAVANNAH and involves a steel containment shell which houses the reactor system in an air environment. Primary shielding is placed around the reactor system in the containment shell, and secondary shielding is placed on the outside of the containment shell. The air temperature in the containment is controlled by a heat exchange system.

The other containment design that will be discussed in this section is referred to as wet containment. This involves submerging the reactor system under water in the steel containment shell. This approach can have several advantages in simplifying the reactor primary system such as reducing much of the fixed shielding and possibly eliminating the decay heat removal system as well as some, if not all, of the waste storage tanks for the reactor system. This concept is presently being studied by AEC-MARAD for possible future use in the N. S. SAVANNAH.<sup>22</sup> This concept is similar to the containment design of the reactor vessel and part of the primary piping of the PM-1 and PM-3A reactor systems.<sup>23</sup>

1. Preoperational and Initial Operational Period of the N. S. SAVANNAH

As far as the N. S. SAVANNAH is concerned, if the thermal insulation presently applied is not allowed to get wet during final construction testing or initial operation, there should be no problems in this time period. If, on the other hand, the insulation gets wet during this portion of the ship's life, a procedure must be available so that corrective action can be taken promptly with some forethought.

The present means provided to protect the system from chloride stress-corrosion cracking is the waterproof sealer used on the insulation. In addition, an additive, sodium silicate, that will provide some inhibiting action against chloride stress-corrosion cracking is incorporated in the insulation. The sealer will keep water from penetrating into the insulation and, thereby, prevent chlorides from being brought

into contact with the primary piping. If the waterproofing fails, chlorides could be introduced externally or could be leached from the insulation. However, the sodium silicate in the insulation will provide some protection against stress-corrosion. The extent of this action is uncertain as it has been shown to be dependent on the amount of water and chlorides introduced for a given amount of sodium silicate.

If the primary system insulation becomes wet within the next few years, the means for handling such an incident would be to repeat the procedure outlined in this report; namely, to remove all insulation that had been or was suspicioned of being wet, inspect the exposed steel surfaces, repair any defects in the piping surface, clean the surfaces and reinsulate with a low chloride insulation containing a stress-corrosion inhibitor. Other innovations could be added if sufficiently developed and proven.

## 2. Initial Major Overhaul Period of the N. S. SAVANNAH

The first major overhaul of the N. S. SAVANNAH will likely be made three to five years after initial operation. During this operation, some reoutfitting may take place. Pipeline inspection and reinsulation may be included. If either operation is performed or if within this general time period reinsulation is required because of insulation deterioration and/or water permeation into the insulation, another more advanced method might be used that would guard more positively against the hazard of stress-corrosion cracking. The following section reviews those means which presently are known to be beneficial and those which might be developed and/or proven as practical.

1. An inhibitor used with the thermal insulation might prevent stress-corrosion for a usefully long period--a period long enough to protect the system between maintenance inspection periods. Such a protective inhibitor would be most convenient if it were introduced in the thermal insulation. The inhibitor would be equally useful if it could be painted on the insulation prior to sealing. Painting the piping is certainly a much less satisfactory approach unless the effectiveness of the material is such that one does not ever expect to have to inspect the piping surface for corrosion defects.
2. A means of employing a less noble metal (a more electrochemically positive metal) in contact with the stainless steel might prove to be a very satisfactory solution to this problem. An obvious approach would be to wrap aluminum foil or wire around the pipe before applying the insulation. Any corrosive attack on the stainless steel would be diverted to the sacrificial material. Additional work on the design of this method should add certainty as to its usefulness and reliability. Again, however, this approach is subject to the same drawback as that of the inhibitor approach; this means of protection can be depleted, and the design must provide for maximum depletion.



3. The main insulating problem when operating in a dry containment design is to keep out of the insulation any water that may be present from water system leaks or ruptures inside the containment compartment. This waterproof protection is provided by the insulation sealer. A design of a high reliability sealer that can be easily applied would be very useful. Cladding the insulation with metal would be one approach that should have high reliability; however, economic considerations may encourage less expensive solutions.

4. In addition to having a reliable sealer, an insulation that contains very low (preferably zero) chlorides would be very useful in reducing the chloride stress-corrosion problem. It would also be desirable to have an insulation that could vent itself of a vapor buildup but which would not soak up water in the liquid form. This would preclude insulation damage from pressure buildup following a leak in an insulated pipe.

The above ideas for minimizing the insulation stress-corrosion cracking problems of austenitic stainless steel pipelines are only a few of the approaches that will likely be developed. Those mentioned could be used in several combinations as is considered necessary in viewing past experience and what insurance is felt necessary for future operation.

### 3. Subsequent Generations of the N. S. SAVANNAH

A second-generation SAVANNAH-type ship or a major reoutfitting of the N. S. SAVANNAH will likely occur in a period of five to ten years

from now. The general direction that the development work for this long-range period could take would appear to involve a combination of the following approaches:

1. Retain the dry containment compartment concept with conventional means of insulation but with a perfected means of preventing stress-corrosion cracking of the austenitic stainless steel piping.
2. Employ a submerged containment design. With this concept the insulation design would have to be such as to reduce the system heat losses to an acceptable degree. The insulation could operate on an austenitic stainless steel system if the insulation could be properly sealed and/or if the water could be maintained at a sufficiently high purity level.

One design that appears attractive involves allowing water to permeate the insulation during operation. The ideal solution with this approach would be to have an inhibitor that could be added to the containment water to prevent stress-corrosion. The water could be sampled periodically to insure that a sufficient quantity of inhibitor was always present. The purity level of the containment water could be maintained at the minimum level required for tolerable corrosion conditions. Because of the large water volume in the containment, the containment water purity would not be seriously altered by minor leaks that develop in the various water systems within the containment compartment.

3. Either of the two previous schemes could be used, i.e., wet or dry containment of the primary system. However, the problem of stress-corrosion cracking would be solved more directly by using a material in the primary system that was not susceptible to this type of failure. Such a material substitution could involve replacing the austenitic stainless material of the primary system with duplex piping and plate. This is similar to the usual practice in the design of PWR-type pressure vessels where austenitic stainless steel is used internally in vessels made of carbon steel. The other alternative would be to substitute a material such as carbon steel or Inconel completely for the austenitic stainless steel used in the primary system. This approach requires a material that is suited for long periods of use in the reactor system as well as a material that is able to operate under the required external conditions.

The development approaches suggested above are primarily controlled by the containment design. Utilizing the dry containment approach in subsequent designs will allow use of technology that will be developed under the present N. S. SAVANNAH design concept. Such developments may be tested on the SAVANNAH before the second-generation efforts are actively started.

If development studies of the wet containment design prove to be feasible and advantageous over the dry system for the N. S. SAVANNAH, the

canned insulation concept will need to be investigated. There will likely be some overlap in insulation technology of the power system with either containment concept. If an unsealed metal insulation used in conjunction with a stress-corrosion inhibitor in the containment water is developed, the metal insulation might also be made of a less noble metal placed on the austenitic stainless steel pipelines for additional stress-corrosion protection. If it is difficult to control the water purity and/or if the inhibitor that is developed is not completely reliable, a primary system material substitution will probably be necessary. Therefore, a substitute material program for the primary system appears to be needed along with the submerged insulation work for austenitic stainless steel.

#### D. Concepts Requiring Development

In this report several ideas have been mentioned for combating chloride stress-corrosion cracking associated with thermal insulation in pressurized-water reactor systems. Some of these suggestions could be employed with little or no development. Some would require considerable development effort. The suggestions that have been made which require further development are now summarized below categorized under the two types of containment presently conceived for use in marine PWR application. Work on ideas such as these will provide improved protection and may very likely provide absolute protection against stress-corrosion cracking.

### 1. Dry Containment

In this design the insulation environment is normally free of water. However, if leaks develop inside the containment vessel, the water chloride content can vary from the primary water system of 0.10 ppm chloride to the sea water system of approximately 17,000 ppm chloride; and means must be provided to protect the stress-corrosion susceptible materials such as are used in the primary piping (austenitic stainless steel). Some suggested means that will require development are as follows:

(a) Chloride-Free Insulation. If the system design is such that the only water systems in the containment are high-purity water lines and if the likelihood of a sea water leak is remote, the development of a thermal insulation which is free of chlorides would be a very important improvement. Manufacturing methods including the possibility of post-manufacturing water leaching to remove soluble chlorides might be investigated in this effort.

(b) Stress Corrosion Inhibitors. Some investigational effort has been carried out on inhibitors in thermal insulation. Additional efforts should be made in determining the protective mechanism of such inhibitors as sodium silicate, the protective limits of such inhibitors, the best means of utilizing inhibitors with the insulation, and the most effective inhibitor. This effort could provide a firm basis of insulation design and corrosion protection, possibly leading to an absolute protection against stress-corrosion.

(c) Cathodic Protection. Protection of materials with more electropositive metals has been widely used in industry for many years. The only development that appears to be required with this concept is developing a convenient design with sufficient protection to insure trouble-free operation between inspection periods.

(d) Waterproof Sealers and Insulation. Both of these materials exist today. Further work might be placed on the development of insulation sealers to find a longer lasting, more reliable sealer for mobile nuclear-power plants such as the N. S. SAVANNAH. Likewise, further development of waterproof low-conductivity insulations would appear to be a continuing goal for nuclear application.

(e) Water-Permeation Indicators. In order to be able to more positively identify any areas of insulation that have become wet, the development of some type of indicator that would positively show water permeation in the insulation would be of considerable aid in safeguarding the primary system. An approach that might be found practical is to add to the insulation a water-soluble dye that would run and stain all insulation that became wet.

(f) Coatings. The development of a coating that would not deteriorate within the life of the propulsion system would be very useful in maintaining the piping surface free of water and chlorides. Such a coating should be able to withstand the heat, the thermal cycling, and the radiation for a period of around 20 years. To use a coating that is not easily stripable, however, can be very inconvenient if the metal

surfaces it covers have to be inspected. To use nonstripable coatings, high reliability should be proven.

(g) Insulation Joint Designs. In the maintenance operation, insulated components are taken apart for inspection or replacement; consequently, insulation and sealer overlap joint designs must be developed to prevent any water from running into or under in-place insulation when a joint is broken.

(h) System Piping Designs. Work should be directed toward an investigation of packed or bolted joint designs to minimize or eliminate leakage from water systems within the containment enclosure.

## 2. Wet Containment

In order to insulate the primary system which is submerged in water with this type of containment and protect it from corrosion effects, particularly stress corrosion, the following general development efforts are suggested:

(a) Insulation Cladding. In order to keep the water out of the insulation and away from the austenitic stainless steel pipelines, design and testing of insulation cladding and cladding joints might be undertaken. This is the approach that has been taken on the PM-1 and PM-3A reactor systems.<sup>23</sup>

(b) Insulation Providing Cathodic Protection. Metal is used in some applications as a reflective insulation, and in such applications the insulation is sometimes submerged in water. A developmental effort might well be directed toward providing metal insulation that allows

water permeation. If the water contains chlorides and the piping and primary components are of a stress-corrosion susceptible material, then protection might be obtained using an insulation made of a metal that is electrochemically more positive than the primary system materials.

(c) Stress-Corrosion Inhibitor in Containment Water. Use of an unsealed water-permeable insulation appears to be an attractive concept if an additive could be developed which when placed in the containment water would render any contained chlorides in the presence of oxygen ineffective to cause stress-corrosion cracking of the austenitic stainless steel system. This protective scheme would have to be capable of inhibiting the containment water at normal purity levels and at higher impurity levels if water systems in the containment should leak and contaminate the containment water.

(d) Coatings. The development of a coating for the wet containment application would be very useful as discussed previously in the section under Dry Containment. The coating would have to have the additional requirements of being able to withstand water submersion and wetting and drying cycles.

(e) Stress-Corrosion Resistant Materials for Primary System. Several materials are known that are not susceptible to chloride stress-corrosion cracking. These materials might be found to be practical to use as primary system material and should be investigated further for PWR marine application for either containment concept. The use of carbon steel is attractive because of its economic advantages. Duplex piping



and clad plate also might provide a reasonable solution to this problem. Work on nickel-base alloys should be considered as well as general alloy development and testing.

## VII. REFERENCES

- (1) Letter, R. O. Mehann to L. D. Schaffer, "Primary Loop Conditions Preceding Zygloing," April 4, 1961
- (2) Letter, E. D. Dunton to L. D. Schaffer, "Wetting of Insulation within Containment," April 14, 1961.
- (3) Arthur W. Dana, Jr., "Stress-Corrosion Cracking of Insulated Austenitic Stainless Steel," ASTM Bulletin No. 225 (1957), pp. 46-52.
- (4) "Case Histories of Stress-Corrosion Cracking on Austenitic Stainless Steels," NACE-ASTM (October, 1956).
- (5) "Physical Metallurgy of Stress-Corrosion Fracture," Metallurgical Society Conferences, vol. 4, Interscience Publishers, Inc., New York (1959).
- (6) Telephone conversations on problems with thermal insulation chloride stress-corrosion cracking and protection against this mechanism, L. D. Schaffer, January, 1961, with:  
H. K. Marks, Division of Reactor Development, Naval Reactors, USAEC.  
P. M. Seran, KAPL, Westinghouse Corporation.  
Norman Hackerman, University of Texas.  
M. J. McGoff, Mine Safety Appliance.  
Rolf Eliassen, Massachusetts Institute of Technology.  
H. H. Uhlig, Massachusetts Institute of Technology.  
Don Warren, E. I. DuPont Experimental Station.

- (7) Telephone conversations with insulation manufacturers, L. D. Schaffer, ORNL, and J. A. Klapper, Ebasco, December-January, 1961.
- (8) Telephone conversation between Consolidated Edison Company of New York and J. A. Klapper, Ebasco, January 19, 1961.
- (9) M. J. McGoff, C. J. Glaser, and E. C. King, "Final Report on Stress Corrosion of Insulated Austenitic Steel by Sea Water and Search of Preventive Measures," Technical Report No. 64, MSAR Contract Nobs-77023, Index NoNS-200-023 and 200-027 (January 30, 1959).
- (10) M. J. McGoff, "Corrosion of Austenitic Piping by Sea Water - Air Atmosphere," Technical Report No. 66, MSAR 59-112 (October 16, 1959).
- (11) M. J. McGoff, "Sodium Silicate as a Stress Corrosion Inhibitor," Technical Report No. 67, MSAR 59-113 (October 16, 1959).
- (12) Telephone conversation between Dennis Foley, Alco Products, Inc., and H. C. McCurdy, ORNL, January 5, 1961.
- (13) Homogeneous Reactor Project Quarterly Progress Report, April 30 and July 31, 1958, ORNL-2561, pp. 154-158.
- (14) Personal communications on chloride stress-corrosion cracking studies and cathodic protection work at ORNL, J. L. English and L. D. Schaffer, January and February, 1961.
- (15) Alco Specification PM-2A-INSUL-1, November 16, 1959.
- (16) Telephone conversations with Aluminum Company of America, New Kensington Laboratories, Pennsylvania, January 3, 1961, and January 11, 1961, J. A. Klapper, Ebasco.

- (17) J. L. English, "Stress-Corrosion Cracking Study with Type 304 Stainless Steel Pipe Removed from Primary System of the N. S. SAVANNAH," ORNL-CF-61-5-50 (May 8, 1961).
- (18) HRP Specifications, Oak Ridge National Laboratory, "Modified Type 347 Stainless Steel Tubular Products," HRP-200-2, October 30, 1958, p. 8.
- (19) Letter, T. M. Christian to L. D. Schaffer, "N. S. SAVANNAH, Insulation of Stainless Steel Piping," April 24, 1961.
- (20) W. G. Ashbaugh, Union Carbide, South Charleston Plant, Technical Memorandum No. 411, May 21, 1952.
- (21) T. P. Hoar, J. G. Hines, "The Stress-Corrosion Cracking of Austenitic Stainless Steels, Part I - Mechanics of the Process in Hot Magnesium-Chloride Solutions," Journal of the Iron and Steel Institute (February, 1956).
- (22) Personal communication on future Maritime work, J. E. Robb and L. D. Schaffer, February 13, 1961.
- (23) Telephone conversation, L. D. Schaffer and J. F. O'Brien (The Martin Company), July 6, 1961.

## VIII. BIBLIOGRAPHY

- Campbell, K. K., and P. S. Kingsley, "Teflon Liner Repairs Corroded Pipe," Chemical Engineering 68(16), 156-160 (August 7, 1961).
- Collins, J. A., Corrosion 11, 11t-18t (1955).
- Dana, A. W., and W. B. DeLong, Corrosion 12, 309t-310t (1956).
- Edeleanu, G. J., Iron and Steel Institute 173, 140-146 (1953).
- Fink, F. W., "Corrosion of Metals in Sea Water," Research and Development Report No. 46, U. S. Department of the Interior (December, 1960).
- Hegar, J. J., Metals Progress 69, 109-116 (March, 1955).
- Leu, K. W., and J. N. Helle, "The Mechanism of Stress-Corrosion of Austenitic Stainless Steels in Hot Aqueous Chloride Solutions," Corrosion 14, 249t-253t (1958).
- Logan, H. L., "Studies of Stress-Corrosion Cracking of Austenitic Stainless Steel," Welding Journal 37, 463s (1958).
- MacDonald, H. J., and James T. Waber, "Cathodic Protection in the Control of Stress-Corrosion Cracking," Cathodic Protection, A Symposium by J. Electrochem. Soc. and NACE, 192-203 (1949).
- Nathorst, H., "Welding Research Council Bulletin Series," No. 6, New York, 1950.
- Scheil, M. A., "Symposium on Stress-Corrosion Cracking of Metals and Alloys," New York, ASTM-AIME, 395-410, 433 (1945).
- Slunder, C. J., and W. K. Boyd, Environmental and Metallurgical Factors of Stress-Corrosion Cracking in High-Strength Steels, DMIC Report No. 151 (April 14, 1961).
- Staehle, R. W., R. W. Beck, and M. G. Fontana, "Mechanism of Stress Corrosion of Austenitic Stainless Steel in High Temperature Chloride Waters," Technical Report No. 2, Ohio State University (April, 1958).
- "Stress-Corrosion Cracking and Embrittlement," Electrochemical Society Symposium, 1954, Wiley and Sons (1956).
- "Symposium on Stress-Corrosion Cracking of Metals, 1944," ASTM, AIME (1945).

Williams, W. L., and J. F. Eckel, "Stress Corrosion of Austenitic Stainless Steel in High Temperature Waters," ASNE Journal, 93-104 (February, 1956).

## IX. APPENDICES

## APPENDIX A

### Task Assignment and Program Relations

Ebasco Services Incorporated is retained as engineers by States Marine Lines, who have the responsibility to operate the N. S. SAVANNAH. Ebasco has served as engineers in design, review, and upgrading of the N. S. SAVANNAH. Ebasco was asked by the Government (AEC-MARAD) to investigate the primary system insulation and piping, analyze the problem, and recommend action necessary for correcting the situation. See the following letter.

ESI/2475/L4-3/942/MIA/3584

RD:MAR

December 28, 1960

Ebasco Services Incorporated  
2 Rector Street  
New York 6, New York

Attention: Mr. W. C. Stamm, Project Engineer

SUBJECT: INVESTIGATION OF PRIMARY COMPONENT INSULATION  
N. S. "Savannah" Upgrading Program  
Contract AT(30-1)-2475

Reference (a): Telephone conversation between W. C. Stamm and  
M. I. Andrea, December 21, 1960

Gentlemen:

In confirmation of reference (a), you are requested to immediately undertake the investigation of the primary component insulation presently installed on board the N. S. "Savannah". This task consists in Ebasco



Services, Incorporated, inspecting, evaluating, recommending, and reporting to the Atomic Energy Commission on the following specific problems:

1. How much insulation has been subjected to excessive moisture which may require removal and/or cleaning and procedures therefor.
2. Which primary components should be dye penetrant inspected and procedures therefor.
3. Should an aluminum or other cathodic protective layer be installed under the insulation to prevent chlorides from damaging the stainless steel? Give procedures and material specifications.
4. Determine amount and distribution of chlorides present in the insulation being used.
5. Determine amount of moisture content permissible before reinstallation.
6. Procedure for drying of damaged insulation, if feasible.
7. Procedures for installation of insulation, including filling of gaps and holes, and for final sealing.

For your background information, the following appear to be the pertinent facts:

1. The stainless steel piping was not cleaned on the outside prior to the installation of the insulation.
2. The insulation which has been installed to date has not been covered by the waterproof seal.
3. Some insulation has been excessively wet during the testing, the exact extent being unknown. Estimates range from 0 to 100% so far.
4. The insulation in way of and below the valving arrangement preceding the letdown coolers was extensively subjected to water when the valve packing blew out.
5. Preliminary information indicates present insulation contains 700 ppm chlorides.

In view of the above situation, your analysis of the magnitude of the problem and your recommendations for correction are solicited. It is also requested that you assume the role of principal engineers for the Government in this matter and oversee the work of New York Shipbuilding Corpora-

tion to your satisfaction throughout its accomplishment. Your efforts will be greatly appreciated.

Sincerely yours,

(Signed) Mario I. Andrea

John E. Robb, Chief  
Nuclear Projects Branch  
(Maritime Reactors)  
Division of Reactor Development

The Oak Ridge National Laboratory provides technical assistance to the Division of Reactor Development, Maritime Reactors, U. S. Atomic Energy Commission. The Small Reactors Group at ORNL performs research and development as well as provides consulting and analytical services to the Maritime Reactors Group. ORNL was asked by AEC-MARAD by telephone on December 29, 1960, to perform the metallography and chemical analysis investigation of these samples and to work with Ebasco in developing a solution to this problem.

## APPENDIX B

### Report on Pipe Cleaning, Inspection, and Reinsulating Program

#### 1. Introduction

1.01 The pipe inspection program was completed January 28, 1961; and the reinsulation was completed February 14, 1961, on the austenitic stainless steel pipelines within the N. S. SAVANNAH containment vessel.

The inspection program called for examination of "all surfaces that are known to have been wet, all suspect areas such as areas near or under flanged or packed components." In addition, 2 per cent of the surfaces not inspected as described are to be examined.

The system that was positively identified as being wet was the Primary Purification System around the letdown coolers. Suspected areas included the primary system valves and primary system pump volutes. Considerably more than the additional 2 per cent of suspect areas was inspected as inspection was performed on the pressurizing system, emergency cooling system, buffer seal system, and pipe well beyond the primary pumps and valves.

1.02 The inspection, cleaning, and insulating procedure followed was as listed in Items 1 through 10 of Section 3 in this Appendix.

1.03 Inspectors for the Government were:

W. Beckwith	AEC-MARAD
J. C. Dedrick	ORNL
H. Heffan	Ebasco
J. A. Klapper	Ebasco

These inspectors were assisted by the following persons from AEC-MARAD: Messrs. Dunton, Fiscus, and Gregurech.

## 2. Inspection

- 2.01 Table 1 lists the pipelines inspected under this program. The basis of selection of these lines is given in Items 3 and 4 of Section 3. Indications noted by the Government inspectors were removed by sanding and/or grinding within the limits set forth in Item 7 of Section 3.
- 2.02 A record of all "reportable indications" (see Section 3, paragraph 6-e) found is given in Table 2. The areas including the indications were measured with a micrometer prior to, during, and at the end of sanding and/or grinding operations.
- 2.03 Grinding was performed only on those lines noted in Table 2. Locating dimensions are in all cases approximate.
- 2.04 The Babcock & Wilcox Company supplied personnel (C. Johnson, J. Makepeace, D. Ross, and M. Slominsky) to witness sanding and/or grinding operations to assure against removal of metal which could affect the structural integrity of the piping.
- 2.05 Indications noted occurred either in irregular patterns or else were sparsely dispersed over the length of the pipe run. Linear

Table 1. Piping Inspected

---

Primary Purification System (around letdown coolers)	PP-1-3"
	PP-2-2"
	PP-3-2"
	PP-4-2"
	PP-5-2"
	PP-6-2"
	PP-7-2"
	PP-8-2"
	PP-9-2"
	PP-10-2"
	PP-11-2"
	PR-3-2"
	SA-1-1"
	SA-2-1"
	SA-8-1"
Primary System	SA-15-1"
	WL-2-1"
	PS-6-12-9/16"
	PS-7-12-9/16"
	PS-5-8-9/16"
Primary Pump Volutes	PS-12-12-9/16"
	PS-P1
	PS-P2
	PS-P3
	PS-P4
Primary Valves	PS-1V
	PS-3V
	PS-4V including lines PR-8-1", PD-9-1"
	PS-6V including lines PR-9-1"
Pressurizing System	PE-2-1 1/2, Pressure Gage Glass Line
Emergency Cooling System	PE-3-1 1/2"
	DK-12-1"
	DK-15-3"
	DK-16-1 1/2"
	DK-17-1 1/2"
	DK-22-3"
	DK-24-1 1/2"
	DK-25-1 1/2"
Buffer Seal System	SL-8-1 1/2"

---

Table 2. Reportable Indications

Line	Location	Micrometer Readings		Metal Removed
		Before	After	
PP-2	5 in. from upstream end-linear, longitudinal	2.389	2.387	.002
	12 to 15 in. from upstream end-linear, longitudinal	2.387	2.387	.000
	18 to 20 in. from upstream end-linear, longitudinal	2.382	2.381	.001
	22 to 24 in. from upstream end-linear, longitudinal	2.385	2.382	.003
	26 to 30 in. from upstream end-linear, longitudinal	2.382	2.379	.003
	30 to 34 in. from upstream end-linear, longitudinal	2.384	2.378	.006
	34 to 36 in. from upstream end-linear, longitudinal	2.383	2.379	.004
	36 to 40 in. from upstream end-linear, longitudinal	2.384	2.379	.005
PP-3	12 in. from upstream end	2.393	2.391	.002
	2 in. below ell	2.393	2.392	.001
	24 in. below ell	2.393	2.393	.000
PP-7	2 in. from cooler	2.393	2.388	.005
	10 in. from tee	2.383	2.370	.13
PP-8	6 in. above valve PP-8V	2.390	2.383	.007
PP-10	6 in. downstream from ell	2.390	2.389	.001
PP-11	24 in. from tee	2.395	2.390	.005
DK-24	4 in. below tee	1.907	1.905	.002
	1 1/2 in. below tee	1.904	1.900	.004
	Aft end 4 in. below tee	1.904	1.902	.002

Table 2. Reportable Indications--contd

Line	Location	Micrometer Readings		Metal Removed
		Before	After	
	Aft end 8 in. below tee	1.895	1.893	.002
	Aft end 1 1/2 in. below tee	1.906	1.904	.002
	Aft end 2 ft below tee	1.904	1.897	.003
SA-2	6 in. upstream of valve SA-4V	1.312	1.308	.004
SL-8	3 in. above bend	1.905	1.903	.002
	12 in. above bend	1.906	1.902	.004
	18 in. above bend	1.903	1.902	.001
	40 in. above bend	1.907	1.905	.002
	42 in. above bend	1.904	1.903	.001
SL-8	46 in. above bend	1.904	1.903	.001
	Bend Radius	1.865	1.862	.003
	3 ft from bend	1.903	1.903	.000
	5 ft	1.901	1.897	.004
	7 ft	1.901	1.897	.004

indications ran along the longitudinal axis of the pipe. Very few transverse indications were found. Some linear indications on the outer radii of bends were noted. A few spots were noted containing inclusions. Generally the indications noted were found on the upper side of the pipe or the outer exposed surface.

3. Cleaning, Inspection, and Insulation Procedures

- 3.01 Remove all insulation on stainless steel surfaces in piping systems within containment vessel and establish Class "C" conditions (B&W Specification AEC-381-2/480000).
- 3.02 Stainless steel brushes not used on other materials and/or emery paper shall be used on stainless steel pipe surfaces to remove residual tape and other contaminants as preparation for penetrant inspection.
- 3.03 Fluorescent-penetrant inspection shall be performed on all surfaces that are known to have been wet and on all suspect areas such as areas near or under flanged or packed components.
- 3.04 Spot-check fluorescent-penetrant inspection at the direction of the Government inspector on a minimum of 2 per cent of the surfaces not inspected in No. 3 above.
- 3.05 A visual inspection shall be performed on all pipeline surfaces for the detection of gross defects.
- 3.06 The fluorescent-penetrant inspection shall be performed with a fluorescent penetrant (Zyglo-Magnaflux) in accordance with



the following procedure and using MIL-STD-271A (SHIPS) 2 January 1959 as reference material for TYPE II penetrant inspection.

- (a) Degrease surfaces with Zyglo cleaner ZC-7; permit 5 min for evaporation.
- (b) Apply ZL-22 oil penetrant at a minimum of 60°F and permit to remain on surface for 15 to 20 min.
- (c) Remove ZL-22 with Zyglo cleaner ZC-7 using the black light as a guide to ensure removal. Removal is complete when the surface appears purple-black under the black light.
- (d) Wipe down surface with a clean cloth, apply developer fluid ZP-9 and then examine under black light.
- (e) All indications must be reported. Indications more numerous than six in a six-in.<sup>2</sup> area and indications greater than 1/16-in. diameter or length shall be removed.
- (f) In addition, all linear as well as aligned penetrant indications, whether linear or circular, shall be removed. Aligned penetrant indications are those in which the average of the center-to-center distances between any one indication and the two adjacent indications in any straight line is less than 3/16 in. Any indications may be directed to be removed by the Government inspector.
- (g) Indications shall be removed using emery paper No. 60-80 grit or an air-driven pencil grinder employing a No. 60-

80-grit, rubber-bonded, burr-shaped wheel or tip. The tip shall be frequently cleaned to remove embedded metal. Caution shall be taken not to gouge or score the surface. After grinding, the removal surfaces shall be smoothed with No. 60-80-grit emery--again being careful not to score or scratch deeply.

#### Pencil Grinder

- (1) Air driven.
- (2) Speed 5000 to 7000 linear ft/min, about 24,000 rpm for a 1-in.-dia conical tip.
- (3) Use rubber-bonded wheel No. 60 to 80 grit.
- (4) Do not apply heavy pressure as stainless steel thermal conductivity is low and friction quality is high. Overheating and scorching, therefore, are likely to occur. Scorching will increase susceptibility to many types of corrosion.
- (h) Removal of indications shall be checked with the black light without adding new penetrant.
- (i) When the black light reveals no further traces of indications, the surface shall then be cleaned and reinspected according to 3.0-6-a, b, c, d, and e.

3.07 The thickness of metal which can be removed routinely by polishing and/or grinding has been determined by The Babcock & Wilcox Company for each size pipe and is termed Arbitrary

Thickness Limit. This thickness has been determined by requiring that, in general, 75 per cent of the excess metal shall remain after polishing. If a defect is found which exceeds this arbitrary limit, a new allowable thickness will be established for the pipe involved, based upon the excess metal available. Local USCG, ABS, MARAD, and B&W concurrence on each adjusted allowable thickness will be obtained.

- (a) The list of piping schedule numbers, pressures, maximum excess metal thickness and arbitrary thickness removal limits are given below:

<u>Pipe Size (in.)</u>	<u>Design Pressure (psia)</u>	<u>Schedule</u>	<u>Maximum Excess Metal (in.)</u>	<u>Arbitrary Thickness Limit (in.)</u>
.25	2000	80	.048	.010
.50	2000	80	.042	.010
.75	2000	80	.088	.010
1	2000	80	.021	.005
1	186	80	.147	.010
1	2000	160	.083	.010
1.50	2000	160	.051	.010
2	2000	160	.056	.010
2.50	2000	160	.093	.010
3	2000	160	.024	.005
4	2000	160	.004	None
8.625	2000		.011	None
12.625	2000		.098	.010

- (b) Attention is called to the column entitled Maximum Excess Metal. To prevent any confusion, this means that the thicknesses listed determined by B&W are the maximum metal which can be removed and still have piping which meets code. It is also the minimum excess metal present at any one place on the pipe.

### 3.08 Cleaning Procedure

- (a) Remove penetrant and contaminants with Zyglo cleaner-solvent ZC-7 using as many clean rags as necessary.
- (b) Wash all pipe surfaces with a 1 per cent solution (by weight) of Alconox detergent in demineralized water (approximately 90°F). (The Alconox detergent is manufactured by Alconox Incorporated, 853 Broadway, New York.) The solution shall be scrubbed on the pipe surfaces with nylon bristle brushes for a minimum of 15 min.
- (c) The cleaning operation is extremely important and must be performed with all care to ensure that all surfaces and crevices have been thoroughly wet with Alconox solution.
- (d) The solution, while in contact with the pipe shall be maintained at the prescribed temperature. This may be achieved by repeatedly dipping the brush in a warmed solution or by circulating hot water through the pipelines so that approximately 90°F surface metal temperature is maintained.

- (e) Fresh solution only shall be used. The spent solution in the brush shall be shaken out after each pass.
- (f) Rinsing shall be performed by wiping the pipe surface for approximately 5 min with clean rags wet with demineralized water.
- (g) Spent solution and rinse water shall not be reused.

### 3.09 Insulation

- (a) After cleaning, all pipelines shall be covered with a thermal insulation consisting of asbestos with the addition of 20 per cent by weight sodium silicate (water glass). Commercially, this type of insulation is known as Unibestos and is manufactured by the Union Asbestos and Rubber Company. Installation of the Unibestos shall be according to the general requirements in existing specifications as proposed by The Babcock & Wilcox Company Specification No. AEC-356-3/489091, dated April 20, 1959. The insulation shall be sealed immediately after installation for fire and water resistance.
- (b) The asbestos insulation cement (mud) employed as insulation around irregular shaped components and to fill crevices in the formed insulation shall be mixed with demineralized water and shall have added to the mixture 30 to 50 per cent by weight sodium silicate (water glass). It is recommended that irregular shaped components be

wrapped with asbestos cloth or tape not exceeding a thickness  $3/32$  in. prior to troweling on or packing the sodium silicate--asbestos cement. The tape or cloth is intended to act as a lath for the cement.

3.10 Should the completed asbestos-containing insulation be wet by water leaking from the pipelines or by water from external sources, then the following shall apply:

- (a) If it is known exactly where wetting occurred, then the insulation shall be removed from these areas and for at least three feet on either side of the wet area.
- (b) The pipe surfaces shall then be cleaned in preparation for a fluorescent-penetrant inspection. The requirements in Items 3 through 9 in this procedure shall then apply.

## APPENDIX C

### Tentative Specification for Austenitic Stainless Steel Piping Insulation, Cleaning, and Inspection in Marine Nuclear Service

#### Introduction

The procedures that follow incorporate what is believed to be the best known practices to date for the inspection, cleaning, and insulating of austenitic stainless steel pipe for pressurized-water reactor systems. These procedures can be applied to an insulated austenitic stainless steel system that has its asbestos-type insulation wet by primary water or water from an external source.

The portions of these procedures referring to inspection, cleaning, repairing, and insulating can be applied to a system under construction or test. Alternates are offered for cleaning and insulating since at this time these alternates appear to be satisfactory for the purposes.

#### Scope

The procedures herein were originally developed for the austenitic stainless steel pipelines within the N. S. SAVANNAH containment vessel exclusive of inaccessible primary piping penetrations of the shield water tank and the inaccessible primary piping directly under the pressurizer. These procedures include: removing existing calcium silicate insulation, cleaning pipeline surfaces for a fluorescent-penetrant inspection, cleaning pipe surfaces to remove water and oil-soluble chlorides and other contaminants, and installing new insulation.

In the following procedure, the letters N and E are included in parentheses after each item to indicate its applicability to new (N) or existing (E) systems either under test or operation reported to have wet insulation.

#### Procedures

1. Remove all insulation on stainless steel surfaces in piping systems within the containment vessel and establish clean conditions. (E)
2. Stainless steel brushes not used on other materials and/or emery paper shall be used on stainless steel pipe surfaces to remove residual tape and other contaminants as preparation for penetrant inspection. (N,E)
3. Fluorescent-penetrant inspection shall be performed on all surfaces that are known to have been wet and on all suspect areas, such as areas near or under flanged or packed components. (E)
4. Spot-check fluorescent-penetrant inspection at the direction of the authorized inspector on a minimum of 2 per cent of the surfaces not inspected in No. 3 above. (E)
5. A visual inspection shall be performed on all pipeline surfaces for the detection of gross defects. (N,E)
6. The fluorescent-penetrant inspection shall be performed with a fluorescent-penetrant (Zyglo, Magnaflux) in accordance with the following procedure and using MIL-STD-271A (SHIPS) 2 January 1959 as reference material for Type II penetrant inspection. (N,E)
  - a. Degrease surfaces with Zyglo cleaner ZC-7; permit 5 min for evaporation.



- b. Apply ZL-22 oil penetrant, either by brushing or spraying, at a minimum of 60°F and a maximum of 120°F and permit to remain on the surface for 15 to 20 min.
- c. Remove ZL-22 with Zyglo cleaner ZC-7 using the black light as a guide to ensure removal. Removal is complete when the surface appears purple-black under the black light.
- d. Wipe down surface with a clean cloth, apply developer fluid ZP-9, and then examine under black light.
- e. All indications must be reported. Indications to be removed are as follows: No more than six (6) indications shall be permitted in a six-square-in. area, and there shall be no indications greater than 1/16 in. in diameter or length. In addition, all linear as well as aligned penetrant indications, whether linear or circular, shall be removed. Aligned penetrant indications are those in which the average of the center-to-center distances between any one indication and the two adjacent indications in any straight line is less than 3/16 of an in. Removal of any indication found may be directed by the authorized inspector.
- f. Removal of Indications and Rejection Criteria
  - (1) For pipe sizes up to 2 in. IPS

If indications exceed 3 per cent of the nominal wall thickness, as measured by the amount of surface metal removed, these indications shall be marked and located on a sketch. These indications shall be reported to the proper authorities for a decision

to grind further or to reject the pipe or fitting. The pipe or fitting shall be rejected if the minimum wall plus 10 per cent has been reached by grinding.

The depth of grinding shall be measured with a pointed spindle micrometer depth gauge or a pointed spindle and pointed anvil micrometer. Prior to removal of any indications, wall thickness of the pipe in the area to be ground shall be established with the aid of an ultrasonic-type thickness gauge. The ultrasonic thickness gauge (e.g., audigage) shall be calibrated with test blocks of the same configuration, wall thickness, and surface condition as the pipe to be measured. If the pipe size is such that the ultrasonic thickness gauge cannot be employed effectively and accurately, then the thickness of the pipe wall shall be established by referring to inspection and purchasing records or other pertinent data.

(2) For pipe sizes larger than 2 in. IPS

If indications exceed 0.010 in. in depth as measured by the amount of surface metal removed, the defect may be further ground out to a depth not to exceed 10 per cent of the nominal wall thickness. Prior to grinding to depths greater than 0.010 in., these indications shall be marked and located on a sketch and reported to the proper authorities for a decision to grind further or to reject the pipe or fitting. The pipe or fitting shall be rejected if the minimum wall plus 10 per cent has been reached by grinding.

The depth of grinding shall be measured with a micrometer depth gauge having a pointed spindle or a micrometer with a pointed anvil and spindle.

Prior to removal of any indications, wall thickness of the pipe in the area to be ground shall be established with the aid of an ultrasonic-type thickness gauge in conjunction with inspection and purchasing records or other pertinent data. The ultrasonic thickness gauge (e.g., Audigage) shall be calibrated with test blocks of the same configuration, wall thickness, and surface condition as the pipe to be measured. If excess wall thickness can be established by manufacturing records, this shall be considered adequate information prior to grinding.

- g. Indications shall be removed using emery paper No. 60 to 80 grit or an air-driven pencil grinder employing a No. 60- to 80-grit rubber-bonded, burr-shaped wheel or tip. The tip shall be frequently cleaned to remove embedded metal. Caution shall be taken not to gouge or score the surface. After grinding, the removal surfaces shall be smoothed with No. 60- to 80-grit emery--again being careful not to score or scratch deeply. The areas around indications that have been removed shall be blended into the surface of the pipe or fitting so that abrupt changes in section are avoided.

#### Pencil Grinder

- (1) Air driven.

- (2) Speed 5000 to 7000 linear ft/min, about 24,000 rpm for a 1-in.-dia wheel.
  - (3) Use rubber-bonded wheel No. 60 to 80 grit.
  - (4) Do not apply heavy pressure as stainless steel thermal conductivity is low and friction quality is high. Overheating and scorching, therefore, are more likely to occur. Scorching will increase susceptibility to corrosion of many types.
- h. Removal of indications shall be checked with the black light without adding new penetrant.
  - i. When the black light reveals no further traces of indications, the surfaces shall then be cleaned and reinspected according to 6-a, b, c, d, and e.

## 7. Cleaning

Two cleaning procedures are given to remove crevice and surface contaminants, including chlorides. (N,E)

### a. Cleaning Procedure I

- (1) Remove penetrant and contaminants with Zyglo cleaner-solvent ZC-7, using as many clean rags as necessary.
- (2) Wash all pipe surfaces with a 3 to 5 per cent solution of  $\text{HNO}_3$  in demineralized warm water (approximately 85 to 90°F). Soak clean rags in solution to the extent required to wet the pipe surface--wipe back and forth for a minimum of 15 min making sure excessive dripping does not take place on nearby equipment.

- (3) The cleaning operation is extremely important and must be performed with care to ensure that all surfaces and crevices have been thoroughly wet with the acid solution.
- (4) The acid shall be commercial 70 per cent  $\text{HNO}_3$  and the water shall be demineralized. The solution shall be made by mixing 3 to 5 per cent of acid by volume. Caution must be exercised not to exceed a 5 per cent solution as this may defeat the purpose of removing chlorides and other contaminants. The solution shall be prepared prior to being brought into the containment vessel.
- (5) The solution while in contact with the pipe shall be maintained at the prescribed temperature. This may be achieved by repeatedly dipping the cleaning rags in a warmed solution or by circulating hot water through the pipelines so that a surface metal temperature of approximately 90°F is maintained. The solution containers can be polyethylene buckets that have been thoroughly washed in the acid solution.
- (6) Fresh solution only shall be used. Spent solution shall be wrung out of rags after each pass.
- (7) This solution is relatively mild. However, it is recommended that rubber gloves and eye shields be worn as a precautionary measure. Caution must be exercised not to drip or spray the acid solution on cable insulation, copper or copper alloy components, or carbon steel or other ferritic steels. This

can be accomplished by protecting these surfaces with polyethylene sheets.

(8) Rinsing shall be performed for approximately 5 min by wiping the pipe surface with clean rags wet with demineralized water.

(9) Spent solution and rinse water shall not be reused.

b. Cleaning Procedure II

(1) Remove penetrant and contaminants with Zyglo cleaner-solvent ZC-7 using as many clean rags as necessary.

(2) Wash all pipe surfaces with a 1 per cent solution (by weight) of Alconox detergent in demineralized water (approximately 90°F). (The Alconox detergent is manufactured by Alconox Incorporated, 853 Broadway, New York.) The solution shall be scrubbed on the pipe surfaces with nylon-bristle brushes for a minimum of 15 min.

(3) The cleaning operation is extremely important and must be performed with care to ensure that all surfaces and crevices have been thoroughly wet with Alconox solution.

(4) The solution while in contact with the pipe shall be maintained at the prescribed temperature. This may be achieved by repeatedly dipping the brush in a warmed solution or by circulating hot water through the pipelines to be cleaned so that approximately 90°F surface metal temperature is maintained.

- (5) Fresh solution only shall be used. The spent solution in the brush shall be shaken out after each pass.
- (6) Rinsing shall be performed by wiping the pipe surface for approximately 5 min with clean rags wet with demineralized water.
- (7) Spent solution and rinse water shall not be reused.

8. Insulation

Three systems of insulation are proposed to eliminate either the problem of chloride stress-corrosion cracking on the outside surfaces of the pipeline or to inhibit chlorides found in present commercial insulations should the insulation be wet. The systems are listed in the order in which it is believed the most effective protection can be provided for the austenitic stainless steel pipelines. (N,E)

a. System I

- (1) After cleaning, all pipelines shall be covered with aluminum reflective insulation. The insulation may be made up as a sandwich with an aluminum honeycomb core or with aluminum corrugations.
- (2) Irregularly shaped components in the pipelines shall be carefully fitted so as to provide the maximum insulation effect.

b. System II

- (1) After cleaning, aluminum sacrificial anode foil shall be wrapped tightly on the surfaces of the pipelines in a helix with a 1/2-in. overlap at the edges. The aluminum

foil shall conform to alloy 1100 or alloy 1145. The final aluminum wrapping shall have a minimum thickness of 0.010 in. If multilayers are used, each succeeding layer shall cover the joints in the previous layer by starting each layer in the mid-point of the previous foil sheet. Soft aluminum alloy 1100 wire approximately 0.062-in. diameter shall be wound and twisted on the completed foil layers to hold the foil in place. Aluminum wire loops shall be placed on approximately 18-in. centers.

- (2) Aluminum foil shall be fitted to the contours of the irregularly shaped components in such a way as to give a 0.010-in. thickness, and the foil then should be secured with aluminum wire.
- (3) The thermal insulation (Thermobestos, Johns-Manville; Unibestos, Union Asbestos or equivalent) shall be installed according to the general requirements in existing specifications as proposed by The Babcock & Wilcox Company Specification No. AEC-356-3/489091 dated April 20, 1959. The insulation shall be sealed for fire and water resistance immediately after installation. Caution must be exercised not to tear or damage aluminum during installation of the thermal insulation.
- (4) The asbestos insulation (mud) employed as insulation around irregularly shaped components and to fill crevices in the formed block insulation shall be mixed with demineralized



water and shall include in the mixture 30 to 50 per cent by weight sodium silicate (water glass). Care must be exercised during application of the insulation mud not to tear or damage the aluminum.

c. System III

- (1) After cleaning, all pipelines shall be covered with a thermal insulation consisting of asbestos with the addition of 20 per cent by weight sodium silicate (water glass). A commercial insulation of this type is known as Unibestos and is manufactured by the Union Asbestos and Rubber Company. Installation of the Unibestos or equivalent shall be according to the general requirements in existing specifications as proposed by The Babcock & Wilcox Company Specification No. AEC-356-3/489091 dated April 20, 1959. The insulation shall be sealed immediately after installation for fire and water resistance.
- (2) The asbestos insulation cement (mud) employed as insulation around irregularly shaped components and to fill crevices in the formed insulation shall be mixed with demineralized water and shall have added to the mixture 30 to 50 per cent by weight sodium silicate (water glass). It is recommended that irregularly shaped components be wrapped with asbestos cloth or tape not exceeding a thickness of 3/32 in. prior to troweling on or packing the sodium silicate--asbestos

cement. The tape or cloth is intended to act as a lath for the cement.

9. Should the completed asbestos-containing insulation (System II or III) be wet by water leaking from the pipelines or by water from external sources, then the following shall apply: (E)
  - a. If it is known exactly where wetting occurred, the insulation shall be removed from these areas and for at least 3 ft on either side of the wet area.
  - b. The pipe surfaces shall then be cleaned in preparation for a fluorescent-penetrant inspection. The requirements in Sections 3 through 8 in this procedure shall apply.
10. In the event a leak from the primary system occurs, thereby wetting the all-aluminum insulation, it is not required that the insulation be removed prior to startup. However, should the all-aluminum insulation be wet by leakage occurring from systems containing sea water or from systems not containing primary water, the removal of insulation should be dictated by the amount of physical damage to the insulation, by the number of times that wetting occurred, and by the contaminants of the water. As long as the aluminum has not been torn from the pipe, it will present itself as a sacrificial anode and thereby is expected to protect the pipe. (E)

APPENDIX D

Letter to Maritime Administration Requesting Removal  
Of Stainless Steel Pipe Section

Ebasco Services Incorporated

December 27, 1960  
Metallurgical Inspection  
Report - PP-IV

Mr. J. Czudak  
MARAD  
New York Shipbuilding  
Camden, New Jersey

The 2 inch schedule 160 line (PP-IV) welded to the cast letdown cooler valve and the 2 inch forged 90° elbow welded to this line are rejected because of linear indications on the pipe and elbow.

It is believed that these indications would be detrimental to the letdown cooler system.

The origin of these indications is unknown; as such it is requested the above-mentioned components be removed for laboratory investigation by the Babcock & Wilcox and Ebasco Services Incorporated.

Any replacement parts must be non-destructively tested to ensure freedom from defects.

Very truly yours,

(Signed) Joseph A. Klapper

Authority to recommend removal of the pipe specimen is incorporated in Appendix A-1--letter dated December 28, 1960, confirming telephone conversation between W. C. Stamm and M. I. Andrea on December 21, 1960.

## APPENDIX E

### Investigation of Sacrificial Anode Protection

#### Introduction

This portion of the report presents the results of a laboratory investigation at Ebasco to ascertain the suitability and adaptability of commercially pure aluminum to act as a sacrificial anode to type 304 stainless steel at approximately 150°F in an electrolyte leached from the calcium silicate asbestos (Thermobestos) block insulation used on the N. S. SAVANNAH stainless steel piping systems. Normal operating temperature of these lines is approximately 500°F but will be cycled down to approximately 150°F.

#### Summary of Conclusions

The type 304 stainless steel piping systems on the N. S. SAVANNAH were covered with Johns-Manville Thermobestos block-type insulation and with Johns-Manville No. 301 cement. Portions of the insulation were accidentally wet during hydrostatic testing before the moisture sealer was applied. The possibility of chloride stress-corrosion cracking was established based on the conditions of chlorides, moisture, temperature, and stress.

Tests conducted during the course of this investigation indicated that aluminum acted as a sacrificial anode when coupled to type 304 stainless steel in an electrolyte obtained from an extract leached from Johns-Manville Thermobestos insulation or No. 301 cement. In this investigation,

four cycles of complete wetting and drying were experienced without substantial increase in cell resistance. This was confirmed by tests with the calcium-silicate insulation used for insulating the austenitic stainless steel pipelines on the N. S. SAVANNAH. It is likely that additional wetting and drying cycles can be tolerated and that the galvanic protection cells will continue to operate. However, this would require additional tests to establish.

The aluminum wrapping under the thermal insulation was found not to deteriorate as a result of moist contact with the calcium-silicate type of insulation. In addition, the New Kensington Laboratories of the Aluminum Company of America have tested Johns-Manville Thermobestos insulation in a humidity cabinet for six-month periods and found that aluminum foil in contact with this insulation did not deteriorate.

It is believed that with the information presently available, the aluminum foil would not introduce any additional problems and would act as a protective medium.

The advantages of the wrapped aluminum foil sacrificial anode are as follows:

- a. An additional protection against stress-corrosion is available if the insulation becomes water soaked.
- b. This design will prevent the thermal insulation or insulation cement (mud) from baking on or adhering to the pipe surfaces as a result of normal water-cooled reactor service temperatures. Routine maintenance examination of pipe surfaces could be more

easily performed since it would not be necessary to scrape off portions of insulation and cement.

### Recommendations

It is recommended that the lines be protected by spiral wrapping 1145 alloy aluminum, using a 1/2-in. lap, directly over clean stainless steel and under the insulation. The foil could be held in place by aluminum wire loops placed on 18-in. centers. A tight reverse spiral winding of aluminum wire, with the ends fastened under flange bolts, could aid maintenance of electrical continuity between the aluminum and the stainless steel. The pitch of the wire wraps should be the same as the pitch of the foil wraps. The complete aluminum wrap should be approximately 10 mils thick and the wire approximately 1/16 to 1/8 in. in diameter. Convenience for wrapping indicates width of the aluminum sheet should be approximately as follows:

<u>Pipe Diameter (in.)</u>	<u>Sheet or Foil Width (in.)</u>
< 2	2
2 to 4	4
6 to 10	6
12 to 30	9

Unfortunately sufficient time was not available during this phase of the investigation to compare the aluminum-stainless steel couples with stainless steel specimens under wet insulation but without the

aluminum anode. Consequently, it is recommended that AEC-MARAD authorize a continuation of this investigation. The results and data developed at Ebasco in addition to the work that had been performed at ORNL indicate that the use of a sacrificial anode for the protection of stainless steels, under chloride-bearing thermal insulations, may offer a great degree of inhibition to or possibly eliminate the chloride stress-corrosion cracking problem of austenitic stainless steels under wet thermal insulation.

It is suggested that a continuation of this investigation should include the following:

- a. Approximately 10 aluminum-stainless steel couples tested to 2000 hr for at least three types of insulation. Couples will be removed from the test conditions and evaluated at intervals of 100 hr, 250 hr, 500 hr, 750 hr, 1000 hr, 1250 hr, 1500 hr, 1750 hr, and 2000 hr.
- b. Approximately 10 stainless steel specimens wrapped in wet thermal insulation tested to 2000 hr. These specimens will be evaluated at the same time intervals as the aluminum stainless steel couples.
- c. The test conditions will be similar to those in this report and will include cycling between 150°F to 500°F.
- d. Stainless steel tube or pipe specimens will be tested in a severely stressed condition.
- e. An attempt will be made to establish aluminum foil thickness for a specified life or for a number of wettings with each type of thermal insulation.

- f. Three types of thermal insulation shall be investigated:  
calcium-silicate, sodium-silicate, and magnesia.
- g. The metals shall be type 304 stainless steel and aluminum alloy 1100, aluminum alloy 1145, or aluminum alloy 3003.
- h. Investigate the remote though possible effects of an alkali atmosphere which might be developed in the aluminum-stainless steel couples.

In addition to the possibility of preventing chloride-induced stress-corrosion cracking of austenitic stainless steel under wet thermal insulation, it may also be determined that high chloride-bearing inexpensive thermal insulation can be employed when an aluminum anode wrap is used. It is also conjectured that this investigation may develop an inexpensive composite insulation with a sacrificial aluminum foil anode as the inside surface of the insulation block.

#### Discussion of Procedures and Results

Chemical analyses were conducted on the Thermobestos insulation and the No. 301 cement. It was found that an extract leached from the cement which had been wet during testing on the N. S. SAVANNAH contained 168 ppm chloride ion, and an extract leached from the block insulation also wet during testing on the SAVANNAH contained 68 to 91 ppm chloride ion.

Chloride analyses at ORNL made on additional samples of insulation and cement revealed chloride contents of 118 to 183 ppm for the cement and 47 to 83 ppm for insulation.



The resistivity of crushed block insulation was found to be 3130 ohm-cm at 95°F when wet with demineralized water. Resistivities of this magnitude are conducive to operation of strong galvanic cells and without mitigating influences would permit considerable galvanic corrosion of mild steel if this had been used in lieu of stainless steel.

Inasmuch as stress corrosion can be controlled by cathodic protection, tests were started to ascertain the desirable current density on the stainless steel in an environment of warm crushed block insulation and demineralized water.

The first approach involved the use of a Corrosometer, an instrument which will measure directly the rate of uniform corrosion. A special test probe is usually made of the metal being investigated. Where a corrosion rate can be established with this instrument, cathodic protection can be applied to the probe of the instrument and adjusted to determine the current (amperage) density required to stop this corrosion.

A Corrosometer probe of type 304 stainless steel inserted in a beaker containing crushed insulation and water was placed in a warming oven at approximately 70°F. Examination of the probe by fluorescent penetrant indicated that no cracks were in the probe at the start of the test. No measurable corrosion of the probe occurred; consequently, cathodic-protection tests on the probe were not attempted since this test did not prove to be sufficiently sensitive in this particular application.

Subsequent tests were made on aluminum foil to determine its performance under elevated temperatures as well as its corrosion resistance

when exposed to wet calcium-silicate insulation. After determining these characteristics, special cells (couples) were prepared to ascertain the degree of protection that would be offered by an aluminum sacrificial anode to type 304 stainless steel under simulated service conditions. The type 304 stainless steel tubes in this test were subjected neither to internal pressure nor to piping flexibility stresses. The magnitude of stress was unknown; however, the tubes were in the cold finished condition.

The type 304 stainless steel discs that were used in this investigation were in the hot-rolled annealed and pickled condition.

Aluminum foil alloy 1145, which is reported by the manufacturer to have a purity greater than that of aluminum alloy 1100, was placed in a furnace for two days at 500°F to determine whether change in reflectance would occur as caused by development of an insulating oxide. Examination showed no change in appearance upon visual or microscopic examination after the sample was removed from the furnace and compared with a control sample maintained at room temperature.

Aluminum foil was placed in contact with wet crushed-block insulation at a temperature of approximately 70°C. Brown staining was observed and had the appearance of water stains associated with aluminum. In addition, a waxlike deposit was found on the foil which had been in contact with the moist block for three days (see Fig. 1E). No corrosion was observed on the foil after having been in contact with the moist Thermobestos.

UNCLASSIFIED  
PHOTO 36598-P

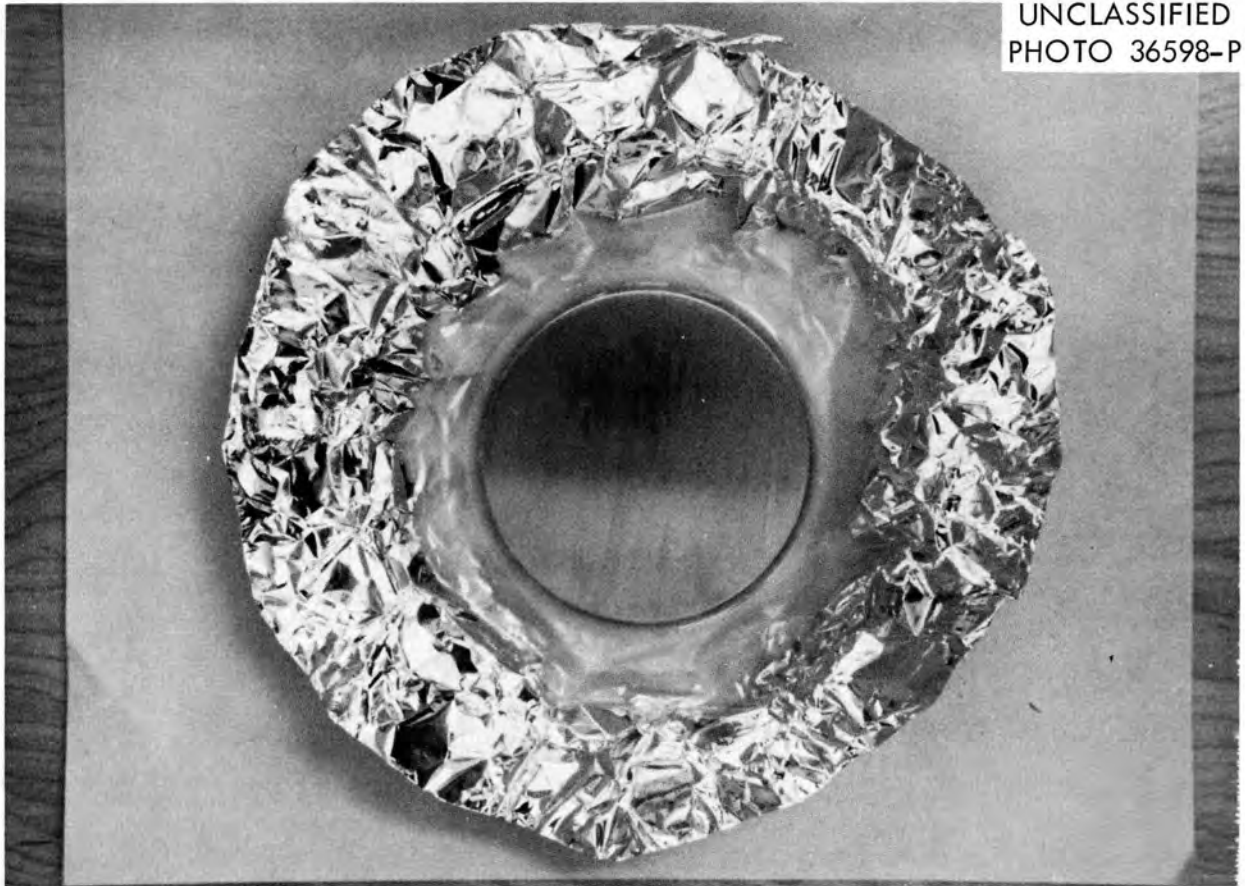


Fig. 1E. Water Discoloration of Aluminum in Contact with Wet Insulation.

Galvanic cells No. 1 and No. 2 were constructed of type 304 stainless steel tubing (5/8 in. OD by 17 gage) with an overwrap of Fiberglas mat and aluminum foil. The parts from which the cells were constructed are shown in Fig. 1E, and the assembled cell in Fig. 2E. The Fiberglas mat was wet with chloride-bearing extract leached from the Thermobestos insulation, and cell No. 1 was installed in the warming oven as shown in Fig. 3E.

The Fiberglas used during the laboratory investigation was analyzed by the Mohr method for chloride content. Samples (36.76 g) were leached in demineralized water for a total of 96 hr (36 hr at 175°F and 60 hr at 80°F). At the end of this time the water was filtered and diluted to 500 ml. The analysis revealed a chloride content of 2200 ppm.

The open-circuit voltage and the short-circuit current were measured in order that the cell resistance could be calculated.

Cell No. 2 was placed in a furnace at 500°F for approximately 18 hr prior to wetting the cell to simulate service conditions and to promote formation of any aluminum oxide film that might occur under such exposure. The intent was to learn if such a film would affect the ability of the aluminum to provide sacrificial anodic protection to the stainless steel. The cells were dried in the warming oven after each set of readings and had to be remoistened with the extract before each set of measurements. Some difference in the resistance observed for cells 1 and 2 was observed. Sealing wax, which was placed on the edge and bottom of the aluminum foil to retain the extract as long as possible,

UNCLASSIFIED  
PHOTO 36597-P

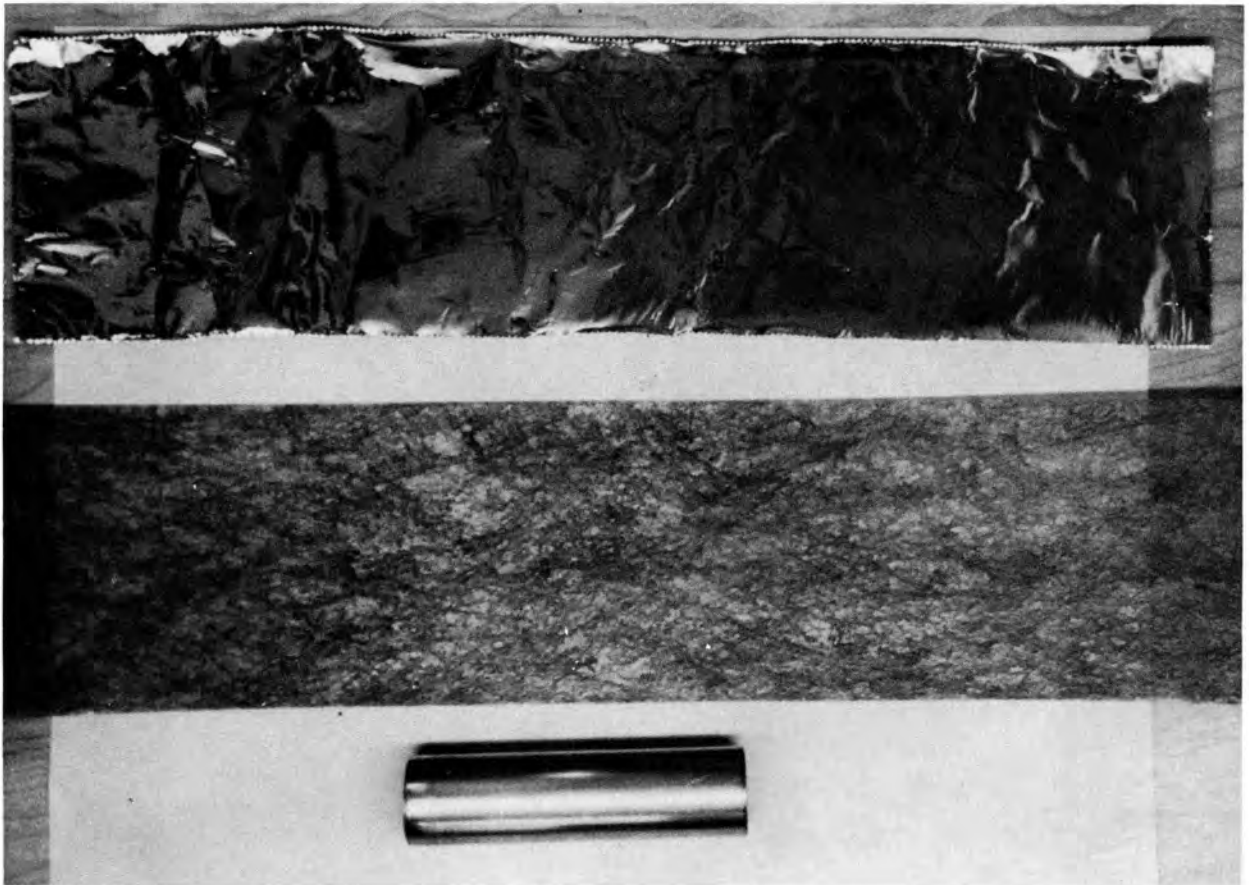


Fig. 2E. Components Making up the Aluminum-Stainless Steel Couple--  
Type 304 Stainless Steel Tubing, Fiberglass Mat, Aluminum Foil Alloy 1145.

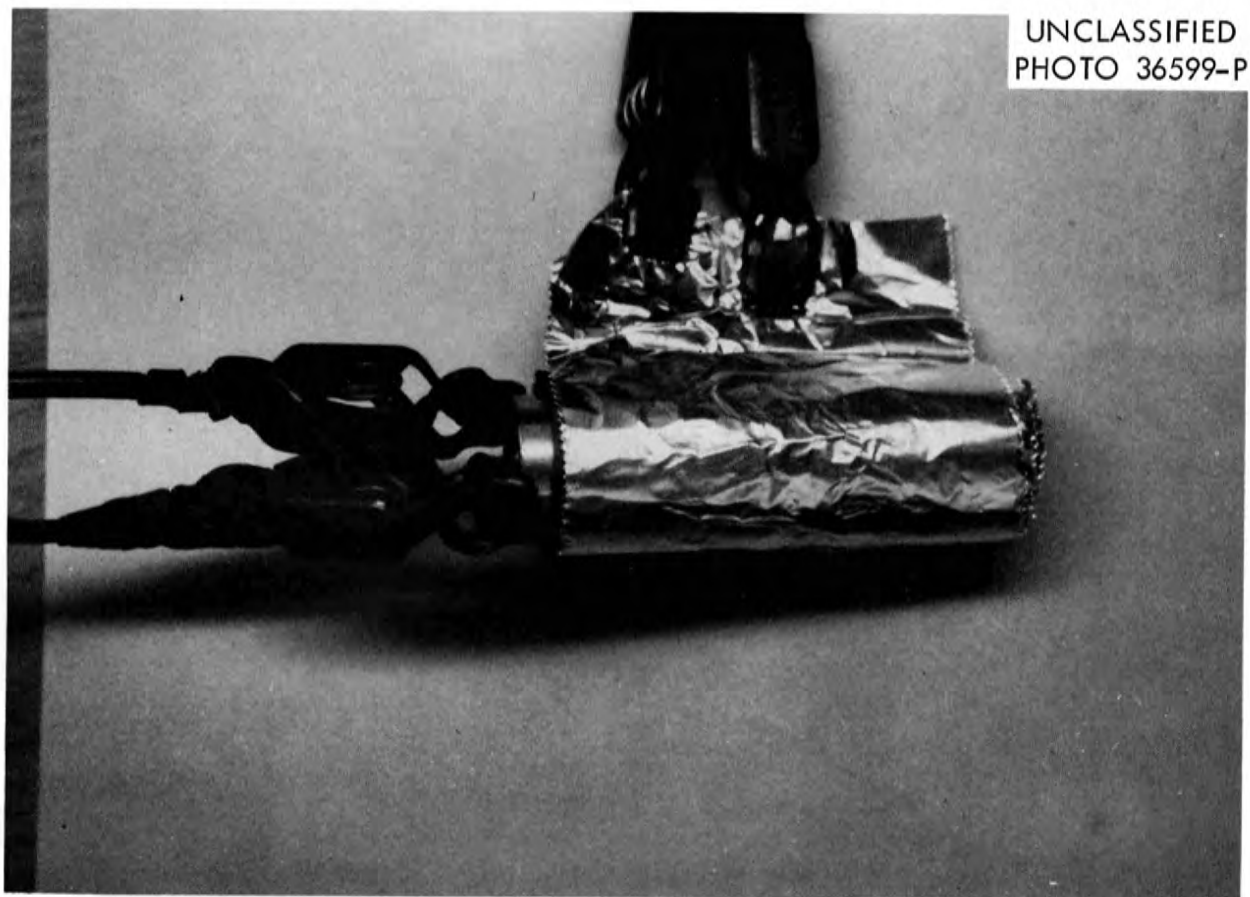


Fig. 3E. Completed Aluminum-Stainless Steel Couple Showing Glass Fiber between the Tube and Foil and Method of Maintaining Electrical Contact.

was absorbed by the glass mat of cell No. 2 to a greater extent than it was on cell No. 1. This resulted in a difference in the exposed areas.

Although the resistance of cells 1 and 2 increased with the number of drying cycles, it is considered significant that cathodic protection current was produced in a reasonable amount after each cycle. The increase of resistance of the cells is attributed to different areas becoming wet by the chloride-bearing extract after each drying cycle. The liquid was added with a dropper to the exposed edge of the glass mat and filled the annular space between the aluminum and the stainless steel.

Cells 3 and 4 were constructed of a  $3\frac{1}{3}$ -in.-dia by  $\frac{1}{2}$ -in.-thick piece of type 304 stainless steel separated from aluminum foil by filter paper. The foil was backed by another disc, and the cell clamped together. The clamps created a stress in these annealed plates. Cell No. 4 differed from cell No. 3 because holes were punched in the filter paper. This made no substantial difference in the operation of the cell, which was controlled primarily by access of oxygen to the electrolyte. Perforations of the aluminum indicated that it provided cathodic protection current to the stainless steel for the duration of the test, but limited access to oxygen caused cathodic polarization.

Cells 5 and 6 were constructed without clamping so as not to limit access to oxygen to the electrolyte. These were constructed of  $3\frac{1}{8}$ -in.-dia by  $\frac{1}{4}$ -in.-thick type 304 stainless steel discs separated from aluminum foil by filter paper wet with chloride-bearing extract. These plates were not clamped; therefore, the annealed stainless steel plates

did not have a significant stress imposed on them. The cell construction is illustrated on Data Sheet No. 6 and Fig. 4E. Cell No. 5 was wet with extract from the insulation cement, and Cell No. 6 was wet with extract from the block insulation. Both cells produced cathodic protection current which continued without excessive polarization of the cells. Examination of the foil after 18 hr showed pin holes indicating activity of the cells. The amount of current depended upon the resistivity of the electrolyte, which in turn depended upon the chloride concentration.



UNCLASSIFIED  
PHOTO 36600-P

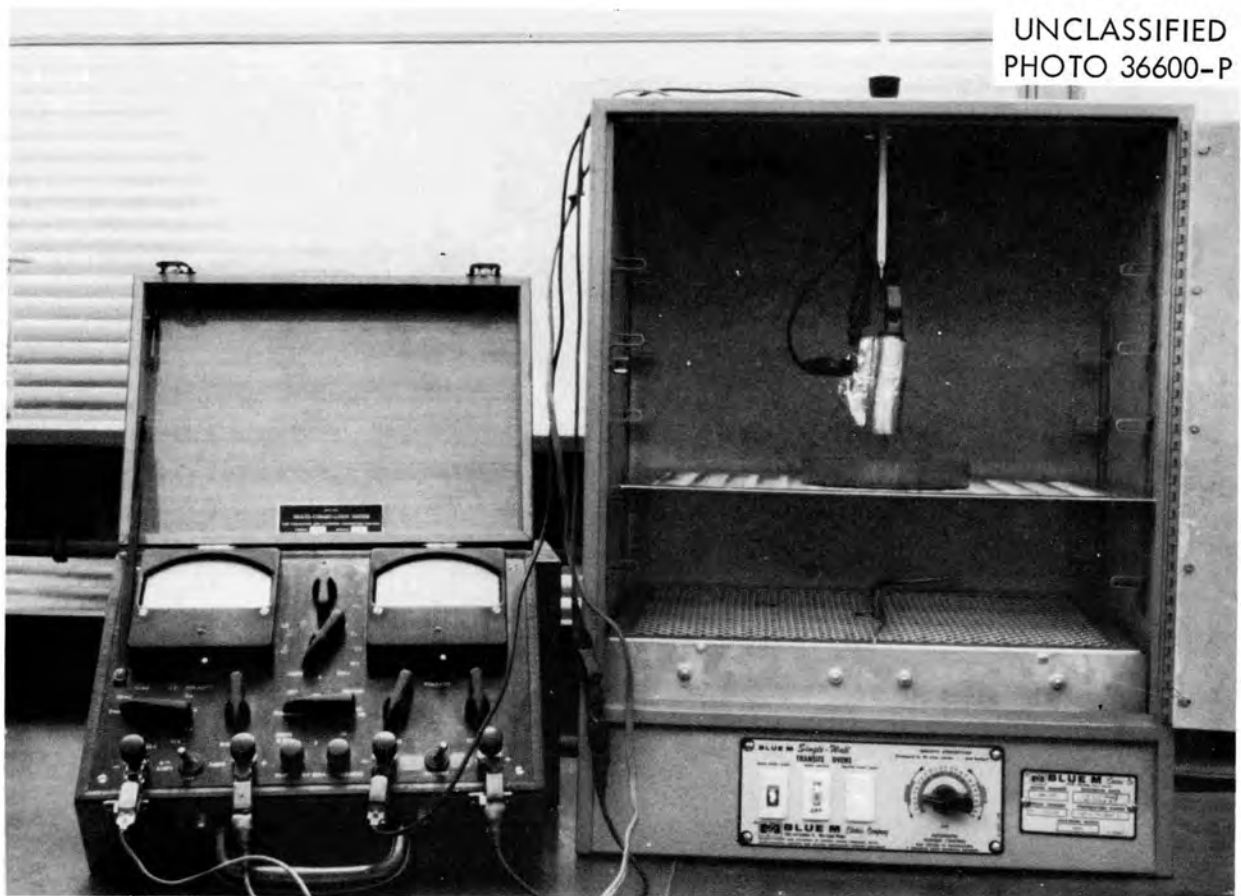


Fig. 4E. Experimental Set-Up.

## Experimental Data

1/10/61

The resistivity of the leach solution obtained from leaching the block insulation for 1/2 hr in demineralized water was measured. The leaching was performed in the warming oven.

$$\Delta V = 2500 \text{ mv}$$

$$\Delta I = 0.8 \text{ ma}$$

$$P = 3130 \text{ ohm-cm}$$

$$T_s = 97^\circ\text{F}$$

$$\text{pH} = 8.5$$

Cell No. 1 was constructed of a 5/8-in.-OD tube made of type 304 stainless steel, a glass mat, and aluminum foil. The foil was 3 in. long as measured parallel to tube axis. The edge and bottom of the foil was sealed with wax. The cell was wet with the leach solution.

$$V_{oc} = 0.535 \text{ v}$$

$$I_{sc} = 0.8 \text{ ma (varied)}$$

$$R = 670 \text{ ohms}$$

$$T_s = 80^\circ\text{F}$$

The cell remained short-circuited for approximately 5 min.

$$V_{oc} = 0.40$$

$$I_{sc} = 0.4 \text{ ma}$$

$$R = 1000 \text{ ohms}$$

The cell was installed in the warming oven.

$$T_o = 131^{\circ}\text{F}$$

$$V_{oc} = 0.60 \text{ v}$$

$$I_{sc} = 0.5 \text{ ma}$$

$$R = 1200 \text{ ohms}$$

The foil used in this experiment was Planet Pure Aluminum Foil Wrap (1 mil thick), Biltmore Paper Company, New York 51, New York.

A foil made into a cup with crushed-block insulation and water was placed in the warming oven.

Cell No. 2 was constructed similar to Cell No. 1 and was placed in a furnace at  $500^{\circ}\text{F}$ .

A piece of aluminum foil was placed in a furnace at  $500^{\circ}\text{F}$ .

1/11/61

Cell No. 1 after being in the warming oven for 18 hr was measured.

$$V_{oc} = 0.610 \text{ v}$$

$$I_{sc} = 0.01 \text{ ma}$$

$$R = 61,000 \text{ ohms}$$

$$T_o = 135^{\circ}\text{F}$$

The glass mat of Cell No. 1 was wet with additional leach solution.

$$V_{oc} = 0.68$$

$$I_{sc} = 0.42-0.48 \text{ ma (varied)}$$

$$R = 1600 \text{ to } 1400 \text{ ohms}$$

The foil of Cell No. 1 which was in contact with crushed-block insulation overnight in the warming oven was examined. Tan staining of aluminum was noted where the aluminum had been cycled from wet to dry. This appeared to be water staining, not corrosion.

Leach solution from crushed-block insulation was placed into a cup folded from aluminum foil and placed in the warming oven at 11:30 A. M. The solution was replenished with water as required to keep insulation moist.

Cell No. 2 was removed from the furnace. The glass mat was wet with leach extract from block insulation.

9:00 A. M.

$$V_{oc} = 0.61 \text{ v}$$

$$I_{sc} = 0.68 \text{ ma (increases and varies)}$$

$$I_{sc} = 0.85 \text{ to } 1.00 \text{ after 2 min (avg} = .92 \text{ ma)}$$

$$R = 660 \text{ ohms}$$

$$T_F = 450^\circ\text{F}$$

Cell No. 2 was installed in the warming oven.

$$T_O = 162^\circ\text{F}$$

The Corrosometer probe of 304 stainless steel was examined with fluorescent penetrant and ultraviolet light for cracks. No defects were

found in the probe metal. The probe was installed in a mud slurry of crushed-block insulation and demineralized water and placed in a warming oven.

Probe T<sub>4</sub> x 2

12:00 P. M.

61 DU

CK = 676 DU

The aluminum foil that had been in furnace approximately 20 hr was examined. No change in reflectance was noted. Examined surface under low magnification showed no change.

12:15 P. M.

$V_{oc} = 0.73 \text{ v}$

$I_{sc} = 0.22 \text{ ma}$

$R = 3300 \text{ ohms}$

$T_F = 500^\circ\text{F}$

Corrosometer Probe

$t = 12:20 \text{ P. M.}$

64 DU

$T_s = 91^\circ\text{F}$

$T_o = 158^\circ\text{F}$

$t = 12:45 \text{ P. M.}$

63.5 DU

$T_s = 104^\circ\text{F}$

t = 3:00 P. M.

63 DU

$T_s = 133^{\circ}\text{F}$

$T_o = 154^{\circ}\text{F}$

t = 4:00 P. M.

62 DU

$T_s = 138^{\circ}\text{F}$

$T_o = 156^{\circ}\text{F}$

t = 5:00 P. M.

62 DU

$T_s = 140^{\circ}\text{F}$

$T_o = 154^{\circ}\text{F}$

Cell No. 3 consisting of aluminum foil, filter paper, and type 304 stainless steel disc 3 1/8-in.-dia on filter paper was constructed. The paper was wet with leach extract from the block insulation. The cell was clamped together.

$$V_{oc} = 0.32 \text{ v}$$

$$I_{sc} = 40 \text{ ma}$$

$$R = 8000 \text{ ohms}$$

1/12/61

Cell No. 3 was left short-circuited overnight.

10:20 A. M.

$$I_{sc} = 0.01 \text{ ma}$$

$$V_{oc} = 0.38 \text{ v}$$

$$R = 38,000 \text{ ohms}$$

$V_{oc}$  increased to 0.42 volt in 1 min;  $V_{oc}$  increased to 0.45 volt in 1.5 min.

Cell No. 3 was dismantled. Twelve pinhole perforations were noted in the aluminum foil.

Corrosometer Probe

t = 10:30 A. M.

62 DU

$$T_s = 149^\circ\text{F}$$

$$T_o = 158^\circ\text{F}$$

Cell No. 4 was constructed of a 3 1/8-in-dia type 304 stainless steel plate and filter paper with a pattern of 1/4-in.-dia holes punched in it. The filter paper was wet with leach solution and clamped into the cell.

$$V_{oc} = 0.265 \text{ v}$$

$$I_{sc} = 0.010 \text{ ma}$$

$$R = 26,500 \text{ ohms}$$

Cell No. 4 was left short-circuited.

Cell No. 1 completed two wet/dry cycles and was then wet with leach solution.

$$V_{oc} = 0.605 \text{ v}$$

$$I_{sc} = 0.4 \text{ ma (increased to 0.46 ma)}$$

$$R = 1300 \text{ ohms}$$

Cell No. 1 was left short-circuited.

Cell No. 2 completed one wet/dry cycle and was then wet with leach solution.

$$V_{oc} = 0.975 \text{ v}$$

$$I_{sc} = 0.2 \text{ ma to } 0.22 \text{ ma}$$

$$R = 4900 \text{ ohms}$$

After 5 min

$$I_{sc} = 0.27 \text{ ma}$$

$$V_{oc} = 0.75 \text{ v}$$

$$R = 2800 \text{ ohms}$$

Water was added to extract in the aluminum cup in the warming oven. It was observed that the aluminum sample in furnace at 500°F had some gloss and reflectivity as unheated sample at room temperature.

1/13/61

Corrosometer Probe

63 DU

$$T_s = 149^\circ\text{F}$$

$$T_o = 162^\circ\text{F}$$

Cell No. 2 was found dry. The cell was wet with leach solution.



$$V_{oc} = .960 \text{ v}$$

$$I_{sc} = 0.18 \text{ ma}$$

$$R = 5300 \text{ ohms (left open-circuited)}$$

Cell No. 1 was found dry and was wet with additional solution

$$V_{oc} = 0.50 \text{ v}$$

$$I_{sc} = 0.18 \text{ ma}$$

$$R = 2800 \text{ (left short-circuited)}$$

Cell No. 4 read:

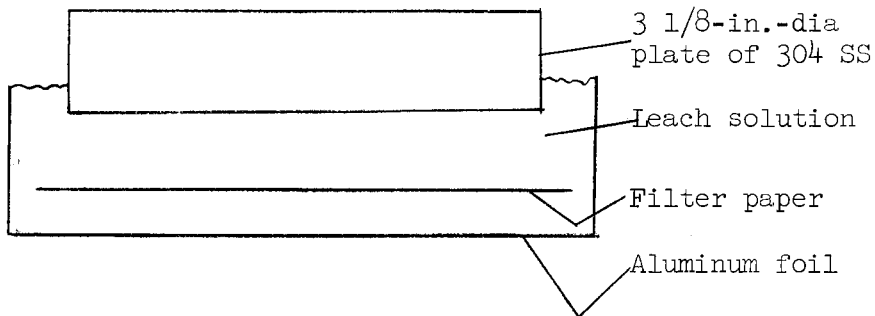
$$V_{oc} = 0.3 \text{ v}$$

$$I_{sc} = 0.01 \text{ ma}$$

$$R = 30,000 \text{ ohms}$$

Dismantled Cell No. 4 and examined parts. Pinhole perforations were noted in aluminum foil.

Cell No. 5 was constructed of aluminum foil and type 304 stainless steel with filter paper spacer and a leach solution from the cement (containing 168 ppm Cl) as an electrolyte.



$$V_{oc} = 0.3 \text{ v}$$

$$I_{sc} = 0.12 \text{ ma (holds up for 10 min--left shorted)}$$

$$R = 2500 \text{ ohms}$$

The block insulation that was used was Johns-Manville Thermobestos.  
The cement that was used was Johns-Manville No. 301 cement.

Cell No. 6 was constructed similar to Cell No. 5 except with the leach solution from the Thermobestos (contained 68 to 91 ppm Cl).

$$V_{oc} = 0.28 \text{ v}$$

$$I_{sc} = 0.02 \text{ ma}$$

$$R = 14,000 \text{ ohms}$$

Additional leach solution was added.  $I_{sc}$  increased to 0.04 ma and then dropped to 0.025 ma.

Cell No. 1 was found dry and was wet with leach solution.

$$V_{oc} = 0.59 \text{ v}$$

$$I_{sc} = 0.23 \text{ ma (drops to .19)}$$

$$R = 2500 \text{ ohms}$$

The cell was left short-circuited.

Cell No. 2 was wet with leach solution.

$$V_{oc} = 0.685 \text{ v}$$

$$I_{sc} = 0.02 \text{ ma (additional extract, .06 ma drops to .04 ma)}$$

$$R = 11,400 \text{ ohms}$$

Cell No. 2 was left open-circuited.

Corrosometer Probe

63 DU

CK 676 DU

## APPENDIX F

### Comparison of Solutions of Nitric Acid and Alconox Detergent To Remove Chlorides from Austenitic Stainless Steel Piping

#### Introduction

This portion of the report concerns the laboratory investigation that was made to evaluate the cleaning ability of a 3 to 5 per cent  $\text{HNO}_3$  solution and a detergent (Alconox) solution in order to remove chlorides from austenitic stainless steel piping.

Alconox is a commercially available detergent and is manufactured by Alconox Incorporated. It is a sulfonated hydrocarbon and is reported to contain complex phosphates. Alconox is reported to have been used by Atomics International and The Babcock & Wilcox Company to clean fuel elements prior to being placed in service. The manufacturer reports that Alconox is low in chlorides in the order of a few parts per million. (This was confirmed by an Oak Ridge analysis.)

#### Conclusions

From this test, the Alconox solution appears to have the ability to remove chlorides as effectively as the 5 per cent  $\text{HNO}_3$  solution. It is possible that after longer exposures the  $\text{HNO}_3$  would be more effective.

#### Procedures

A highly porous weld was produced on a type 304 stainless steel tube 2-in. OD x 1/16-in. wall with a tungsten electrode and stainless

steel filler metal in air. This tube was sectioned in four segments 1 1/2 in. long. Each segment contained one-quarter of the weld. The segments were placed in a boiling solution of magnesium chloride and demineralized water for 3 hr. The solution contained 28.5 g of MgCl per 100 cc demineralized water. After 3 hr, the samples were removed and permitted to air dry.

Sample No. 1 was washed in 100 cc of demineralized water at room temperature for 15 min.

Sample No. 2 was washed in 100 cc of Alconox solution for 15 min. The Alconox solution was prepared as a 1 per cent by weight solution in demineralized water.

Samples No. 3 and No. 4 were washed in 100 cc of 5 per cent by volume solution of  $\text{HNO}_3$  in demineralized water for 15 min.

It was not possible to analyze the Alconox solution by the Mohr method after washing as the phosphates in the Alconox shielded the chlorides. Consequently, each of the four specimens was washed for 15 min in 100 cc of demineralized water at room temperature. These water samples were then analyzed by the Mohr method for chlorides and were found to contain less than 1 ppm chlorides. This indicated that, if any chlorides existed on the sample surfaces, the demineralized water had little or no effect in removing chlorides.

Each metal sample was washed again in 100 cc of a 5 per cent  $\text{HNO}_3$  solution for 15 min. The solutions were then analyzed for chlorides. Table 1F lists the results.

Table 1F

Sample	First Wash		Second Wash		Third Wash	
	Solution	ppm $\text{Cl}^-$	Solution	ppm $\text{Cl}^-$	Solution	ppm $\text{Cl}^-$
1	Demineralized Water	Not Made	Demineralized Water	<1 ppm	5% $\text{HNO}_3$	17.5
2	1% Alconox	Phosphates Shielded Chlorides	Demineralized Water	<1 ppm	5% $\text{HNO}_3$	5
3	5% $\text{HNO}_3$	Not Made	Demineralized Water	<1 ppm	5% $\text{HNO}_3$	Not Made
4	5% $\text{HNO}_3$	Not Made	Demineralized Water	<1 ppm	5% $\text{HNO}_3$	8

### Discussion

In the analysis for sample No. 1, after two washes in demineralized water and one wash in 5 per cent  $\text{HNO}_3$ , 17.5 ppm chloride could yet be found. Sample No. 2, which was originally washed in the 1 per cent Alconox solution, was found to have 5 ppm chloride in the final wash. Sample No. 4, originally washed in 5 per cent  $\text{HNO}_3$  with subsequent washes in demineralized water and 5 per cent  $\text{HNO}_3$ , produced 8 ppm chloride in the final wash.

The Alconox and  $\text{HNO}_3$  cleaning solutions removed chlorides more effectively than demineralized water. The difference in effectiveness to remove chlorides between the Alconox solution and 5 per cent nitric acid solution (5 to 8 ppm) is not believed to be significant. It appears that both the detergent and acid solutions will adequately remove chlorides. It is also believed that, if the washing were performed at a higher

temperature, 90°F, a greater amount of chloride would have been found in the final wash.

## APPENDIX G

Summary of the ORNL Nondestructive Inspection Procedures Employed  
on the Piping Samples Taken from the Primary System of the N. S. SAVANNAH  
and the New York Shipbuilding Corporation As-Received Storage

### Zyglo Fluorescent-Penetrant Inspection Procedure

1. Preclean by vapor degreasing.
2. Apply penetrant--ZL-22 Zyglo Super-Pentrex penetrant.
3. Emulsify for 1 1/2 min with ZE-3 emulsifier.
4. Wash in lukewarm water spray.
5. Dry with warm air blower.
6. Apply developer--ZP-4 developer for 10 min.
7. Inspect with 100-watt black light held 6 to 10 in. from sample.

### ORNL Ultrasonic Inspection Procedure

Ultrasonic testing was performed with an Immerscope using a 5-mc crystal of  $\text{LiSO}_4$ , 3/4-in. dia. The samples were compared with a 15-mil notch.



# APPENDIX H

## ORNL Analysis for Chloride in Thermobestos Insulation

January 17, 1961

Three samples of the Thermobestos insulation were submitted to the Special Analysis Laboratory for chloride analysis on December 30, 1960. The significant results are presented in the following chart:

<u>Test No.</u>	<u>Sample</u>	<u>Sample Form</u>	<u>Leach Solution</u>	<u>Leach Time (hr)</u>	<u>Cl<sup>-</sup> (ppm)</u>
1	Dry	Bulk	Cold H <sub>2</sub> O	47	85 <sup>a</sup>
2	Dry	Bulk	Boiling H <sub>2</sub> O	45	215 <sup>a</sup>
3	Dry	Shredded	Boiling H <sub>2</sub> O	44	230 <sup>d</sup>
4	Dry	Bulk	9 N H <sub>2</sub> SO <sub>4</sub>	1	75 <sup>a</sup>
5	Dry	Bulk	9 N H <sub>2</sub> SO <sub>4</sub>	1	110 <sup>b</sup>
6	Dry	Bulk	9 N H <sub>2</sub> SO <sub>4</sub>	1	65 <sup>c</sup>
7	Dry	Shredded	9 N H <sub>2</sub> SO <sub>4</sub>	44	275 <sup>d</sup>
8	PP-IV	Bulk	9 N H <sub>2</sub> SO <sub>4</sub>	1	35 <sup>a</sup>
9	PP-IV	Bulk	9 N H <sub>2</sub> SO <sub>4</sub>	1	40 <sup>b</sup>
10	PP-IV	Bulk	9 N H <sub>2</sub> SO <sub>4</sub>	1	65 <sup>c</sup>
11	PP-IV	Shredded	Boiling H <sub>2</sub> O	84	185 <sup>d</sup>
12	PP-IV	Shredded	9 N H <sub>2</sub> SO <sub>4</sub>	84	190 <sup>d</sup>
13	PS-PI (mud)	Bulk	9 N H <sub>2</sub> SO <sub>4</sub>	1	120 <sup>a</sup>
14	PS-PI (mud)	Bulk	9 N H <sub>2</sub> SO <sub>4</sub>	1	185 <sup>b</sup>
15	PS-PI (mud)	Bulk	9 N H <sub>2</sub> SO <sub>4</sub>	1	165 <sup>c</sup>

<sup>a</sup>Inner concave section.    <sup>b</sup>Outer convex section.

<sup>c</sup>Center section between a and b.    <sup>d</sup>Cross-sectional sample.

Test specimens weighing 12 g to 70 g were cut from various parts of the three samples. Each test specimen was placed in a 2-liter reflux flask, 500 to 1000 ml of leach solution added, and the flask heated to a slow boil. At intervals the flasks were cooled and an aliquot withdrawn for chloride analysis. One test specimen from the "Dry" sample was leached with water at room temperature with no agitation.

Chloride was analyzed in the aliquots by oxidation to  $\text{Cl}_2$  with potassium permanganate in sulfuric acid. The  $\text{Cl}_2$  was swept by a stream of nitrogen gas into a beaker containing potassium iodide. The resulting  $\text{I}_2$  was determined by titration with sodium thiosulfate using starch indicator. The known possible interferences are the  $\text{NO}_2^-$  and  $\text{Br}^-$  ions.

#### Reagents

$\text{KMnO}_4$ , 9.1 M.

$\text{H}_2\text{SO}_4$ , 1:1. Add 500 ml of conc.  $\text{H}_2\text{SO}_4$  to 500 ml  $\text{H}_2\text{O}$ .

KI, Cp crystals.

$\text{Na}_2\text{S}_2\text{O}_3$ , 0.01 N. Dilute 10 ml of standard 0.1 N  $\text{Na}_2\text{S}_2\text{O}_3$  to 100 ml with  $\text{H}_2\text{O}$ .

Starch Indicator. Triturate 2 g of starch and 10 mg of  $\text{HgI}_2$  with a little water. Add to 1 liter of boiling water and boil until clear.

$\text{Cl}^-$  standard, 35  $\mu\text{g}/\text{ml}$ . Dilute 100  $\mu\text{l}$  of standard 1 N HCl to 100 ml with  $\text{H}_2\text{O}$

#### Apparatus

Distillation apparatus. A 50-ml round-bottom flask is used as the distillation pot. The nitrogen inlet tube enters the flask through

the ground glass joint at the top of the neck and extends to within 1/4 in. of the bottom of the flask. The gas outlet is also in the joint at the neck of the flask. The exit gas passes through a Kjeldahl trap into a small condenser. A 50-ml beaker containing a KI solution is placed so that the tip of the condenser is beneath the surface of the KI solution. A variac controlled heating mantle supplies the heat.

Titration apparatus. A magnetic stirrer agitates the solution as the titrant is added from a Micro-Metric buret with a 1 cc/in. syringe.

#### Procedure

1. Pipet an aliquot to contain 10 to 100  $\mu\text{g}$  of  $\text{Cl}^-$  into the 50-ml round bottom flask.
2. Add 10 ml of 1:1  $\text{H}_2\text{SO}_4$  to the flask.
3. Add 10 ml of 0.1 M  $\text{KMnO}_4$  to the flask.
4. Put about 25 ml of water into a 50-ml beaker. Add about 200 mg of KI and 2 to 3 ml of starch indicator. Position the beaker properly beneath the condenser tip.
5. Place the flask on the distillation apparatus and adjust the  $\text{N}_2$  flow to 2 bubbles/sec.
6. Turn on the variac and distill for 15 min. The heat should be adjusted so that it takes about 5 min for the steam to rise to the Kjeldahl trap and that no more than 10 ml of volume will be distilled into the KI solution.
7. Remove the beaker and titrate the  $\text{I}_2$  with 0.01 N  $\text{Na}_2\text{S}_2\text{O}_3$ .

8. Run aliquots of the standard  $\text{Cl}^-$  solution to determine a factor and use it to calculate the  $\text{Cl}^-$  content of the samples.

Below is a more detailed description of each of the tests performed. Blanks of water and 9 N  $\text{H}_2\text{SO}_4$  were carried along with each set of test specimens. In no case was any chloride found in the blank solutions.

Test 1, Dry Sample

Location of test specimen: left side of inner concave surface.

Specimen weight: 14.36 g.

Treatment: not shredded.

Leach solution: 500 ml  $\text{H}_2\text{O}$ .

Leach conditions: specimen and  $\text{H}_2\text{O}$  in a beaker at room temperature.

Results: after 6 hr, 45 ppm  $\text{Cl}^-$ ; 12 hr, 60 ppm; 23 hr, 70 ppm; 47 hr, 85 ppm.

Test 2, Dry Sample

Location of test specimen: right side of inner concave surface.

Specimen weight: 12.55 g.

Treatment: not shredded.

Leach solution: 500 ml of  $\text{H}_2\text{O}$ .

Leach conditions: under reflux.

Results: after 6 hr, 155 ppm  $\text{Cl}^-$ ; 12 hr, 190 ppm; 23 hr, 195 ppm; 47 hr, 200 ppm.

Test 3, Dry Sample

Location of test specimen: a cross-sectional slice taken from the center of the sample.

Specimen weight: 36.47 g.

Treatment: shredded.

Leach solution: 500 ml  $H_2O$ .

Leach conditions: under reflux.

Results: after 2 hr, 215 ppm  $Cl^-$ ; 4 hr, 215 ppm; 20 hr, 220 ppm; 38 hr, 230 ppm; 44 hr, 230 ppm.

Tests 4, 5, and 6--Dry Sample

Location of test specimen: Test 4, inner concave section; Test 5, outer convex section; Test 6, center section between Test 4 and Test 5.

Specimen weight: Test 4, 14.02 g; Test 5, 53.14 g; Test 6, 27.77 g.

Treatment: not shredded.

Leach solution: 500 ml of 9 N  $H_2SO_4$ .

Leach conditions: under reflux.

Results: Test 4, after 1 hr, 75 ppm  $Cl^-$ ; Test 5, after 1 hr, 110 ppm  $Cl^-$ ; Test 6, after 1 hr, 65 ppm  $Cl^-$ .

Test 7, Dry Sample

Location of test specimen: a cross-sectional slice taken from the center of the sample.

Specimen weight: 31.39 g.

Treatment: shredded.

Leach solution: 500 ml of 9 N  $H_2SO_4$

Leach conditions: under reflux.

Results: after 2 hr, 245 ppm  $Cl^-$ ; 4 hr, 245 ppm; 20 hr, 265 ppm; 28 hr, 275 ppm; 44 hr, 275 ppm.

Tests 8, 9, and 10--PP-IV Sample

Location of test specimen: Test 8, inner concave section; Test 9, outer convex section; Test 10, center section between Test 8 and Test 9.

Specimen weight: Test 8, 27.09 g; Test 9, 37.96 g; Test 10, 29.72 g.

Treatment: not shredded.

Leach solution: 500 ml of 9 N  $\text{H}_2\text{SO}_4$ .

Leach conditions: under reflux.

Results: Test 8, after 1 hr, 35 ppm  $\text{Cl}^-$ ; Test 9, after 1 hr, 40 ppm  $\text{Cl}^-$ ;  
Test 10, after 1 hr, 65 ppm  $\text{Cl}^-$ .

Test 11, PP-IV Sample

Location of test specimen: a cross-sectional slice taken from the center of the sample.

Specimen weight: 53.75 g.

Treatment: shredded.

Leach solution: 1000 ml of  $\text{H}_2\text{O}$ .

Leach conditions: under reflux.

Results: after 12 hr, 155 ppm  $\text{Cl}^-$ ; 19 hr, 160 ppm; 36 hr, 180 ppm; 60 hr, 185 ppm; 84 hr, 185 ppm.

Test 12, PP-IV Sample

Sample of test specimen: a cross-sectional slice taken from the center of the sample.

Specimen weight: 67.99 g.

Treatment: shredded.

Leach solution: 1000 ml of 9 N  $\text{H}_2\text{SO}_4$ .

Leach conditions: under reflux.

Results: after 12 hr, 185 ppm  $\text{Cl}^-$ ; 19 hr, 190 ppm; 84 hr, 190 ppm.

Tests 13, 14, and 15--PS-PI (mud) Sample

Location of test specimen: Test 13, inner concave section including a yellow stain; Test 14, outer hard mud crust only; Test 15, center section between Test 13 and Test 14.

Specimen weight: Test 13, 32.15 g; Test 14, 64.03 g; Test 15, 37.43 g.

Treatment: not shredded.

Leach solution: 500 ml of 9 N  $\text{H}_2\text{SO}_4$ .

Leach conditions: under reflux.

Results: Test 13, after 1 hr, 120 ppm  $\text{Cl}^-$ ; Test 14, 1 hr, 185 ppm;  
Test 15, 1 hr, 165 ppm.

Comments: All acid-treated specimens disintegrated more than the water-treated specimens.

From the good agreement between  $\text{H}_2\text{O}$  leached and 9 N  $\text{H}_2\text{SO}_4$  leached specimens and the length of some of the tests, we believe that all of the soluble chloride has been leached and that the results are good to  $\pm 5$  ppm  $\text{Cl}^-$ .

## APPENDIX I

### Ebasco Procedure for Determination of Chlorides in Thermobestos Insulation

1. Insulation leached in demineralized water, liquid decanted, filtered, and diluted to suitable known volume.
2. Reagents.
  - (a)  $\text{AgNO}_3$  0.01  $\frac{1}{4}$  N = 1 ml  $\text{AgNO}_3$  = 0.5 mg Cl.
  - (b)  $\text{K}_2\text{CrO}_4$  indicator 5 per cent.
  - (c) Phenolphthalein 0.5 per cent.
  - (d)  $\text{H}_2\text{SO}_4$  ~ 0.5 N.
  - (e) NaOH ~ 0.5 N.
3. Procedure.
  - (a) Use 100-ml samples in white porcelain casseroles.
  - (b) Prepare a blank of 100-ml demineralized water in one casserole and 100-ml sample of unknown in another casserole.
  - (c) Add five drops of Phenolphthalein to the blank and the sample and adjust the pH of the solutions with either NaOH or  $\text{H}_2\text{SO}_4$  so that they are just colorless to Phenolphthalein.
  - (d) Add 20 drops (1 ml) of  $\text{K}_2\text{CrO}_4$  indicator to the blank and the sample.
  - (e) Titrate blank with  $\text{AgNO}_3$  until bright-yellow color changes to organish-yellow (this requires approximately 0.4 to 0.5 ml  $\text{AgNO}_3$ ).



- (f) Then titrate sample with  $\text{AgNO}_3$  until color changes from bright-yellow to organish-yellow and is the same color as the blank. The end point is determined by comparison with blank. Subtract blank reading from sample reading to obtain amount of standard  $\text{AgNO}_3$  required to precipitate the chlorides in the sample.

# APPENDIX J

## Case Histories--Failure of Austenitic Stainless Steel Associated with Thermal Insulation<sup>9</sup>

<u>Source of Data</u>	<u>Trent Tube Co.</u>	<u>E.I. du Pont Company</u>	<u>E.I. du Pont Company</u>	<u>Inter-national Nickel Company</u>	<u>Armco Steel Corp.</u>	<u>Armco Steel Corp.</u>	<u>Allegheny Ludlum Steel Corporation</u>
<u>1. General Information</u>							
a) Type of process & equipment	Welded tube carrying non-filtered and softened water to dye machine.	Magnesia insulated SS water pipe (16 failures).	Column 30 ft x 2 ft.	Test spool in boiler feed water deaerating heater.	Maleic anhydride storage tank insulated with foam glass.	Hot water tanks for hot beverage dispensers.	Water heating tank 48 in. diameter x 10 ft 0 in. long.
b) Time to cracking	16 months	9 months	2 years	244 days	One year	Unknown	Not disclosed
c) Location of cracks	Longitudinal cracks in and adjacent to welds--also 180° from weld.	At outer radii of 90° bends and near welds.	OD of column 3 to 6 ft from top, beneath magnesia insulation.	Adjacent to punched holes--partially shielded.	OD--more severe in weld zones.	Practically the entire outer surface.	One large deep crack traversing the center of the sample examined. The sample had almost broken in half at this point. Close inspection revealed a network of fine cracks throughout the sample.

<u>Source of Data</u>	<u>Trent Tube Co.</u>	<u>E.I. du Pont Company</u>	<u>E.I. du Pont Company</u>	<u>Inter-national Nickel Company</u>	<u>Armco Steel Corp.</u>	<u>Armco Steel Corp.</u>	<u>Allegheny Ludlum Steel Corporation</u>
d) How was failure identified as stress-corrosion cracking	Micro-transgranular cracks.	No information.	No information.	Profuse cracking exclusively transcrystalline.	Some rust.	Rust & pitting. Water scale on inside of tank.	Metallographic study showed highly branched transcrystalline cracks. No precipitated carbide was evident.
e) Other conditions associated with cracks.	OD pitting.	Severe pitting.	No information.	Some cracks parallel to surface filled with oxide--flaking occurred.			A thin brown film covered the inside while the outside revealed a white deposit. Neither deposit was apparently related to the cracking.

## 2. Material and Fabrication

a) AISI Type No. (and composition)	304 L (.03 C, 9.40 Ni, 18.80 Cr).	304	304	304 (18.56 Cr, 9.44 Ni); 316 (18.06 Cr, 15.05 Ni, 2.5 Mo).	304 (.054 C, 18.59 Cr, 9.47 Ni).	304 (.053% Cr, 18.50% Cr, 9.49% Ni).	304
------------------------------------	-----------------------------------	-----	-----	--	----------------------------------	--------------------------------------	-----

<u>Source of Data</u>	<u>Trent Tube Co.</u>	<u>E.I. du Pont Company</u>	<u>E.I. du Pont Company</u>	<u>Inter-national Nickel Company</u>	<u>Armco Steel Corp.</u>	<u>Armco Steel Corp.</u>	<u>Allegheny Ludlum Steel Corporation</u>
b) Thickness of failed section	.083 in.	Approximately 1/8 in.	1/4 to 3/8 in.	304 = .031 in.; 316 = 1/8 in.	1/4 in. plate.	20 gage	3/16 in.
c) Heat treatment or mill condition prior to service	Fully annealed.	Not known - probably annealed.	Annealed after fabrication.	No information.	Annealed.	Cold worked - as fabricated tanks.	Mill annealed before forming.
d) Hardness	RB 68	Not determined.	Not determined.	No information.	RB 80	RB 82 to RC 30.	Not determined.
e) Surface condition prior to service	Pickled	Pickled	Pickled	No information.	Pickled	Polished	Commercial 2-B finish.
f) Fabrication method used.	Tube welded into stock line.	Improperly fabricated 90° bends, welded not annealed prior to welding.	Welded.	Stamped (304), welded (316).	Rolled and welded.	Rolled section inserted between halves of Bain-Marie tank. Several lugs and fittings soldered on outside of tank.	Roll formed and welded into cylindrical tank.

<u>Source of Data</u>	<u>Trent Tube Co.</u>	<u>E.I. du Pont Company</u>	<u>E.I. du Pont Company</u>	<u>Inter-national Nickel Company</u>	<u>Armco Steel Corp.</u>	<u>Armco Steel Corp.</u>	<u>Allegheny Ludlum Steel Corporation</u>
3. <u>Corroding Media and Service Conditions</u>							
a) Chemicals present	MgCl <sub>2</sub> & NaCl	Chlorides leached by rain water from magnesia. Material scraped from OD contained 347 ppm chloride.	Rain water leached chlorides from magnesia.	H <sub>2</sub> O + 30 ppm H <sub>2</sub> SO <sub>4</sub> , 70 ppm CO <sub>2</sub> , 10 ppm O <sub>2</sub> .	Maleic anhydride inside, atmosphere outside contains chlorine and hydrogen sulfide.	Hot water on inside, zirconium base cement insulation outside.	Water ran through a single zeolite softener.
b) Chlorides of other halogens	NaCl - 10% possible HCl.	Chlorides	Chlorides	Trace assumed.	Chlorides on OD & insulation.	Chlorides in corrosion products & insulation.	Chlorides were present in white deposit.
c) pH	No information.	Not determined.	No information.	No information.	Leachings - 3.3.	No information.	No information.
d) Temperature	180°F	Exposed to heat from sun.	Approximately 100°C.	175°F Avg. 100°-200°	70-90C.	Unknown.	From 40° to 180°.

<u>Source of Data</u>	<u>Trent Tube Co.</u>	<u>E.I. du Pont Company</u>	<u>E. I. du Pont Company</u>	<u>Inter-national Nickel Company</u>	<u>Armco Steel Corp.</u>	<u>Armco Steel Corp.</u>	<u>Allegheny Ludlum Steel Corporation</u>
e) Aeration	Not determined.	Exposed to air.	Exposed to air.	10 ppm O <sub>2</sub> .	None.	None.	No information.
f) Velocity	No information.	None.	None.	No information.	None.	None.	No information.
g) Method of heating	Water heated prior to reaching tubes.	Exposed to sun.	No information.	No information.	Steam plate coils outside bottom of tank. One coil leaked.	Electric elements.	No information.
4. <u>Origin of Stress</u>	Vibrational stresses.	Stresses from bending & welding.	Possibility of thermal stresses and/or improper annealing.	Caused by punching center holes in specimens.	Roll-forming & welding.	Heavy water scale probably increased temperature differential. Stressed from fabrication. Stress calculated from spring-back of sawed rings indicated stresses of 60 to 70 kips in drawn portion of cans.	Stresses were caused by fabrication - rolling and welding.

5. Comments

Trent Tube Co.

Magnesium insulation material absorbed NaCl solution drippings. Corrodent probably mixture of  $MgCl_2$  and NaCl. A change in insulation material was suggested.

E.I. du Pont Company

Chlorides leached from insulation probably caused failure. Material was changed to carbon steel.

E.I. du Pont Company

Chlorides concentrated on hot metal surface probably caused failures. Replace magnesia insulation with glass fiber.

International Nickel Company

Concentration of chlorides in crevice between insulation and specimen plus residual stresses around punched hole caused the cracking. Other stainless specimens did not fail.

Armco Steel Corp.

Chlorides were present from acid leachings from insulation. Recommended change in heater design and different insulation protected from rain drippings.

Armco Steel Corp.

A combination of chloride and stresses caused the failure. Recommendations included solution anneal, better cleaning of soldering flux, substitution of dry insulation material, periodical cleaning, and continuous operation to prevent condensation.

Allegheny Ludlum Steel Corporation

Chloride concentration from magnesium block insulation and possible chloride solution spillage. The existence of this chloride along with residual fabrication stresses caused cracking. One possible remedy would be to apply a protective coating such as "Black Kopak" to the outside of the tank prior to insulation with magnesium block insulation. Another possible remedy would be the use of extreme caution so as not to allow chloride containing liquids to penetrate the magnesium block insulation.





## DISTRIBUTION

Internal

- |                      |                       |
|----------------------|-----------------------|
| 1. T. D. Anderson    | 29. H. W. Hoffman     |
| 2. S. E. Beall       | 30. S. I. Kaplan      |
| 3. R. J. Beaver      | 31. O. H. Klepper     |
| 4. M. Bender         | 32. R. B. Korsmeyer   |
| 5. A. L. Boch        | 33. P. G. Lafyatis    |
| 6. R. B. Briggs      | 34. R. N. Lyon        |
| 7. F. R. Bruce       | 35. H. G. MacPherson  |
| 8. D. W. Cardwell    | 36. W. D. Manly       |
| 9. T. E. Cole        | 37. E. R. Mann        |
| 10. B. W. Colston    | 38. H. C. McCurdy     |
| 11. J. A. Conlin     | 39. H. F. McDuffie    |
| 12. W. B. Cottrell   | 40. E. C. Miller      |
| 13. J. A. Cox        | 41. M. L. Myers       |
| 14. R. S. Crouse     | 42. F. H. Neill       |
| 15. F. L. Culler     | 43. P. Patriarca      |
| 16. J. E. Cunningham | 44. G. C. Robinson    |
| 17. J. C. Dedrick    | 45. H. W. Savage      |
| 18. I. T. Dudley     | 46-50. L. D. Schaffer |
| 19. J. L. English    | 51. I. Spiewak        |
| 20. W. K. Ergen      | 52. W. C. Thurber     |
| 21. A. P. Fraas      | 53. D. E. Tidwell     |
| 22. J. K. Franzreb   | 54. D. B. Trauger     |
| 23. J. H. Frye, Jr.  | 55. B. J. Ward        |
| 24. J. C. Griess     | 56. G. D. Whitman     |
| 25. W. R. Grimes     | 57. C. L. Whitmarsh   |
| 26. E. E. Gross      | 58. C. E. Winters     |
| 27. V. O. Haynes     | 59. M. L. Winton      |
| 28. F. M. Hill       | 60. F. C. Zapp        |

- 61-62. Central Research Library (CRL)
- 63. Document Reference Section (DRS)
- 64-73. Laboratory Records (LRD)
  - 74. Laboratory Records - Record Copy (LRD-RC)
  - 75. Reactor Division (ORO)
  - 76. Research and Development Division (ORO)
- 77-91. Division of Technical Information Extension (DTIE)

External

- 92-93. D. F. Bollender  
States Marine Lines  
C/o New York Shipbuilding Corporation  
Post Office Box 620  
Camden 1, New Jersey
- 94-95. J. M. Dempsey, Jr.  
States Marine Lines  
90 Broad Street  
New York 4, New York
96. H. E. Hansen  
States Marine Lines  
Albee Building  
Washington, D. C.
- 97-101. J. A. Klapper  
Ebasco Services Incorporated  
Two Rector Street  
New York 6, New York
102. R. O. Mehann  
States Marine Lines  
C/o New York Shipbuilding Corporation
- 103-106. R. E. McGrath  
States Marine Lines  
C/o New York Shipbuilding Corporation
- 107-126. J. E. Robb, Chief  
Nuclear Projects Branch  
Office of Research and Development  
Maritime Administration  
Washington 25, D. C.
- 127-128. R. T. Schomer  
The Babcock & Wilcox Company  
Atomic Energy Division  
Post Office Box 1260  
1201 Kemper Street  
Lynchburg, Virginia
- 129-138. W. C. Stamm  
Ebasco Services Incorporated  
Two Rector Street  
New York 6, New York