MASTER**GEOHERMAL
ANALYTICAL REPORT**

Contract No. DE-AC03-81SF11503

DCN: 81-212-011-08

Title: RAFT RIVER CONDENSER-TUBE EXAMINATION

DOE/SF/11503--T1

Report Date: 4/3/81

DE82 008003

Source Contact: Dan F. Suci

Address: EG&G Inc.
P. O. Box 1625
Idaho Falls, Idaho 83415**RECEIVED**
APR 26 1982
DOE OFFICE OF PATENT
COUNSEL/LIVERMORE

Resource: Raft River, Idaho

Purpose/Background: This Geothermal Analytical Report is part of DOE's continuing support of development of a water treatment for the 5 MW Raft River Power Plant's carbon steel heat rejection system. Four carbon steel tubes were analyzed in this batch.

Radian Analyst: Dennis M. Anliker

RESULTS

All four tubes were subjected to similar treatment schemes by EG&G with a 60 day exposure and cycled five times. Chemical additives and pH range for each tube were as shown in Table 1.

TABLE 1

<u>ADDITIVE</u>	<u>TUBE 1</u>	<u>TUBE 2</u>	<u>TUBE 3</u>	<u>TUBE 4</u>
Betz 20-20	150 ppm	150 ppm	150 ppm	150 ppm
Betz 426	100 ppm	100 ppm	100 ppm	100 ppm
Betz 526-C (TTA)	10 ppm	10 ppm	10 ppm	10 ppm
Zinc	3-5 ppm	3-5 ppm	3-5 ppm	3-5 ppm
Betz 20-40	----	40 ppm	40 ppm	----
Betz 35A	40 ppm	----	----	40 ppm
pH	6.2-6.8	6.8-7.2	6.2-6.8	6.8-7.2

The deposit analysis was performed on an uncleaned segment of each tube with energy dispersive x-ray spectroscopy (EDS). The EDS results are shown in Table 2.

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

gms

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TABLE 2

	<u>TUBE 1</u>	<u>TUBE 2</u>	<u>TUBE 3</u>	<u>TUBE 4</u>
MAJOR ELEMENTS	Fe	Fe	Fe	Fe
MINOR ELEMENTS	None	None	None	None
TRACE ELEMENTS	Si	Si	Si	Si
	S	S	S	S
	Cl	Cl	Cl	Cl
	K	Cu	K	K
	Mn		Cu	Cu
	Cu			

Compound identification of the tube deposits was attempted with x-ray diffraction techniques. Only amorphous material was detected which indicates that no identifiable crystalline compounds were present in the tube deposits.

The following pages present the results of visual and scanning electron microscope (SEM) examination of the tubes. In the Gross Visual Examinations, the general appearance of the tube at 1X is noted. A 1.5 inch section is then scrubbed with a soft brush and water to remove non-adherent deposits. Results of visual examination of the scrubbed sample are recorded under Stereomicroscopic Examination of Film.

The 1.5 inch samples were then immersed in ambient temperature 10 percent inhibited sulfuric acid in an ultrasonic bath for 15 minutes, rinsed, dried and examined stereomicroscopically at 20X. Observations are recorded under Stereomicroscopic Examination of Acid Cleaned Metal.

The depth of five deepest pits and depth of features at five random points on the sample surface were measured to $\pm 1 \mu\text{m}$ using the calibrated stage of a metallograph. The sample was then viewed with a SEM and a typical area was photographed in dual magnification at 50X and 200X.

Four condenser tubes as received 3/23/81.

RAFT RIVER CONDENSER TUBE EXAMINATION

Job Id. 212-011-02 Job 8

Tube # 1 Exposure 60 days Rec'd 3/23/81

Gross Visual Examination:

Gross general corrosion and pitting running longitudinally. Very thin coating of olive colored deposit on O.D.

Pit Density = $1 \times 10^4/\text{m}^2$

Pit Size = $0.5\text{mm}^2 - 2.0\text{mm}^2$

Stereomicroscopic Examination of Film (Scrubbed Area):

General appearance indicates overall corrosion, predominantly on twenty percent of the tube circumference. Pitted areas are large and appear to be cleanly etched. Surface was clean of deposits but some oxidation film remained (20X).

Stereomicroscopic Examination of Acid Cleaned Metal:

Rough surface texture with all deposits and film removed. Areas of pitting evident at 20X.

Metallographic Examination of Acid Cleaned Metal:

<u>feature depth (μm)</u>		<u>Comments</u>
<u>Discrete Pits</u>	<u>Other Morphology</u> *	
1.66	48	* Mesa and canyon morphology with random pitting.
2.47	47	
3.94	72	
4.72	71	
5.44	62	
mean 65	60	

SEM Examination of Acid Cleaned Metal:

Rough surface with irregular pits at 50X. Some adherent scale still evident at 200X.

Control tube at left with tube 1 at right after cleaning in inhibited 10% sulfuric acid. Magnification: 8X.

Scanning electron micrograph of tube 1 after acid cleaning. The micrograph on the right (200X) is a higher magnification of the outlined rectangle on the left (50X). Some adherent scale is still evident after acid cleaning.

RAFT RIVER CONDENSER TUBE EXAMINATION

Job Id. 212-011-02 Job 8

Tube # 2 Exposure 60 days Rec'd 3/23/81

Gross Visual Examination:

Broad spreading pits with gross general corrosion running longitudinally and circumferentially. Very thin olive colored deposit covering O.D. surface.
Pit Density = $5 \times 10^5/\text{m}^2$
Pit Size = $>24.5\text{mm}^2$

Stereomicroscopic Examination of Film (Scrubbed Area):

Olive film removed. Broadly etched area on 30% of circumference (20X).

Stereomicroscopic Examination of Acid Cleaned Metal:

Rough surface texture with deep etching and discrete pits at 20X.

Metallographic Examination of Acid Cleaned Metal:

<u>feature depth (μm)</u>		<u>Comments</u>
<u>Discrete Pits</u>	<u>Other Morphology *</u>	
1. 48	72	* Predominantly mesa and canyon type morphology.
2. 54	55	
3. 45	42	
4. 50	45	
5. 46	62	
mean 45	55	

SEM Examination of Acid Cleaned Metal:

Rough surface with broad pitting. Most pits too large to view at 50X. Some scale is adhering after acid cleaning.

Control tube at left with tube 2 at right after cleaning in inhibited 10% sulfuric acid. Magnification: 8X.

Scanning electron micrograph of tube 2 after acid cleaning. The micrograph on the right (200X) is a higher magnification of the outlined rectangle on the left (50X). Some adherent scale is still evident after acid cleaning.

RAFT RIVER CONDENSER TUBE EXAMINATION

Job Id. 212-011-02 Job 8

Tube # 3 Exposure 60 Days Rec'd 3/23/81

Gross Visual Examination:

Gross pitting over entire surface. Covered with powdery red deposit.

Pit Density = $1 \times 10^5/\text{m}^2$

Pit Size = $0.5 \text{ mm}^2 - 2.0 \text{ mm}^2$

Stereomicroscopic Examination of Film (Scrubbed Area):

Gross pitting over entire surface with powdery red deposit removed (20X).

Stereomicroscopic Examination of Acid Cleaned Metal:

Very rough surface texture with gross pitting over entire surface.
Pits are oriented longitudinally over the entire tube length (20X).

Metallographic Examination of Acid Cleaned Metal:

<u>feature depth (μm)</u>		<u>Comments</u>
<u>Discrete Pits</u>	<u>Other Morphology</u> *	
1. 69		* Extremely pitted with no discernible mesa and canyon effect.
2. 70		
3. 60		
4. 76		
5. 45		
mean 64		

SEM Examination of Acid Cleaned Metal:

Very rough surface entirely covered with pits at 50X.

Control tube at left with tube 3 at right after cleaning in inhibited 10% sulfuric acid. Magnification: 8X.

Scanning electron micrograph of tube 3 after acid cleaning. The micrograph on the right (200X) is a higher magnification of the outlined rectangle on the left (50X).

RAFT RIVER CONDENSER TUBE EXAMINATION

Job Id. 212-011-02 Job 8

Tube # 4 Exposure 60 Days Rec'd 3/23/81

Gross Visual Examination:

Gross pitting over entire surface. Covered with powdery red deposit.
Pit Density = $1 \times 10^5/\text{m}^2$
Pit Size = $0.5\text{mm}^2 - 8.0\text{mm}^2$

Stereomicroscopic Examination of Film (Scrubbed Area):

Gross pitting over entire surface with powdery red deposit removed. Drab gray film under red deposit (20X).

Stereomicroscopic Examination of Acid Cleaned Metal:

Very rough surface texture with gross pitting in longitudinal orientation at 20X.

Metallographic Examination of Acid Cleaned Metal:

<u>feature depth (μm)</u>		<u>Comments</u>
<u>Discrete Pits</u>	<u>Other Morphology</u> *	
1. 48		* Extremely pitted with no mesa and canyon effect discernible.
2. 59		
3. 48		
4. 45		
5. 59		
mean 52		

SEM Examination of Acid Cleaned Metal:

Very rough surface entirely covered with pits at 50X.

Control tube at left with tube 4 at right after cleaning in inhibited 10% sulfuric acid. Magnification: 8X.

Scanning electron micrograph of tube 4 after acid cleaning. The micrograph on the right (200X) is a higher magnification of the outlined rectangle on the left (50X).

TABLE 3 SUMMARY OF RESULTS OF 60 DAY TEST

<u>Treatment (ppm)</u>	<u>Tube 1</u>	<u>Tube 2</u>	<u>Tube 3</u>	<u>Tube 4</u>	<u>Control</u>
Betz 35A	40	-	-	40	
Betz 20-40	-	40	40	-	
Betz 20-20	150	150	150	150	
Betz 426	100	100	100	100	
Betz 526-C (TTA)	10	10	10	10	
Zinc	3-5	3-5	3-5	3-5	
pH	~6.5	~7.0	~6.5	~7.0	
<u>Results</u>					
Pit density (pits/m ²)	1·10 ⁴	5·10 ⁵	1·10 ⁵	1·10 ⁵	-
Pit area (mm ²)	0.5-2.0	>24.5	0.5-2.0	0.5-8.0	-
Pit depth (μm) at 60 days					
mean	65	45	64	52	-
range	44-94	40-54	45-76	48-59	-
Max. Pitting Rate (μm/wk)					
mean	8	5	7	6	-
range	5-11	5-6	5-9	6-7	-
Mean non-pit feature depth (μm)	60	55	*	*	21

* no areas free of discrete pits were observed.

DISCUSSION AND CONCLUSIONS

This section represents Radian's input as to the significance of the results obtained in this 60 day test.

Given the limitations resulting from schedule and budget constraints, this test program, of course, can not provide the statistical data for estimation of the area effect on pit penetration rate or for quantitative evaluation of the effect of time on pit penetration rate. It is our view, therefore, that the current testing methodology can only indicate a treatment program with a high probability of long-term protection when the following four conditions are met:

- the uniform corrosion rate, determined by electrochemical or weight-loss methods, is acceptable; and
no discrete pits are observed, and
- the mean feature depth of exposed tubing does not vary significantly from the mean feature depth of an acid cleaned and prefilmed control sample; or
- The mean feature depths and pit depths do not vary significantly between tests of short and longer duration, indicating the inhibition of pits formed immediately upon exposure of the treated steel to treated water.

Measurements performed by Dan Suciú will provide information about the first point. The objective of our examination of the four tube samples was to determine if the second two conditions are satisfied, indicating an absence of localized corrosion. Comparison of the 60 day test results with results of 18 day tests in water with similar treatment was made to determine if the final condition was satisfied.

After 60 days exposure all four tubes showed pitting. In the case of Tube 3, the pits were extremely broad, greater than 3mm in diameter. As in prior examinations, the deepest pit in each of five random fields (having dimensions about 35mm x 0.75mm) on each tube was measured and reported. For Tubes 1 and 2, depth of surface feature in five random fields (of about 0.75mm diameter) which did not exhibit discrete pitting were also measured. Tubes 3 and 4 exhibited no such areas. The results are summarized in Table 3.

The results of this 60 day test series are most significant when compared to the 18 day test series previously evaluated by Radian in DCN 81-212-011-03. The results of that test are summarized in Table 4. Comparison between the two tests, which used similar treatments, shows an order of magnitude increase in pit density in the 60 day tests as compared to the 18 day tests. However, the pit depths in the 60 day tests are not significantly greater than in the 18 day tests. This observation indicates strongly that with the treatments used, the rate of pit penetration decreases sharply with time. This finding supports the opinion of Paul Puckorius and probably justifies an estimated condenser life of several years.

TABLE 4 SUMMARY OF RESULTS OF 18 DAY TEST PERFORMED 4-22 DEC. 1980

<u>Treatment (ppm)</u>	<u>Tube 1</u>	<u>Tube 2</u>	<u>Tube 3</u>	<u>Tube 4</u>	<u>Control</u>
Betz 35A	50	-	-	50	
Betz 20-40	-	75	75	-	
Betz 20-20	150	150	150	150	
Betz 426	100	100	100	100	
Betz 526-C (TTA)	10	10	10	10	
Zinc	3	3	10*	10*	
<u>Results</u>					
Pit density (pits/m ²)	$\sim 1 \cdot 10^4$	$\sim 5 \cdot 10^4$	$\sim 2.5 \cdot 10^3$	$\sim 1 \cdot 10^5$	-
Area per pit (mm ²)	<0.5	0.5	<0.5	2.0	-
Pit depth (μm) at 18 days					
mean	75	63	55	165	-
range	33-134	23-105	40-67	149-189	-
Max. Pitting Rate (μm/wk)					
mean	29	25	21	64	-
range	13-52	9-41	16-26	58-74	-
Mean non-pit feature depth (μm)	38	25	25	29	21

* Dan Suciu reports that all but 3-4 ppm of the zinc precipitated.