NUCLEAR REGULATORY COMMISSION

IN THE MATTER OF:

COMMONWEALTH EDISON COMPANY

(Zion Station, Units 1 and 2)

Docket Nos. 50-295 50-304 (Spent Fuel Pool Expansion)



Place Zion, Illinois Date -15 June 1979

Pages 1195 - 1329 (IN CAMERA session 1330 - 1354) ** 1355 - 1365

1* IN CRIEFA session not included herein

2326 001

Telephone: (202) 347-3700

V

ACE - FEDERAL REPORTERS, INC.

Official Reporters

444 North Capitol Street Washington, D.C. 20001

NATIONWIDE COVERAGE - DAILY 7906290082

CR 4828 WRBloom/wb WELandon	. 1195
(1 of 2) 1	UNITED STATES OF AMERICA
2	NUCLEAR REGULATORY COMMISSION
3	
4	In the matter of:
5	COMMONWEALTH EDISON COMPANY : Docket Nos. 50-295
6	(Zion Station, Units 1 and 2) : (Spent Fuel Pool Expansion)
• 7	
8	
9	Lincoln Ballroom, Holiday Inn Illinois Beach Resort.
10	Sheridan Road at Wadsworth Road, Zion, Illinois.
11	Friday, 15 June 1979.
12	
13	The hearing in the above-entitled was reconvened,
14	purusant to adjournment, at 9:00 a.m.
. 15	BEFORE:
16	JOHN WOLF, Esq., Chairman,
17	DR FORREST J REWICK Member
* 18	DR. LINDA W. LITTLE. Member.
• 19	APPEARANCES:
21	On behalf of the Licensee, Commonwealth Edison Company:
22	MICHAEL I. MILLER, Esq.,
22	PHILIP STEPTOE, Esq., ALAN P. BIELAWSKI, Esq.,
24	Isham, Lincoln and Beale, One First National Plaza,
25	Chicago, Illinois 60603.
	2326 002

wb i	On behalf of Intervenor State of Illinois:
2	SUSAN N. SEKULER, Esq.,
	ANNE K. MARKEY, Esq.,
3	Assistant Attorneys General, Environmental Control Division
4	188 West Randolph Street.
	Chicago, Illinois 60601.
5	
6	On benall of the Regulatory Staff:
	RICHARD J. GODDARD. Esg.
7	STEVEN C. GOLDBERG, Esq.,
	Office of Executive Legal Director,
8	United States Nuclear Regulatory Commission,
ell	washington, D. C. 20555.
10	
12	
13	0704 007
14	2326 003
. 15	
16	
17	
10	
19	
20	
20	
21	
22	
23	
24	
25	

							11	97
6/15/79	1	5	<u>ON</u> Z	ENT	<u>s</u>			x
•	2	Witnesses	Diract	Cross	Redirect	Recross	Board	cn 3d.
0	3	Frank M. Almeter) Edward Lantz) (Continued)		1198	1257	•••••	1261	1271
	5 6	A. Burtron Johnson, Jr. (Resumed)	1276	1278			1281	
*	7. 8.	Joseph E. Draley	1287	1292	1357		1359	
	93	er 19 de						
	11							
	12	Exhibits			Ident	ified	Pazaiva	
•	:a-	Intervenor's 6 (Ltr of 5	-29-79	to	200110	11.150	NECISIVE	-
	14:	Pliml from Mollerus re Welding, Zion Fuel Sto	: Closu prage Tu	re bes	12	32		
	15	Licensee's 1 (Spent Fuel Receiving Inspection C	Racks,	+.)	12	= 3		
	7			/	14	55		
•	8	8						
` ,	9:				2326	004		
2	20							
2	1							
2	2							
2	3							
2	4							
2	5							

•

SRB100m	-
ebl i	PROCREDINGS
3	CHAIRMAN WOLF: We'll be back on the record
) 3	Whereupon.
γ 4	FDANK M ATMENTED
5	and
G	EDWARD LANGT
-	resumed the stand on behalf of the NPC Populatory Staff and
	having been praviously duly sucre wars evenined and tertificat
0	further as follows.
10	CHAIDMAN NOTE: No. Coludion and the
	MS SERVICEP: MS. Sexuler, are you ready?
2	CHATRMAN WOLF: Very well wer not merced
-	maintain doir: very weit, you may proceed.
14	CROSS-EXAMINATION (Continued)
	O are sither of you continue to the f
5	gentlemen shie to testifu shout the effect of you
.6	or fueld
17	
•	A (Witness Lantz) 1'm not.
19	A (Witness Almeter) I'm not.
20	Q May I just ask if either or both of you has ever
21	seen a paper I do not intend to put this into evidence,
22	I'm just asking if they have over seen this particular do:u-
23	ment. It's called "Fission Gas Release from Fuel at High
24	Burnup." It is written by R. O. Meyer, C. E. Beyer, and J. C.
25	Vogerweed. Meyer and Vogelweek are of the Division of Systems
	2326 005

	1	
		.199
eb2	1	Safety, Office of Nuclear Reactor Regulation, U. S. Nuclear
	2	Regulatory Commission. Beyer is an NRC consultant from
	3	Battelle Pacific Northwest Laboratories, or he was when this
	4	work was performed.
	5	This article was published in Nuclear Safety,
	6	Volume 19, Number 6, November - December 1978.
	7	I will give you this document to read. Just tell
	8	me if you can identify it, if you've ever seen it.
	9	(Handing document to the witness panel.)
	:0	A I've not read this document.
	1	A (Witness Lantz) I've seen it, but I didn't read
	2	it in detail.
	3	Q Thank you.
	4	Are sither one of you aware of the experimental
	5	use of higher burnup at Zion?
	16	A Not until I heard about it here.
	17	2 Mr. Almeter, were you aware?
	8	A (Witness Almeter) I hadn't heard about it until
	9	this proceedings.
	20	Q Was the consideration of higher burnup fuel being
	21	placed in the spent fuel pool taken by either of you in taking
	22	your assessments of this modification?
	23	A (Vitness Lantz) The assessment is, to my way of
	24	thinking, is independent of the burnup of the fuel.
	25	CHAIRMAN WOLF: I think the question was, did you
		2326 006
	-	[2] - 2 - 2 - 2 - 2 - 2 - 2 - 2 - 2 - 2 -

eb3

3

2

3

2

5

3

7

3

9

10

11

12

15

12

15

15

1

21

25

take it into consideration?

WITNESS LANTZ: Yes.

CHAIRMAN WOLF: Is that correct, Ms. Sekuler? Was that your question?

MS. SERULER: Yes, Mr. Wolf. Thank you.

WITNESS ALMETER: I did not take this into consideration in my area of review.

BY MS. SEKULER:

In the testimony you presented for this hearing, 0 on page 11 you discuss recent surveys by Vesterlund and Olsson in Sweden, by Johnson at Battelle, by Weeks at Brookhaven.

You then discuss, a little further down in the paragraph, defective fuel that was placed in water pools at Windscale, and examined after nine years storage.

Was any of the fuel in the defective fuel high burnuo?

(Witness Almeter) I cannot recall. I was just 2 A citing the references there, and the observations that were .9 given in those references. I cannot recall about the buraup 20 on the Windscale.

On page 6 of your testimony you cite data from Q 22 the Draley and Ruther study of 1956 in the first complet: 23 paragraph on page 6. 24

Do you know of any later studies that have been

2326 007

done in this area?

A No, I could not find any later studies than this that would relate to specific aspects of the type of corresion rates I was looking for in my literature search to find the types of environments that would be typical or applicable to the Zion spent fuel pool.

I was looking specifically for experiments dong in the pH range and the temperature range, and the type of distilled water, pure water.

Can you tell me how the Draley and Ruther experi-2 ments of corrosion rate in distilled water of pH 7 at 212 degrees Fahrenheit relates to the storage of spent fuel in borated water with a pH of 4.5 at approximately 120 degrees Fahrenheit?

It would not relate to a borated water. I gave A this as an example to scope the type of corrosion that would occur in deionized water which is distilled water.

And in Draley's experiments, he went further and 18 tried to give a type of corrosion that would occur in perhaps a dilute acid or a dilute alkaline solution. This would scope the range of the type of corrosion rate that would occur in perhaps a borated water where they had a pH of around 5, which would be slightly acidic.

> But boron is a very mild type of acid solution. Does the Draley study consider pitting of aluminum

> > 2326 008

1201

eb4

1

2

3

1

5

6

7

8

9

10

11

12

12

14

15

16

17

C

20

21

22

23

24

25

eb5

1

2

3

4

5

8

7

3

9

12

12

14

15

18

17

8

25

at a pH of 5 or less?

A I could not find that he was directing this specifically to pitting type of corrosion.

Q On page 6 of your testimony, the first sentence of the first full paragraph states:

"Unanodized 1100 aluminum also forms an initial protective film within the first five days of immersion in distilled water before the corrosion rate becomes linear."

Do you have a quantification of the rate of corrosion in the first five days?

A I believe that was approximately one order of magnitude larger or higher than you would find after you established a lower rate of corrosion after the formation of the protective film.

Q Is this the result of galvanic corrosion or general corrosion?

A This would be general corrosion.

9 Q Are galvanic corrosion and general corrosion 20 additive?

A In the case of stainless steel coupled to aluminum it would not be additive.

Q What would the rate be if the aluminum was anodized?

A In reference to general corrosion?

2326 009

eb6 1 In reference to the statement that you made here, Q "Unanodized 1100 aluminum," et cetera, "....the first five 2 3 days of immersion in distilled water," under this rate rather than unanodized 1100 aluminum, if you had anodized A 5 1100 aluminum, if necessary? E I don't believe you would find any accelerated A corrosion with an anodized surface. In fact, I don't believe 7 you'd find a lower rate of corresion. The anodized surface 8 would have a very adherent and very protective film. 0 ie. I'm not sure if I understood you correctly. You 0 11 would or would not find that the--You would not find the type of fast corrosion 12 A rate with an anodized surface upon first immersion into a 3 water or aqueous solution. 14 15 0 Okay. Thank you. On page 7 of your testimony you cite some more 16 research by R. A. U. Huddle and AERE-Harwell. 17 This individual is from the Atomic Energy Research A 13 Establishment at Harwell. 30 I'm sorry, it looked like a name the way it was 0 20 stated there. 21 Would you give me the name of the ABRE section 22 again? What does that stand for? 23 Atomic Research Establishment -- I'm sorry, Atomic A 24 Energy Research Establishment at Farwell. 25

2326 010

eb7

1

2

3

4

5

6

7

: 3

. 9.

-,10

- 11

12

13

14

15

16

7

18

19

20

21

22

23

14

25

la

Thank you.

And the paper was written by R. A. Y. Muddle. Is that correct?

A Yes.

Q

Q And it was written in 1955; is that correct?

A Yes.

Q And presented in 1956.

Would you please expand a bit on the contents of the research that was reported in this paper? What were the test conditions?

A This individual wasn't giving any specific experimental conditions. He was giving a theory of how corrosion of aluminum would occur in an aqueous solution, and he was stating, from perhaps his previous experiments or his knowlege about how the aluminum would react in a pH range of 4 to 8.

1B ag	jbl	Q Did he specify any parameters?
0		A No, he did not.
~	3	Q Did he specify any test period?
60	4	A No, he did not. He was giving an example of the
	5	theory between anodic type of corrosion, cathodic type of
	6	corresion and the theory of if it was coupled to a dissimilar
	7	metal.
	3	O Did he use any test data as a basis for his
	9	theory?
	10	A No, he didn't give any specific test data.
	11	2 Did he discuss the possibility of pitting?
	12	Did you hear the question. I asked if the research
•	13	that you gite by Huddle discussed nitting
	1.3	Nor he sid
	15	A res, heald.
	16	What were his conclusions about pitting?
	17	A As I stated in my testimonv, he found that a
	10	protective film would be negligible as far as the dissolution
	10	or breakdown in a slightly acidic or alkaline aqueous environ-
-	19	ment, but it would revert to an anodic attack in the adjacent
	20	area of the coupling or right at the coupling between
	21	dissimilar metals. And this did not result in a general
0	42	type of corrosion. It would result into a localized mitting
	23	type of corrosion at only a few spots in the area of the
	24	coupling.
-	25	CHAIRMAN WOLF: Ms. Sekuler, before you ask the

1

2326 012

1.205

agb2

1

2

3

4

5

6

7

3

9

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

next question:

Do you agree with the conclusions you have just stated?

WITNESS ALMETER: Yes.

CHAIRMAN WOLF: And what's the basis for your conclusions? What other work have you done other than read that article?

WITNESS ALMETER: I've done some experimental work in aluminum alloys.

Ch^{*}.RMAN WOLF: What is some? I don't understand that.

WITNESS ALMETEP: When I was in the aerospace industry, I was working on some corrosion problems with aluminum alloys. And I have sponsored under contract work, when I was with the Department of Interior, aluminum allows for desalinization, where I was responsible for monitoring at our research laboratory in Preeport, Texas -- it was under contract by the Dow Chemical Company -- and I was directing this type of research looking at different types of alloys. We looked at aluminum 1100 allows, 300 series aluminum alloys, 600 -- 6000 series aluminum allows.

And the results that we saw in high concentration brine would be typical of reaction we would see perhaps in normal or other aqueous type solutions.

The corrosion of aluminum, when it is coupled

1 agb3 to dissimilar metals, does not result in a general corresion 2 of the whole surface of the aluminum, it results in a pitting 3 in the local vicinity of the coupling. This was in a welded 4 joint or in a mechanical joint to a dissimilar metal. 5 CHAIRMAN WOLF: Thank you. ŝ MS. SEKULER: May I proceed? 7 CHAIRMAN WOLF: Yes. 3 BY MS. SEXULER: 3 0 In reaching the conclusions regarding the 10 degree of pitting corrosion, did Huddle cite any test data? 11 A (Witness Almeter) No, he didn't cite any 12 specific test data. 13 0 Did he specify how deep the pits would be in 14 these localized areas of pitting corrosion? 13 A No, he didn't go into that type -- that depth 19 of analysis. 17 Was the aluminum which was theoretically open 0 18 to attack by pitting 1100 aluminum? 19 A I don't believe I understand your question. 20 0 I mean was the substance he was discussing 21 1100 aluminum? 22 A He was discussing 1100 aluminum and other series 23 of aluminum alloys. 24 Q Did he distinguish between any one series of 25 aluminum alloys and any other in terms of their corrosion rates? 2326 014

agb4

1

2

3

4

5

S

7

3

3

10

11

12

13

121

15

16

17

18

19

20

21

22

23

24

313

A He did not specifically discuss a corrosion rate for any of these alloys. He was discussing the theory of the type of corrosion that would occur on these alloys.

Q Was there any statistical sample at all? A Not in this study. He was more -- as I state, he was looking and discussing the theoretical basis for the corrosion.

Q Do you think this is a reliable study for the purposes of this particular problem?

A Yes, I do. That's why I read this article, because it was relating to the theory of the type of corrosion that would occur, whether it would be looking at the possible film breakdown to where you could get additional corrosion in the alloy and how it would be passivated by the type of general corrosion.

The article was really a theoretical analysis on the theory of corrosion for these types of alloys.

Q Later in the same paragraph on page seven of your testimony, you cite Oak Ridge National Laboratory tests, Report Number ORNL-TM-1030.

A Yes.

0

-- published in September, 1966:

"...tests on 1100 alrminum in contact with stainless steel in an oxygenated demineralized water at a pH of five and at 194 degrees

2326 015

Fahrenheit ..., " and state that the results:

"...show that galvanic corrosion between dissimilar metals results in pitting corrosion of the anodic material, aluminum, and no attack of the cathodic material of stainless steel."

Do you know how much pitting was recorded in these tests?

A They did not state the depth of pitting or the size of the pit. They found that the coupling did not result in a general corrosion of the aluminum surface, it resulted in localized pitting. And this was their purpose in their studies, to determine how a specific coupling between dissimilar metals would perform in this type of environment.

Q Do you know what the rate of pitting corrosion was?

A Their experiments would not relate to a specific rate of pitting. It was based, again, on weight gain or weight loss type of measurements, which would not specifically give you a specific rate of pitting in this case.

O Did they mention how much of an area of the exposed metal was covered by pits?

A Yes, it was only at the immediate contact surface area where pitting would occur in this case.

Q Do you know how long the test interval was in

2326 016

1209

agb 5

1

2

3

4

5

3

7

3

9

10

11

12

13

14

15

15

17

18

19

20

21

22

in.

24

the Oak Ridge test?

-

2

3

4

5

5

3

9

10

11

12

13

13

15

16

17

18

19

20

21

22

23

20

25

agb6

A They ran these tests for approximately one year.
Q In relation to the present hearing, what areas
of the racks will be subject to pitting?

A In the type of design of this rack, when placing the Boral between the two stainless steel shrouds, there is a dimpling along the full length to give support to the storage cell as far as a type of structural integrity to prevent buckling and also to hold the Boral plate in place. In this case, there perhaps will be some pitting or galvanic action at these locations.

Ω Could this occur where the shroud and clad flat surfaces come into contact?

A Yes.

0

Q Now in the testimony on page seven, the last paragraph, you refer to the Exxon Nuclear tests of 1979 Over what period were those tests conducted?

A They looked at samples at three months, six months and one year.

You state in your testimony:

"The frequency of pitting did not increase with longer exposure time."

Now much was the longer exposure time? A They looked at samples after six months, and they compared these samples with their observations after one year.

1210

agb7

1

2

3

4

5

5

7

3

3

10

11

12

13

专派

15

15

17

13

19

20

21

22

23

24

25

And their conclusions were that they didn't observe any additional pitting other than the pitting that was already there.

Q Did the pitting that existed already continue?A In some cases, it did.

Q What would be the results for 40 years?

A They did not give an anticipation for 40 years, as far as the rate of pitting. I think if we looked at the mechanism of pitting, if the corrosion product was filling the area of the pit, the route of the pit, perhaps the solution conditions would change, and eventually if there was not a replenishment of the solution, it perhaps would eventually be limiting.

Q What would happen if there was a replenishment of the solution?

A If the corresion product was completely washed out of the pit area, it perhaps wou'd continue at the normal rate of pitting.

Ω And so olong as there was a continuous solution there could be continuous pitting?

A The bulk solution conditions would remain the same. And if the bulk solution did not wash all the oxide out of the pit, I believe then it would come to be limiting. In this case, you would have to have a very high velocity flow across the surface to begin to wash out the pit area.

1211

agb8

1

2

3

3

5

6

7

3

9

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

I've observed this in my other observations of work that I've performed.

Q You state in that same paragraph that the edge attack was confined to the area of the leak path.

For a vented cell, what is the leak path? A Well that would be the -- if there was a hole at the bottom and perhaps a hole at the top, you would find some, as far as a leak path, you would begin to see galvanic attack if the stainless steel was touching the aluminum in this vicinity.

Q Would the whole surface of the edge of the Boral in a vented call be the leak path?

A Yes. You'd begin to fill up the cavity with water if you had a hole at the bottom or at the top, it would begin to fill up eventually. And in this case, there would be the aqueous environment at the edge of the Boral.

Q Would the aqueous environment or the leak path also be the entire flat surface of the aluminum clad of the Boral?

A Yes, I think it would be.

Q Would there be any difference in the leak path in a cell that was closed at the bottom but open at the top?

A In that case it would take some time, I believe, for the water to sink completely to the bottom of the cell as far as the 14-foot length. Within time, I believe, the

3

3

3

3

3

10

生活

12

13

14

13

13

: 7

:8

19

20

25

22

13

1.1

13

whole cell would be filled with the pool water, but I believe there would be the initial attack -- if there was coupling, there would be the initial attack right around the top went hole.

Q Has there been any experience using a vented cell which was closed at the bottom and open at the top?

CHAIRMAN WOLF: Before he answers that, I'd like to point out that his last answer was not responsive to your question.

> Your question called for a yes or no answer. WITNESS ALMETER: Oh. I'm sorry.

CHAIRMAN WOLF: Do you want it read back? WITNESS ALMETER: Yes.

(Wheraupon, the Reporter read from the record, as requested.)

WITNESS ALMETER: My colleague just informed ma that at Monticello they had a hole at the top of the cell. And initially the gas bubble out of the hole --

CHAIRMAN WOLF: What I'm trying to get you is yes or no and then explain it.

WITNESS ALMETER: Oh, I'm sorry.

CHAIRMAN WOLF: The record becomes very difficult if you don't answer the precise question. Counsel will allow you to explain any answer you make. You don't have to do it before --

1213

WITNESS ALMETER: Yes. In this case it would be different.

MS. SEKULER: I'm afraid I sort of lost track of where I was.

CHAIRMAN WOLF: Yes, but I thought it was important to have the record clear.

So now will you explain your answer, please? And then you can get back on to the cross-examination.

WITNESS ALMETER: The reason it was different was because the gas that was formed during the initial corresion of the aluminum when the water entered the cell in the area of the top vent hole was that the gas began to bubble out of the hole, whereas if there was not a hole at the top but a hole at the bottom, you would see the gas, the reaction and the water would continue to come in through the bottom hole and the gas then would begin to go to the top of the cell. So there would be -- yes, there would be a difference as far as the rate, I believe, the rate of replenishment of the water to the corrosion area.

2326 021

endBloom Landonflys 1

2

3

4

3

3

7

3

3

10

11

12

13

13

15

13

17

18

12

20

.21

22

23

22

25

agb10

fls MRB	
MEL/Wer I	Q My next question, I believe, was:
2	Was there any experimental data regarding vented
3	tubes where they were closed at the bottom and open at the
4	top?
3	Can you answer that?
5	A No, I've not seen any
7	(The panel conferring.)
3	Mr. Lantz says that was the same case at Monticello.
9	Q Okay. Now, when you have a closed a tube that
10	is closed at the bottom and open at the top, is there any
11	difference in the loak path?
12	(Pause.)
13	Does Mr. Lantz know the answer?
14	A I can't visualize at the moment the type of
. 13	mechanism that would occur there.
16	If you had water entering the hole and you had
17	corresion occurring, if there was hydrogen gas involved from
10	the corresion reaction, it would try to be forced out of the
19	hole.
20	This is difficult for the right now, to visualize
31	the difference between the two, of the water trying to enter
12	the bele and the gas coming out simultaneously.
13	Q You said the Exxon test showed the galvanic ccupie
24	did not accelerate the general corrosion rate of aluminum
25	in the boral matrix.
	2326 022

	1216
wel 2	
1	What is the general corrosion rate of this matrix,
2	aluminum?
3	A Their experiments didn't explain specifically
4	about the general corrosion rate of the matrix in the boral.
5	Their observations indicated they didn't see an accelerated
G	general corrosion. If the pit formed, that was it. There
7	was just a pit forming in the matrix.
а	Q Does general corrosion cause weight gain or weight
9	loss?
10	A It's weight gain.
11	Q Does pitting cause a weight gain or a weight less?
12	A It could cause, in this case, a weight gain.
13	Q Why is that?
14	A Because the difference in the density between the
. 15	oxide and the base material.
'6	Q The tests you cite in your testimony were only
	a year or so in duration, is that correct?
:8	A Yes. The maximum time they did these tests wis
19	one year.
20	2 How do you, therefore, decide with certainly the
.21	effects of corrosion over a four-year lifetime?
22	A In their data the results they presented were
23	based on an extrapolation of the potential total weight chin
24	after 40 years, on a percent basis.
25	Q What was that? Can you give me a number?
	2326 023

A COMPANY

wel 3

-217
A I think they extrapolated that to a maximum of
4.3 percent.
Q Percent of what? By weight?
A By weight, yes
Ω How thick is the aluminum clad on the Boral?
A It's 10 mills, or 1/100ths of an inch.
Ω Mr. Almeter, in your deposition I'm sorry in
your affidavit which was filed in this case as a part of the
Nuclear Regulatory Commission Staff's motion for summary
disposition, filed January 31, 1979 which I hand to you
(Document handed to the witness.)
It has been marked as part of the Almeter deposition
number 1 for identification, and which I would like you to
identify.
A Yes. This is the affidavit I filed, based on sy
initial review in this case.
Q In that affidavit you stated on page 5 and I
quote:
"Corrosion tests of Boral with a leak in the
stainless steel covering have shown a corrosion rate
of 1.8 x 10 ⁻⁴ to 3.4 x 10 ⁻⁴ inches per year for the
aluminum in the Boral composite plate."
Extrapolated out to 40 years, would this not be
in excess of the thickness of the aluminum clad on the Berry 12
A Yes.
2326 024

1	
wol (. 1218
1	Q Did your testimony filed in May in this hearing
2	for this hearing include any figures to show corrosion rate
3	of the aluminum clad on the Boral plate?
4	A No, I don't show any specific figure in my testimony.
5	Q Why did you not include such figures in your
6	testimony?
7	A I finally obtained the original article, and
3	compared that I looked at in my affidavit, and I
9	reevaluated this data, and realized that the corrosion rates
10	that were stated, if you extrapolated that it would and it
11	was masked by the point that it is really pitting that was
12	occurring, not general corrosion.
13	And in my initial analysis, I was considering as
14	looking at the summary and their conclusions of what they
. 15	found, and when I got the original article and could study
16	the method of how they did their experiments, then I realized
17	that my initial interpretation of their summary was perhaps
18	in error, and I'd have to reevaluate and correct that.
19	And I corrected that in my testimony.
20	Q Would you say that the original figures apply to
.31	the rate of pitting over 40 years?
2	A Yes, I think that would have to apply to pitting

Q What was the original article you mentioned? You 24 did not mention its name. 25

in this case.

23

wel 5	1.19
3	A It was titled, "The Carolina-Virginia Nuclear
2	Power Associates, Incorporated."
3	The initial work on that was done by Westinghouse,
4	but it was under the sponsorship of this organization.
5	Q Do you know what the test that was done in that
3	particular situation was?
7	A These tests were done in deionized water.
3	Q What was the pH?
9	A They didn't specify the pH. It specified the
10	temperature of 190° F.
11	Q Do you know if there was any boric acid in that
12	water?
13	A No, there was no boric acid in the water.
14	Q Did they do other tests that also were in a
. 15	similar temperature but had acidic aqueous solutions?
16	A No, they didn't do similar tests in aqueous
17	solucions.
13	Q Your testimony on page 12 mentioned that frequency
[0]	of pitting did not increase with longer exposure time.
20	That's in relation to the Exxon studies, is the' correct?
21	A Yes.
.12	Q But your testimony does not mention a second
23	finding regarding pitting in the Exxon study.
24	I show you for purposes of identification, to
?5	make sure we're talking about the same thing, a document
	2326 026

H

*

6	
7	that has been supplied to me in discovery by Exxon Nuclear
2	with a number at the top, XN-NS-TP-009/NP, entitled "Fuel
3	Storage Racks Corrosion Program, Boral Stainless Steel, Non-
4	Proprietary Version, March 1979."
5	This is the one without the numbers in it.
G	(Document handed to the witness.)
7	A Yes. I reviewed this report.
8	Q This is the one that was the basis the proprietary
9	version for your testimony?
10	A Yes.
11	Q On page 4.5 and 4.6 of this document it states:
i2.	"Table 4.6 shows that the pitting characteristics
13	after 12 months were very similar to those after 6
14	months. Those specimens and environment combinations
15	which did not pit cr showed little pitting tendancy
iG	after 5 months showed no or few pits after 12 months."
7	That's substantially what your testimony says, is
18	that correct?
19	A Yes.
20	Q It goes on to say:
21	"However, those with significant pits after 6
22	months had a large number of pits after 12 months.
23	Increased pitting was observed in the plain specimers
34	in the A environment, and in the edge sealed specimen
25	in the A and B environments. The other specimens showed
	2326 027
	6 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 13 14 15 16 17 13 14 15 16 17 13 14 15 16 17 10 11 12 23 24 25 25 26 26 27 20 20 20 20 20 20 20 20 20 20

3 nearly the same number of pits after 12 months as wal 7 2 after 6 months. The pit depth, however, increased 3 with the extended 12-month exposure. In some cases 12 where pits had not penetrated the aluminum clad in 15 5 months, they had done so after 12 months." 6 MR. MILLER: Mr. Chairman, for the convenience of 7 the Board, that article is an attachment to Dr. Draley's prepared testimony, and it might be of some convenience to 8 9 you. :0 CHAIRMAN WOLF: Thank you. 1 MS. SEKULER: Thank you, Mr. Miller. BY MS. SEKULER: 2 Did it not seem significant to you, Mr. Almeter, 13 0 that samples with significant pits after 6 months had a large 12 number of pits after 12 months? 5 Yes, it seemed significant to me, but there were A 6 three types of samples they used. 17 There was a plain Boral, not coupled to aluminum --18 I mean, I'm sorry, -- stainless steel. 19 There was another type of sample that was a Boral 0 with two sheets of stainless steel on each side, and the 59 edge was exposed. 12 There was another sample that was a completely 23 enclosed Boral sample in chainless steel shrouds, and there 24 was a hole drilled through the stainless steel to assimilate 25 2326 028

a leak path to the Boral.

wel (

1

2

3

4

5

3

7

3

9

17

2

2

3

â,

5

6

7

8

9

2.6

25

This is the type of specimen that I consider would be typical of the fuel cell storage rack in Zion, and this is the data that I was looking at on that sample.

The frequency of pitting and continuing of pitting that you're quoting was a summary that they saw in the sample that was a plain Boral sheat. They did not observe that specifically in all of the samples that had two stainless. steel sheets, and the edge of the Boral exposed.

So I disregarded that sample -- or these two samples, because it was not representative of the actual condition of the Zion fuel cell rack, if it was vented.

Q Is the reason that you did not mention the fact that the pits deepened and ate through the clad similar to the reason you just gave for the other observation?

A Yes. The pit in the enclosed cell type with a leak path, the pits in those particular samples weren't as deep as those in the cell with just the plain stainless steel sheets on each side of the Boral.

That is what I could derive from the types of experiments that they were performing. They did not observe as deep a pits.

Q At another point in the Exxon study, 4.7, there's another paragraph. You relied on the Exxon study to mention some findings regarding bulging, but it seems that you did

wel 9	. 1223
1	not include the findings from this paragraph, which is the
2	first paragraph on page 4-7 under 4.5.3. Bulges, which
з	states:
4	"Several bulges were observed on the 12-month
5	exposure specimens. Similar bulges were not observed
5	on specimens exposed for 2 or 6 months."
7	Bulgas are defined here as:
6	"Separations between the aluminum clad and the
3	B4C aluminum matrix."
10	Is that correct?
1	A That was their observations
2	0 And it is stated that the bulcas.
2	" appeared to result from reg processor cauged
-4	by internal corrosion."
5	Would you agree with that statement?
G	A Ves
	0 Did it not seem significant to you that it in the
5	at least 12 months for the bulles to least 12
0	at reast 12 months for the buildes to develop?
	na the conclusion on their observations with that
51	bording of the binder in the star there wasn't a complete
	on the core led the statistic to the aluminum cladding
	on the core. And they attributed this bulging to the fact
23	that it was a void there, and the gas accumulated in this
2.6	logich and caused a slight bulging of the aluminum the
. 5	2326 DZD
	2320 030

C

C



EL2 eb1	
1	Q How long were those experiments carried out?
2	A Those were the up to one year experiments.
3	Q So there is no way of knowing how much more
\$ C	bulging would have occurred after the year?
5	A I believe they concluded that that was the limiting
6	amount of bulging that would occur in this case.
7	Q But there is no substantive data on which to base
8	that conclusion? That was an extrapolation?
9	A I believe that was an extrapolation.
0	Q Is it not significant that that type of bulging
1	occurred in a vented cell?
2	A I don't consider that as significant because it was
3	apparently a defective sample.
4	If you had a good sample that was completely bonded
. 5	to the aluminum matrix in the core to the aluminum sheets
6	I don't believe you would see this type of bulging occur.
7	Q Then what you're saying is that this bulging was
9	atypical and due to a deficient Boral matrix?
9	A Yes. I think you perhaps see that in a deficient
.0	type of bonding.
21	Q Was it the matrix or the bonding?
2	A Excuse me?
2	0 Was the deficiency in the matrix or the bonding?
.4	I'm afraid I asked you about the matrix and you referring to
.5	the bonding. I want to make sure I understand what was the
	2326 032

WEL/eb2 1

2

3

4

5

6

7

8

9

10

11

12

13

14

13

6

7

8

9

:0

.1

4

5

deficiency.

A Apparently there wasn't a -- In the Boral core there's aluminum used as a bonder, and apparently there wasn't a sufficient amount of aluminum intermixed with the Boroncarbon powder to form a uniform area throughout the full surface. In this one particular spot there was no bonding between the aluminum bonder to the aluminum sheet.

Q I see.

Are you satisfied that that problem that you just described is an atypical problem and will not occur in the future?

A I believe that would depend on the quality control formulation of the Boral plates, the particle size of the boron carbon, and the uniform mixing of the aluminum bonder with the boron carbon in the formulation of these plates.

If this is under good quality control I believe that you would not see this in a typical fuel cell.

2 Okay.

Are you familiar with the Exxon design for Boral racks for spent fuel storage pools?

A Yes.

2 Are you aware that as a result of their tests they 3 decided not to vant the cells?

A I believe at these proceedings there was a paper circulated on that issue. That was my first knowledge of this,

MEL/eb3

x

End WEL

Bloom fls.

1

2

3

4

5

6

2

8

9

10

1

12

3

4

5

6

7

8

9

20

28

12

13

1. Eg

75

and also that the Exxon at the SAlem case -- it was the preference of the utility to have the sealed cell.

Q In your opinion, is this a more conservative or less conservative approach?

A I'm not partial to either approach. I believe either approach could be successful, and I would not be biased to any one approach, to say that I would want to control that type of -- in my position, to say that they would have to have a vented or a sealed cell.

MS. SEXULER: Mr. Chairman, I have a few morr questions to ask of these witnesses but I believe it's about 10:15. I wonder if we might take a five-minute break.

CHAIRMAN WOLF: Yes, you may. Let's make it ten minutes.

(Recess.)

WRBLoom 1c	
c3 ebl	CHAIRMAN WOLF: We'll be on the record.
2	Will you proceed, please?
3	BY MS. SEKULER:
0 4	Q Mr. Almeter or Mr. Lantz, is either of you f.mi-
5	liar with the history of the swollen racks at Monticello?
6	A (Witness Lantz) Is it not true, Mr. Lantz, that
- 7	although those racks were vented after the swelling was
8	detected, that several of those wollen racks were never to
	returned to normal size, or became reswollen?
10	A Would you repeat that again, please?
11	Q Is it not true that although the racks which were
2	swollen and then vented Let me rephrase it. I'll break
S	it down so you can understand it better.
.4	Is it true that the way that they alleviated the
. 5	svelling of the racks was to drill holes in them and vent
6	them?
7	A Yes.
- 6	Q They also did On some of them they had to
9	press the wall back.
20	A What happened when they swelled up, the thin
1	wall got stretched and they had to push that stretched will
	back.
13	Q Which is the thin wall? 2326 035
4	A The inner wall.
• (5	Q The inner stainless steel wall?

	100	
eb2	1	A Yes.
	2	Q Okay.
	3	So that drilling itself did not alleviate the
	4	problem in all of the swollen racks; is that correct?
	5	A That is correct, after the swelling.
	6	Q Are there still racks at Monticello which have
	7	some swelling in them?
	8	A Not due to gas pressure.
	9	Q Whit are the swollen racks at Monticello In
	10	the swollen racks which exist now at Monticello, what is the
	11	swelling attributed to?
	12	A The stretched inner wall.
	13	Q These were racks that once did swell?
	14	A Yes.
	15	Q These are racks that had to have mechanical means
	16	to push them back into their original shape?
	17	A Yes.
	8	Q Is it definitely known whether the continued
	19	swelling was due to a failure of the racks to return to
	20	normal size, or is it a so possible that they became re-
	:1	swollen despite venting
	.2	A It's known that they did It's a failure to
	.23	return to You can't push that stainless back to its normal
	:14	position. It's stretched material and it has to buckle
	25	somehow. And the problem is entirely due to the buckling.
		2326 036
Contract (March	· · · · · · · · · · · · · · · · · · ·	new wanter the strategy and the second strategy and the strategy and the second strategy and the secon

eb3

1

2

3

4

7

3

9

10

11

12

3

4

5

ĉ

7

18

9

10

1.1

12

23

14

15

It's not due to gas generation.

Q How do you know that?

A Because the vent holes are open. There's no gas in there.

Q Do you know that there's no other possible source
of swelling?

A I don't know of any.

Q Is the fact that the swollen tubes did not return--Excuse me.

Is the fact that the swollen tubes did not return to their original configuration an indication that the metal in those tubes went beyond yield strength?

A (Witness Almeter) That's a problem with the forming of any metal as far as when you stretch it, it has gone beyond its yield strength and when you try, it causes a certain amount of deformation in the metal so that it does not always return to its original shape.

In this case they could not force, because the metal, the stainless steel on the inner side had to take -had to have a larger area to consume the amount of deformation that it saw during the bulging. So when they tried to go back and mechanically form it to the original shape, there wasn't enough space there to reform that metal back beyond the area so that they could restretch it into a normal shape. It would have to be taken out and reformed in a die

eb4

1

2

2

4

5

6

7

8

0

0

1

2

3

Q.

3

3

19

8

C

0

21

22

13

4

.5

again in this case.

Q Are you familiar with tests, either of you, which have been done by Brooks and Perkins to test the stainless steel Boral galvanic couples for PWR environments?

A I think you have to clarify specifically what you're asking us have we seen.

Q I'll show you a document. The one that I have is the Jacond report to D. J. Wanger and Al Mollon from Hughes A. Karzmar of Brooks and Perkins, the June update dated June 7th, 1979, Subject: Interim Report on Stainless Steel Boral Galvanic Couples for FWR Environments.

This is a report of testing that was done to determine correction behavior of a PWR tube in spent fuel which was done to find out whether or not venting configurations would be preferable for use in such spent fuel pools.

MS. SEKULER: Mr. Chairman, this is one of the documents which I meantioned I was unable to duplicate. Would it be preferable to take a minute and pass it around so that people will know what I'm talking about?

CHAIRMAN WOLF: I think it would help, yes, please. MS. SEKULER: Thank you. I'll show it to the Board first, and then to Counsel, and then give it to the witnesses. (Pause.) 2326 038

1 1D agbl MS. SEKULER: Mr. Chairman, I've just been 2 3.090 informed that the document I was about to use is a proprietary 3 document and has not been previously supplied to the witnesses. 4 As a result of that information, rather than 5 delay the hearing, I will withdraw my question regarding that 5 particular document. 7 CHAIRMAN WOLF: Very well. Thank you. 3 BY MS. SERULER: 3 Mr. Almeter and Mr. Lantz, are you familiar with 0 10 a letter dated May 29, 1979, written by Fred J. Mollerus 11 of Nuclear Services Corporation to Mr. George Pliml of 12 Commonwealth Edison on the subject Closure Welding, Zion 13 Fuel Storage Tubes? 14 (Witness Almater) Yes, I'm familiar. My first A 15 knowledge of this memo is at these proceedings where I 16 received a copy of that. 17 MS. SEKULER: Mr. Chairman, I would like to have 18 this latter marked for identification as Intervenor's 19 Exhibit Number 5. 20 (Whereupon, the documen : 21 previously referred to as 22 Intervenor's Exhibit o 23 was marked for identif .cation.) 20 BY MS. SEKULER: 25 Q Do you have a copy of that letter in front of you? 2326 039

gb2

÷

2

3

4

3

5

7

8

9

10

11

12

13

14

15

16

7

3

9

20

21

22

23

24

25

A

(Witness Almeter) Yes, I do.

Q And can you tell me what that letter regards? A It regards some experiments apparently that were performed for Nuclear Services Corporation in regard to the corrosion rates of Beral and stainless steel in a particular environment. And the environment was a PWR pool with 5,600 parts per million of boric acid versus 2000 parts per million of boric acid and a pH range, at the 5,600 boric acid condition the pH was 3.8 versus the normal pH of 5.

It says also the samples were not representative of the Zion tubes.

Q However, as a result of this research that's being reported to Mr. Pliml, on page two of the letter, the last paragraph reads, does it not:

> "In summary, NSC recommends weld closure of the tube corners as a prudent change based on available data showing deaerated corrosion rates to be low and lack of corrosion data for long-term aerated PWR conditions."

Is that a corract statement the way I read that? A It's correct as it states in this letter here. Q Now, do you agree with this solution? A I'm not at this stage to give an evaluation of this, because I've not had time to fully review the type of experiments that were done here and under specific conditions

1233

agb3

1

2

3

4

5

8

7

3

9

10

11

12

13

14

15

16

17

18

10

20

21

12

13

14

25

with such a short mem o.

Normally in my procedures of reviews of these cases, I like to contact the source, get more information to fully evaluate what their experiments entailed, so that I can relate it to my review in the normal processes of my work at the NRC.

This letter was dated on May 29. I was out on travel when this, particularly when this memo was given, and I really haven't -- I can't give an opinion at this stage, because I haven't had the time in the day or two to fully evaluate what these people have done.

Y ID CHAL FLUE LOL ML. LANCA	¥ .	char tri	ns rot	MI.	Lancz	a1307
------------------------------	-----	----------	--------	-----	-------	-------

A (Witness Lantz) Yes.

Q Okay. Thank you.

MS. SERULER: Mr. Chairman, at this time I would like to have entered into evidence this letter from Nuclear Services Corporation to Mr. George Pliml.

CHAIRMAN WOLF: Well, you know, I don't think you've qualified it, Counsel. Mr. Pliml was here. These parties can't qualify it.

> MS. SEKULER: In terms of authenticity and --CHAIRMAN WOLF: I beg your pardon?

MS. SEXULER: All right. I will reserve and put this in at another time. I have it marked for identification, and I'll just leave it like that.

BY MS. SERULER:

1

2 1

agb4

0.0

2	Q On page 14 of your testimony, you state that
3	criticality calculations for the spent fuel pool modification
-	were made using minimum values of 0.02 grams of boron-10
0	isotope per square centimeter of Boral plate.
2	And you state you were depending on Commonwealth
	Edison to assure the verification of the B-10, is that
3	correct?
9	A (Witness Lantz) Yes.
10	Q And Commonwealth Edison replied that it, in turn,
	was depending on Brooks and Perkins' quality assurance program,
12	is that correct?
13	A I don't know as that's correct. It's not only
14	the Brooks and Perkins, but also it's their cwn OA program.
13	Q Does it not state on page 14:
16	"During our review of the applica-
7	tion, we asked the Commonwealth Edison Company
18	how the minimum value would be verified for all
19	of the Boral plate area. Its response, which
20	was transmitted to us by letter dated
31	January 24, 1979, is as follows:
2	'The manufacture of Boral and
:3	fabrication into plates is controlled by the
14	Brooks and Perkins quality assurance program,'"
:5	That's in your testimony; isn't it?
	2326 042

1	A	Yes.
2	Q	Are you aware of the recent shipment of Brooks
3	and Perkins	tubes without proper documentation to Leckenby?
4	A	Yes.
5	Q	Are you aware of the fact that Leckenby accepted
5	the shipment	without documentation?
7	A	No, I was not aware of that.
8	Q	Are you aware that Nuclear Services Corporation
9	released the	at shipment without docume tation?
10	A	No.
11	٥	Are you aware that it was finally determined
12	that the tub	es were defective and that they did not contain
13	the minimum	specified amount of B-10?
14	A	I learned that the minimum amount, one of them
15	had a 0.0186	grams per square centimeter value.
16	Ω	If the tubes with insufficient B-10 had been
17	made into ra	icks, how would they have been checked?
18		Do you understand my question?
19	A	Yes.
20		I don't understand how they found out. They
-11	found out th	at they were low, right?
22	Q	Yes.
:3	A	WAsn't this part of their ordinary procedure?
-24	Q	Well the question is if the ordinary procedures
.5	were followe	d in the fashion in which they were followed and
		2326 043

.

agb5

1235

1 it had not been detected --2 If the error had not been detected? A 3 0 Yes. And in that case then --4 Then that plate could have gone into the racks. A 5 And how would they then check the racks to find 0 5 that out? 7 A I don't know as they would. I don't know the 3 full procedure. 9 0 Does Commonwealth Edison use neutron attenuation 10 tests to check such B-10 content? 11 A It doesn't have the accuracy to determine that 12 number. 13 Have you seen Commonwealth Edison's proposed 0 14 procedure for neutron absorption testing? 115 Not in detail, but I understand they're going A 16 to check every storage location with a source and detector. 17 Would you recommend the use of underwater 0 18 neutron attenuation tests to find out if the racks were 10 properly filled with boron once they were installed? 20 You can't get sufficient accuracy at that shage. A 21 Are you still confident of the statement that 0 22 you made on page 15 of the testimony: 23 "... there will indeed initially be 24 at least 0.02 grams of B-10 per square centi-25 meter of Boral plate."? 2326 044

agb6

1 A As far as the k-effective of the fuel pool, yes. 2 Are you still confident that it is correct Q 3 that there will indeed be 0.02 grams of B-10 per square 4 centimeter of Boral plate? 5 A Not at every square centimeter, but on the average, 6 yes. 7 0 Are the NRC criteria for monitoring of corrosion 8 -+ excuse me. Are there NRC criteria for the monitoring 9 of corrosion of the Boral tubes and the racks, as referred 10 to in Contention 2(e)? 11 A Would you please repeat the question? 12 Are there NRC criteria for the monitoring of 0 13 corrosion of the various types mentioned in 2(e) (3) and 14 2(e) (4)? 15 A (Witness Almeter) No. The Staff has not form --16 lated any criteria to monitor these samples. 17 Will technical specifications be required for 0 13 each surveillance program? 19 A (Witness Lantz) No. 10 A (Witness Almeter) No, I don't think we would 21 require a technical specification for this type surveillance. 22 0 Will the pool be allowed to be reracked prior 23 to a final plan for surveillance being approved? 24 (Witness Lantz) We already have their plan. A 25 0 Have you approved it? 2326 045

15.07

.	
1	A Yes.
2	Q Has it officially been approved on paper?
3	A No, that won't be done until they get their
4	amendment change.
5	0 Will the remark be done prior to the official
6	anproval?
7	approval.
8	A NO.
9	Q Will the rerack go forward before actual
10	monitoring program becomes available?
11	MR. MILLER: Objection, Mr. Chairman, the
12	question is vague 13 stated. The word "available" is
12	unclear.
13	BY S. SEKULER:
14	Q Will the rerack go forward before the monitoring
15	devices are being placed in the pool for use?
16	A ('litness Lantz) I really don't know, but it's
. 17	immaterial because there's nothing in the short period
18	of time that these samples are going to tell you.
19	2 Is it not true that certain types of corrosion
20	occur in the accelerated form in the first five days of
21	impersion in water?
22	A Yes, but that's going to hannen, we expect that
23	to happen.
24	
25	weil is it not grue that if you have the racks
	in prior to putting the samples in the pool, that you will
1	2520 040
1	

agb8

agb9

not be able to track exactly the amount of corrosion on the racks?

3	
4	A This is going to be accelerated corrosion. It's
5	been done, oh, five or 10 times. We know it's going to happen
6	and it's not going to disintegrate the aluminum or anything.
_	You're just going to build up your layer in the first
7	couple of days, you're going to bubble, and then it's going
3	to be over with.
9	Q The samples then will not be an accurate
10	duplication of the exact corrosion as it applies to the mack,
11	Boral and tubes in the pool?
12	A It'll be essentially accurate, yes.
13	Q Essentially accurate or identical?
14	A Well it'll be accurate enough for our purposes.
15	Q How much leeway will there be between placement
16	of the racks in the pool and the installation of the coupons
17	before it becomes inaccurate?
13	A Well I don't know, maybe a year.
19	
20	
21	2326 047
22	
23	
24	
_	
23 1	

lel ebl1

2

3

4

5

6

7

3

9

10

12.

2

3

4

 U_1^{*}

5

17

18

19

2.1

22

:3

24

25

4

Q Does the NRC intend to give Commonwealth Edison a year beyond the time the racks are placed in the pool before it implements its monitoring program?

A No.

A (Witness Almeter) I would like to make a statement, that Mr. Lantz and I are a part of a Staff team and I don't think that either of us can state the policy at this stage, or what the license amendment will be, as individuals, because it is the team work of the NRC STaff. And when that license amendment is written, then that will be the NRC policy.

Q After the license amendment is written and other members of your Staff take over, will I&E inspections involve review of testing procedures?

A I cannot make a statement about that at this stage.

Q Do you know if there will be inspections that will verify that the tests are being done and are being properly carried out?

.0

A I don't know.

A (Witness Lancz) I don't know.

Q Do you know whether there are any plans or procedures which have been developed which will be put into effect if accelerated corrosion, severe pitting, loss of neutron absorber, swelling, or another unanticipated event occurs?

	1	이에 집안 것같은 것은 것은 것 같은 것은 것은 것을 가지 않았다. 것은
eb2	1	A Would you repeat that question, please?
	2	Q Do you know if there are any plans or procedures
	3	which have been developed and will be put into effect if it
	4	is indicated that any of the following occur: accelerated
	5	corrosion, severe pitting, loss of neutron absorber, swelling,
	6	or another unanticipated event affecting the racks, tube,
	7	and Boral?
	3	A There's none for accelerated corrosion because
	9	we expect that in the first five days or so.
	10	We expect some pitting.
	11	What we don't except is the loss of B4C, and if
	12	there were a loss of B4C, it would be a gradual thing which
	13	we will pick up in the surveillance testing.
	14	Q Are there any plans or procedures developed to
	15	deal with a loss of B ₄ C?
	16	A Not at the present time.
	17	Q Are there any plans or procedures developed to
	18	deal with swelling?
	19	A We have dealt with swelling in the past. I
	30	suppose we'd use the same plan.
	1	Q Are there any plans, procedures, or NRC policies
	22	to deal with unanticipated problems?
	23	A No.
	24	Q is there any plan you know of to deal with pro-
	25	tecting fuel in the rack should it become necessary because
	1	2326 049

eb3

1

2

3

4

5

6

7

B

3

10

11

12

13

14

15

16

17

18

19

20

21

22

23

20.

25

A

of swelling or damage to the fuel?

A (Witness Lantz) There again we'd do the same thing as when the Haddam Neck fuel swelled, I suppose.

Q Are there any plans involving Commonwealth Edison presently developed which would make it possible to investigate the nature of detected damage to each of the racks?

A (Witness Almeter) Yes, they have submitted to the NRC Staff a plan for surveillance in the spent fuel pool, and outlined the type of specimens they will put in the pool, and the period of time they will inspect these samples.

Q Is there any plan, however, with relation to the actual racks in the pool, other than the inspection of the coupons?

MR. MILLER: Objection, Mr.Chairman. I'm not certain that the inspection plan itself is limited to coupons only. The question lacks foundation on that basis.

BY MS. SEKULER:

Q If by means of the test coupons and other means of test paraphernalia that are used in the pool -- that's probably the wrong word -- as listed by Commonwealth Edison, it is discovered that some damage may have occurred to the racks, is there any plan or procedure currently developed by which it would be possible to investigate the actual spen: fuel racks in the pool?

(Witness Lantz) We have general -- I could say we

had experience at Haddam Neck and we'd follow essentially the eb4 1 2 same procedures. 3 MR. GODDARD: Objection to the question, Mr. Chairman, even though the . witness has already answered A it. These questions would more properly have been put to 5 Mr. Kohler of the Third Region I&E when he was testifying 6 on these procedures in the audit of Commonwealth Edison's 7 procedures several days age. 8 0 MS. SEKULER: Mr. Chairman, I'm asking these questions in relation to the monitoring program, and how the 10 monitoring program will affect the use of the racks in the 11 12 pool. CHAIRMAN WOLF: The question has been asked an ! 13 answered. 3 We'll proceed, Counsel. 13 MS. SEKULER: Thank you. 16 BY MS. SEKULER: 7 Will the NRC routinely be advised of the results 3 0 of the monitoring tests? 9 MR. GODDARD: Same objection, Mr. Chairman. 20 CHAIRMAN WOLF: I'll overrule it. 21 You may answer, if you know . 22 WITNESS LANTZ: I don't know. 23

24 WITNESS ALMETER: I don't know. We haven't set 25 any standards of what the utility is supposed to be looking

2326 051

2

3

4

5

3

7

10

19

20

23

24

25

at, at this stage.

BY MS. SEKULER:

Will the NRC be advised of abnormalities that 0 might be discovered as a result of monitoring?

MR. MILLER: Objection, Mr. Chairman. Again the word "abnormalities" is extremely vague in the context of this examination.

8 CHAIRMAN WOLF: Can you reword that question, please? 9

BY MS. SEKULER:

Will the NRC be advised of any unanticipated 0 11 corrosion effects which are indicated by the monitoring 12 devices? 13

A (Witness Almeter) I don't know at this stage. 14 The normal procedure for advising the Staff and NRC of un-15 anticipated events is through the Licensee Event Report. 16

Now if that is required in the license amendment 17 when that is drafted, then it will be reported to the Staff. 18 But at this stage, I cannot say what the full scope of the license amendment will be.

CHAIRMAN WOLF: Shouldn't such a report be re-21 quired? 22

WITNESS LANTZ: In general practice it is. WITNESS ALMETER: It is, siz, but that is dependent on -- If it is like a technical specification, it has to be

	100 D. T. M.	
eb6	1	reported to the Staff, or it can be written into a license
	2	amendment, that it be reported to the Staff.
	3	BY MS. SEKULER:
	4	Q Should the monitoring program reveal certain con-
	5	ditions for which Commentee the Edison decides remedial
	6	programs are necessary, will the NRC have any involvement or
	7	make any contributions to the design of such programs?
	8	A (Witness Lantz) I would say yes. If we feel that
	9	that number on the average, the amount of boron in the racks,
	10	has gone below .02 on the average grams per square centimater
	11	of Boral place, they would be involved, yes.
	12	Q Were you involved in Haddam Neck?
	13	A Yes.
	14	MS. SEKULER: Thank you.
	15	I have no more questions.
	16	CHAIRMAN WOLF: Thank you.
	17	Do you have any questions, Mr. Miller?
	18	MR. MILLER: Yes, I do, Mr. Chairman.
	19	BY MR. MILLER:
	20	Q Dr. Almeter, turning first to page 6 of your
	31	prepared testimony, certain corrosion rates are expressed in
	22	the first full paragraph of that page. Is that right?
	23	A (Witness Almeter) Yes.
	24	Q Do you know, Dr. Almeter, whether or not the
	25	corrosion rate of unanodized 1100 aluminum varies over time?

1246

eb7

Yes, it varies over time.

1 A 2 Q And is the rate greater at the first exposure of 3 the aluminum to an aqueous solution than it is at a subsequent time after a longer exposure to the aqueous solution? 4 5 A Yes, the corrosion rate is much greater during the 6 initial five days. 7 And it's a fact, is it not, that after the initial 0 period of corrosion, the rate of corrosion essentially tapess 3 off and is barely discernable. Isn't that correct? 9 Yes. It becomes stabilized. 10 A Now have you had an opportunity to review 11 Q Dr. Draley's prepared testimony and attachments which are 12 submitted in this proceeding? 13 A Yes, I looked at his 14 And one of the attachments to Dr. Draley's pre-Q 15 pared testimony -- Excuse me. 16 Do you have it before you? 17 I'm sorry, I don't. A 19 We'll supply you with one. It might expedite 0 19 things. 20 (Document handed to the witness panel.) 21 CHAIRMAN WOLF: What page are you referring to, 22 Mr. Miller? 23 MR. MILLER: I'm about to do that, sir. 14 BY MR. MILLER: 25

2326 054

ab8 1	Q One of the attachments to Dr. Draley's testimony
2	is an article entitled "The Corrosion of 1100 Aluminum in
3	Water from 50 Degrees to 95 Degrees C." It's by J. E. Draley,
4	Shiro Mori, and R. E. Loess. It's a two-page article, and
5	I believe it's the third attachment to Dr. Draley's testi-
6	mony.
. 7	There are two diagrams at the bottom of the page.
3	Do you see those?
9	A (Witness Almeter) I believe I have the wrong
10	page here.
11	• Q Perhaps Mr. Steptos can direct you to the proper
12	page.
13	A I don't see any diagram here.
14	(Pause.)
. 15	Q Have you found the article, sir?
16	A Is this the one from the Electrochamical Society
17	Publication?
18	Q Yes, sir, the one that is Volume 114, 4 April
19	1967.
.20	A Yes, that's it. I have it.
21	Q Have you seen that article before you saw it
.22	attached to Dr. Draley's testimony?
23	A No, I did not read this article of Dr. Draley's.
24	Q I see.
3.5	Well, would you take just a minute and look at the
	2326 055

C

,

1

eby

1

2

3

à.

5

6

7

3

9

:0

3

2 di

5

13

17

20

25

.3

A.

25

diagrams on the bottom of the first page?

A Yes.

Can you tell me what, if anything, those diagrams 0 disclose about the rate of corrosion of 1100 aluminum over time?

It shows in -- In Figure 1 it shows corrosion of A a sample where it's giving the units as far as corrosion in milligrams per square decimeter, showing with time in days--ONe curve shows weight gain and one curve shows metal corroced. Q Yes, sir.

And the time scale along the bottom of the diagram 11 is a log scale, is it not? 12

> A Yes.

Now the line for metal corroded, that is the plot 0 for metal corroded on the diagram, shows as a straight ascending line, does it not?

> A Yes.

Q If we were to translate that plot from a loga-15. rithmic time scale to a linear time scale, what would the plot :0 show after the first five days?

It would show a rapid increase and then it would A become a horizontal scale.

In other words, it would be a straight horizontal 0 line across the plot?

Right.

A

eblo 1 Q And that would indicate, would it not, that there 2 was no significant corrosion after the first five days; is 3 that correct?

A That's correct.

1

5

5

7

3

13

50

21

22

25

Q So that, turning back to your prepared testimony at page 6, in fact the rates of corrosion that are expressed in that testimony probably overstate the amount of corrosion that will take place over a 40-year period. Is that correct?

A Yes. I think that the lates quoted are really
on the conservative side.

11 Q When you say "conservative," you mean they are 12 conservatively high?

A Yes.

14 Q Now during cross-examination by Ms. Sekuler, very 15 early in the examination she asked you about whether or rot 16 pitting causes the surface to lose any material, and I 17 believe your response in substance was that there was a 13 corrosion product formed and that some of it might flake away 19 if there is a high surface velocity across the pit.

Do you recall that testimony?

A Yes.

A

2 All right, sir.

You used the term "high surface velocity." Can you quantify what you mean by a high surface velocity?

In my previous experience, in order for this to

2326 057

	1251
ebll i	occur and the pitting to be increased or accelerated, flow
2	velocities would have to be something like up to 32 feet per
1	second across the surface of the material.
1 4	
2	2326 058
6	
7	
s	
9	
10	
Li	
12	
13	
14	
. 15	
16	
17	
18	
19	
20	
.11	
32	
23	
24	
25	
The second contraction of the	4 second s

1 Do you know what the velocity, if any, is of the 0 WRB/Wb-1 2 aqueous solution in the spent fuel pool over the boral and 3 aluminum-- well, over the 1100 aluminum that's in the tube?

1E(2)

4

5

3

7

3

9

10

11

12

13

14

15

16

17

18

19

22

23

20

25

A I don't believe that has ever been measured, but I think it would be almost nil. Because there's very little -- In observing the pool, you see no turbulence in the water as far as any current.

I understand at the inlet there is a certain velocity to bring the water in, and it flows across the Lottom of the pool and goes into circulation. But as far as in a small vented hole, for that velocity to even get into the cell, it's almost inconceivable.

Well, do you have an opinion as to whether or not 0 the velocity of the aqueous solution in the spent fuel pool is sufficiently high to cause any material that is formed as a corrosion product in a pit to flake away?

No, I don't think it's going to cause it to flake A away in the cell.

> Q Thank you.

Now I'd like to turn to Mr. Lantz for just a 20 second. 11

You were examined, Mr. Lantz, by Ms. Sekuler regarding page 14 of your prepared testimony. The single spaced material on that page starts out with a paragraph which she read into the record, in which the significant words 2326 059

for the purposes of the question were that the fabrication 1 by Brooks and Perkins is "controlled" by the Brooks and 2 Perkins quality assurance program. 3

Mr. Lantz, do those words mean to you that the Commonwealth Edison Company quality assurance program has no role in assuring the quality of the boron-10 loading in each boral plate?

A

4

5

3

7

3

12

13

14

19

20

21

2

3

20

.5

(witness Lantz) No.

9 Q Do you know what procedures, if any, Commonwealth Edison Company will utilize to assure that the boral borca-30 10 is in accordance with specifications? 11

I don't know specifically, and I don't review the A QA program. But I do know you have an approved QA program, and that's what I rely on.

MR. MILLER: Mr. Chairman, at this time I would 15 like the Reporter to mark as Licensee Exhibit No. 1 a two-16 page document which is entitled "Spent Fuel Racks - Receiving 17 Inspection Checklist." 18

CHAIRMAN WOLF: For identification.

MR. MILLER: For identification.

(Whereupon the document referred to was marked Licensee Exhibit No. 1 for identification.)

BY MR. MILLER:

Q

Mr. Lantz, I represent to you that that is the

KZXZXZX

3

4

5

6

14

15

16

17

22

23

24

:5

1 spent fuel racks receiving inspection checklist which has been developed by the Quality Assurance Department of Commonwealth Edison Company with respect to the modified spent fuel racks which are the subject of this proceeding. And it was identified by Mr. Shewski in his cross-examination by Ms. Sekuler, I believe it was two days ago.

7 Now I'm not asking you to accept my word that that 8 is in fact the case, but, assuming that it is, would you 9 look at numbered paragraph 6 on the first page of Licenses 10 Exhibit No. 1 for identification, and I ask you whether you 11 can determine from looking at that paragraph whether there is 12 a check at the time the racks are received by Commonwealth Edison Company with respect to the boron content of the tubes? 13

> A Witness Lantz) Yes.

And is there such an inspection required? 0 A Yes.

0 All right, sir.

MR. MILLER: Mr. Chairman, I don't believe it's 18 appropriate to offer Licensee's Exhibit No. for identification 19 through this witness, but we'll do so at some subsequent ap-20 propriate time in the proceeding. 21

CHAIRMAN WOLF: Very well.

BY MR. MILLER:

Now, Mr. Lantz, if you would please turn to 0 Dr. Draley's prepared testimony, and I believe the fourth

1254

wb4 attachment to his prepared testimony is a four-page document 1 entitled "Neutron Absorber Sampling Plan - In Pool," dated 2 May 5, 1979. 3 Have you found it, sir? 4 (Witness Lantz) Is it the last one? A 5 Q No, it's not quite the last one. It's just before 3 the Exxon Nuclear report. 7 Yes, I have it. A 3 It's a fact, is it not, that the second paragraph Q 3 of that attachment commits Commonwealth Edison Company to 10 install the test samples in the spent fuel pool when the racks 11 are installed; is that right? 12 A Yes. 13 0 All right, sir. 14 And turning to the second page of that attachment 15 to Dr. Draley's testimony, it's also a fact, is it not, that 16 in addition to coupons there are additional samples that are 7 going to be placed in the spent fuel pool; isn't that also 18 correct? 19 A Yes. 20 Q What is the nature of those test samples, sir? 21 The statement is that, "Additionally, two full A 22 length vented fuel storage tubes will be suspended in the 23 pool. They will be observed periodically for signs of 24 swelling, and they will be opened and examined should the small 25

2326 062

1:55

1 specimens indicate any loss of absorber material below .02 wb5 2 grams per square centimeter of boron-10." 3 0 Thank you. 4 By the way, Mr. Lantz, what is a coupon? We've 5 been talking about those. Can you describe what a coupon 3 is for us, please? 7 It's a small piece of aluminum -- boral sandwiched A in stainless steel which simulates the composition of the 3 9 racs. 10 Q All right, sir. 11 Perhaps you are not familiar with this area, but Ms. Sekular went into it and I would like to for just a minute 12 as well. 13 Do you have any familiarity with the technical 14 specifications that are presently in effect and applicable 15 to the operating license for the Zion Station? 16 A No. 17 Are you generally familiar with the format of 0 18 technical specifications? 19 A Yes. 20 Q Ckay. 21 It's a fact, is it not, that ordinarly there are 22 reporting requirements contained in technical specifications 23 which a licensee is obligated to follow? 2d A Yes. 25 2326 063

wb	6 1	Q Do you have any reason to believe that those
•	2	technical specifications would be any different for the Zion
	3	Station?
	4	A No
	5	Q All right, sir.
	6	Assuming there was some unanticipated loss of
	7	neutron absorbing capacity or some structural deficiency in
	8	the absorber plates the absorber racks, would you expect
	9	that Commonwealth Edison would be obligated to report that
	0	as a matter of just routine under its present reporting re-
	1	quirements?
	2	A Yes.
0	3	Q Thank you.
	4	MR. MILLER: I have no further questions.
	. 5	CHAIRMAN WOLF: Do you have any redirect,
	6	Mr. Goddard?
	7	MR. GODDARD: I have just a few questions, sit.
KZXZXZX	6	REDIRECT EXAMINATION
•	9	BY MR. GODDARD:
	:0	Q Dr. Almeter, on questioning by Ms. Sekuler you
	.1	stated you did not take into consideration the situation where
	:2	high burnup fuel might be placed in the Zion pool; is the
	:3	correct?
•	-4	A (Witness Almater) Yes.
-	25	Q How would you define high burnup fuel?
		2326 064
<i></i>		

wb7 I'm not in that field to really explain that to 1 A you. My background is metallurgy. I'm not that familiar 2 in the nuclear area. Mr. Lantz is a nuclear engineer. 3 In my review -- That is beyond my scope to even be prepared to 4 comment, because I've addressed my review in this particula: 5 case to corrosion of materials in the spent fuel pool. 6 If you will assume from the questioning here that 0 7 high burnup fuel will be placed in the Zion pool and that: 8 this fuel is Zircaloy-clad PWR fuel with a burnup of approx -9 mately 50 percent more time than the normal burnup for such 10 fuel, are you able to state an opinion as to whether you 11 would expect adverse effects upon the Zircaloy cladding in 12 the Zion spent fuel pool environment? 13 I don't think I would anticipate adverse effects. A 125 MS. SEKULER: Objection, Mr. Chairman. I believe 15 that Mr. Almeter has just said that he has no knowledge of 16 this particular type technology, and I don't believe hes 17 qualified to render an opinion. 18 MR. GODDARD: I asked the witness, Mr. Chairman, 13 if he could express an opinion as to an adverse effect up on 20 the Zircaloy cladding. The cladding of this fuel is a sub-11 ject within the knowledge of the witness. If he can ans er 12 this question I ask thathe be allowed to do so. If he cannot, 13 he can so state. · A.

CHAIRMAN WOLF: Does this come within your

25

2326 065

8da	1	metallurgical knowledge, Mr. Almeter?
	2	WITNESS ALMETER: I'm not an expert in this area.
	3	I've read some on this. I could make an opinion from my
	4	general readings on this. I haven't made any studies.
	5	If you would like an opinion
	3	CHAIRMAN WOLF: Mr. Goddard, don't you think we
	7	ought to have it from someone who's qualified in that parti-
	8	cular area?
	9	MR. GODDARD: We may have to, sir.
	10	CHAIRMAN WOLF: Let's proceed, then.
	11	BY MR. GODDARD:
	12	Q Mr. Lantz, in the event that ventod spent fuel
	13	storage racks were to swell, could they be revented?
	14	A (Witness Lantz) Yes.
•	5	Q Would you anticipate that such a reventing of a
	16	can would cause any additional problems?
	7	A No.
	18	Q If you assume that all of the aluminum clad on
	9	the boral in a vented rack were converted to a corrosion
	:0	product by virtue of interaction with the water in the post.
		what would you expect to be the effect upon the stainless steel
	2	shroud?
	3	A It would swell somewhat. But the thickness of
	:4	the boral initially is 76 mills, .076 inches, and you would
	25	expect that it would not more than about double if all the

0

1.59

		1260
WDY	1	aluminum were corroded to aluminum oxide. And this is not
0	4	sufficient to stick a fuel assembly in the storage rack.
	3	Q What, if any, effect would such corrosion, such
	4	extreme corrosion have upon the neutron absorption capability
	5	of the racks?
	3	A We don't expect it would have any. We expect
~	7	the B4C would stay in the compacted aluminum oxide held by
	3	the stainless steel.
	9	MR. GODDARD: Thank you, Mr. Lantz.
	10	I have no further questions for these witnesses.
End Bloom	11	
PG: 003 113	12	
	13	2721 067
•	14	2320 007
	15	
	16	
	17	
•.	18	
	19	
•	20	
	24	
G	-4	
	:3	
•	24	
-	25	

	fls WRE 1WEL/*el	. 1261
	1	EXAMINATION BY THE BOARD
)	2	BY CHAIRMAN WOLF:
	3	Q Dr. Lantz, would you give me a definition of
2	4	high burnup fuel?
	5	A (Witness Lantz) My definition would be something
	6	beyond 45,000 megawatt days per metric ton.
	7	CHAIRMAN WOLF: Thank you.
	8	Dr. Remick?
	Э 🛛	BY DR. REMICK:
	10	Q I'm not sure which of you two gentlemen to
	11	address the question to, but would you rafer first to page
	12	1 of the joint testimony. The very last sentence at the
	13	bottom of that page says:
	i4	"Boral is a composite panel of B C/aluminum matri::
	. 15	clad with 1100 aluminum alloy."
	16	Now, as for the question:
	17	Do you think that is a good definition of Borel?
	18	A (Witness Almeter) Yes.
	19	Q Now, let me refer to page 5 of your joint
	30	testimony, last paragraph, last sentence. It says:
	21	"The aluminum cladding of the Bral neutron
	12	absorber plates"
	23	Is that inconsistent with the first page of that,
	24	for Boral?
)	25	A No. 2326 008
	New York Contraction	

wel 2	
1	Q Well, one place it says Boral includes the
2	cladding, and in another place which is the correct
3	definition of Boral?
4	A (Witness Lantz) The first page is the correct
5	definition of Boral.
6	Q Including the cladding?
7	A I believe so.
8	Q But I thought at times you'd been talking about
9	the Boral aluminum matrix and the aluminum cladding separately.
10	A Yes, that's true. We were ambiguous.
11	A (Witness Almeter) Well, that is my visualization
12	of how the compaction is formed.
13	When they manufacture you see, the sheets of
4	aluminum are on the outside of the core, one solid piece.
. 5	The core between these two aluminum sheets is a mixture of
16	boron carbon powders and aluminum. And then it's rolled out
7	or pressed out into sheet form, and then the aluminum
81	cladding is put on top of this, or on each side.
19	Q Yes. I understand. My concern is for the clarity
20	of the record, when we're talking about corrosion of
31	aluminum, we're talking about corrosion of Boral, and then
12	we're defining the two as one.
23	A (Witness Lantz) For the purpose of the record, all
24	the corrosion is on aluminum. The B_4^{C} does not corrode,
15	which is in the matrix. So for essentially all the corregion
1.2.1.1	

-

0

..

Surveyor Street Street

2326 069

<pre>wel 3 1 is aluminum corrosion, regardless of the statement. 2 Q All right. 3 On page 2, last paragraph, about the middle of</pre>	63
 is aluminum corrosion, regardless of the statement. Q All right. On page 2, last paragraph, about the middle of 	
2 Q All right. 3 On page 2, last paragraph, about the middle of	
3 On page 2, last paragraph, about the middle of	
4 that paragraph, it says: .	
5 "Eighteen vented test samples of Boral	
3 . enclosed in stainless sceel"	
7 Would you explain whether that Boral is clad wi	th
aluminum or it's the B4C aluminum matrix?	
9 A (Witness Almeter) It's clad with aluminum.	
10 Q Thank you.	
Continuing on in that paragraph, the last sente	ice
12 discusses the it says:	
"The program is designed to evaluate the	
14 long-term effects of galvanic corrosion between	
dissimilar metals with a large electrical potential	
difference" and continues.	
7 I believe it's talking about the test samples.	
8 Would those test samples be grounded in any way to the pool	
9 structure or racks?	
20 A I understand that they're going to be placed int	c
the pool similar as a rack. They would not be grounded	
to the pool liner or any other type of structure, the way	
13 I understand it.	
A (Witness Lantz) You mean a deliberate ground who	9.7
You mean that type of thing? I'm pretty sure there will be	
2326 070	

2

3

4

5

6

7

8

Q

25

metal contact between the rack and eventually the pool liner. But if it's a separate ground wire, I'm not sure.

Q Is the electrical potential between the metals a function of whether the coupons would be grounded or not?

A No, I don't believe so.

Q It would be the same, whether the external stainless steel was electrically grounded or if it was floating within the system?

A Yes, I think you can have electrolytic corrosion
 without grounding.

11 (Witness Almeter) In this case, the corresion A 12 would occur just by the contact of aluminum to the stainless steel in the sample, which is the shroud, simulating the 13 14 whole cell structure. As to my knowledge, if you're 15 referring to an electrical ground wire, that could connect it to any other structure in the pool other than along the 18 rack, the ground wire -- any means of hooking it into the 17 pool or hanging it into the pool should not affect the 13 19 sample, to my knowledge.

20 Q So the rate of corrosion would not matter, whether 21 the coupons were electrically grounded to the liner?

A (Witness Lantz) I don't think so. I think the currents are so low that just the conductivity of the water is enough to carry the electrons.

All right. Are you familiar with the number and

wel 5	. 126
1	size of the vent holes that will be used in the fuel tubes,
2	fuel storage tubes?
3	A I've seen it, but I've forgotten exactly whether
4	it's 3/16 or I'm not sure.
5	Q How about the number of holes?
6	A My recollection is that it's only one.
7	Q Is there any danger of clogging of those holes
3	from corresion products?
9	A (Witness Almeter) I don't believe there would be
10	any danger of clogging there, of the vent hole, because that
11	will be only in the stainless steel region of the cell, and
12	not in the area where there would be contact directly with
13	the aluminum.
14	So I wouldn't expect any corrosion product to
. 15	form, from corrosion of the stainless steel to block that
16	hole. And I wouldn't expect to see any aluminum corrosion
17	product floating to the top of the cell to block that hole,
18	because of the density of aluminum oxide or hydroxide.
19	
20	2726 072
21	2320 012
22	

..

.

٠.

٩

23

24

25

1

1265
wel

1266

1 How far will the drilled hole be away from the 0 2 Boral -- what I would prefer to call aluminum clad Boral? 3 We cannot tell from the drawing here. I cannot A say where they're going to place that vent hole at this A 5 stage. 6 Would the possibility of clogging be dependent 0 7 on how close they were? I think you stated that there was no danger because the hole would not be near the --8 9 Well, normally, what I've seen in other -- at A other facilities, the vent hole would be at the corner of 10 the square cell, in one corner. Because that forms a complete 11 channel the full length of the fuel cell, or the storage cell, 12 to allow any gas that accumulates in there to have a fre-13 access to an open channel. 14 Are you aware of whether these holes will be 15 0 drilled in the corner? 18 I don't know what Commonwealth will . . . 17 A All right, could I refer you to page 3 of your 13 0 testimony, third paragraph. The statement is made: 19 "It is our finding that this venting will 20 eliminate the potential for any significant amount 21 of swelling of the stainless steel tubes." 22

Could you just summarize the sources of swelling that you're referring to there? What are the mechanisms that you're making that statement about?

	1	
wel	2	120
	1	A In the case of what I observed in some of the
	2	tests, particularly the Exxon test, there might have been
	3	some slight bulging of the aluminum clad away from the
	4	Boral matrix.
	5	If that occurred, and you had a vent hole, it
	5	would be very minute, because the gas would be immediately
	7	permeated through the open channel and out into the pool
	8	environment.
	9	Q I'm sorry. I don't think you understood my
	10	question.
	11	I'm asking: When you talk about there will be
	12	no significant amount of swelling, from what causes are
	13	you referring to there?
	14	A Well, if there was any corrosion of the aluminum
	15	occurring.
	16	Q So, a volume increase due to corrosion products?
	17	Is that what I should infer from that?
	18	A (Witness Lantz) Yes.
	19	A (Witness Almeter) Yes.
	20	0 Any other cause?
	21	A None that I know of.
	22	A (Witness Lantz) None that I know of.
	23	Q Weren't we talking about the generation of
	-:4	hydrogen from corrosion of aluminum?
	25	A Yes, we assume that venting will take care of
		that.
		2326 074
	1	

0

1

wel 3	1263
1	Q Does your statement include, then, that there'll
2	be no swelling for both of those machanisms?
3	A (Witness Almeter) No, I didn't include it as that,
4	as far as the corrosion product. I considered that the
5	corrosion product wouldn't cause significant I didn't put
6	that into my statement.
7	The statement I made was basically referring to
3	any gas that would be formed. And that's why, if it's verted,
9	then -
10	Q And that gas was hydrogen gas
11	A Yes.
12	Q from the oxidation of the aluminum, is that
13	correct?
14	A Yas.
. 15	Q All right. Were the Exxon samples that indicated
16	that some bulging occurred of the aluminum cladding on the
17	Boral, was that under neutron exposure, by any chance?
18	A No.
19	Q Are you aware of any gases that might be produced
20	under neutron irradiation of Boral?
21	A Yes.
22	Q What is that mechanism?
23	A That would be a neutron absorber place that is
24	fabricated with boron carbon and an organic binder, to hold
25	the boron carbon particles intact.
	2326 075

•

Weil .

1 1

2

3

12

3

A (Witness Lantz) Let's go back. Could I talk to this a little bit, this question?

1.2 13

() Please .

1 The seutron flux in the spant fuel tool is ver-A 5 low, It's many orders of magnitude below that in a meacter, 3 1 and it really isn't significant. But if you're talking show 7 boron in a sectron flux, you do get helium gas concrated. But the amount of helium gas generated here is insignificant 3 Э Q So you have considered, then, the possibility helium gas being generated as a result of neutron absorption 1) 1.E. in the boron?

A. Yes.

13 Q Is there any possibility that that would cause
14 separation of the cladding from the Boral matrix?

A Not in the spant fuel pool, no.

What are the neutron fluxes in the Bion spent for
 pool expected to be with compacted storage?

A It depends on whether they put a source.
An old source sometimes in the life of the plane -- a K and ...
of .95, you have a sub-critical neutron multiplication from
of 20, and your strongest sources stound are around 1. 7 ...
10 ³ neutrons pur square centimeter per second.

So 20 times that is about the max you would explor to have in the pool. But when you consider that the flux in reactor is like 10^{13} or 10^{14} , you're about 6 or 7 orders of

2

3

6

8

2

magnitude down from what's in a reactor, and it's really 1 1 11 insignificant amount of neutron absorption. You have essentially no depletion of your Blo.

4 2 So you did include that possible mechanism in our 1 considerations in this testimony?

> A Yes.

711 Are you familiar with any problems of neutron 0 irradiation of B4C absorber and control rods of pool type reactors?

Yes, we've looked at that experience. BWRs have 10 A had B C for a long time, and they do get depletion. And 17 eventually they're going to have to take them out. But 12 that's not the case in the spent fuel pool. 13

That's a boiling water reactor. I was referring id 0 to pool type research or test reactors used B C powder. 13

Used Boral. There's one in Arkansas, I believ ; A 15 where they used Boral control rods in a research zeactor, in 17 they did have a problem of blistering. 10

But I think that was, like you say, probably dia 1914 to the helium gas generated by the boron fission from neutrons. 20

Q Do you know if they subsequently vented those 31 control rods? 22

No, I did not follow that.

A

23

CHAIRMAN WOLF: Are there any further questions 23 of these witnesses? 25

1273

wel. 6	1271						
1	MR. MILLER: None from the Licensee, Mr. Chairman.						
3	MS. SEKULER: I have one question.						
3	CROSS-EXAMINATION ON EOARD QUESTIONS						
4	BY MS. SERULER:						
5	Q Regarding Licensee's Exhibit Number 1 for identifi-						
6	cation, I believe that you said in response to a question from						
7	Mr. Miller that Step 6(b)(1) would make it possible for						
з	Commonwealth Edison to assure that the boron content of the						
9	tubes was correct.						
10	Is that a correct interpretation of what you said?						
11	A (Witness Lantz) Yes						
12	Q Is that particular step in the QA/QC procedure						
13	a documentation check?						
14	A It's a check to make sure that they can trace						
. 15	the traceability of the boron loading to tube serial number,						
16	and they can trace it all the way back to the manufacture :.						
17	Q It's a document check, though?						
13	A "Review documentation in accordance with "						
19	Yes.						
20	Q Is there any way excuse me. Is there anything						
21	on this check list which would indicate that there was an						
22	kind of physical check of the boron content of the tubes						
23	at that point?						
24	A The physical measurements were made, already made.						
25	It's a matter of making sure that that particular plate in						
	2326 078						
······							

wel 7

2

3

4

5

3

7

3

9

10

11

12

13

2.2

13

16

17

18

19

20

23

2.4

25

in that storage rack.

Q Is there any way by which the Commonwealth Edison QA/QC people will be authenticating the documentation that they receive?

MR. MILLER: Objection, Mr. Chairman. Authentic tion as used in the question seems vague and ambiguous.

MS. SEKULER: I'll clarify it.

CHAIRMAN WOLF: How is this witness qualified to give you an answer to that question, Ms. Sekuler?

MS. SEKULER: He was able to answer the question from Mr. Miller. I assumed he had some knowledge of it.

CHAINMAN WOLF: I don't know that he is qualized from his own knowledge. I think we'd have to ask that ca the Applicant when they put on a witness to qualify the documents.

MS. SEKULER: I'll do it at that time.

CHAIRMAN WOLF: I think that would be better.

The Board wants to take just a minute before we excuse these witnesses.

(The Board conferring.)

CHAIRMAN WOLF: Mr. Goddard, Dr. Remick has a question for you.

DR. REMICK: Does the Staff intend to offer a witness who could speak to the -- what would be the Staff's intended requirements or their requirements for implementation

WEI 8 ĩ and inspection of the corrosion program if the racks are 2 installed? 3 MR. GODDARD: I'll have to check that with the 4 project manager, Dr. Remick. I do not know at this time 5 whether we have in fact formulated inspection and enforce at t 6 procedures to monitor Commonwealth's program. 7 DR. REMICK: I'm not thinking only of inspection 8 and enforcement procedures, but what the Licensing Staff, 1: 9 they intend to require and what they might require about the inspection and monitoring program, what Staff's current intent 10 11 is. 12 MR. GODDARD: I'll have to report back to you on 13 that, sir. 14 DR. REMICK: And, of course, if there is information, if IsE would follow up, that's fine. But our curren: 15 interest is what is the Licensing Staff currently intending, 16 if anything, about requiring these monitoring programs to 17 be in technical specifications, or whatever. 13 MR. GODDARD: We'll report back to you on it, sir. 13 CHAIRMAN WOLF: Is there anything else before We 20 adjourn for lunch? We're going to come back at 1:00 o'clock. 21 The witnesses may be excused. 22 (Witnesses excused.) 23 (Whereupon, at 12:00 noon, the hearing was recasted, 24 to reconvene at 1:00 p.m., this same day.) 23

2326 080

12'3

AFTERNOON SESSION

1

IF agbl

٠.

•

0

21	
-	(1:00 p.m.)
3	CHAIRMAN WOLF: We'll be back on the record.
4	Dr. Ramick has an additional question for you,
3	Mr. Goddard.
3	DR. REMICK: Mr. Goddard, I'm not sure that I
7	made it clear what the Board intended with the question 7
S	raised of the Staff about an additional witness before the
0	luncheon recess.
10	What we had in mind, in some proceedings, the
11	Staff does provide a draft of a proposed licence or a proposed
12	license amendment that would be put into effect if the lice se
3	or amendment re granted.
14	Basically what I had in mind, if the Staff has
5	a draft of what a license amendment, technical specifications
16	and so forth would look like if the license amendment were
7	granted, this would be very helpful to the Board to see that
8	type of conditions the Staff proposes to put on the ameni-
9	ment.
0	MR. GODDARD: Yes, sir.
1	I talked to my project manager, Mr. Gary Zoch
2	over the luncheon break. And he was of the impression I
3	was under the impression at that time that you were referring
4	to a tech spec or license condition referencing the
5	surveillance capsule program, are you now referring to the
	2326 001
	2320 001

entire 'anges to the tech specs which would occur if this modification were granted?

DR. REMICK: That's right, including, I would presume, the monitoring program spoken to.

MR. GODDARD: It's my understanding, after having spoken with Mr. Zech, that the surveillance program by the Licensee is voluntary and would not be included as either part of the license amenûment or technical specifications.

DR. REMICK: I think that answers the quest on

Then the Staff does not intend to require a

surveillance program as part of the proposed license amardment?

MR. GODDARD: That's correct. That's my understanding at this time. Mr. Each will be back next week, and I will ascertain the correctness of what I've just stated to you.

DR. REMICX: Thank you.

MR. MILLER: Mr. Chairman, with the Board's permission, the Licensee would like to re-call Dr. Burtron Johnson to the stand. Dr. Johnson has some information which may be responsive to certain of the Board s questions regarding the effect of the high burnup fuel and corrosion in the spent fuel pool.

So with the Board's permission, if you wish we'd he glad to re-call him for any questions the Board might have. 2326 082

agb2

1

2

3

4

5

3

7

8

9

13

11

12

13

14

15

16

17

18

19

20

21

22

23

24

agb3	CHAIRMAN WOLF: Would you do that, Mr. Miller?
	MR. MILLER: Dr. Johnson, would you resume the
	stand, plaase?
	Whereupon, .
	A. BURTRON JOHNSON, JR.
	resumed the stand on behalf of the Licensee, and, having
	7 been previously duly sorrn, testified further as follows:
	8 CHAIRMAN WOLF: You're still under oath,
	9 Dr. Johnson.
3	FURTHER DIRECT EXAMINATION
t	BY MR. MILLER:
1	2 Dr. Johnson, could you just describe for us
1	3 briefly what effect, if any, high hugawa of final has on the
1	ability of the Zircelov cledding of the fuel to withstend
. 1	the spent fuel peel environment?
1	S Pirch Eld like to mark the second
	7 A First, 1'd like to summarize some information
71	that I'm aware of regarding the effect of the reactor
1	exposure on the fuel, because I believe that gives a perspertive
2(to the question about the subsequent exposure in the smart
,	fuel pool.
	I'm aware of some fuel which was exposed in the
	20rita reactor, which is a Westinghouse PWR, it would involve
2	the same water chemistry as in the Zion reactor primary
3.	system. The fuel is Zircaloy-four cladding, so it's the
23	same cladding.
	2326 083

1.216

1 And hthere were some rods which went as hig. a: 2 62,000 megawatt-days per metric ton of uranium. The 3 terminology there is the peak rod average burnup. 4 In 1977, there was a paper given at St. Charla, 5 Illinois which summarized the examinations which had been m de 3 on fuel from that same lot which had gone to a burnup of 7 58,000 megawatt-days per metric ton. And that paper is 8 available to the public. Э That paper indicated that they say no unusur" 10 and unexpected changes in the properties of either the 11 mechanical properties or the corresion or hydriding. 12 The average corresion film thickness was 0.5 m 11, 13 which is no threat to the cladding. There were some patche: 14 where the crud was relatively thick where they had seen 15 oxide thicknesses up to about 2.5 mills, but again, this lie 16 not present a life-limiting problem for the funl. 17 The other properties also were acceptable. 18 So we're talking here about, in summary, Zircal oy-19 clad fuel which had gone to burnups of 58.000, and that I'v 20 recently spoken with the Spanish junta which -- about other 21 rods which had gone to 62,000. 22 Now it's my understanding that fuel which is in 13

agba

24

25

Zion now is intended to go to sither about 48,000 or, if they decide to, they will leave it in until it goes to about 55,000. So there is already experience which exceeds that

2326 084

which is intended for the fuel which is now being exposed in the Zion zeactor.

1

2

2

25

5

3

7

3

3

10

11

12

13

14

15

15

17

13

19

20

21

22

23

24

25

agb5

There is relatively little experience on long-term exposures of high bernup fuel in pool storage, though there is some. And there is some work going on now in Germany to destructively examine PWR fuel which has gone to burnups of 39,000. The fuel has been in the pool for about four years, it will be destructively examined -- in fact it's underway -- and then they will put the fuel back in to a pool and return for subsequent examinations periodically to confirm that the high burnup fuel is continuing to more satisfactorily.

So I would offer that to the Board, and would be willing to entertain any questions.

CHAIRMAN WOLF: Do counsel have any questions? for this witness?

MR. GODDARD: The Staff has none, sir.

CHAIRMAN WOLF: Thank you.

MS. SEKULER: I have just two or three questicas.

CROSS-EXAMINATION

BY MS. SEXULER:

0 My first question relates to the data you just mentioned, the paper that was given at St. Charles, Illinois.

Were any changes in ductility different from

2326 085

the types of changes that are noticed in lower burnup fuel reported at that time?

A The ductilities due to radiation damage saturate fairly quickly. In the first cycle, or first one or two scles, the ductility saturates and there is very little changes in the ductility on going to higher radiations.

There could be changes in dustility due to hydrogen pickup, but the data from the Spanish fuel rods that went to 58,000 indicated that they had less than 90 parts per million by weight of hydrogen pickup. And this is no threat to the dustility of the fuel from the standpoint of storage in a pool or even exposure in a reactor.

Q When you talk about hydrogen pickup, are you talking about hydriding?

A That's right.

1

2

3

4

õ

5

7

3

9

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

agb6

Q But there was additional hydriding beyond that which would be experienced in fuel, say, with a burnup of 25,0007

A Really, Westinghouse's experience has indicated that, over a range of burnups, that they see pickups of less than 90. And even the high burnup still was within that range of less than 90 ppm., so it falls within the range that has been experienced even iwith lower burnup fuel.

Q Have any of these bundles which were exposed to these 43,000 to 58,000 -- maybe I have the wrong number .

agt7

2

3

4

5

6

7

8

9

0

1

2

3

2

5

6

7

3

9

0

.1

2

3

14

E

58,000.

A

Q 58,000 -- the numbers up to 58,000 megawatt-days per metric ton been stored in spent fuel pools?

A Only for a period of about six months. Teh They were then moved to dry storage, they are now in dry storage at the junta nuclear -- Energie Nucleaire in Madrid.

So the very high burnup rods are in dry storage at this point. There is some indication that they would consider putting them into wet storage. But there are other rods with -- as I've indicated, with burnups of about 40.000 which are in wet storage.

I think the point here is that the fuel rods have survived a much more aggressive environment in the reactor successfully, also in boric acid chemistry. And nor we're putting them at a much lower temperature into spen: fuel pool, which is still boric acid chemistry.

So our projection would be that the spent fuel pool environment would be much less aggressive than the environment that they've already been subjected to.

Q Are there any other studies or reports regarding the reaction of Zircaloy-clad fuel to higher hurnups, other than the St. Charles paper you mentioned?

A There is other experience, but I don't have the details at hand to go into the details on the corrosion

agb3

1

4

3

7

S

10

12

13

13

19

20

22

25

2%

25

0

0

and hydriding to the extent that I'm familiar with on this rate of fuel.

Q Thank you.

MS. SERULER: I have no further questions.

EXAMINATION BY THE BOARD

BY DR. REMICK:

O Dr. Johnson, I'd like to take advantage of you: being on the stand to ack you a question. Mere you present before lunch when the Staff witnesses Almoter and Lantz were being questions by the Board on their testimony?

A I was here periodically. I was asked to go out for a business reason, so I wasn't here during all the testimony.

All right. Let me just ask the question:

Do you know, when one is considering galvanic corrosion, whether it would be important on -- whether one part of the cell was grounded, electrically grounded, versus not being grounded, on the rate of galvanic corrosion that might occur?

A My response would depend very much on conductivity and -- You're talking about a spent fuel pool environment?

The proposed Zion pool conditions.

A And we're talking about grounding of what now?
 Q All right.

2326 088

Apparently coupons are going to be introduced into the pool for surveillance of corrosion. My questice is specifically addressed, does it matter whether those are grounded to the racks, or the steel liner, or not grounded on what the results might be if one is looking at galvanic corrosion?

A It's my recollection that what we have then is a stainless steel sandwich with aluminum-clad Boral between the stainless steel plates. Is that it?

Q And then venting, I believe.

agb9

2

3

4

5

6

7

3

9

10

11

2

3

4

10

6

7

8

9

:0

2.1

2

3

4

15

0

A I think the most important galvanic interaction would be between the stainless steel and the aluminum with which it is in contact, which is prototypic of the couple which one would have in the actual racks. So I believe that the important galvanic interaction is there.

I think that what I might suggest is, there could be some measurements made to see whether it mattered whether that specimen was coupled to the stainless stuel liner or not. That could be easily made with electronic equipment which is readily available, and one could then determine whether coupling was important or not.

But right now I would say that the important couple is probably already present with or without the grounding.

But you're not personally aware of whether or not

2326 089

agb 0

Zu

3

5

3

3

3

10

11

12

13

14

13

19

1 da

15

it is important to the rate of corresion? It's your opinion that it's not important, is that correct?

A Well as I say, I think the important couple is already present in the specimen.

Yes.

0

A But it would be easy to determine that by a fairly simple measurement, measuring the couple stainlessto-fluminum potential with the specimen grounded and with it ungrounded and you can tell then whether there was an important additional potential from grounding to the stainless steel liner.

Q

Thank you.

CHAIRMAN WOLF: Any other questions of this witness?

MR. MILLER: NOt at this time, Mr. Chairman, 10. CHAIRMAN WOLF: You may be excused, thank you.

(The witness ercused.)

HR. GODDARD: Mr. Chaiman, at this time, the Staff would like to recall Dr. Frank Almeter simply for the purpose of clarifying an answer which he gave or was unable to give earlier.

CHAIRMAN WOLF: You may do that.

MR. GODDARD: Would you take the stand, plaas, Dr. Almeter?

2326 090

12:3

Whersupon,

1

2

3

4

5

6

7

3

3

10

11

12

13

10

13

15

17

18

19

20

22

22

23

24

15

agb11

FRANK M. ALMETER

resumed the stand was a witness on behalf of the Regulatory Staff, and, having been previously duly eworn, testified further as follows:

FURTHER DIRECT EXAMINATION

BY MR. GODDARD:

O Dr. Almster, over the lunch hour, I discussed the question which I asked you earlier regarding high burns fuel. This is the question which is incorporated in the record at transcript page 1258, and which I showed to you over the lunch hour.

Did you misunderstand that question as it was originally asked?

A Yes, I did.

Q Would you state the effects on Eircaloy-clad PWR fuel when it's exposed to higher than normal levels of radiation in the reactor?

A Well it perhaps causes some change in the properties of the material. Like perhaps it would cause greater hydriding, cause perhaps some additional corrosion in the reactor, and perhaps we'd see a thicker layer of Zirconium oxide on the cladding while it was in the reactor at this high level, fluxes.

Q

I'm going to reask the question which I asked

you earlier:

agb12

2

3

1

5

6

7

8

9

Ð

1

2

13

4

5

6

7

8

0

0

21

22

3

13

5

If you will assume from the contioning here that high burnup fuel will be placed in the Zion pool and that this fuel is Zircaloy-clad FWR fuel with a burnup of approximately 50 percent more time than the normal burnup for such fuel, are you able to state an opinion as to whather you would expect adverse effects upon the Zircaloy cladding in the Zion spent fuel pool environment?

A I would empect none, because whatever changes have occurred in the Zircaloy cladding as far as mechanical properties, physical properties, that it would have occurred in the reactor. Under more extrame temperatures, pressure, and of course the higher fluxes, you put this atto the pool, the temperature is much lower, there is not the high pressures, and any gamma fluxes that are in the pool are a much greater order of magnitude lower than what you would find in the reactor, so I would expect any additional damage to the Zircaloy.

Q If one such fuel was removed from the reactor in placeddin a spent fuel pool for a period of 40 years, whit if any changes would you expect to occur in the cladding?

A None.

0

Thank you, Dr. Almeter.

MR. GODDARD: I have no further questions. CHAIRMAN WOLF: Any questions as a result of

1:03



		. 1285
a abl	1	MR. STEPTOE: Mr. Chairman, the Applicant's next
9	2	witness is Dr. Joseph E. Draley, and we would like him to take
	3	the stand and be sworn at this time.
0	4	CHAIRMAN WOLF: Very well.
	3	Wheraupon,
	5	JOSEPH E. DRALEY
	7	was called as a witness on behalf of the Licenses, and
	3	having been first duly sworn, was examined and testified as
	Э	follows:
5.240	10	CHAIRMAN WOLF: Will you state your full name and
	11	address for the record?
	i2	THE WITNESS: My name is Joseph E. Draley. I'm
•	13	employed at Argonne National Laboratory. My address is in
	14	Hinesdale, Illinois.
	15	DIRECT EXAMINATION
	16	BY MR. STEPTOE:
	17	Q Dr. Draley, are you familiar with the testimory
•	18	which has been filed in your name in this matter?
:	19	A Yes.
	20	Q 1: consists, does it not, of-15 pages of testimory,
	31	followed by a professional resume consisting of 11 pages,
	22	and a single-page statement of professional qualifications,
	23	and then six references which are used in your written test-
	24	mony proper. Is that not correct?
	25	A Yes. 2326 094

sh2	1	Q And the six references which are attached are
	2	listed on page 15 of the testimony itself. Is that not correct
	3	A Yes, that's right.
)	4	Q Now do you have any corrections or changes you
	5	would like to make to this testimony?
	6	A I'd like to correct what appears to be a typo-
	7	graphical error that may be worth correcting. There are one
	8	or two additional one that I think might not be worth
	Э	correcting.
	10	But on page 13, the last line of my testimony, the
	11	sentence begins, "Generic effects," and it should be "Generic
	12	defects."
,	13	Then I want to bring attention to the fact that
	14	the Reference 5, the copy of Reference 5 that was attached to
	15	the testimony was incomplete.
	16	Q Reference 5 is a two-page document entitled
	17	"Meutron Absorber Sampling Plan - in Pool"?
	18	A Yes.
	19	It was incomplete by virtue of the fact that
	20	Table 1 and Figure 1 were inadvertently omitted in assembling
	21	the material.
	-12	MR. STEPTOE: Mr. Chairman, I believe that all
	23	parties and the Board have been supplied with this Table 1
	34	and Figure 1. Do you have copies?
	25	CHAIRMAN WOLF: Yes, we do.
		2326 095
	11	

BY MR. STEPTOE:

Q Now addressing yourself to Figure 1, is there any change you would like to make on Figure 1?

A As originally prepared, Figure 1 showed, in connection with the identification of a hole that was drilled in the side of the assembly, the words 0.062 diameter hole, typical top and bottom, drilled before assembly.

That should be changed so the words "and potten" are deleted. The reason is that it will now simulate better the actual tubes for fuel storage.

1) 0 So that holes will only be in the top of the 12 corpons; is that correct?

A Yes.

14 Q Now as corrected and supplemented with Table 1 and 15 Figure 1, is your testimony, the professional resume, the 13 statement of professional qualifications, and the references 17 attached thereto, is all that true and correct to the best 18 of your knowledge and balief?

A Yes.

MR. STEPTOE: Mr. Chairman, at this time we acre that the testimony of Joseph E. Draley and the attachments I have stated before in all respects as if they had been read.

> > 2326 096

2

3

4

3

8

7

13

10

23

		1290
eb4	1	CHAIRMAN WOLF: to incorporate Mr. Draley's
	2	testimony into the record? /
	3	Without objection then, the testimony of Josegh
	4	Draley and the attachments thereto which have been enumerated
	đ	by Counsel will be bound into the record as if read.
	5	(The documents follow:)
	7	
	3	2326 097
	9	
	10	
	23	
	12	
	13	
	14	
	15	
	16	
	15	
	19	
	20	
	21	
	-22	
	23	
	24	
	25	

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of Commonwealth) Docket Nos. Edison Company (Zion Station,) 50-295 Units 1 and 2)) 50-304

۰.

2

TESTIMONY OF J. E. DRALEY

Contentions	2 (e) (3) 2 (e) (4)	:	Corrosion Surveillance Program
Contention	2(j)	•	Possible Boral Corrosion and Swelling
Contention	2(k)	:	Possible Degeneration of Boral Density

May 31, 1979

Testimony relative to Commonwealth Edison Company proposed change to Operating License for Zion Nuclear Plant by J. E. Draley.

My testimony is in the form of general statements concerning corrosion and related reactions of the stainless steel/Boral storage rack tubes, followed by specific replies to the contentions of the State of Illinois, as identified as issues in this case by the NRC Licensing Board in the Board's "Order Following Prehearing Conference," January 19, 1979. A statement of my professional qualifications is attached, as are the references which appear in this testimony.

GENERAL STATEMENTS CONCERNING CORROSION

A. Boric Acid Solution

The solution used in the Zion spent fuel storage pool contains boric acid dissolved in high purity dionized water. The solution is purified by passing a stream (approx. 100 gallons per minute) through a mixed bed ion exchanger that does not remove boric acid substantially. This purification process has not been run at all times and the concentration of the boric acid has not been constant. The average concentration of boron has been a bit less than 2500 parts per million (ppm), ranging from 2000 to perhaps 2520 ppm, and the typical pH has been 5.4, ranging from 4.7 to 5.6 in one period. The "normal" temperature of the pool water is 70°F, calculated

to increase to 111°F when a 1/3-core discharge of spent fuel is added (143°F if only one of the two cooling heat exchangers is operating).

Boric acid is typically a benign chemical in otherwise pure water from the point of view of corrosion, so long as the pH is not too low. A significant adverse effect on the aluminum corrosion can be predicted if the pH is below about 4, depending on the temperature, the presence of other solutes, and the rate of flow of solution past the metal surface.

B. Corrosion of Type 304 Stainless Steel

In pure water at storage pool temperatures, the uniform corrosion over the surface of austenitic stainless steels such as Type 304 is so slow as to challenge the ability of experimenters to measure it. In fact, I know of no accurate measurement of this corrosion rate. In my judgment the uniform penetration of 304 stainless steel is likely to be less than one ten thousandth of an inch in 40 years exposure to high purity water or to the 2500 ppm boric acid solution.

Under some circumstances, stainless steels, including Type 304, are susceptible to stress corrosion cracking. However, there is considerable experience with stainless steel racks and pool liners. No stress corrosion cracking of either has been found, even in weld-sensitized and residual stress regions, ⁽¹⁾ and none is expected to occur in the Zion pool.

2326 100

-2-

In sufficiently aggressive solutions such as those containing a high concentration of chloride ion, and especially in the presence of crevices, stainless steel has been known to suffer localized attack or pitting. This type of attack has not been observed in storage pool water and is not expected to occur for the lifetime of the Zion pool.⁽¹⁾ C. Boral

This product is manufactured by Brooks and Perkins, Inc., and, for Zion, consists of about 48% by weight of boron carbide (B_4C) particles embedded in a matrix of commercially pure (1100) aluminum. The size of the B C particles is given as 60-200 mesh. This boron carbide-aluminium material is formed into a plate, clad with 1100 aluminum on both sides. The same aluminum alloy is inserted between the cladding plates at each end so that the resultant piece, after cutting for use in the racks, is covered on four of the six sides by 1100 aluminum; the side edges are left without cladding.

As in the case of stainless steel, the actual corrosion rates of aluminum alloys such as 1100 are so low after an initial period of exposure to pure water as to have challenged the skill of experimenters to determine it. In fact our own observations for tests running nearly three years have shown that after an initial period lasting for several days the amount of corrosion increases only very slowly with further exposure times for temperatures of 50°C (122°F) and 70°C (158°F) in pure water. At 70°C, after the

•

2326 101

-3-

initial period, the amount of corrosion has been shown to vary with the logarithm of time for at least two years. (2) The logarithmic intercepts and rate constants published in 1967 by Draley, Mori, and Loess (3) 'indicate that for storage pool temperatures the amount of uniform corrosion of 1100 aluminum should not exceed one ten-thousandth of an inch in 40 years of exposure in high purity water. Tests in boric acid have not, to my knowledge, extended long enough to predict with precision the uniform corrosion rate to be expected. Short-term tests have shown that less corrosion · occurs in the presence of a dilute boric acid solution than in water but it cannot confidently be stated that the corrosion after 40 years will be as low as or less than that for pure water. Consequently, I can only conservatively judge that the amount of corrosion in boric acid solution in the storage pool should be less than one thousandth of an inch in 40 years of exposure.

There has been enough testing of the bare edges of Boral in which the aluminum-boron carbide core material and the 1100 aluminum cladding is exposed to show that little or no accelerated corrosion occurs. For example, Weeks⁽⁴⁾ reports no measurable deleterious attack in 19-1/2 years exposure in the Brookhaven Medical Research Reactor.

In pure water or in boric acid concentrations not exceeding those in the storage pool no stress corrosion cracking or significant pitting is expected of Boral.

2326 102

-4-

D. Boral-Stainless Steel Couples

When dissimilar metals are held in electrical contact, the corrosion of the metal that is electrochemically more active is sometimes accelerated and the corrosion of the metal that is electrochemically more noble is sometimes retarded. The increased corrosion of the more active metal is known as galvanic attack. In the present instance, 1100 aluminum and the layered Boral product are anodic to or more active than the stainless steel jacket. In deionized water, essentially free of chloride ion, galvanic attack of aluminum coupled to stainless steel is very slight as long as the water purity remains high. In the presence of boric acid solution, at concentrations corresponding to the storage pool water, one can expect some pitting of the edges of the Boral plates and perhaps the 1100 aluminum cladding when the electrical contact with the stainless steel jacket is good. The extent of pitting is not readily predictable because of lack of sufficient data in boric acid solution representative of that expected within the Zion tubes and uncertainties in the contact resistanct between the two metals that form insulating oxide films in air prior to fabrication and in the presence of water or boric acid solution when exposed to that environment. In any event, the resultant galvanic pitting is likely to slow down to such a low rate as to lead to little further pentration. The explanation for this nearly self-limiting process is probably related to the 2326 103

-5-

very limited conductivity of the solution through pores in the oxide that covers the growing pit. It is necessary for such ionic conductivity in the solution for the pit to continue to propagate. The formation of pits of limited depth and the expected existence of oxide on the surface make it unlikely that a significant amount of boron carbide will be lost from the edge of the Boral.

Although there are no known careful examinations of surfaces after galvanic corrosion in boric acid solution containing 2500 ppm boron, Brooks and Perkins has measured the electric current flowing between Type 304 stainless steel and Boral during such exposure, both in aerated and deoxygenated (bubbling nitrogen gas) condition at 65°C (149°F). In addition, a closed experiment has been run at 21°C (70°F), with no addition of gas (herein called stagnant). For the aerated and deoxygenated tests, the current varied irregularly with time, with an apparent trend downward after the first few weeks. The galvanic current deoxygenated was about one-fourth that in the aerated test. In the stagnant test, the current declined throughout, reaching negligible values after two or three months. Additional testing has also been done by Battelle Memorial Institute at a higher boric acid concentration, 32 g/1, containing about 5600 ppm boron. The pH was 3.8, the temperature 49°C (120°F). Galvanic currents between stainless steel and Boral or 1100 aluminum were higher than in the more dilute solution during the 54-day test.

2326 104

-6-

Periodic inspection of the 1100 aluminum specimen during the course of the test showed severe pitting that appeared visually to have grown little deeper but covered an increasing area. This galvanic corrosion was clearly more severe than that which occurred in the more dilute boric acid solution.

REPLIES TO CONTENTIONS

<u>Contention (2)(e)</u> The amendment request and supporting documentation do not adequately discuss monitoring procedures. In the light of the proposed modification and long time storage of nuclear spent fuel the Applicant should clarify the following:

- (3) Method for detecting the loss of neutron absorber material and/or swelling of stainless steel tubes in storage racks.
- (4) Details of a corrosion test program to monitor performance of materials used in the construction of the racks.

Reply

Consideration of the corrosion behavior of the Boral leads to the judgment that significant amounts of boron will not be lost from the Boral composite by corrosion. Similarly it is anticipated that no serious swelling of the vented steel tubes will occur in the storage racks, since the only known mechanisms that might produce substantial swelling involve the entrapment of gas inside the tubes or the production of

-7-

solid corrosion product with a volume greater than that of the metal from which it was produced. The former should not occur because the tubes will be vented and swelling by the latter mechanism should not reach serious proportions, as will be shown in the reply to Contention (2)(j)(3).

To assure that unexpected damage is not occuring, the surveillance program that will be put into effect when the new racks are installed⁽⁵⁾ will provide an opportunity for inspection of specimens that are expected to behave in the same way as the actual tubes. Small vented specimens, 'very similar in character to the 'actual tubes, will be stored in the pool. These will be removed periodically, opened, and examined carefully for corrosion damage. In addition, two full-size storage tubes will be exposed in the pool near stored fuel so as to reproduce the radiation condition as well as exposure to the solution. These tubes will be examined periodically for visual signs of swelling and will be opened and examined for loss of boron if examination of the small specimens indicates ¹⁰boron content in those specimens below 0.02 gm/cm².

It is believed that with this program, indications of corrosion damage involving the possible loss of neutron absorber or swelling or other damage to the tubes will be detected in time to take any necessary remedial action for the storage tubes in the pool. It is believed that the corrosion reactions will be sufficiently slow that any

2326 106

- 9-

damage that occurs will not endanger the safe and effective operation of the storage pool.

<u>Contention (2)(h)</u> The amendment request and supporting documentation have not analyzed the long term (including storage during the operating lifetime of the reactor) electrolytic corrosion effects of using dissimilar alloys for the pool liners, pipes, storage racks and storage rack bases, such as the galvanic corrosion between unanodized aluminum as is used in Brooks and Perkins storage racks, and the stainless steel pool liner.

Reply

As has been indicated above in sections C and D it is not expected that there will be a significant electrolytic corrosion effect between boron carbide and 1100 aluminum, although it is likely that there will be a galvanic corrosion effect between the Boral and the stainless steel tube. Whatever the magnitude of this effect, and it is not expected to pose a problem with respect to the integrity of the Boral, there will be no residual effect of the galvanic interaction outside of the stainless steel tubes, so that the materials inside the tubes will have no interaction with fuel or with the tank liner.

<u>Contention (2)(j)</u> The amendment request and supporting documentation do not give sufficient data to fully assess the durability and performance of the Boral-stainless steel tubes which form the spent fuel storage racks:

2326 107

-9-

 There is inadequate analysis of the corrosion rate of the tubes.

Reply

In Section B above I have provided information concerning the anticipated corrosion behavior of Type 304 stainless steel, the material of which the tubes are comprised. It is expected that the corrosion will be negligible as indicated in that section.

(2) There is no calculation of the effect of water

chemistry on the Boral within the stainless steel.

Reply

This is discussed in Section C above. It is judged that the water chemistry will be favorable for the corrosion of Boral and that the total uniform corrosion of this material will not be in excess of 1/1,000 in. for the forty year lifetime of the racks. There could be a greater amount of local attack on the edges of the Boral and possibly at some locations on the 1100 aluminum cladding on the Boral where it faces the stainless steel. In neither of these two locations is the attack expected to be great enough to lead to serious loss of the neutron absorbing boron, or to cause swelling to an extent that would interfere with free movement of the stored fuel.

(3) There is no mention of the possible swelling of Boral within the stainless steel tubes, a condition which could affect, among other things, removal of fuel assemblies from the racks.
Reply

I am aware of two processes that could lead to swelling of the Boral within the stainless steel tubes. In the first, if the quality of the Boral is poor so that there is porosity, there could be a path for permeability of the core material by water. It would then be possible for reaction of this water with the aluminum at some internal place to produce hydrogen gas in quantities sufficient to expand the Boral, as by the formation of an internal blister. The location of such a blister might be some distance beyond that of the water that produced the gas, the hydrogen diffusing ahead of the water. This type of swelling should be self-limiting, since expansion of the blister should deform the piece enough to allow release of the hydrogen pressure. In the second mechanism some local corrosion or pitting might be induced by galvanic interaction between the aluminum of the Boral and the stainless steel tubes (where the plates are pressed together). The solid corrosion product has a greater volume than that of the corroded metal, and local swelling cculd result.

With respect to the first process, due to accidentally porous Boral, there has been no experience of this kind of swelling at pool temperatures of commercial grade good quality Boral either in the old formulation (see reference to the material in the Brookhaven Research Reactor above in Section C) or in the new formulation, for which

2326 109

-11-

there is less extensive experience. It did occur in some tests run by Exxon Nuclear Company⁽⁶⁾, using speciments of material, not used commercially, containing quantities of fine boron carbide, of the order of minus 300 to 350 mesh. It was at locations of such fine material that Exxon found the blisters to form. During mechanical testing of this type of material (not in contact with water or aqueous solution), Brooks and Perkins found areas of imperfect bonding between the core and cladding. Specifications for the boron carbide powder (size range) were then set at -60 + 200 mesh, and no areas of poor bonding were discovered. This is the product that is used commercially. Because of universally good experience with the commercial product and the non-applicability of the Exxon results to such a product, no swelling of this type is expected in the Zion pool.

Concerning the second swelling mechanism, the extent of galvanic corrosion may be limited by solution depletion, depletion of available oxygen in the stagnant area, or poor electrical contact, as indicated above in Section D. If it is not so limited, it is conceivable that the entire thickness of the Boral might be converted to the aluminum corrosion product, a hydrated oxide, expected predominantly to consist of a crystalline form known as bayerite. Using the density of bayerite (2.42), it can be calculated that the corrosion product will occupy a volume some 3.2 times that of the aluminum from which it is formed. For a total Boral thickness of

-12-

2326 110 -

0.073 inch, the maximum swelling would then be 0.234 inch, an amount that would not interfere with the movement of fuel within storage tubes.

Another possible swelling mechanism for unvented tubes, not involving the swelling of Boral, is the accumulation of entrapped gas between the Boral and the stainless steel tube. Assuming a leak near the bottom, access of solution to the aluminum and the production of some hydrogen as a corrosion product will be allowed. If the resultant gas (perhaps a mixture of the hydrogen and the air originally entrapped during the manufacture of the tube) nearly fills the free space between the Boral and the stainless steel tube, its pressure near the top will be in excess of that outside the tube by an amount that could bulge the stainless steel sheet. This is the mechanism believed to explain the swelling of some tubes in the spent fuel storage pool at the Monticello Plant last year. It should not occur at Zion due to the use of vented tubes.

<u>Contention (2)(k)</u> The amendment request and supporting documentation do not consider possible degeneration of the Boral density due either to generic defects or to mechanical failure which would diminish the effectiveness of Boral as neutron absorber, thus leading to criticality in the spent fuel pool.

Reply

Generic effects in the form of porosity have been discussed

2326 111

-13-

in the preceeding reply. If there are mechanical defects, in which the Boral would fragment or break, the stainless steel tubing would keep it largely in position. However, the fragmentation is considered highly unlikely in view of the good record of Boral products and in view of the excellent record for integrity of the Boral cladding alloy, 1100 aluminum. The risk of developing criticality in the pool on the basis cited is deemed negligible.

2326 112

C

REFERENCES

- L. BNL-NUREG-23021, J. R. Weeks, Corrosion of Materials in Spent Fuel Storage Pools, July 1977 (Brookhaven National Laboratory report); also Affidavit of John R. Weeks before the Atomic Safety and Licensing Board in the Matter of Public Service Electric and Gas' Company, et al, (Salem Nuclear Generating Station Unit 1), Docket No. 50-272, 1979.
- J. E. Draley, Shiro Mori, and R. E. Loess, The Corrosion of 1100 Aluminum in Oxygen-saturated Water at 70°C, J. Electrochemical Society, <u>110</u>, pp. 622-627 (1963).
- J. E. Draley, Shiro Mori, and R. E. Loess, The Corrosion of 1100 Aluminum in Water from 50°-90°C, J. Electrochemical Society, 114, pp. 353-354 (1967).
- BNL-NUREG-25582, J. R. Weeks, Corrosion Considerations in the Use of Boral in Spent Fuel Storage Pool Racks, January 1979 (Brookhaven National Laboratory report).
- Commonwealth Edison Co., "Neutron Absorber Sampling Plan - In Pool," May 25, 1979.
- XN-NS-TP-009; Fuel Storage Racks Corrosion Program, Boral-Stainless Steel, November 9, 1978 (Exxon Nuclear Company non-proprietary version).

Education

Attended the Catholic University of America, 1935-9, awarded Bachelor of Applied Chemistry degree, 1939.

Attended Catholic University, 1939-42 and 1945-46, awarded Ph.D. degree in Chemistry, 1947.

Professional Career

Metallurgical Laboratory, University of Chicago, 1942-1945.

Group Leader in Technical Division, then in Metallurgy Division, in charge of latoratory investigations in corrosion related to design and development of nuclear reactors. Aqueous corrosion of aluminum, uranium, thorium and their alloys; hydriding of uranium and thorium; formation and deposition of hydrous oxide films.

Kellex Corp., New York City, 1945-46.

Project engineer. Established plan for examination and evaluation of corrosion in gaseous diffusion plant; assisted in making company plans for the future.

- Kellex Corp., Applied Physics Lab., Silver Spring, Maryland, 1946-47. Project Engineer. Assisted in ram-jet development; research on heat transfer in supersonic airflow.
- Oak Ridge National Laboratory, Oak Ridge, Tenn., 1947-48. Metallurgy Division Section Chief in charge of corrosion research activities. Studied aqueous corrosion of beryllium and aluminum.

Argonne National Laboratory, Argonne, Ill., Associate Chemist, 1948; promoted to Senior Chemist, 1955.

Group Leader in Metallurgy Division, in charge of basic corrosion research, 1948-1968 (for applied research also during a part of this period). Corrosion of a number of metals and alloys in water, steam, and oxygen; application of materials to nuclear reactors. Coordinator for the Laboratory's program in sodium technology (Liquid Metal Fast Breeder Reactor Program), 1967-1969. Assistant Manager of the sodium technology program (Chemical Engineering Division), 1970-1971. Member Environmental Statruent Project, preparing National Environmental Policy Act impact statements for nuclear power plants, 1971-1974. Ass't. Laboratory Director for Program Planning 1974-1978. Manager, OTEC Biofouling, Corrosion and Materials Project, Materials Science Division, 1978-present. Member, Argonne Senate Committee on Scientific programs, 1968-1972, Chairman 1970-1971. Member, Argonne's CTR (Controlled Thermonuclear Research) Study Group, 1970-1973, Chairman 1972-1973.

Awards:

W. R. Whitney Award (National Association of Corrosion Engineers), 1961, for outstanding contributions to the science of corrosion.

Merit Award of the Chicago Technical Societies Council, 1970, for outstanding - technical and social achievements.

2326 114-

PROFESSIONAL RESUME FOR JOSEPH E. DRALEY (Contd)

Technical Societies:

Member of

American Chemical Society Electrochemical Society American Nuclear Society (1969-1978) Amer. Inst. Min. Met. Pet. Engrs., The Metallurgical Society Amer. Assn. for the Advancement of Science Sigma Xi

Chairman, Corrosion Division, Electrochemical Society, 1956-7 Editor, Corrosion Division, Electrochemical Society Journal, 1957-8 Member, Corrosion Resistant Metals Comm., THE AIME, 1959-, Chairman, 1967-9 Member, Corrosion Research Council, 1963-5 Chairman, Symposium on Corrosion by Liquid Metals, The Met. Soc., 1969

Other Professional Activities:

Originator of periodic AEC Contractor Corrosion Symposia, 1951 Member, Shippingport Fuel Panel, 1953-6 Contributor to International Conferences on the Peaceful Uses of Atomic Energy, Geneva, 1955, 1958, 1964; participated in first and third Chairman, Gordon Research Conference on Corrosion, 1958 Member, Fluid Fuel Reactors Task Force, 1959 Organizer, International Symposium on Aqueous Corrosion of Reactor Materials, Brussels, 1959 Chief U. S. Delegate to International Atomic Energy Agency meeting on Corrosion of Reactor Materials, Salzburg, 1962 Exchange visitor to Russian Corrosion Chemistry Institutes, 1962 Advisor to Advances in Corrosion Science and Technology since 1965 Consultant to the Atomic Energy Commission on Minimization of River Pollution by Radioactive Effluents, 1966-8 Member, ANL Study Group on Environmental Pollution, 1967 Participant, U. S. - U. K. Libby-Crocroft Exchanges on Corrosion, Harwell, 1967 and Columbus, Ohio, 1968 Chairman, International Conference on Sodium Technology, Argonne, 1968 Invited lecturer at the Workshop on Biofouling at Thermal Power Plants, June 16-17, 1975, Johns Hopkins University Invited lecturer at the American Chemical Society, the Electrochemical Society, and the National Association of Corrosion Engineers series of lectures on Chemistry in Corrosion, Chicago, IL, March 30, 1976

TECHNICAL PUBLICATIONS OF JOSEPH E. DRALEY

and of Those under His Supervision

(Publications are listed in the order: journal articles--contributions to books and symposia--Manhattan Project and A.E.C. reports)

I. Dissertation for the Ph.D. degree:

. 1 :

-

Joseph E. Draley, Complex of Cupric Ion with Acetate and Glycinate Ions in Aqueous Solution, the Catholic University of America, 1946.

II. Publications in the Area of the Corrosion of Aluminum and its Alloys by Water:

J. E. Draley and W. E. Ruther: Aqueous Corrosion of Aluminum: Part 1 -Behavior of 1100 Alloy; Corrosion, <u>12</u>, 441-448t, Sept. 1956.

J. E. Draley and W. E. Ruther: Aqueous Corrosion of Aluminum: Part 2 -Methods of Protection Above 200°C; Corrosion, <u>12</u>, 480t-490t, October 1956.

J. E. Draley and W. E. Ruther: Corrosion of Aluminum in Reactor Service; Trans. Am. Nuc. Soc., <u>4</u>, 197-8, Nov. 1961.

J. E. Draley, W. E. Ruther and S. Greenberg: Aluminum Alloys with Improved High Temperature Aqueous Corrosion Resistance; J. Nuc. Mat., <u>6</u>, 732-740, July 1962.

J. E. Draley, Shiro Mori, R. E. Loess: The Corrosion of 1100 Al in Oxygen-Saturated Water at 70°C; J. Electrochem. Soc., <u>110</u>, 622-627, June 1963.

S. Mori, R. E. Loess and J. E. Draley: An Eddy Current Gauge for Measuring Al Corrosion; Corrosion, 19, 269t-271t, Aug. 1963.

J. E. Draley, W. E. Ruther, and S. Greenberg: Corrosion Experience with Al Powder Products; J. of Powder Met., <u>1</u>, 28-41, April 1965.

S. Mori and J. E. Draley: Oxide Dissolution and Its Effect on the Corrosion of 1100 Aluminum in Water at 70°C; J. Electrochem. Soc., <u>114</u>, 352-353, April 1967.

J. E. Draley, S. Mori and R. E. Loess: The Corrosion of 1100 Aluminum in Water from 50 to 95°C; J. Electrochem. Soc., <u>114</u>, 353-354, April 1967.

R. A. Legault and J. E. Draley: An Electrochemical Study of Aluminum Corrosion in Boiling High Purity Water; Corrosion, 23, 365-370, December 1967.

J. E. Draley and W. E. Ruther: Corrosion of Aluminum and Its Alloys at Elevated Temperatures; Proc. Met. Info. Meeting, Oak Ridge April 11-13, 1955; TID-6502, pp. 669-680 (1960).

TECHNICAL PUBLICATIONS OF JOSEPH E. DRALEY (Contd)

J. E. Draley and W. E. Ruther: Aqueous Corrosion of Aluminum Alloys at Elevated Temperatures; International Conference on the Peaceful Uses of Atomic Energy, June 1955, Vol. 9, pp. 391-396 and 441-444 (United Nations).

J. E. Draley: Aluminum Corrosion at Elevated Temperatures; in TID-5606, Technical Briefing Session at Idaho Falls Nov. 1-2, 1955, pp. 5-17.

J. E. Draley and W. E. Ruther: Aqueous Corrosion of Aluminum Alloys at Elevated Temperatures; Progress in Nuclear Energy, Series IV, pp. 333-351, 1956 (Pergamon Press).

J. E. Draley: Contrib. to Conf. Corr. Aluminum in Water at High Temp., Chalk River, Dec. 18-19, 1956, Minutes by M. D. Ferrier, CRMet-700, June 1957.

J. E. Draley, C. R. Breden, W. E. Ruther and N. R. Grant: High Temperature Aqueous Corrosion of Aluminum Alloys; Second United Nations International Conference on the Peaceful Uses of Atomic Energy, September 1958, Vol. 5, p. 113.

Also in Progress in Nuclear Energy Series, IV, Vol. 2, 1960, Pergamon Press pp. 284-300.

J. E. Draley: Problems of Fuel Element Corrosion in Water; First International Symposium on Nuclear Fuel Elements, Jan. 1959, pp. 314-328 (Reinhold Publ. Co.).

J. E. Draley: Aqueous Corrosion of 1100 Aluminum of Aluminum-Nickel Alloys; International Conference on Aqueous Corrosion of Reactor Materials, Brussels, October 14-16, 1959, TID-7587, pp. 165-187.

J. E. Draley and W. E. Ruther: The Corrosion of Aluminum Alloys in High Temperature Water; IAEA Conf. Corrosion of Reactor Materials, Salzburg, June 1962, Vol. I, pp. 477-498.

W. E. Ruther and J. E. Draley: Aluminum Alloy Corrosion; Research Reactor Fuel Element Conf., Gatlinburg, Sept. 17-19, 1962; TID-7642, pp. 601-611.

J. E. Draley and W. E. Ruther: Aluminum Alloys; Contribution to "Behavior of Cladding Materials in Water and Steam Environments", Edited by Sherman Greenberg; Reactor Technology, Selected Reviews -1964, pp. 215-223 (USAEC).

 CT-3027 J. E. Draley, J. W. Arendt, G. C. English, E. F. Story,
 M. M. Wainscott and R. W. Berger: The Corrosion of Aluminum in Dilute Solutions; Laboratory Studies, June 19, 1945.

CT-3057

J. E. Draley and G. C. English: Corrosion Research--The Sealing of Cracks in Aluminum Surfaces; October 19, 1944.

TECHNICAL PUBLICATIONS OF JOSEPH E. DRALEY (Contd)

AECU-2301; J. E. Draley and W. E. Ruther: Aqueous Corrosion of 25 UAC-659 Aluminum at Elevated Temperatures; Oct. 1952. J. E. Draley, W. E. Ruther and Nancy Williams: Aqueous ANL-4958 Corrosion of Aluminum-Lithium Alloys; December 29, 1952. (Classified) ANL-5001 J. E. Draley and W. E. Ruther: Aqueous Corrosion of 25 Aluminum at Elevated Temperatures; Feb. 1, 1953. ANL-5430 J. E. Draley and W. E. Ruther: Corrosion Resistant Aluminum Above 200°C; July 15, 1955. ANL-5658 J. E. Draley and W. E. Ruther: Experiments in Corrosion Mechanism: Aluminum at High Temperatures; April 1957. ANL-5889 Shiro Mori, J. E. Draley and R. B. Bernstein: Deuterium-(Adden.) Hydrogen Exchange in Boehmite Corrosion Product Formed On Pure Aluminum in Boiling Water; April 1961. ANL-5927 J. E. Draley and W. E. Ruther: Corrosion Resistance and Mechanical Properties of Aluminum Powder Products; March 1959. ANL-6015 J. E. Draley, S. Mori and R. E. Loess: Corrosion of 1100 Aluminum in Boiling H₂O and D₂O; July 1959. ANL-6053 W. E. Ruther and J. E. Draley: Corrosion of Aluminum-Uranium Alloys in High-Temperature Water; Nov. 1959. ANL-6207 J. E. Draley, W. E. Ruther and S. Greenberg: Corrosion of Aluminum and Its Alloys in Superheated Steam; April 1961. ANL-6236 S. Mori, J. E. Draley and R. E. Loess: Crevice-Galvanic Corrosion of Aluminum; June 1966. ANL-6785 J. E. Draley, W. E. Ruther and S. Greenberg: Corrosion Experience with Aluminum Powder Products; Nov. 1963. ANL-7227 J. E. Draley and W. E. Ruther: Corrosion of Aluminum Alloys ty Flowing High Temperature Water; January 1967. Publications under his Supervision F. E. DeBoer: Discussion of Impedance Characteristics of Isolated Aluminum Oxide Films, by D. F. MacLennon; Letter to Editor, Crrosion,

R. K. Hart and W. E. Ruther: The Morphology of Surface Reaction Products on Aluminum; J. Nuc. Mat., 4, 272-280, Aug. 1961.

15, 643t, Dec. 1959.

R. K. Hart and J. K, Maurin: Morphology and Structure of Oxides Grown on Aluminum in Superheated Steam; Corrosion, <u>21</u>, 222-234, July 1965. - 4 -

TECHNICAL PUBLICATIONS OF JOSEPH E. DRALEY (Contd)

- R. K. Hart: Morphology of Corundum Films on Aluminum; Fifth Int. Congress for Electron Microscopy, 1962.
- CT-3029 J. W. Arendt and W. W. Binger: Corrosion of Aluminum Tuballoy Alloys; June 5, 1945.
- CT-3030 W. Binger: Galvanic Corrosion of 304 Stainless Steel, 2S Aluminum and 72S Aluminum; June 2, 1945. (Confidential)
- CT-3047 G. English: Corrosion of Unbonded Aluminum-Jacketed Slugs in Aqueous Medium; Jan. 30, 1945 (Confidential).
- CT-3095 John Mann: Improvements in Internally-Heated Slug Test; June 30, 1945.
- CT-3096 John Mann: Internally Heated Slug Test at 100% Power Level; June 15, 1945.
- CT-3040 J. Mann: Simulated Storage Basin Corrosion Tests, June 30, 1945.
- ANL-5500 W. E. Ruther: Corrosion Experiments with 2S Aluminum at 200°C; March 1956.
- ANL-5889 R. B. Bernstein: Hydrogen and Oxygen Isotopes Applied to the Study of Water-Metal Reactions. Exchange of D₂018 with Alpha Alumina Monohydrate; Aug. 1958.
- ANL-6144 Raymond K. Hart and M. J. Heyduk: Metallography of Aluminum and Some Aluminum-lw/o Nickel Alloys; March 1960.
- ANL-6230 Raymond K. Hart and Westly E. Ruther: Film Growth on Aluminum in High Temperature Water; April 1961.

III. Publications in the Area of the Corrosion of Thorium, Uranium, and their Alloys

I. H. Kittel, S. Greenberg, S. H. Paine, and J. E. Draley: Effects of Irradiation on Some Corrosion-Resistant Fuel Alloys; Nuc. Sci. and Engin., 2, 431-449, July 1957.

Sherman Greenberg and Joseph E. Draley: Effects of Irradiation on Corrosion Resistance of Some High Uranium Alloys; Nuc. Sci. and Engin. <u>3</u>, 19-28, Jan. 1958.

- J. E. Draley, S. Greenberg and W. E. Ruther: The High Temperature Aqueous Corrosion Resistance of the Uranium-5% Zirconium-1-1/2% Niobium Alloy; J. Electrochem. Soc., <u>107</u>, 732-740, Sept. 1960.
- J. E. Draley and S. Greenberg: Aqueous Corrosion of 5w/oZr-1 ½w/oNb-Uranium Alloy; Proc. Met. Info. Meet., Oak Ridge, April 11-13, 1955; TID-7502, pp. 640-652 (1960).

- 5 -

TECHNICAL PUBLICATIONS OF JOSEPH E. DRALEY (Contd)

- J. E. Draley: High Temperature Aqueous Corrosion of Uranium Alloys Containing Minor Amounts of Alloying Elements; International Conference on Aqueous Corrosion of Reactor Materials, Brussels, October 14-16, 1959. TID-7587, pp. 390-404.
- J. E. Draley and S. Greenberg: Corrosion of Uranium Alloys; Reactor Handbook, Second Edition, Vol. I, pp. 183-191, Edited by C. R. Tipton, Jr.; 1960 (Interscience Pub.).
- CT-1943 J. E. Draley and G. C. English: Corrosion Research Tuballoy and Alloys; July 1, 1944.
- CT-3043 N. Bensen, R. P. Straetz, and J. E. Draley: Autoclave Tests of Tuballoy Metal and Purified Hydrogen; June 20, 1945.
- CT-3044 R. P. Straetz and J. E. Draley: A Study of the Reaction Rate between Tuballoy Metal and Purified Hydrogen; June 20, 1945.
- CT-3045 R. P. Straetz and J. E. Draley: A Study of the Reaction Rate between Thorium and Purified Hydrogen; June 11, 1945.
- ANL-4862 J. W. McWhirter and J. E. Draley: Aqueous Corrosion of Uranium and Alloys: Survey of Project Literature; May 14, 1952.
- ANL-4908 J. E. Draley: The Corrosion of Thorium; Oct. 3, 1952.
- ANL-5029 J. E. Draley and J. W. McWhirter: Effects of Metal Purity and Heat-Treatment on the Corrosion of Uranium in Boiling Water; April 14, 1953.
- ANL-5030 J. E. Draley, J. W. McWhirter, F. Field, and J. Guon: The Corrosion of Low-Zirconium/Uranium Alleys in Boiling Water; April 14, 1953.
- ANL-5078 J. E. Draley: Preliminary Report on Low-Columbium/Uranium Corrosion Resistant Alloys; June 24, 1953.
- ANL-5530 J. E. Draley, S. Greenberg and W. E. Ruther: The High Temperature Aqueous Corrosion of Uranium Alloys Containing Minor Amounts of Niobium and Zirconium; April 1957.

Publications under his Supervision

Sherman Greenberg: Corrosion of Irradiated Uranium Alloys; Nuc. Sci. and Engin., Letter to Editor, 6, Aug. 1959.

CT-2548 Rosner: Rate of Reaction Between Tuballoy and Water in a Hydrogen Atmosphere at Various Temperatures and Pressures; October 1944.

CT-3023 R. B. Hoxeng: Corrosion of Construction Materials, Bonding Materials, and Uranium - An Electrochemical Investigation; May 2, 1945. (Confidential)

TECHNICAL PUBLICATIONS OF JOSEPH E. DRALEY (Contd)

- CT-3031 Joyce M. Hopkins, Frederick Nelson and W. W. Binger: Corrosion of Tuballoy-Molybdenum Alloys by Water; May 31, 1945.
- CT-3035 Joyce M. Hopkins, W. W. Binger and Frederick Nelson: Aqueous Corrosion of Tuballoy-Silicon Alloys; June 14, 1945.
- CT-3036 J. W. Arendt, W. W. Binger, J: Hopkins and F. Nelson: Aqueous Corrosion of Thorium and Thorium Alloys; June 23, 1945.
- CT-3052 Frederick Nelson, W. W. Binger and Joyce M. Hopkins: Corrosion Testing of Tuballoy-Columbium Alloys; June 19, 1945.
- CT-3055 W. A. Mollison, G. C. English, and F. Nelson: Corrosion of Tuballoy in Distilled Water; June 23, 1945.
- ANL-5672 W. E. Ruther and W. B. Seefeldt: Aqueous Corrosion of Uranium and Uranium-6w/o Zirconium Alloy; Jan. 1957.
- ANL-7006 J. Y. N. Wang: Corrosion of Experimental Thorium-Base Alloys; Feb. 1965.
- IV. Publications in the Area of Corrosion of Zr, Hf, and their Alloys by Water or Oxygen
 - J. Levitan, J. E. Draley, and C. J. Van Drunen: Low-Pressure Oxidation of Zirconium; J. Electrochem. Soc., <u>114</u>, 1086-89,(1967)
 - D. H. Bradhurst, J. E. Draley, and C. J. Van Drunen: An Electrochemical Model for the Oxidation of Zirconium; J. Electrochem. Soc., <u>112</u>, 1171-77 (1965)
 - ANL-5165 W. E. Ruther and J. E. Draley: Solution Potentials of Zirconium Dec. 25, 1953
 - ANL-7252 J. Levitan, J. E. Draley, and C. J.-Van Drunen: Studies in Zirconium Oxidation; December, 1966

Publications under his Supervision

R. D. Misch and W. E. Ruther: The Anodizing of Zirconium and Other Transition Metals in Nitric Acid; J. Electrochem. Soc., <u>100</u>, 531-537, Dec. 1953.

R. D. Misch and E. S. Fisher: Variation of Anodic Film Growth with Grain Orientation in Zirconium; Letter to Editor, Acta Meta. 4, 222, March 1956.

R. D. Misch and E. S. Fisher: Anodic Film Growth on Hafnium in Nitric Acid; J. Electrochem. Soc., 3, 153-156, March 1956.

R. D. Misch: Dissolution of the Oxide Film on Zirconium; Letter to Editor, Acta Metal. 5, 179-180, March 1957.

R. D. Misch: Comments on Corrosion Behavior Zr-U Alloys in High Temperature Water, by W. E. Berry and R. S. Peoples; Corrosion, <u>14</u>, 67, Dec. 1958. 2326 121

- 0 -

TECHNICAL PUBLICATIONS OF JOSE 'H E. DRALEY (Contd)

R. D. Misch and F. H. Gunzel, Jr.: The Electrical Resistance of Oxide Films on Zirconium in Relation to Corrosion; J. Electrochem. Soc., <u>106</u>, 15-20, Jan. 1959.

S. Greenberg: Zirconium Alloys for Use in Superheated Steam; Letter to J. Nuc. Mat., 4, 334-5, Aug., 1961.

R. D. Misch and C. Van Drunen: The Oxidation of Zirconium Binary Alloys in 700°C Oxygen for Times up to 200 Days; Pub. in GEAP-4089, Proc. USAEC Symp. Zr Alloy Dev., Nov. 30, 1962, Vol. II, pp. 15-0 through 15-46.

Sherman Greenberg and C. Arthur Youngdahl: Corrosion of Zirconium Alloys Containing Minor Additions of Iron and Copper or Nickel in Superheated Steam at 540°C and 650°C and 600 psig; Corrosion, 21, 113-124, April, 1965.

- R. D. Misch: Electrode Reactions of Zirconium Metal; The Metallurgy of Zirconium, Editors Lustman and Kerze, pp. 663-677, 1955 (McGraw-Hill).
- ANL-5229 R. D. Misch: Anodizing as a Means of Evaluating the Corrosion Resistance of Zirconium and Zirconium Alloys; Dec. 1953.
- ANL-6149 R. D. Misch: Characteristics of Anodic and Corrosion Films on Zirconium; March 1960.
- ANL-6259 R. D. Misch: Electrical Resistance Studies of Anodic and Corrosion Oxide Films Formed on Zr; May 1961.
- ANL-6370 R. D. Misch, C. Van Drunen: Corrosion Studies of Ternary Zirconium Alloys in High Temperature Water and Steam; July 1961.
- ANL-6434 R. D. Misch and G. W. Iseler: Electrical Measurements on the Growing Scale on Zirconium-Titanium Alloys; Oct. 1961.
- V. Other Corrosion Studies and Reviews
 - J. E. Draley: Fundamental Corrosion Studies; In Hearings Before Subcommittee on Res. and Dev. of the Joint Com. of At. En., Eighty-fifth. Congress of U. S.; Second Session in Phys. Res. Prog. Rel. At. Energ., Feb. 3-14, 1958; pp. 304-313.
 - J. E. Draley, J. A. Ayres, W. E. Berry, E. Hillner and S. P. Rideout: Corrosion in Aqueous Systems; 3rd Int. Conf. Peaceful Uses At. Energy, Oct. 1964, Vol. 9, pp. 470-481.
- J. E. Draley: Some Consequences of the Maintenance of Equilibrium of Alloying Constituents Between the Surface of Stainless Steel and Sodium in a Recirculating System; Proc. AIME Symp. Chemical Aspects of Corrosion and Mass Transfer in Liquid Sodium, Detroit, Oct. 1971, Ed. S. Jansson, AIME, 1973; pp 242-252.
- CT-1944

C. Wohlberg and J. E. Draley: Corrosion Res., Film Problems, 1944

2326 122

- 7 -

- 8 -

TECHNICAL PUBLICATIONS OF JOSEPH E. DRALEY (Contd)

- ANL-4837 J. E. Dreley and P. G. Drugas: Corrosion of Materials for Transparent Radiation Shields; October 28, 1949.
- ANL-6206 J. E. Draley, S. Greenberg and W. E. Ruther: Corrosion of Some Reactor Materials in Dilute Phosphoric Acid; April 1961.

Publications under his Supervision

- W. E. Ruther and R. K. Hart: Influence of Oxygen on High Temperature Aqueous Corrosion of Iron; Corrosion, 19, 127t-133t, April 1963.
- R. D. Misch: (Discussion); Corrosion, 19, 420t, Dec. 1963.

James Y. N. Wang: Titanium and Titanium Alloys in Mercury - Some Observations on Corrosion and Inhibition; Nuc. Sci. Engin. <u>18</u>, 18-30, Jan. 1964.

W. E. Ruther and S. Greenberg: Corrosion of Steels and Nickel Alloys in Superheated Steam; J. Electrochem. Soc., <u>111</u>, 1116-1121, Oct. 1964.

- James Y. N. Wang: Effect of Metallic Additives on Mercury Corrosion of Titanium; Corrosion, 21, 57-61, Feb. 1965.
- R. K. Hart and J. K. Maurin: Growth of Oxide Nuclei on Iron; Sixth Int. Cong. Electron Microscopy, Kyoto, Japan, pp. 539-540, Maruzin Co. Ltd., 1966.
- CT-1703 Raymond B. Hoxeng, Interim Report: Electrochemical Corrosion Research; May 1, 1944.
- ANL-6070 S. Greenberg and W. E. Ruther: Aqueous Corrosion of Magnesium Alloys; July 1960.

VI. Publications Concerned with General Corrosion Theory and Test Methods

- J. E. Draley and W. E. Ruther: Some Unusual Effects of Hydrogen in Corrosion Reactions; J. Electrochem. Soc., <u>104</u>, 329-333, June 1957.
- J. E. Draley: Discussion to paper by Carlsen; Corrosion, 14, 55t-56t, Jan. 1958.

S. Greenberg, J. E. Draley and W. E. Ruther: A New Dynamic Test Facility for Aqueous Corrosion Studies; Corrosion, <u>14</u>, 191t-192t April 1958.

J. E. Draley, W. E. Ruther, F. E. DeBoer, and C. A. Youngdahl: Measuring Equipment for Polarization Studies in Distilled Water; J. Electrochem. Soc., 106, 490-494, June 1959.

2326 123

- 9 -

TECHNICAL PUBLICATIONS OF JOSEPH E. DRALEY (Contd)

- J. E. Draley, F. E. DeBoer and C. A. Youngdahl: The Polarization of Metals in Boiling Distilled Water; J. Electrochem. Soc., <u>108</u>, 622-628, July 1961.
- J. E. Draley: Corrosion of Film Forming Metals I; Chem. Engin., <u>69</u>, 256-259, Nov. 12, 1962.
- J. E. Draley: Corrosion of Film Forming Metals II; Chem. Engin., <u>69</u>, 152-156, Nov. 26, 1962.

J. E. Draley: (Discussion); Corrosion, 19, 407t, Dec. 1963.

- J. E. Draley: High Temperature Corrosion Tests; in Nuclear Reactor Experiments, pp. 329-335, Feb. 1958; (D. Van Nostrand).
- S. Mori, R. E. Loess and J. E. Draley: pH Microelectrodes for Use Near Corroding Metal Surfaces; Corrosion, <u>19</u>, 165t-168t, May 1963.
- J. E. Draley and J. R. Weeks (Ed's): Corrosion by Liquid Metals; Proc. TMS AIME Symp., Philadelphia, October, 1969; Plenum Press, New York, 1970.
- J. E. Draley: Corrosion by Valve Metals; pp 185-234 in Corrosion Chemistry, Ed's. George R. Brubaker and F. Beverly P. Phipps, American Chem. Soc., Washington, 1979.

Publications under his Supervision .

- W. E. Ruther: An Eddy Current Gauge for Measuring Aluminum Corrosion; Corrosion, 14, 387t-388t, Dec. 1958.
- C. A. Youngdahl and R. E. Loess: Instrumentation for Potentiostatic Corrosion Studies in Distilled Water; J. Electrochem. Soc., <u>114</u>, 489-492, May 1967.

itte .

2326 124

ANL-5227 W. B. Doe: Eddy Current Type Diameter Gauge for Corrosion Measurements.

VII. Published Educational Lectures

1

- CL-606 Part 5 J. E. Draley: Corrosion; in Training Program Lecture Notes, 1943.
- J. E. Draley: Aqueous Corrosion of 2S Aluminum at Elevated Temperatures; A Short Course in Corrosion, U. of California, Feb. 1953; pp. 106-109 (U. of Calif. Press).
- J. E. Draley: Corrosion in the Atomic Energy Industry; Corrosion Short Course, Univ. of Oklahoma, April 1958, pp. 215-240.

VIII. Publications Concerned with Specific Reactor Systems

J. E. Draley: Fluid Fuel Power Reactors; Trans. Am. Nuc. Soc., 2, 46-47, Nov. 1959. TECHNICAL PUBLICATIONS OF JOSEPH E. DRALEY (Contd)

TID-8507 Joseph E. Draley, with 14 Co-authors: Report of the Fluid Fuel Reactors Task Force; Feb. 1959.

J. E. Draley and S. Greenberg: The Application of Materials in Low Temperature Water and Organic Liquid Cooled Reactors; Symposium on Behavior of Materials in Reactor Environment, Feb. 20, 1956, (Institute of Metals Division of AIME) Special Report No. 2, pp. 33-53.

ANL-6360 C. E. Stevenson, J. E. Draley, L. W. Fromm, Sheffield Gordon, H. P. Iskenderian, A. A. Jonke and R. R. Rhode: Organic Nuclear Reactors - An Evaluation of Current Development Programs; May 1961.

IX. Publications Related to the Environment and to Fusion Reactors

Report of the Study Group on Environmental Follution, Argonne National Laboratory, February, 1967

- J. E. Draley, B. R. T. Frost, D. M. Gruen, M. Kaminsky, and V. A. Maroni: An Assessment of Some Materials Problems for Fusion Reactors; Proc. 1971 Intersociety Energy Conversion Engineering Conference, Boston, 1971, pp 1065-75.
- Summary of Recent Technical Information Concerning Thermal Discharges into Lake Michigan, by Center for Environmental Studies and Environmental Statement Project, ANL, for the Environmental Protection Agency, August 1972 (Section VI. Chemical Inputs, by J. E. Draley).
- J. E. Draley and S. Greenberg: Some Features of the Impact of a Fusion Reactor Power Plant on the Environment; Proc. Symp. Tech. Controlled Thermonuclear Fusion Experiments and Engineering Aspects of Fusion Reactors, Austin. Texas, Nov. 1972; Tech. Information Service, 1974.
- ANL/ES-12 Joseph E. Draley: The Treatment of Cooling Waters with Chlorine, February 1972.
- ANL/ES-23 J. E. Draley: Chlorination Experiments at the John E. Amos Plant of the appalachian Power Company, April 9-10, 1972; June, 1973.

ANL-8019/LA-5336 T. A. Coultas, J. E. Draley, V. A. Maroni, R. A. Krakowski: An Environmental Impact Study of a Reference Theta Pinch Reactor, February 1974.

X. Other Publications

R. A. Gustison, E. J. Frederick, E. F. Story, Jr. and J. E. Draley: The Determination of Small Amounts of Impurities in Water; April 30, 1945.



CC-3019

TECHNICAL PUBLICATIONS OF JOSEPH E. DRALEY (Contd.)

- CM-436 Joseph E. Draley: Convective Cooling of Heated Surfaces by a Parallel Supersonic Air Stream. Applied Physics Laboratory, Silver Spring, Md., May 1947.
- TID-17940 J. E. Draley and F. W. Young, Jr.: Visit to Soviet Corrosion Chemistry Institutes; June 25 - July 4, 1962.

Publications under his Supervision

F. E. DeBoer: Analysis for Magnesium in High Purity Aluminum; Letter to Editor, Nature, <u>184</u>, 54-55, July 4, 1959.

F. E. DeBoer: Purification of Metals by Gas Chromatography; Letter to Editor, Nature, <u>185</u>, 915, March 1960.

Raymond K. Hart: Electron Diffraction Techniques and Their Applications to the Study of Surface Structure; Progress in Nuc. Energy Series IX, Analytical Chemistry, Vol. 7, pp. 1-20, Pergamon Press, 1966.

R. K. Hart and D. G. Pilney: A Compact Vacuum Path 20 Scanner; The Electron Microprobe, Edited by McKinley, Heinrich and Wittry, pp. 472-479, John Wiley and Sons, Inc. 1966.

R. K. Hart, T. F. Kassner and J. K. Maurin: Residual Gas Analysis in an Auxiliary Pumped Siemens Electron Microscope; Sixth Int. Cong. Electron Microscopy, Kyoto, Japan, pp. 161-162, Maruzin Co. Ltd., 1966.

Raymond K. Hart: Composite Aluminum-Nickel Evaporated Films; J. Appl. Phys., 37, 2918-2919, June 1966.

R. K. Hart; Electron Microscopy: The High Voltage Approach; Twenty-Fifth Annual Meet. Electron Micr. Soc. Am., Aug. 29-Sept. 1, 1967, Chicago, Illinois.

R. K. Hart and D. G. Pilney: Effect of Spectral Line Shift on Microprobe Data, Sec. Nat. Conf. Electron Microprobe Analysis, June 14-16, 1967, Boston, Mass.

CT-3049 C. Wohlberg, A. Schwebel, R. W. Berger and F. Nelson: Film Studies and Protection of Hydrous Oxides; June 18, 1945.

II. Patents

J. E. Draley and W. E. Ruther: Nuclear Reactor Component Cladding Material; U. S. Patent 2,871,176; Jan. 27, 1959.

2326 126

Joseph E. Draley and Westly E. Ruther: Nuclear Reactors and Subassembly Therefor; Br. Patent 811,528; April 8, 1959.

- 11 -

Professional Qualifications of

Joseph E. Draley

At Argonne National Laboratory I manage the OTEC (Ocean Thermal Energy Conversion) Biofouling, Corrosion, and Materials Project, carrying out a national program for the Department of Energy. In the present instance, testifying before the NRC Licensing Board, I speak on my own behalf and do not represent Argonne National Laboratory. At the Metallurgical Laboratory of the University of Chicago (3 years), Oak Ridge National Laboratory (1-1/2 years), and Argonne National Laboratory (20 years) I studied the corrosion and oxidation of metals, serving as group leader or Section Chief before going into management. A considerable amount of the corrosion work done has been of direct interest for nuclear power plants. I have also studied the environmental impact of nuclear power plants in connection with construction permit or operating license applications. A professional resume is attached, giving these and other details.

Over 150 technical publications have been authored by me or people working in groups I headed. Of these, I was author or coauthor of nearly 100 publications. The preponderant majority of all these publications were on the topic of corrosion or oxidation; many dealt with the aqueous corrosion of aluminum and a smaller number with the aqueous corrosion of stainless steel and zirconium alloys. In a number of instances, publications dealt with nuclear systems. A list of technical publications is attached.

I have been active in corrosion affairs in the Electrochemical Society and the Metallurgical Society of the AIME, serving as Corrosion Division Chairman and corrosion editor of the official journal for the former, and chairman of the Corrosion Resistant Metals Committee of the latter. I helped to originate American Corrosion symposia related to nuclear energy and an international meeting (Brussels, 1959) on the same topic. I participated in the Geneva Conferences on the Peaceful Uses of Atomic Energy.

I hold a bachelor's degree in chemical engineering (1939) and a PhD degree in chemistry (1947).

1



BNL-NUREG-23021 INFORMAL REPORT

CORROSION OF MATERIALS

· . ·

· .

1

IN

SPENT FUEL STORAGE POOLS

J.R. Weeks

July 1977

2326 129

Corrosion Group Department of Applied Science Brookhaven National Laboratory Upton, New York 11973

TABLE OF CONTENTS /

LIS	TOF	TABLES	11
INT	RODUC	TION	1
I	NAT	ERIALS	2
II	WAT	ER CHEMISTRY	3
	1.	BWR Fuel Pool Chemistry	3
	2.	PWR Fuel Pool Chemistry	3
	3.	Biocides	4
III	COR	ROSION OF MATERIALS IN FUEL STORAGE POOLS	5
	1.	Stainless Steels	5
	.2.	Aluminum Alloys	5
	3.	Zircaloy Cladding	6
	4.	Other Materials	6 .
•	5.	Stress Corrosion	6
	6.	Galvanic Corrosion	7
IV	SURVEILLANCE		9
•	SUMMARY AND CONCLUSIONS		10
ACK	NOWLE	DGEMENTS	11
REF	ERENC	12	
TAB	LE	13, 14, 15	

1

LIST OF TABLES

:-

1

TABLE 1 MATERIALS AND WATER CHEMISTRIES IN LWR FUEL

. .

STORAGE POOLS-----

INTRODUCTION

The current delays in establishing a national fuel reprocessing center have required many of the LWR licensees to expand their fuel storage capabilities either by modification of existing pools or addition of new fuel storage pools. This report reviews the potential corrosion problems that might develop during the longterm (10 plus years) storage of nuclear fuels in these storage pools. A detailed review of the integrity of the fuel in storage pools is being prepared by Johnson for ERDA, ⁽¹⁾ which has served as a basis for much of this report. Zircaloy-clad fuels with burnups up to 33,000 MNd/MTU have been successfully stored in fuel storage pools for periods up to 13 years in U.S. pools and 14 years (at lower burnups) in Canadian pools.

1

MATERIALS

I

Three types of materials are generally in contact with the fuel storage pool water: the pool liner which is commonly stainless steel, the storage racks which are commonly stainless steel or aluminum, and the materials present in the fuel element bundles which commonly include stainless steel, Incomel 718, 17-4 PE, and Zircaloy 2 or Zircaloy 4 cladding. Table 1 lists the materials and water chemistry used in the fuel storage pools at a number of LWR nuclear stations, as available to the writer as of July 15, 1977.

Experience with storing these materials for long periods of time in reactor canals has been reviewed by A.B. Johnson, Jr.⁽¹⁾ Maximum residence in U.S. Pools of spent zircaloy-clad fuel is 13 years. None of these materials should suffer significant corrosion in this environment in periods well in excess of 10 years, as has been borne out by experience.

II WATER CHEMISTRY

-

1

Because during the fuel unloading procedure the water in the fuel storage pool and the reactor primary coolant mix, an attempt is made to maintain water purity in the fuel storage pool to approximately the same limits that are set for the primary reactor coolant.

1. BWR Fuel Pool Chemistry

In a BWR this means that high purity demineralized water is typically maintained with a filter-demineralizer to a total heavy ion content of < 0.1 ppm, a pE range of 6.0 to 7.5, and a conductivity of < 1 umho/cm. The water is sampled daily to measure conductivity, and weekly for other impurities, including chlorides. The demineralizers primarily remove silicates from the water, and are typically checked for their capacity to remove this species once weekly. The primary source of the silicates may be dust from the air; the pools are normally uncovered. On the aver- . age, fresh resin beds are installed monthly, primarily because of increased pressure drops from silicate absorption. (2) The primary contribution to the conductivity is dissolved CO2; when the conductivity exceeds 1 umho/cm the demineralizers are changed. (2) During a visit in June, 1977, the water in the Vermont Yankee fuel pool appeared extremely clear, with a distinct blue tinge to it, apparently as a result of scattering of the longer light waves by the water and the use of mercury wapor lighting.

2. PWR Fuel Pool Chemistry

In a PWR, the fuel pool frequently contains several thousand ppm boric acid, which is added to other otherwise highly pure water. No neutralization with LiOE is used in the fuel storage pools; a typical pH⁽³⁾ value is 4.5. A portion of the fuel pool

coolant is continuously passed through a demineralizer resin and impurities, such as halides or sodium ions, maintained below 0.15 ppm. Periodically the demineralizer resins are checked for their ability to remove halides and sodium ions; resins have been developed by Rohm and Haas that are specific for removing halides in the presence of boric acid. The manufacturer's claims in this matter have been confirmed experimentally by one of the reactor vendors.⁽⁴⁾

3. Biocides:

5

Biocides are not commonly used in fuel storage pools at nuclear power plants. Maintaining the water of the high purity needed for safe storage of fuel appears to inhibit biological growth, and the use of stainless steel liners in the storage pool also tends to control biological growth. The radiation levels from the spant fuel stored in the pool also tend to sterilize the water, although radiation resistant bacteria are known. Finally, the continuous demineralization of a portion of the pool water serves to filter out any biological growth. No biological fouling has been observed in 3 1/2 years operation of the Prairie Island spent fuel pool, ⁽³⁾ in 3 1/2 years operation of the Vermont Yankee, > 5 years operation of the Maine Yankee, and > 10 years operation of the Yankee-Rowe fuel storage pools, ⁽²⁾ and no biocides have been added.

The use of biocides can lead to the presence of chloride ions in the pool which are potentially harmful to the corrosion resistance of the materials stored in the pool, and would be unacceptable during the mixing with the reactor primary coolant that occurs during refueling. They have been used in the ICPT fuel pool at Idaho Falls, which is a painted concrete pool.⁽¹⁾

III CORROSION OF MATERIALS IN FUEL STORAGE POOLS

The corrosion rates of zirconium, stainless steels and Inconel in water of the quality maintained in the fuel storage pools should be negligible during periods upwards of twenty years. General corrosion rate measurements for these materials in water of this quality and temperature are not generally available, and any estimates of corrosion rates must be extrapolated from measurements at much higher temperatures. The primary difference between the water chemistry in the fuel pools and that in the reactor (other than the temperature) is that the pools are exposed to the air and are presumed to contain dissolved oxygen up to the saturation point. Since all the materials used are passivated by oxide films, the presence of oxygen in the water should not affect their corrosion rates.

1. Stainless Steels

Since the stainless steels are used for the primary piping at substantially higher temperatures and in the presence of oxygen in BWR's where stainless steels are deemed satisfactory for periods up to 40 years, corrosion in the fuel pool should be much less than in the reactor, because of the lower temperature.

2. Aluminum Alloys

5

The anticipated corrosion of the aluminum alloys, 1100 or 6061, is negligible in water of this quality at temperatures up to the boiling point of water: at $125^{\circ}C$ ($257^{\circ}F$) a corrosion rate of 1.5 x 10⁻⁴ mils/day⁽⁵⁾ has been measured for alloy 6061 aluminum, in water of pE 7, which corresponds to a total corrosion of 1.1 mils in twenty years. Since the oxidation rate will continue to decrease slightly over this period, this estimate should be conservative. At lower temperatures, the rate will be even

2326 136

lower. There is little difference in the corrosion rates of these two alloys at temperatures below 150°C. The anodization of the aluminum components, which is occasionally used, should protect them even further from corrosion.

3. Zircaloy Cladding

.

:

The rate of corrosion of sircaloy in fuel storage pool waters is very low. Berry⁽⁶⁾ gives a corrosion rate in 500° water of 2 x 10^{-2} mils/year, and shows it to be continually decreasing up to times in excess of 10 or 15 years. At the lower temperatures that prevail in fuel storage pools, the corrosion rates should be even lower. Morgan ⁽⁷⁾ describes the corrosion rate of zircaloy in pool water as being sufficiently low to provide an adequate containment barrier for at least 100 years.

The oxygen concentration in the pool water should not adversely affect corrosion of zircaloys. Zirconium and its alloys are protected from aqueous corrosion by a strongly passivating oxide film. The oxygen in the water should serve to promote and maintain this passivation. Further, Uhlig⁽⁸⁾ has stated that this passivity is maintained both in strong acids and in strong alkalis.

4. Other Materials

The fuel bundle and storage rack materials may also include type 17-4 PH stainless steel and Inconel 718. Neither of these alloys should undergo measurable general corrosion in fuel storage pool waters.

5. Stress Corrosion

Stress corrosion of stainless steels and zircaloys in fuel storage pools is highly unlikely to occur provided the water

2326 137

chemistry is maintained within the specified limits. Stress corrosion of sensitized stainless steels that are highly stressed has been observed in oxygenated water acidified to pE 5 mitric acid at temperatures up to 140°F. (9) This is, however, a slow process which took 6 years to develop and occurred only in one highly . stressed, highly sensitized area. While it is impossible to rule out completely that stress corrosion of the stainless steel or Inconel components will occur in the fuel storage pool, any such occurrence would be highly localized and rare, and not lead to serious problems with the storage racks or fuel bundle components. No significant difficulties have been observed in fuel bundles examined from a number of yeactors. Stress corrosion of 17-4 PH is unlikely to occur if the material has received an 1100 T heat treatment. This heat treatment is commonly specified for this material when it will be exposed to reactor coolants. Components of 17-4 PH given this heat treatment have been in service in the Brookhaven High Flux Beam Reactor (EFBR), which contains high purity D_0 acidified with nitric acid to a pD cl 5 and containing greater than 8 parts per million of oxygen, for periods in excess of 12 years without any evidence of stress corrosion or pitting. (10) This water chemistry and temperature (145°F max.) are similar to that prevelant in PWR fuel storage pools.

6. Galvanic Corrosion

:

Galvanic couples between stainless steels, Inconel and zircaloy do not appear to give rise to any localized corrosion in fuel pool environments, since all of these materials are protected by highly passivating oxide films, and are, therefore, at similar potentials in pure water. Aluminum alloys, which are also protected by passivating films, nevertheless can be pitted in an acid environment such as that present in PWR fuel storage pools, when coupled to stainless steel. The anodization of aluminum fuel storage racks 2326 138

LULUIU

should minimize this occurrence. In BWR storage pools, the high electrical resistivity of the water should also serve to prevent galvanic attack.

At the Oyster Creek Buclear Power Station, aluminum racks were originally placed directly in contact with the stainless steel pool liner. Some of these racks have been removed and examined after approximately 7 years of service in typical BWR pool water. ⁽¹¹⁾ No observable pitting of the aluminum was found at the point where it contacted the stainless steel. ⁽¹¹⁾ At least one nuclear utility (Vermont Yankee) has also elected to provide additional protection against this potential problem by placing stainless steel feet on the racks, which, in turn, are electrically insulated from the aluminum with ABS plastic inserts. These have been determined to be sufficiently far from the radiation source to prevent their decomposition by high energy gamma flux. ⁽²⁾ These organic inserts are, in By opinion, additional insurance that galvanic corrosion will not occur.

IV SURVEILLANCE

A spent UnReprocessed Fuel (SURF) program is under development by the ERDA Division of Waste Management, Production and Reprocessing, to be initiated in FY 1978.⁽¹²⁾ Under this program, the characteristics and condition of spent fuel in storage will be evaluated on a continuing basis. Although the details of the examination to be performed in this program have not yet been worked out, the uational scope of this program, including periodic examination of a few selected fuel bundles from both FWR and EWR storage pools, will provide additional assurance to the ERC of the continued integrity of fuels in storage throughout the country.

9

V SUMMARY

Significant corrosion of nuclear fuel components is highly unlikely to occur during storage in fuel storage pools at the reactor sites in periods of upwards of 20 years, provided that the water quality in the fuel storage pools is maintained within specifications, and that chloride levels in the pool water are kept to minimum levels (< 1 ppm). Stress corrosion of stainless steel components or Zircaloy cladding cannot be entirely ruled out because of the lack of understanding of the stress states and the degree of sensitization of stainless steel. Should such a problem develop on the Zizcaloy cladding it would be readily detected by routine monitoring of the fuel pool water for radioactivity. Should it develop on the stainless steel or Inconel components of the fuel bundles, it would be highly localized and unlikely to lead to significant overall deterioration. Periodic surveillance of the materials in storage at a number of nuclear utilities is being planned under the auspices of the U.S. Energy Research and Develop-Bent Administration.

COOK ALED GENENTS

The assistance of Dr. A.B. Johnson, Jr., of Battelle Facific Morthwest Laboratory, in providing draft copies of his review (Reference 1) and in several useful discussions is gratefully acknowledged. Representatives of the Northern States Power Company, Yankee Atomic Electric Company, Duquesne Power and Light Company, Jersey Central Power and Light Company, and the Portland General Electric Company were very helpful in preparing this review. This work was performed under the auspices of the United States Nuclear Regulatory Commission

11

REFERENCES

- A.B. Johnson, Jr., "Behavier of Spent Nuclear Fuel in Water Pool Storage", BNWL-2256, Draft, May, 1977, also private communications, May, June and July, 1977.
- John R. Hoffman, Yankee Atomic Electric Company, Private communications, June 6 and 7, and July 14, 1977.
- Peter Jones, Northern States Power Company, Private communications June 1 and July 15, 1977.
- C. McCracken, Combustion Engineering, Private communication, June 3, 1977.
- J.E. Draley and W.E. Ruther, Report No. ANL-5001, February, 1953.
- W.E. Berry, "Corrosion in Nuclear Applications", John Wiley
 Sons, N.Y., 1971, pages 107-116
- 7. W.W. Morgen, "The Management of Spent CANDU Fuel", Nuclear Technology 24, 1974, pages 409-417.
- H.H. Uhlig, "Corrosion and Corrosion Control", John Wiley & Sons, N.Y., Second Edition, 1971, pages 367-371.

1

- R.W. Powell, J.G.Y. Chow, W.J. Brynda, M.E. Brocks, J.R. Weeks "Experience With Stress Corrosion Cracking and Materials Compatibility at the High ?!ux Beam Reactor", CONF-730801, 166-180, 1973.
- R.W. Powell & J.G.Y. Chow, Brockhaver National Laboratory, Private communications.
- T.J. Madden, Jersey Central Power & Light Company, Private communication, May 19, 1977.
- 12. C.R. Cooley, U.S.E.R.D.A., Private communication, July 14, 1977

TABLE I

MATERIALS AND WATER CHEMISTRIES IN LWR FUEL STORAGE POOLS

PLANT	MATERIAL	. USE	ENVIRONMENT
ARJEANEAS (IPHR)	304 35 A-276-71 or A-167-74 308 or 308L 304L ASTN-A-167	Rack Electrode Liner	1800 pps boron as boric acid 120°F
BEAVER VALLEY (FWR)	85, 17-4 FE	Racks, bolts	2000 ppm boron as boric acid, cl., F < 0.15 ppm
BRONSIGER (BWR)	304 88 E308 17-4 7E - E1150, E1025	Liner, racks Electrodes Bolts	125°7 (max 150°7) cond < unho/cm pH 6.0 - 7.5 C1° < 0.2 ppm
DRESDEN 1, 2 and 3 (BINR)	Stainless steel Al-6061-T6 ASTN-3-209	Liner Racks	Demineralized water sumo filters and deep bed deminer- alizers
FT. CALECUN	304 85 ASTM-A-276-71 or A-167-74 308 or 308L	Racks Weld	120°7 2000 ppe boron as boric acid
GINNA, R.Z. (PWR)	304 85	Racks	Borie acid
LACROSSE (BWR)	Borated \$5 and 304 \$5	Racks	Demineralized water
NELLSTONE BOINT I (INR)	304 85	Liner, racks	Demineralized water Filter and deminer- alizer
NELLSTONE POINT 2 (PNR.)	304 \$5	Liner, racks	Demineralized water + 2000 ppm boron as boric acid

13

Ó

2
TABLE I

(continued)

PLANT	MATERIAL	USE	THVIRONMENT	
NINE MILE POINT 1 (INNR)	304 85	lack	Demineralized water of BMR primary cool- ent quality 125°?	
OYSTER CREEK	Entira rack 304 SS ASTH-A-240 ASTH-A-193 ASTH-A-194 308 SS, ASHE SFA 5.9	Plats, bar sheet Rivets, bolts Ruts Weld material	Dumineralised water Obdissolved solids < 0.5 ppm	
PALISADES . (PWR)	304 55	Rets	122°7 - 157°7 2000 ppm boron as boric acid	
CLORIN (BWR)	Same rack design as Vermont Tankee		•	
NUDIT BEACH 1 and 2 (FWR)	304 55	Backs .	2000 ppm boron as boric acid 130°7	
PRAINTE ISLAND 1 and 2 (PWR)	304 SS Zircaloy, DN-718	Racks, liner Funl bundles	Demineralized water (C1 ⁻ , F ⁻ < 0.15 ppm + 2000 ppm boron as boric acid pf 4.5, 120 ^o F	
: QUAD CITIES 1 and 2 (BWE)	Same rack design as Dresden			
CIVIR.)	304 SS Inconel 17-4 FE - Elloo	Racks, liner Grid Mat'l. Bolts and Module threaded feet	2000 ppm boron as boric acid 140°7 Cl., F., 0.15 ppm marinum each	

TABLE I

0

;

0

. ..

(continued)

PLANT	MATERIAL	USE	ENVIRONMENT	
TURKEY POINT 3 and 4 (PWR)	Entire rack 304 SS Free standing rack ASTM-A-240 ASTM-A-276 AMS-E-308-15 AMS-E-308-16	Sheet, plate Bar Wold wire Wold wire	Demineralized water with 1950 ppm boron as boric acid	
VERMONT YANKEE (BWR)	356-T51 ASTM-B-26 Alum. 6061-0 or 5052-E32 Alum. 6061-T651 Alum. 2024-T4 Alum. All aluminum alloys, anodized 304 SE ABS plastic insulators between feet 6 alum. Cans	Grid castings . Cans Flates Bolts, Fins Liner, feet	<pre>pE 6 - 7.5 (Cu, Hi, Fe, Eg, etc.) < 0.1 ppm 125°F Radionuclide < 10⁻⁴</pre>	
THE ROWE	6061-TE Alum. Stainless Steel	Rack Liner	130°F, some boron, chlorides < 0.5 ppm	
ZION (PWR)	304 55	k d	Borated water 105°r	

2326 146

15

.

DISTRIBUTION LIST

...

L.C. Shao (5) R.J. Stuart W.S. Easelton F.M. Almeter E. Levin (5) W.Y. Kato D.E. Gurinsky Corrosion Group Files (10)

1 ----

3

\$

.

.

Vol. 110, No. 6, June. 1963 Printed in U. S. A.

The Corrosion of 1100 Aluminum in Oxygen-Saturated Water at 70°C

J. E. Draley, Shiro Mori, and R. E. Loess Argonne National Laboratory, Argonne, Illinois

ABSTRACT

In oxygen-saturated distilled water at 70°, the rate and amount of corrosion during short exposure are influenced by experimental conditions. One noteworthy effect is that contamination of the water by the reaction increases the corrosion rate. Subsequent to the first several days, the amount of corrosion varies with the logarithm of the exposure time. This behavior holds for at least 180 days; it is believed to hold for as long as tests have provided reasonable data, the longest being about 650 days. These results are interpreted in terms of local film rupture and growth. A method of averaging the over-all corrosion rate on the basis of cyclical local reactions is derived.

The corrosion of aluminum in nearly pure water has been under study in this laboratory for a number of years. Originally 1100 aluminum (then 2S) was chosen for study at temperatures below 100° because it was under consideration for use in water-cooled nuclear reactors. Subsequently, when the research objective became simply the determination of corrosion mechanisms, the same alloy was continued under study. Although this alloy contains a number of impurities, the major ones being iron, silicon, and copper, its behavior is reproducible, and the backlog of information previously obtained is helpful in interpreting more recent results and in testing hypothesized mechanisms.

A certain amount of research has also been done with pure aluminum in water. From the point of view of kinetic studies this material does not lend itself to relatively simple treatment because of the local penetrating attack which takes place at grain boundaries, and because of a sensitivity to the amount of impurities present.

In a previous publication (1), many of the features of the corrosion of 1100 aluminum in oxygensaturated distilled water at 70° have been described. Of particular interest to the present investigation are: (A) No gross pitting occurs, although micropits of the order of 20µ in diameter form. These do not grow in size, but their number increases. Localized, self-stifling reaction is indicated. (B) After sufficiently extended exposure, bits of the corrosion product slough or flake off, leaving a metallic sheen. The corrosion product does not again grow thick in those places, and there is no observable increase in corrosion of the specimens. It is apparent that, at least at long exposure times, the presenting critic is thin and the told by and corrosion privatet coating is not significantly protective.

Also in the same publication, some aspects of the kinetics of the reaction were given. For the first sev-

by a period of diminishing corrosion rate. The shape of this part of the curve was not established.

In the present publication, some of the features of the initial period of corrosion are explored, the kinetics of the reaction during long exposure is determined, and for the latter there is derived a rate expression which seems to fit the known facts.

Experimental

Water.—High quality water was provided for all tests by passing laboratory steam condensate through ion exchange resins and then distilling. Occasional spectrographic analyses showed only a few metallic elements present above the limit of detection. Sodium, potassium, and magnesium contents varied from a few ppb (grams per 10^{9} g H₂O) up to 50 ppb.

This water was vigorously boiled in Pyrex carboys at room temperature (by pumping with a steam ejector) for degassing, and oxygen was bubbled through it for a period of time. Periodic measurement showed the water to have a pH of 6.5 ± 0.2 and specific resistance $1.4 \pm 0.2 \times 10^6$ ohm-cm. No noticeable change in pH was caused by passage over the specimens; there was sometimes a slight increase in resistivity, indicating that the oxide-covered specimens had somewhat purified the water.

Method of exports.—Eight (or fewer) specimens were suspended on Pyrex glass in the chamber shown in Fig. 1 (thermostatted to $70^{\circ} \pm 1^{\circ}$ C). Fresh water from the carboy was added continuously through a regulating section of Pyrex capillary, and the excess water was discharged to the drain.





Fig. 1. Correction test chambe

Vol. 110, No. 6

1.

623

The difference between the temperature and pressure in the test chamber and those in the storage carboy (2-4 psig O_2) caused continuous slow evolution of oxygen gas during the corrosion exposure. For the test of long duration, two chambers were used in series, with the refreshing water passing through each in turn; the rate was about 15 cc/min for the first 5 days and 7 cc/min thereafter.

Material and sample preparation.—The material source was one batch of commercially extruded 1100 aluminum rod. Analyses showed impurities to consist of: 0.54% Fe, 0.12% Cu, 0.07% Si, 0.017% Zn, 100-200 ppm Ti, 25-50 ppm Zr, 5 ppm Mo. Samples were prepared by careful machining to a size just slightly too large for use in the eddy current thickness gauge. They were then degreased and etched (10 cc conc. HNO₂, 1 cc 48% HF, 89 cc H₂O; about 60° C) until approximately 50µ had been removed. Specimens were rinsed and annealed (15 min at 360° C, slow cooled) before being weighed, measured in the thickness gauge, and corroded.

Determination of amount of corrosion .- Since the predominant corrosion product is an adherent oxide. specimen weight gain provides an approximate measure of the amount of corrosion. However, some of the oxide is lost to the water (dissolution, spallation, etc.), and the composition of the product changes with time as well as with exposure conditions. These features are illustrated in Fig. 2 where, for a single specimen, the gain in weight (G), the amount of metal corroded (L), determined by the eddy current gauge to be described, and the amount of aluminum lost from the specimen (ξ) during exposure to O2-saturated water at 70°C are shown. The amount of metal lost was determined by chemical analyses of the effluent solution from the test chamber, after it had been concentrated by evaporation. It was necessary to correct these values for the amount of aluminum initially present in the water.

Using the approximation that the composition of the corrosion product is $Al(OH)_x$, the value of x is

readily shown to be equal to $\frac{G+\xi}{L-\xi} \cdot \frac{27}{17}$. This ratio

is observed to decrease with exposure time for the present experiment, although other types of change have sometimes been observed. It is typically not equal to 3.0, the stoichiometric composition of the



Fig. 2. Corresion product composition and loss to water

oxide (bayerite) indicated by x-ray diffraction to comprise the bulk of the corrosion product.

There are two chemical methods available for determining directly the amount of unreacted metal at the end of an exposure. The metal can be dissolved in a solution of iodine in methanol (2), or the oxide can be dissolved from the surface (1). Both of these methods have been considered unsatisfactory for the present research. The errors for the specimens used range from about 0.1 mg (for the film removal method) to something several times this magnitude for the metal dissolution method. These errors are objectionably high and would make impossible a satisfactory determination of the kinetics of the reaction of 1100 aluminum with water after the first few months of exposure.

In addition to the inaccuracy of these two methods there is another problem. Different specimens characteristically corrode to a different extent, even though the corrosion rates in an individual test are generally identical, as well as can be measured, after extended exposure. Any method of determining the amount of corrosion which destroys the sample for subsequent exposure adds a kind of statistical scatter in the data which has made it impossible to determine curve shapes with reasonable confidence.

A specially developed eddy current thickness gauge is insensitive to the amount of oxide costing. For a few years it has been used in obtaining data which are believed reliable and of acceptable precision (\pm 25A penetration). The change in the inductive properties of a cvil are measured as a function of the thickness of me'al placed within it. Details of this gauge are yet to be reported, although a first model (3) and a usable but less sensitive version have been described (4). The calibration curve, as used in the present investigation, is given in Fig. 3. The straight line drawn through the points for samples which were etched in HNO3-HF solution continued linearly, beyond this figure, up through 200 mg of metal removed per sample. Since all specimens had the same surface area (29.19 \pm 0.01 cm²), this calibration curve could readily be used to determine the amount of corrosion in mg/dm².

The solid points are for specimens which had been co.roued in water; most of those showing more cor-





.

.

rosion than 10 mg/sample were the ones used in determining the kinetics for extended exposure. In all such cases, the weight of metal corroded was obtained after removal of the corrosion product coating following exposure. It is noted that these points generally fall below the line. This is apparently a consequence of uneven corrosion of the specimens. During the early part of the exposure the specimens had less corrosion product near the ends than in the center, suggesting that less corrosion had taken place at the ends. As a consequence it is believed that data reported at present can be expected to apply to the central portion of the specimens only. The phenomenon is believed related to a water contamination effect during the initial stages of the corrosion reaction (see next section). For the longest exposure times, there is also another factor contributing to deviation of the points from the line. This will be described later.

Data and Results

Short time behavior.—In ref. (1) it was indicated that the amount of corrosion in water at 70° is proportional to the logarithm of time through about the first 7 hr of exposure. The characteristics of the corrosion kinetics in this stage have been investigated somewhat further. It is not considered suitable to discuss here all of the experimental parameters which influence the rate and amount of corrosion during early exposures. However, it is considered desirable to point out a few of the important observations for the purpose of adding perspective in the consideration of the longer time corrosion.

Effect of exposure interruption.—If it is desired to make a series of measurements of the amount of corrosion on the same sample, with further corrosion exposure between measurements, it is important to know whether the amount of corrosion has been influenced by removal from the test water and drying. Subsequent to the first several days of exposure, when reaction rates have become low, it has been demonstrated that there is no discernible effect of this interruption of the exposure.

For short exposures the situation is different. A series of 10 specimens was placed in one chamber and corroded together. These specimens were removed one at a time for exposures up through 48 hr, dried, and the amount of metal corroded determined with the eddy current thickness gauge. Each of these specimens was subsequently reinserted in the test for further exposure, up to a total of about 13 days. The points representing continuous exposure are connected by a solid line in Fig. 4. This line is quite similar in character to data previously reported (1). There is apparently a logarithmic corrosion behavior up to something less than half a day, followed by an increase in slope of the line on semilog coordinates.

Note that after initial exposures through 1 day all specimens corroded at much lower rates on reexposure to the water. The dependence of the rate on further exposure is not well determined, but there is a common break upward in the curves after a time of the order of 5 days. It is thus evident that removing the specimens and drying them causes a substantial reduction in subsequent corrosion rate and a delay of the upward break in the semilog plot.

Number of specimens.—There are a number of indications that during the initial stages, a product of the corrosion reaction contaminates the water and increases the amount of corrosion occurring. One of the indications of this is illustrated in Fig. 5. Two tests were run identically except that one chamber contained eight specimens and the other contained only one. It is characteristic that substantially more corrosion occurred per specimen in the chamber containing the greater area of corroding metal.

A number of other such comparative experiments have shown that the time of onset of the upward break in the semi-log plot and its magnitude are the most sensitive aspects of the corrosion reaction to this variable.

Refreshment rate.—When the number of specimens in the chamber was made the same but the rate of addition of refreshing water was changed from 5 to 16 ml/min similar results were obtained. Apparently the higher flow rate diluted the contaminant and reduced the magnitude of its corrosion-inducing effect.

Further illustration of this effect is shown in Fig. 6. Here the gain in weight of specimens corroded in identical fashion for 16 hr is plotted as a function of the rate of refreshment. It is indicated that for these particular conditions, something above 20 ml/min refreshment rate minimizes the effect of the



Fig. 4. Effect of exposure interruption



Fig. 5. Influence of number of specimens in test, refreshment rate 6 ml/min. 2326 150

:

CORROSION OF 1100 ALUMINUM







Fig. 7. Various effects of water contamination

contaminant, and that further increase in the refreshment has no further effect. The specimens in this series of experiments were wet-ground before exposure, but the results are believed to be indicative of the behavior of initially etched surfaces. The weight gain provides only an approximation of the amount of metal corroded, but the trend is evident.

In Fig. 7 are shown curves which seem to illustrate all of the three effects so far discussed: interruption, number of specimens, and refreshment rate. Comparison of the top two curves indicates that a high refreshment rate provides a smaller amount of corrosion (abetted by early interruption). Comparison of the middle and bottom curves shows that the effect of the number of specimens was greater than that of the refreshment rate. The middle curve was run at conditions which have now been taken as standard. For the earliest part of the exposure the flow rate was maintained high to minimize the effect of contamination: subsequently the

ing the long time experiment.

Reproducibility.—For longer tests it is characteristically observed that different specimens in the same test show amounts of corrosion which differ by perhaps 10% although the rates of corrosion seem to be identical. This effect is a consequence of variable behavior of specimens during early exposure. The slopes of the logarithmic curves generally have been equal prior to the upward break: however the time at which the break occurs has varied over a



Fig. 8. Long term kinetic behavior; 0, uncorrected; 0, corrected

fairly wide range, and this has influenced the height of the final plateau.

Long Time Behavior

The results of one long test will be described here. As a precaution against possible metallurgical changes in the specimens which would influence the readings taken on the eddy current thickness gauge, three specimens were maintained in a helium environment. These were kept in the same constant temperature bath which was used for the corrosion exposure, and they were removed and replaced at the same times as the corroding specimens. Their apparent thicknesses, as determined by the gauge, were recorded periodically.

The changes in thickness gauge readings were significant, but very erratic. The general trend and all total changes were in the direction opposite to the change caused by corrosion, although there were irregular reversals, sometimes quite large. It was concluded that some metallurgical changes, influencing thickness gauge readings, were occurring at corrosion temperature. Aging was suspected as the primary change; its rate and even the rate law were not satisfactorily determined. It was clear that the change was minor for about the first 180 days of test.

For corroding specimens, plots of thickness gauge readings from 8 days onward showed that corrosion was legarithmic for 180 days exposure. Such data for one specimen (No. VI) are shown as the open circles in Fig. 8. A good straight line is formed, with relatively little scatter. Subsequent to 180 days, consistent deviation of the points from a straight line is observed. Only one reading, at one day, was taken for each specimen at times less than 8 days.

olated long-time line. It is indicated that at that time the amount of corrosion had not yet reached the plateau following the upward short time break in the corrosion curve.

At 180 days, there remained six specimens in each chamber; two from each had been removed earlier to provide data for calibrating the thickness gauge. Data from these twelve were plotted (uncorrected) as in Fig. 9, and the basic constants of the logarithmic curves were determined for all except No. XV

2326 151



Fig. 9. Suggested corrosion at one point

(which unexplainably showed too much scatter to be used). The slopes and the extrapolated amounts of corrosion at one day (logarithmic "intercepts") are shown in Table I. The intercept values perhaps reflect the fact that the exposure was interrupted at 1 day and thus must be considered representative only of the particular experimental conditions employed.

Specimens II through VII were in the second chamber; their refreshing water was the effluent from the first chamber. The chamber containing specimens X through XIV received refreshing water directly from the storage carboy. Both the slopes and intercepts of the second chamber specimens were greater than those of the specimens in the first chamber (by about 17%).

It was clear that the available information was not sufficient to determine whether corrosion continued logarithmically to the end of the test at 547 days. In an effort to provide a reasonable estimate, corrections were calculated from the thickness gauge readings of the stat and samples which had been aged in helium. Is was assumed that the aging (or other metallurgical change) had occurred at a constant rate throughout the time they were kept at 70°, and that the average for the three standard specimens could legitimately be applied to each corrosion specimen. Accordingly the "least squares" slope of all of the thickness gauge changes of the standards (as a function of time) was determined and used to calculate "corrections" to be added to the basic data for the corrosion specimens. As illus-

1	able	. Cont	tents	for	logeri	thmic	corrosion
100	Alum	inum,	distill	ad .	water.	10°C.	O-saturated

Specimen No.	Blope.* mg/dmi-cycle	L at 1 day." mg/dmª (extrapolated
п	3 15	35.36
III	3.22	36.70
IV	3.28	33.47
-	2,10	20.20
	v.=-	12.00
Average	3.23	35.59
x	2.62	30.20
XI	2.83	30.37
XII	2.91	30.15
XIII	2.77	30.95
XIV	2.78	29.32
Average	2.78	30.20

* Determined from uncorrected data.

1

trated in Fig. 8, the "corrected" points formed reasonably good straight lines on the semilog plots for the full test duration. There was also a slight increase in slope in going to corrected values, but in view of the uncertainties in the corrections it is not considered desirable to report the corrected slopes and intercepts.

Some years ago, before the thickness gauge had been perfected, a corrosion test was run, at the same nominal conditions as those for the present report, for a total exposure time of 940 days. The average gain in weight of all the specimens varied linearly with the logarithm of time from 18 through 650 days. Beyond that time, the weight gain showed some decrease and some erratic behavior, probably because of the sporadic sloughing of some of the corrosion product. Although the weight gain is not considered to be a truly reliable indication of the amount of corrosion, these observations tend to support the opinion that long-term corrosion remains logarithmic.

Discusison

The dependence of short time corrosion on many experimental parameters indicates the need of extensive investigation to understand the reactions. In particular, the nature of the water contamination by the corrosion reactions and how this influences corrosion rate should be studied. Some efforts to do this are being made in this laboratory. The variation of the pH of the water is being measured as a function of time and position, both along the surface and normal to it. Substantial pH changes do occur, particularly close to the corroding surface (0.1 mm).

It has seemed to be true that initial corrosion is logarithmic and is followed in turn by an increase in rate and by a subsequent extended period of logarithmic reaction. It has not been determined for how long this extended period endures. The rate law seems clearly to hold for at least 180 days; subsequently, it can only be guessed that to a total observation time of 650 days no change in kinetics occurs.

It is interesting to speculate as to the mechanism which is responsible for the long time, reproducible, logarithmic corrosion behavior. Previous observations, as pointed out in the introduction, have indicated that at any one time much of the corrosion reaction occurs at a small number of localized points, and that most of the corrosion product coating is not influential in determining corrosion rate. These observations suggest that previous derivations (5) are not sufficient to explain the corrosion behavior. The following development of a rate expression is based on the periodic logarithmic growth and breakdown of protective oxide.

surface corrosion follows logarithmic curves of the type indicated in Fig. 9. Subsequent to each time that breakdown of the protective film occurs the initial rate of reaction is less than at the preceding break. The total amount of corrosion occurring in each cycle is the same; consequently the duration of succeeding cycles is longer.

It is also assumed that at any time the various points on the corroding specimen are behaving as

2326 152



Fig. 10. Hypothetical rate carve for one time

though at random points along a characteristic logarithmic growth curve. Thus, corrosion rates of points on the specimen are equal to slopes of various portions of the following general equation from 0 to t_i^* (illustrated in Fig. 10)

 $L^{*} = a + b \ln (t^{*} + f)$ [1]

The value of f determines the initial slope. t_i^* is the end of the curve segment, and s is the (constant) amount of corrosion occurring in the cycle.

The average corrosion rate will be the average slope of this line from 0 to t_i^* . The value of this is

$$\frac{dL^{\bullet}}{dt^{\bullet}} = \frac{s}{t_{\bullet}^{\bullet}} \qquad [2]$$

Now, realizing that s is equal to $L_1^{\circ} - L_0^{\circ}$, an expression for it can readily be obtained from Eq. [1]. Rearranging, by solving for t_i° , gives Eq. [3]

$$t_i^* = f(e^{i/b} - 1)$$
 [3]

substituting this into Eq. [2] gives Eq. [4], which is the average (over the surface) rate of corrosion for the specimen at any one time.

$$\frac{dL^*}{dt^*} = \frac{s}{f(e^{s/b}-1)}$$
 [4]

[5]

In order to decrease (with respect to time) the corrosion rate immediately following the various breaks in the local corrosion curve, it is now assumed that f = ct. Substituting this into Eq. [4] and dropping the *, since we are dealing with actual corrosion rather than a hypothetical curve for some particular correst and the set of the set. [5] is obtained.

$$\frac{dL}{dt} = \frac{s}{ct (e^{s/b} - 1)}$$

Integrating, and using the boundary condition that L = a when t + ct = 1, the expression given in Eq. [6] is obtained.

$$L = a + \frac{s}{c(e^{s/b} - 1)} \ln [t(c+1)]$$
 [6]

This is observed to be a simple logarithmic equation of the form $L = K_1 + K_2 \ln t$.

It has not been possible to demonstrate that this derivation correctly explains the logarithmic dependence of the amount of corrosion on time. It does seem to fit the known observations. It is an attractive hypothesis in that the amount of corrosion for each cycle at any particular point on the specimen surface is constant. This suggests that the cause of the break is some direct effect of the total amount of corrosion which occurred during this cycle. At this time the part of the corrosion process which is preferred to explain this is the liberation of gaseous hydrogen beneath the protective oxide film. It is assumed that a fixed percentage of the corrosion product hydrogen is produced beneath the oxide film (6); that when the gas at any point reaches the amount required to generate pressure sufficient to rupture the oxide, the film is broken and the next cycle of the logarithmic growth is ready to begin. This analysis suggests that a given area is alternately cathodic and anodic (in accordance with surface appearance), and that the cathodic activity is largely responsible for activation and the change to active anodic corrosion.

There is nothing in the present research which offers an explanation for the apparent fact that local oxide growth is logarithmic. Evans (5) has derived such a rate expression in which it is assumed that there is healing or filling of internal cracks and voids in the (protective part of the) oxide film. On the basis of a number of observations, this explanation seems tenable, although the actual porefilling mechanisms seem "kely to be different from the simple one used by Evans.

It is believed that the present method of deriving an over-all rate expression for nonuniform corrosion is potentially applicable to many corrosion systems. A limitation to the value at the present time is that it appears to be quite difficult to determine experimentally the constants basic to the mechanism.

The work on this paper was performed under the auspices of the U.S. Atomic Energy Commission.

Any discussion of this paper will appear in a Discussion Section to be published in the December 1963 JOURNAL.

REFERENCES

- and of Aluminum-Nickel Alloys," Proceedings of AEC-Euratom Conference on Aqueous Corrosion of Reactor Materials, Brussels, Oct. 14-17, 1959: TID-7587 (U.S. Atomic Energy Commission), pp. 165-187.
- M. J. Pryor and D. S. Keir, This Journal. 102, 370 (1955).
- W. B. Doe, "Eddy Current Type Diamet r Gauge for Corrosion Measurements," ANL-5001 (Feb. 1, 1953) Argonne National Lab.
- 4. W. E. Ruther, Corrosion, 14, 387t (1958).
- U. R. Evans. "The Corrosion and Oxidation of Metals." pp. 829-30, 834-35, 837, Edward Arnold. Ltd., London (1960).
- J. E. Draley and W. E. Ruther, This Journal, 104, 329 (1957).

2326 153

2-



Inprinted From Journal of the Electronomical Becom Vol. 114, No. 4. April 1987 Printed in U. S. A. Copyright 1987

The Corrosion of 1100 Aluminum in Water from 50° to 95°C

J. E. Draley, Shiro Mori, and R. E. Loess

Metallurgy Division, Argonne National Laboratory, Argonne, Illinois

After an initial period of a few days duration, the amount of corrosion of 1100 aluminum in water below the boiling point varies with the logarithm of time (1-3). Reproducibility in measured rate constants has not been good. This is felt to be due largely to variation in test parameters such as the water refreshment rate and flow pattern, and the number and position of the specimens in the chamber. Sensitivity to these things has appeared to be maximum during the initial exposure period [cf. ref. (2)].

For purposes of considering reaction mechanisms it is desirable to know the dependence of corrosion behavior on temperature and dissolved oxygen concentration. Because of the variability of past results, it has not been possible to determine reliably the influence of these parameters. The present experiments were therefore run with identical flow rates and specimen disposition in order to provide comparable data.



Fig. 1. Corresion of a single specimen in Ho-asturated H2O at 70°C.

Materials and general methods were the same as described previously (2). Water resistivity remained well above 1 megohm-cm; it was saturated with cylinder oxygen or helium to provide a choice of two levels of dissolved oxygen, and passed at a low rate (18 cc/min for first 4 days, then 8 cc/min) through the test chamber containing 4 specimens. For those instances where the saturating gas was helium, the oxygen content was monitored with a thallium column (small modification of Industrial Instruments Analyzer type OA-1). For the 50° and 70° tests, the water entering the cell averaged 0.41 mg O₂/1 (range: 0.31-0.50); entering the 95° cell dissolved oxygen averaged 0.60 mg/1 (range 0.43-1.00). Perhaps 3/4 of this amount would be expected to be lost to the gas phase when the solution was heated to 95°.

Specimens were from the same extruded rod as had been used previously. They were machined, annealed,



Table I. Logarithmic slopes and intercepts for correction of 1100 eleminum in vator

	Oresture	lad	He-esturated		
Temp. "C	Slope.	Intercept.	Slope.	intercept.	
•	1.34 3.13 3.39	37.04 37.34 38.60	15	38.91 37.65 38.36	
10	Avg 3.14 3.60 3.79 3.36	38.50 38.00 37.43 38.00	1.40 3.77 3.57 3.57	37.42 39.40 39.25 38.44	
•	Ave 3.60 8.45 9.30 7.35	38.70 37.55 7.70 2.80 6.13	3.43 3.46 5.75 4.62 6.14	38.46 11.25 13.32	
	Ave 7.83	6.23	6.13	0.01	

and etched under the same conditions as before. They were removed periodically from the test, starting after 4 days' exposure, weighed to \pm 10 g (29 cm² area) after air drying (in the constant temperature and humidity balance room), and the change in the average metal radius determined to a \pm 50.4 with the eddy current gauge developed for the purpose (4). Gauge corrections for metallurgical change in the specimens at corrosion temperature were required only at 95°. Total test duration was typically 45 days.

Corrosion was approximately logarithmic in all six tests, for the 4-45 day interval. Data for two typical specimens in helium-saturated water are shown in Fig. 1 (70°) and Fig. 2 (95°). Slopes and logarithmic intercepts (extrapolated values at 1 day) of the metal corroded curves are given, for all specimens, in Table I.

There is a consistent increase in rate constant (slope) with increasing temperature, and with increased oxygen concentration. Intercepts are much lower at 95° than at 50° or 70° .

The specimen weight gains increased with time slightly more rapidly than did the metal losses at 50° and 70°, as illustrated in Fig. 1. At 95°, however, it can be calculated from Fig. 2 that (old) corrosion product was being lost to the water more rapidly than new product was being formed during the interval 4 to 47 days.

There is evidence in Table I that precautions were not sufficient to provide rate constants and intercepts which can be compared to obtain accurately the effects of temperature and oxygen content. It is possible, however, to make qualitative comparisons. At 95° there was an inverse relationship between intercept and rate constant. In fact, a continuous trend was observed in these values for specimens from the two tests (oxygenated and low oxygen). Generally, higher oxygen content resulted in lower intercepts and higher slopes. This is logical in view of: (a) known ability of oxygen to diminish the local pH increase observed at the specimen surface during the initial stages of corrosion (1, 5), (b) the direct dependence of intercept on solution pH (1). From these factors, the absence of oxygen can allow the development of a higher pH and a thicker oxide (boehmite) film during initial stages; later, when the alkalinity has dispersed, the thicker film might lead to lower corrosion rate.

At 50° the presence of oxygen again generally led to lower intercepts and higher rate constants. Within each test there was correlation opposite to that at 95°: higher rate constants accompanied higher intercepts. At 50° (but not at 95°) a relatively heavy layer of porous bayerite $[Al(OH)_3]$ forms during the initial exposure period. It is suggested that, when this layer is heavier, conditions are less favorable beneath the bayerite at what is believed to be the rate-controlling film of boehmite (AlOOH).

An Arrhenius plot of rate constants does not lead to a particularly good straight line. The approximate slope corresponds to the low activation energy of 4 kcal/g-atom. On the basis of the best kinetic model we have to date been able to develop, the corrosion rate is detarmined by the properties and thickness of a cracked layer of boehmite formed by degradation of the (always thin) primary product, perhaps also boehmite. Variation of the protectiveness (related to porosity) of such a layer with temperature is unknown; if the porosity decreased with increasing temperature, an unusually low temperature coefficient for the corrosion rate constant would be expected.

Manuscript received April 11, 1966; revised manuscript received Dec. 21, 1966. This work was done under the auspices of the United States Atomic Energy Commission.

Any discussion of this paper will appear in a Discussion Section to be published in the December 1967 JOURNAL.

REFERENCES

- J. E. Draley, Aq. Corr. 1100 Aluminum and of Al-Ni Alloys, Proc. AEC-Euratom Conf., Aq. Corr. Reactor Materials, Brussels, Oct. 14-16, 1959; TID-7585 (AEC), pp. 165-187.
- M. Kawasaki, S. Nomura, H. Itami, Y. Kondo, T. Kondo, N. Ito, and C. Akutsu; Work on Corrosion of Aluminum in Water at Japan Atomic Energy Research Institute; Proc. Conf. Corr. Reactor Materials, Salzburg, June 4-8, 1962, Vol. I, pp. 427-475 (Int. At Energy Agency).
- 475 (Int. At. Energy Agency). 4. S. Mori, R. E. Loess, and J. E. Draley, Corrosion, 19, 269t (1963).
- 5. S. Mori, R. E. Loess, and J. E. Draley, ibid., 19, 165t (1963).

BHL-HUREG -25582 INFORMAL REPORT

CORROSION CONSIDERATIONS

IN THE USE OF BORAL IN SPENT FUEL STORAGE POOL RACKS

J.R. WEEKS

JANUARY 1979

.

2326

TMENT OF NUCLEAR ENERGY BROOKHAVEN NATIONAL LABORATORY DEPAR UPTON, NEW YORK 11973

> U.S. Nuclear Regulatory Commission Office of Nuclear Reactor Regulation . Contract No. EY-76-C-02-0016

ENL-NUREG-25582 INFORMAL REPORT LINITED DISTRIBUTION

CORROSION CONSIDERATIONS

IN THE

USE OF BORAL IN SPENT FUEL STORAGE POOL RACKS

J.R. Weeks

December 1978

2326 15?

Corrosion Science Group Department of Nuclear Energy Brookhaven National Laboratory Upton, New York 11973

NOTICE: This document contains preliminary information and was prepared primarily or interim use. Since it may be subject to revision or correction and does not represent a final report, it should not be cited as reference without the expressed consent of the author.

TABLE OF CONTENTS

이 같은 것은 것 같은 것은 것은 것은 것은 것은 것은 것은 것이 같이 많은 것이 같이 많이	Page
LIST OF TABLES	11
LIST OF FIGURES	111
INTRODUCTION	1
CORROSION OF BORAL	2
PITTING OF ALUMINUM IN CONTACT WITH STAINLESS STEEL	3
CONCLUSIONS AND RECOMMENDATIONS	5
ACKNOWLEDGEMENTS	6

1

-

C

LIST OF TABLES

TABLE I	BMRR WATER CHEMISTRY	7
TABLE II	HFBR SFP CHEMISTRY	8

0:

• • • •

 \bigcirc

LIST OF FIGURES

9°

2

0

	1.140		-
FIGURE	1	Typical Corrosion Pattern for 1100 Al in Water (From ANL-5001)	9
FIGURE	2	BMRR Reactor Assembly. Hand drawn arrows indicates exposed Boral Sheets. From BNL-600	10
FIGURE	3	Schematic of 1/4" Boral Sheets in BMRR, Indicating Location of Punchings	11
FIGURE	4	Microstructure of Sample #1 as polished with 600 grit	12
FIGURE	5	Microstructure of Sample #2 as polished with 600 grit	13
FIGURE,	6	Microstructure of Sample #3 as polished with 600 grit	14
FIGURE	7	Microstructure of Sample #4 as polished with 600 grit	15
FIGURE	8	Microstructure of Sample #5 as polished with 600 grit	16
FIGURE	9	Microstructure of Sample #6 as polished with 600 grit	17
FIGURE	10	Neutron Attenuation Results on Samples 1-6 (Performed at U. of Michigan, Courtesy of Brooks & Perkins	18
FIGURE	11	Aluminum Surfaces in Contact with Stainless Steel After 6 1/2 Months Exposure in the HFRE SFP. 2.5	19

2326 160

Page

INTRODUCTION

Boral is a cernet of Boron Carbide "B4C" in aluminum clad in aluminum. It is manufactured in rolled sheets using techniques similar to those used in the production of uranium aluminum fuel elements. The core of the standard Boral contains 35% boron carbide by weight. Cladding material is typical 1100 aluminum. Where it is exposed to water in service, the edges of the Boral are recommended by the manufacturer to be clad with aluminum by welding.

In Spent Fuel Pool (SFP) racks, the Boral is usually not a structural member but is inserted in cavities between the spent fuel storage positions in the racks. In these locations it is sealed by welding to prevent access of water. Inherently, however, the corrosion of the Boral, both the boron carbide-aluminum cermet and the aluminum cladding, should be minimal in a spent fuel storage pool. The cavities into which the Boral is sealed are typically fabricated of aluminum alloys, i.e. type 6061, or stainless steel. In either case, these are the structural members of the SFP racks.

In an SFP, water chemistry tends to be strictly controlled because the S7P water mixes with the reactor coolant during refueling procedures. In SFP's at BWR sites, water chemistry is typical of that of a BWR i.e. high resistivity neutral water. In SFP's at PWR sites water chemistry typically contains 2 to 3,000 parts per million ppm boron as boric acid, which is there primarily to prevent dilution of the reactor primary coolant during refueling and is not relied on for criticality considerations. The water chemistries and anticipated

1

corrosion of SFP materials were reviewed in an earlier report. BNL-NUREG 23021, July, 1977.

CORROSION OF BORAL

Corrosion problems have developed in SFP's where water has inadvertently leaked into the cavities containing the Boral. In a BWR pool, swelling of the racks has been observed when water leaked into the cavities through a flaw in the seal weld at the bottom of the cavity.

The swelling observed arises from the rapid initial corrosion of Al by water. Draley and Ruther (ANL-5001, Feb. 1, 1953) have shown that aqueous corrosion of 1100 Al can be described in terms of a steady state slope and an intercept, as sketched in Fig. 1. This intercept was measured by them to be $21 \pm 5 \text{ mg/dm}^2$ "metal corroded" over a range of temperatures (100 - 175°C) and pH (5 - 8.5). This "intercept" corrosion occurs within the first 5 days of immersion in water by a reaction of the type

 $2A1 + (3+x)H_20$ $Al_203.x H_20 + 3H_2.$ Thus 21 mg Al can produce 21×3 , or slightly more than 27×2

1 millimole H₂ per dm² of surface. The Brooks & Perkins Report #577 says there are 3.4 x 10² dm² Boral per tube in SPF racks such as those at Monticello or Brown's Ferry, so one could produce approximately 3.4 X 10² x 22.4 = approximately 7500cc H₂/tube, at STP. This is more than enough to produce the necessary 6 psi to bulge the cladding in a void volume of 130cc.

There is no reason to believe, however, that any B4C will be lost from the Boral by corrosion in the SFP water. In the Brookhaven

2

Medical Research Reactor, Boral has been exposed to the reactor coolant since January, 1959. Figure 2 shows a schematic of this reactor. The 1/4 inch Boral sheets are in the form of 2 half-cylinders. The upper edge of these sheets is unclad. The vertical edges appear by examination in situ with a periscope to be clad. In July of this year, samples were removed in the form of small punchings, three from each of the half-cylinders as shown on the attached sketch, figure 3. Each of these six specimens was cut in half, and one-half mounted for metallography. The resultant microstructures are shown in figures 4-9. Clearly there appears to be no systematic loss of the boron carbide. The other half of each of these specimens was analyzed by neutron attenuation at the University of Michigan under contract with Brooks and Perkins, the primary supplier. The neutron attenuation results are shown in figure 10. All the results are within 20%, which with the small size of the specimens is probably within analytical error. One specimen, #5, was analyzed wet chemically by Brooks and Perkins to contain 41.3% B4C in the core, which is in the upper range of boron concentrations for material produced in the 1950's. It, therefore, seems reasonable to conclude that no boron was lost from the core of this Boral by exposure to the BMRR coolant over the 19 1/2 year period. In the location of the BMRR where it is used, there is little measureable neutron flux. Water chemistry in this reactor is outlined in Table 1.

٠.

PITTING OF ALUMINUM IN CONTACT WITH STAINLESS STEEL

When aluminum is contacted with stainless steel in impure water, a potential exists for a galvanic attack of aluminum at the point of contact. In a SFP environment, this attack is especially likely in a PWR pool containing boric acid at a pH around 4.5. Further, aluminum

borates can be produced which appear as a white fluffy dispersion in the water at a pH greater than about 4.5. Maintaining the pH below 4.2 causes the white fluffy material to disappear. Corrosion currents at a stainless steel to aluminum galvanic couple in boric acid were measured to average 2 mils per year although the presence of oxygen or hydrogen peroxide increased this value substantially.

A number of references exist showing that pitting corrosion can occur in slightly acid waters at aluminum to stainless steel junctions. English and Griess (ORNL-TM-1030, 1966) report pitting depths up to 45 mils in 12,500 hours (1 1/2 years) in pH 5 nitric acid solutions at 100°C. Lennox et al. (Materials Performance, Vol. 13, #2, page 31, 1974) measured pitting where type 5086 aluminum is coupled to type 304 stainless steel of the order of 30 mils in a year and one-half in Gatum Lake, Panama, and up to 40 mils in two years in the Potomac River at Washington. The general corrosion of this alloy was negligible in both environments.

In the HFBE SFP, water chemistry is similar to that in a BWR SFP except that conductivity may be slightly higher, and the pH slightly lower. Typical data are given in Table 2. Specimens of aluminum and stainless steel in contact with one another have been exposed in the HFBR pool for a period of six months at which time they were examined and then reinserted for continued testing. There appears to be a general discoloration of the aluminum where it contacted the stainless steel and a small amount of pitting around the edges as shown in figure 11. It is highly unlikely, however, that pitting of this magnitude would result in significant loss of the boron should the Boral containing cavities be flooded over an extended period of time.

2326 1.4

Venting the upper end of the Boral chambers would probably alleviate any concerns over swelling due to hydrogen generation. It might produce pitting corrosion and some of the white aluminum borate deposits. I would recommend that a surveillance program including aluminum to stainless steel couples be installed in SFP's in which the Boral cavities are vented. Any swelling due to hydrogen production should occur within a week or so of the time the water enters the annulus containing the Boral. However, should a leak develop in one of the seal welds at some future date after the racks are installed, the swelling could occur at that time. For this reason, venting or the capability for future venting, is probably desirable. In general, I think the localized pitting corrosion that might result from venting the Boral cavities in SFP racks would be less of a safety concern than the swelling that might occur should they not be vented. In all SFP's the rack design should prevent contact between Al a the zircaloy fuel cladding, as this galvanic couple (especially in boric acid pools) can lead to hydriding of the sircaloy during storage, as described by A. B. Johnson in BNWL 2256, September, 1977.

CONCLUSIONS AND RECOMMENDATIONS

C

:

:

1. The swelling that has occurred in the Monticello SFP racks and might be anticipated to occur in other similar SFP racks results from initial corrosion of aluminum and not from corrosion of the boron carbide cermet.

2. Venting of these cavities in a BWR pool should not produce significant loss of the boron and should, therefore, be accepted by NRC provided the venting occurs at the upper edge so that any hydrogen pressure from corrosion of the aluminum cladding will not build up to cause swelling of the racks.

5

3. Venting of the Boral cavities in a FWR rack might produce more pitting corrosion of the Boral. Again, however, it should not lead to major loss of the boron carbide.

4. Anodizing the Boral in these cavities would tend to reduce the hydrogen production in the cavities should SFP water leak in to them. Anodizing would probably not, however, prevent pitting of the aluminum.

5. In any fuel pool in which the Boral cavities are flooded intentionally or inadvertently, surveillance specimens should be present to determine on a periodic basis, i.e. once every few years, what is happening to the Boral in these cavities.

6. In any SFP, galvanic coupling between Al in the racks and the zircaloy fuel cladding should be avoided, to prevent hydriding of the cladding during long term storage.

ACENOWLEDGEMENT S

The assistance of the BNL Reactor Division staff, R.W. Powell, Head, in obtaining the Boral punchings from the BMRR spent fuel shielding is deeply appreciated. The metallography was performed by K. Sutter of BNL. The neutron attenuation and wet chemistry results were obtained through the courtesy of Mr. R. C. Karzmar of Brooks and Perkins, Inc. More detailed analyses of these specimens are underway at G.E., by A. Jacobs, and at Brooks and Perkins, and will be the subject of a future report.

TABLE I

BMRR WATER CHEMISTRY

. .

9

• •

٩

;

C

Temperature	Inlet	Outlet	T.S.
Reactor ON	100°r	115°7	136°F
Reactor OFT	75-80	75-80	

(Reactor ON less than 10% of time)

Conductivity	Normal	Regenerate	Alarm	T.S.
(umho/cm @25°C)	<2	2	5	10

Alarmed only once in 20 years, during HX leak. T.S. never exceeded.

TABLE II

HTER SPP CHEMISTRY

Resistivity mag-ohm-cm	Temp. C	ppb C1	pH
.246	30-35	4-20	5.9-7.0

.

(low pE coincides with low resistivity)

.

;

0

.







* Exposed 5

PIG. 4

z

< 2 Sample × FIG. 5 2326 173 13

M PIG. 6 2326 174

X100 # AO E Sam い 2326 175 PIG. 7 15

X100 ら# Samp FIG. 8 2326 176 16

X100 0 30 2326 177 FIG. 9 17





FIG. 11 Aluminum Surfaces in Contact with Stainless Steel after 6 1/2 months Exposure in the HFBR SFP 2.5x

DISTRIBUTION LIST

MRC Division of Operating Reactors

....

31

·: ··

۰.

.

:

.!

•

V. Noonan W.S. Hazelton F.M. Almeter (10)

Division of Systems Safety

J.P. Knight S.S. Pawlicki H.F. Conrad B. Turovlin

Brooks and Perkins

R. Karzmar

Brockhaven National Laboratory

W.Y. Kato R.W. Powell Corrosion Science Group Files (25)
NEUTRON ABSORBER SAMPLING PLAN - IN POOL

A sampling plan to verify the integrity of the neutron absorber material employed in the high density fuel racks in the long-term environment is described.

The test conditions represent the vented conditions of the spent fuel tubes. The samples will be located adjacent to the fuel racks and suspended from the spent fuel pool wall. Eighteen (18) test samples are to be fabricated in accordance with Figure 1 and installed in the pool when the racks are installed.

The procedure for fabrication and testing of samples shall be as follows:

- Samples shall be cut to size and dried in an oven for five hours at 170°F, followed by a cycle at 600°F for three hours.
- Samples shall be weighed immediately following removal from the oven and weight in milligrams recorded for each sample.
- 3. Samples shall be fabricated in accordance with Figure 1 and installed in pool.

4. Two samples shall be removed per schedule shown in Table 1.

:

- 5. Carefully cut samples apart at the weld without damaging the neutron absorber, Wash with a soft brush in a mild abrasive and detergent solution, immerse in nitric acid to remove surface products, followed by a rinse of clean water and alcohol. Dry in a 175°F oven for five hours, followed by a cycle at 600°F for three hours.
- Weigh the samples and evaluate the weight change in the neutron absorber material in milligrams per square centimeter per year.
- Visually examine the clad surface for pitting. Take micrographs of the edge surface and any other suspect areas.
- If pitting is present, the depth of the four major pits are to be recorded and the average pit penetration in mils of an inch per year determinet.

- 9. Prepare report of sample test results and observations.
- Should any adverse conditions be detected, the samples may be subject to a B¹⁰ loading analysis.
- 11. Additionally, two full length vented fuel storage tubes will be suspended in the pool. They will be observed periodically for signs of swelling, and they will be opened and examined should the small specimens indicate any loss of absorber material below .02gm/cm², Boron¹⁰.
- 12. Retain samples.

- 2 -

				Date Install	ed
SAMPLE NO.	SCHEDULE	INITIAL WEIGHT (mg/Cm ² -Yr)	FINAL WEIGHT (mg/Cm ² -Yr)	WEIGHT CHANGE (mg/Cm ² -Yr)	PIT PENETRATION mil/yr
1					
2	90 day	+			
3					
4	180 day	• •			
5			22	26 183	
6	l year		2.5	20 100	
7		·			
8	5 year				
9					
10	10 year				
11					
12	15 year				
13					
14	20 year				
15					
16	30 year				
17					
18	40 year				
			· · · · · · · · · · · · · · · · · · ·		

٩.

TABLE 1



Figure 1.



:

٩.

2

FUEL STORAGE RACKS CORROSION PROGRAM,

1

· ·

BORAL - STAINLESS STEEL

(NON-PROPRIETARY VERSION)

MARCH 1979

IMPORTANT NOTICE REGARDING CONTENTS AND USE OF THIS DOCUMENT

41.

- 1. Exxon Nuclear Company's wirranties and representatives concerning the subject mather of this document are those set forth in the Agreement between Exxon Nuclear Company, Inc. and the Customer pursuant to which this document is issued. Accordingly, except as otherwise expressly provided in such Agreement, neither Exxon Nuclear Company, Inc. nor any person acting on its behalf makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this document, or that the use of any information, apparatus, method or process disclosed 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 document.
- The information contained herein is for the sole use of Customer.

VALIDATING SIGNATURES

4 ..

VALIDATING SIGNATURES:

Revision No. and Date Revised Sections Revised Pages

Rev. 0 (11-10-78)	Rev. 0 (3/14/79)	
Proprietary	A11	
Version	Non-Proprietary	
	Version	

Prepared By

1

2

oject Manager

11/10/73

To allet

Hhille

3/14/79

Date

Concurred By

Date

Date

Approved By

Mechanical Engr.

10/78

11

Licensing/ Compliance 110 /78

Mgr. Sto Services Storage

11/10/78

3/14/19

Date

2326 187

XH-NS-11-009/NP

.

EXON

14

1

2

TABLE OF CONTENTS

		Page
ABSTRAC	T .	i
1.0	INTRODUCTION	1-1
2.0	TEST PROGRAM DESCRIPTION	2-1
2.1	Specimen Description	2-1
2.2	Environment Description	2-2
2.3	Initial Measurements	2-3
3.0	SUMMARY	3-1
4.0	RESULTS	4-1
4.1	Internal Environment of Edge-Sealed and Storage Cell Specimens	4-1
4.2	Visual Appearance	4-2
4.3	Weight Gain	4-3
4.4	Pitting	4-5
4.5	Metallography	4-6
4.5.1	Surface Corrosion Films	4-6
4.5.7	Edge Attack	4-7
4.5.3	Bulges	4-7

LIST OF REFERENCES

2

ABSTRACT

Exxon Nuclear Company, Inc. has conducted a Boral*-Stainless Steel Corrosion Program during the past 18 months to establish additional performance information for use of Boral clates in spent fuel storage applications. The program consisted of a detailed review of related literature, an evaluation of test programs conducted by others, and additional corrosion tests performed at Exxon Nuclear facilities.

The objective of the Exxon Nuclear test program was to obtain corrosion data for Boral-304 stainless steel test specimens in 'simulated PWR fuel pool environments so that reliable predictions could be made of what physical changes would occur in a defective, i.e., unsealed spent fuel storage cell after a 40-year exposure.

The Exxon Nuclear tests indicate that storage cells, containing a leak simulating hole, will sustain aluminum corrosion at a rate which can be expected to consume of the aluminum in the Boral core after a 40-year exposure.

Should Boral plates be exposed to a typical PWR pool environment, the material is subjected to pitting, edge attack, and internal gas pressurization; but no effect on criticality safety is expected over the lifetime of storage cells due to dislodgement of B_AC particles.

2326 189

GR-005

* The Boral test samples discussed in this report are a neutron absorbing, shielding material manufactured by the Brooks and Perkins Company. The Boral specimens are a composite material consisting of boron carbide evenly dispersed within a matrix of aluminum and clad with aluminum.

2.0 TEST PROGRAM DESCRIPTION

2.1 SPECIMEN DESCRIPTION

Exxon Nuclear's test program placed emphasis on investigation of Boral utilized in conditions typical of expected storage cells and PWR pool water environments. Consequently, storage cell component sections were fabricated which resembled the larger, full-size storage cells. Specifically, these reducedsize storage cell specimens consisted of inner and outer stainless steel 304 shrouds into which four (4) Boral plates were inserted. The complete assembly was sealed welded, resulting in 6" high x 6" wide test specimens. Each completed cell specimen was made to simulate a leaking condition by drilling 1/16-inch holes as described in Appendix A.

In order to separately observe and measure various corrosion and material properties during the test, additional test specimens were utilized. These additional specimens consisted of 2" x 2" coupons made as follows:

- Open-edge Boral/stainless steel composite;
- Sealed-edge Boral/stainless steel composites with a leak simulating hole; and,
- Unencapsulated Boral coupons.

2.2 ENVIRONMENT DESCRIPTION

Insulated nine (9) gallon polyethylene tanks, with fitted covers, were used for the plain Boral and open-edged Boralstainless specimens. Thirty (30) gallon tanks of the same construction were used for the closed-edge tests. Each tank was fitted with a stainless immersion heater and stirring mixer, which were affixed through openings in the tank covers.

A stainless steel screen was used to hold the specimens off the bottom of the tanks and permit circulation of the environment on all sides. In order to isolate the plain Boral specimens from the stainless steel screen, a pedestal was fashioned from phenolic plastic. The open-edged composite samples, a 2" x 2" Boral piece sandwiched between two 2" x 2" stainless steel pieces, were held together with four (4) Met-clip springs, one along each edge. These were placed on the stainless screens so that the clips held the specimens in a horizontal position over the screen.

The initial environment in each tank was deionized water with a pH of 5.85 and a conductivity of 0.75 μ mno/cm. Boric acid (H₃BO₃) and lithium hydroxide (LiOH H₂O) additions were made to produce the following:

Environment A) C

Deionized water plus 13.3 g/l Boric Acid (resulting in 2300 ppm Boron at 150°F).

2326 191

Environment B)	Deionized water, 13.3 g/l Boric Acid, 0.0121 g/l lithium hydroxide
Environment C)	Deionized water plus 0.0121 g/l lithium hydroxide

The specimens, were immersed in each environment on July 1, 1977. The initial temperature and pH of each environment were measured as follows:

Environment	pH	Temperature, °F
1	5.20	146.4
2	5.53	147.2
3	9.15	153.4

The temperature and pH were measured daily. The temperature showed some fluctuations and variacs were installed in order to gain better temperature control. The pH in the borated solutions, 1 and 2, remained constant but in the alkaline tank, C, it dropped into the 7 range within days. In order to keep the solution pH in the alkaline range, additional additions of lithium hydroxide were made.

2.3 INITIAL MEASUREMENTS

.

Appendix A of this report contains descriptions of all Boral and stainless steel specimens utilized for the test program. The initial measurements and cleaning programs are also provided in Appendix A.

2326 192

3.0 SUMMARY

41.

No corrosion, pitting, nor stress-corresion cracking was observed on any of the stainless steel coupons, or storage cell specimens used in this study. The austenitic stainless steel can be expected to withstand exposure to borated fuel pool environments for the projected forty-year life of spent fuel racks. Similarly, without a leak path through the stainless steel liners, the interior Boral plates would not be subject to degradation as a result of aqueous corrosion. In the situation of a leak path through the stainless liners which permits the interior space to fill with the pool environments, the results of the 2 month, 6 month, and 12 month exposure studies, show that Boral is subject to general corrosion, pitting and edge attack, and clad deformation due to internal gas pressurization. To various degrees, the severity of each of these corrosion effects depends on the particular environment chemistry and the specific geometry of the exposed materials. Based on comparisons between the four (4) specimen types and the three (3) environments used in this study, the following summary can be drawn concerning the corrosion resistance of Boral and its suitability for use when exposed in stainless lined storage cells to borated environments.

The general corrosion rate, as determined by weight gain measurements,

When all the storage cell specimen data are examined on a semi-log plot, the amount of aluminum consumed in conversion to oxide after a 40-year exposure, is: percent for the low pH and percent for the higher pH environments.

2326 193

The weight gains were lowest for the storage cell specimens in each of the three (3) environments, followed in general by the plain, open-edged, and edge-sealed specimens. The weight gains, measured for the plain and open-edged specimens, were nearly identical to each o her in the three (3) environments. This similarly indicates that galvanic coupling between the stainless steel in the openedged specimens does not accelerate general corrosion in the Boral. In all three (3) environments, the edge-sealed specimens showed the greatest weight gain.

41.

Similar considerations apply to edge attack of the Boral. However, the depth of edge attack did not increase significantly between the

3

6 and 12 month exposure. The deepest edge penetration, 0.028", was measured on the open-edged specimen in the low pH environment. No measurable edge attack was observed in the vicinity of the leak simulating hole in the Boral plates of the storage cell specimens.

Gas generation, due to corrosion of the aluminum in Boral, has been observed in the edge-sealed specimens and the storage cell specimens. This gas has been observed to bubble from the upper hole in each of the storage cells. In several of the specimens removed after 12 months, bulges were observed between the aluminum cladding and the B_4C aluminum core.

The occasional unbonded layers of the Boral matrix occurred randomly and were observed in concentrated areas of very small B_4C particles (i.e., ≥ 150 mesh). It has been determined that the Boral specimens provided by Brooks and Perkins for the ENC corrosion test program contained a much higher concentration of small B_4C particles than utilized for production Boral plates. Accordingly, it is possible that the small bulges observed on the sealed specimens may not occur in finished plates where improved B_4C and aluminum bonding result with larger B_4C particles.

The occasional lack of bonding between B_4C and aluminum particles also allows a small amount of water to enter the inner portions of the bulged specimens. Normally, water does not penetrate into well-bonded Boral plates and no internal corrosion can occur.

The small bulges have not been reported or observed in prior related corrosion test programs. They appear to be a self-limiting phenomenon,

3-3

where the gaseous corrosion product both causes the bulge and displaces the water causing the corrosion. An inspection of both the aluminum cladding and igner Boral matrix demonstrates that no clad pitting or deterioration of the inner face of cladding and Boral material occurred near the bulged areas. Consequently should random small bulges occur, any dislodgement of B_4C particles will be of no significance on neutron shielding or attenuation properties.

2326 196

4.0 RESULTS

On June 30, 1978, after a nominal 12-month exposure, the remaining three (3) plain Boral and three open-edged Boral-stainless composite specimens, were removed from the three (3) heated tanks. On August 10, 1978, the edge-sealed, and storage cell specimens, were removed from their environments. These twelve (12) samples were subjected to visual, metallographic, weight gain, and pit depth measurement analyses.

This section of the report places emphasis on the detailed results obtained from the storage cell specimens. Appendix B presents additional test results for other specimens and contains most referenced tables and figures for information presented in this section. Table 4.1 provides specimen identification numbers and exact lengths of exposure for each of the twelve (12) specimens evaluated during the final period.

4.1 Internal Environment Of Edge-Sealed And Storage Cell Specimens

The pH of the solution, within the edge-sealed and storage cell specimens, was measured using indicator paper for the former, and a Beckmann pH meter for the latter. Approximately 2.5 grams of solution was contained in the edge-sealed specimens and 39 grams in the cell specimens.

In Table 4.2 is a summary of the interior pH of the edgesealed and cell specimens for the 2-, 6-, and 12-month exposures.

2326 197

For the high pH lithium environment, the interior pH consistently shows a decrease in pH toward a neutral value for all exposure times. A similar trend toward a more neutral pH is exhibited for the acidic environments for exposures up to 6-months. After 12-months, the interior pH is the same as the bulk solution or, slightly more acidic.

41.

4.2 Visual Appearance

The storage cell specimens were disassembled and cut open to separate the Boral plates from the stainless liners. A visual examination of each Boral piece was conducted using a low power stereo-microscope. The following observations were noted:

Storage Cell Specimen #3 (S.C.S.-3)

Surfaces were generally metallic in coloration. Extra corrosion products, and some pitting, were seen on the faces and along the edges where the leak simulating holes were drilled through the stainless liners.

Storage Cell Specimen #6 (S.C.S.-6)

Specimens are darker than SCS-3. Pitting is much less. Rust existed along edges where holes were drilled. Bulges were observed in the dimple area of plate S.C.S.-6(1), on both the outside and inside.

2326 198

Storage Cell Specimen #9 (5.C.S.-9)

Specimens were white in coloration with rust colored deposits along the edges where holes were drilled. B_4C stringers were evident, but no pitting. Plate S.C.S.-9(4) had a 1-1/4" pure aluminum strip on one short edge.

4.3 Weight Gain

After the visual analysis, the appropriate Boral plate specimens were weighed, oven-dried, and reweighed in order to determine the amount of absorbed moisture in the core and the change in weight due to exterior and interior corrosion. The specimens were dried in stages in an air-circulating oven for two (2) hours at 150, 200, 250°F, and for 24 hours at 300°F. The original weight, the weight prior to oven-drying, and the dried weight for each specimen, is listed in Table 4.3.

A summary of the moisture absorbed weight percentages, for the 2-month, 6-month, and 12-month exposures, is given in Table 4.4. The overall average for all specimens, environments, and exposures, was This corresponds to a minimum average porosity level in the Boral core of approximately The absorbed moisture decreased between 2-months and 6-months and increased between 6-months and one year. This may be the result of an initial decrease in porosity as corrosion products were generated in the core followed by a porosity increase as additional corrosion enlarged the pores. The greatest moisture absorption occurred in the open-edged specimens in the A environment. This specimen also showed the greatest number of pits and would, therefore, contain the greatest amount of material capable

4-3

of absorbing moisture. The least moisture, on the average, was in the storage cell Boral plates, which may be due to their larger size and lower edge to volume ratio.

In Table 4.5, the corrosion weight gain percentages are summarized for all the specimens tested in the program. The values, in brackets, have been corrected to account for the fact that certain of the 6" x 4" Boral plates in the cell specimens contain a strip of solid aluminum along one edge. Since this strip did not contain the normal porous core structure, it could contribute weight gain only by external surface corrosion. To make valid comparisons, using these specimens, their weight was reduced by a factor corresponding to the reduced core volume. Under the assumption that the weight gain per- centages are an indication of the extent of uniform corrosion in these specimens, the results presented in Table 4.5 show that the corrosion rates have decreased with increased exposure time. The results are plotted for each specimen type as a function of environment in Figures 4.4 through 4.6.

The weight gains are largest for the edge-sealed specimens in each environment. Similarly, they are the smallest for the storage cell specimens. In between, with very similar results, are the plain and open-edged specimens. The similar weight gains, experienced by these two (2) specimen types, show that the general corrosion is not accelerated due to coupling with stainless steel.

2326 200

C.D. 004

When the weight gain values for the storage cell specimens are considered on a semi-logarithmic scale, the relationship appears to be amenable to extrapolation, as shown in Figures 4.7 through 4.9. From these figures, the extrapolated weight gain percentage and the calculated percent of aluminum consumed after 40 years exposure, are:

Pitting

4.4

To evaluate the extent of pitting in the 12-month exposure specimens, the corrosion products were cleaned from the surfaces of a portion of one of the four (4) plates from each cell specimen. A summary of the pitting frequency and pit depth, for the 6-month and 12-month exposures, is given in Table 4.6. The pit diameter for the 12-month specimens is also given in the table.

Table 4.6 shows that the pitting characteristics after 12-months were very similar to those after 6-months. Those specimens and environment combinations which did not pit or showed little pitting tendency after 6-months, showed no or few pits after 12-months, however, those with significant pits after 6-months had a large number of pits after 12-months. Increased pitting was observed in the plain specimens in the A environment and in the edgesealed specimens in the A and B environments. The other specimens showed nearly the same number of pits after 12-months as after 6-months.

4-5

4 .

The pit depth, however, increased with the extended 12month exposure. In some cases where pits had not penetrated the aluminum clad in 6-months, they had done so after 12 months.

4.5 Metallography

Sections of Boral from each specimen were mounted and metallographically polished in order to observe the thickness of surface oxidation films, the depth of edge attack, the undercutting around drilled holes, and the nature of surface bulges. Sections were made along an edge for the plain and open-edged specimens, and through the drilled hole in the Boral for the edge-sealed and storage cell specimens. In addition, sections through bulges in the specimens were made to characterize these structures. The specimens were back-filled with epoxy under vacuum conditions to impregnate surface porosity, then rough polished on silicon carbide papers and final polished on diamond using automatic vibratory equipment.

4.5.1 Surface Corrosion Films

The surface corrosion films on several of the specimens were thick enough to measure using a filar eye piece at a magnification of The film thickness, as measured for these specimens, is listed in Table 4.7. The thickness for the C environment specimens was thickest, being a maximum of for the plain specimen. Where the bulge in this specimen caused the surface layer to break apart, the corrosion films were much thicker. Appendix B contains photographs showing the surface film in one area away from a bulge and, for comparison, on a bulge.

4.5.2 Edge Attack

Table 4.7 also shows the depth of corrosive attack at the Boral coupon edges in the plain and open-edged specimens. The attack was greatest in the A environment and was somewhat greater in the open-edged specimen than in the plain specimen. Only one specimen of the six (6) edgesealed and storage cell types showed accelerated corrosion around the partially drilled leak simulating hole. This was the edge-sealed specimen in the C environment. The similarity in edge attack between the plain and open-edged specimens again indicates a lack of corrosion acceleration due to galvanic coupling of the Boral to stainless steel.

41.

4.5.3 Bulges

Several bulges were observed on the 12-month exposure specimens. Similar bulges were not observed on specimens exposed for 2- or 6-months. Table 4.8 lists the number of bulges observed on each specimen. Photographs demonstrating bulged areas are shown on Figures 4.2 and 4.3.

The bulges are separations between the aluminum clad and the B_4 C-aluminum matrix. They appear to result from gas pressure caused by internal corrosion. The corrosion of aluminum would generate hydrogen gas following the reaction

2A1 + 3H20 ---- A1203 + 3H2.

2326 203

Such gas generation has been observed in the edge-sealed and storage cell specimens. To generate a bulge would require sealing of the edges with corrosion products to enable the internal gas pressure to increase sufficiently to expand the ten mil aluminum cladding. The edge-sealed specimens each had four (4) bulges. These specimens also showed the largest corrosion weight gains which could result in the sealing of edges in these specimens.



XN-NS-TP-009/NP

2326 205

*

NUCLEAR

REFERENCES

- (1) Corrosion Data Survey Fifth Edition, MACE 1974, P. 34.
- (2) A Guide to Corrosion Resistance, J. P. Polar, Climax Molybdenum Co., P. 54.
- (3) Corrosion and Corrosion Product Release in Neutral Feedwater, E. G. Brush and W. L. Pearl, Corr. V. 28, No. 4, April 1972, Pp. 129-136.
- (4) Stress Corrosion Cracking Problems and Research in Energy Systems Proceedings ERDA Meeting 2/24/75. ERDA 76-98, Edited by L. C. Janniello
- (5) Corrosion Resistance of Metals and Alloys, F. L. LaQue and H. R. Cobson, Chapter 5, Corrosion Testing, P. 136. (1963) Reinhold Publishing Corp.
- (6) <u>Fundamental Aspects of Stress-Corrosion Cracking</u>, NACE 1969, Stress-Corrosion Cracking of Iron-Nickel-Chromium Alloys, R. H. Latanision, R. W. Staehle, P. 214.
- (7) Corrosion and Corrosion Control Herbert H. Uhlig, John Wiley & Sons, New York 1971, P. 309.
- (8) "Aqueous Corr. of Aluminum Part I Behaviour of 1100 Alloy" J. E. Draley and W. E. Ruther, Corr. 12 441t 1956.
- (9) Reactor Technology Selected Reviews 1964 USAEC Aluminum Alloys, J. E. Draley and W. E. Ruther, P. 215.
- (10) "Resistance to Corrosion and Stress Corrosion," W. W. Binger, E. H. Hollingsworth and D. O. Sprowls, in Aluminum Vol. 1, ASM, Ohio, 1967.
- (11) Atlas of Electrochemical Equilibria in Aqueous Solutions, Marcel-Pourbaix. Pergamon Press, New York (1966).
- (12) Aqueous Corrosion of Aluminum Part I Behavior of 1100 Alloy, J. E. Draley and W. E. Ruther, Corr. 12 441t 1956.
- (13) 'Observations on the Mechanisms and Kinetics of Aqueous Aluminum Corrosion,"
 V. H. Troutner, Corr. 13 595 (1957)
- (14) A Survey of Materials and Corrosion in Dry Cooling Applications, A. B. Johnson, Jr. D. P. Pratt and G. E. Zima, BNWL-1958, UC-12 1976.
- (15) Private Communication between R. McGoey and B. C. Fryer.
- (16) Dynamic Corrosion Studies for the High Flux Isotone Reactor, J. L. English and J. C. Griess, ORNL-TM-1030 1966, Oak Ridge National Laboratory.
- (17) Galvanic Corrosion of Al Alloys I Effect of Dissimilar Metal. F. Mansfeld. D. H. Hengstenberg and J. V. Kenkel Corr. Vol. 30, No. 10, Oct. 1974, P. 343.

BY MR. STEPTON:

Q Now, Dr. Draley, just a few minutes ago Dr. Reminic repeated his question concerning whether it made a difference for the accuracy of the coupon monitoring program whether the coupons were electrically grounded or not.

Can you answer that question?

A Yes. My answer would be that from the point of view of the corrosion processes inside of the coupons, electrical connections outside the coupons would be of no consequence and therefore, it doesn't matter from that point of view whether they're grounded or not.

If one is interacted in the performance of the outside of the coupons, there is a conceivable difference associated with grounding or not grounding, but I think not on the inside.

0 Is this true even though the coupons will have holes through the stainless stoel?

A Zes.

MR. STEPTOE: Mr. Chairman, at this time we hand a the witness for cross-emmination.

CHAIRMAN WOLF: Thank you.

Any cross-examination, Mr. Goddard?

MR. GODDARD: No questions from the Shaff, sin.

CHAIRMAN WOLF: Do you have any cross-examination.

Mc. Sakulon?

2326 206

2

3 1

12

17

13

10

22

2.8

2.2

	MS.	SEKULER:	Yes,	Ξ	have	sever 1	quest:	ions.
--	-----	----------	------	---	------	---------	--------	-------

CROSS-EXAMINATION

BY MS. SEMULER:

Q Dr. Draley, you are an expert in corresion of aluminum; is that correct?

Yes.

A

Have you done any research personally with Boral?
 A A small amount only.

Q Can you describe that research, please?

A We have exposed Boral specimens to high temperature water and we have examined them subsequent to the exposure and we have exposed specimens of Boral at water temperatures in the order of 50 to 70 Centigrade for short periods and examined those after test.

15 Q Can you tell me what "short periods" are defined 16 as?

A I think not more than a week or two. Let's say a few weeks; that's a little more accurate -- a the low tomperature, and at the high temperature, probably a month or two.

2 Q Are the low temperatures equivalent to those that 22 would be found in the spent fuel pool at Sion?

A Toward the upper range of temperatures, yes.

2: Q Was the water in which these samples were immersed 25 bonated?

2326 207

340

2

2

3

4

3

6

...

3

0

10.

22

12

13

12

18

19

20

16 1

eb2

2

3

5

5

7

3

3

10

11

12

13

10

12

23

17

18

10

20

A No. It was essentially pure water.

Q What were the recults of this particular survey that you made?

A The behavior in the pure water was quite good. There was no local attack evident, and although we had no measurement of the amount of uniform attack, it was quite evidently not very large.

At the high temperature, the Boral showed local swellings that is typical of the behavior of aluminum alloys other than those that are specifically designed to avoid the problem.

Q Was the aluminum in the Boral that you used in your experiments 1100 aluminum?

A Yes.

Q Was it anodized?

A No.

Q When you said that the swelling was typical of what you'd expect, can you toll so what would be typically expected at those temperatures of that kind of aluminum in that type of matrix?

A If the temperature of the water is high enough, most aluminum alloys will suffer a kind of local attack, starting with the appearance of local swelling or blistering and increasing with time and accelerating to an ultimate lisintegration caused by the inability of the material and

1293

64	1	its correction product film to protect it from the attack.
	2	Q Would cladding the Boral protect Excuse me.
	3	Would cladding the Boral with aluminum protect
	43	the Boral matrix from exposure to this type of swelling and
	5	deterioration?
	3	A No. As I think you asked the guestion, the answer
	7	is No.
	3	It's possible It would be possible in my judg-
	9	ment to clad it with specially designed and prepared alloys
	10	that would make a difference.
	11	Q What type of alloy would that be?
	12	A Well, the only one that I know that is commercially
	13	available is called 8001, and it contains nickel added to
	12	the alloy.
*	15	Q Would an anodized clad of 1100 aluminum prevent
	15	that problam?
	17	A No.
	13	MR. STEPTOE: Objection, Mr. Chairman. I believe
	19	we're talking about high temperature exposure of Boral and
	20	there is simply no foundation in the record which supports
	21	the assertion that the Boral racks will be exposed to this
	22	kind of environment, or that the problem to which Counsel
	23	refers is evident in the Zion spent fuel pool.
	34	MS. SEXULER: Mr. Chairman, may I respond?
	25	CHAIRMAN WOLF: We'll permit the witness to answer.
		2326 209

MS. SEKULER: Thank you.

1295

BY MS. SEKULER:

3 0 The question was whether an anodized aluminum 4 1100 clad would prevent the type of effect that you had described in the Boral at the higher temperatures? 3 G2 The answer is no. 7 Can you tell me what those higher temperatures 0 3 WET 3? A Something over 300 degrees Centigrade. I think 3 probably 315 would be about the temperature we did the test 10 in. 1 Q Did you do any tosting at about 170 degrees? 12 2 Centigrade? 13 Q Centigrade. 14 No, I don't think so. I made an effort to look 15 A back in the records in the last few weeks and have been un-ES. able to find any such record, and I think we did not. 17 Q What about 170 degrees Fahranheit? Did you do 18 anything in that range? 19 Well, I've kind of forgotten the conversion between 20 . A . . . Contingrade and Fabrenheit. 21 Q It's .2 to one, or something, I believe, or maybe 21 a little less. 23 A Mo, I don't think we did. I'm not really certain, 24 theu h. The tests were not very extensive, and we haven't 25 2326 210

eb5

ţ.

1295 eb6 even Bublished them. And I don't think that we tested at 1.1 that temperature. It could be that we did in fact test to 2 1 higher temperatures, on up to the boiling point, but I don't 3 remember them. Could you just tell me when those tests were done? 0 In the garly 1960s, I think would be the time ñ. frame, somewhere between 1960 and '65. 3 Have you done any additional research on Boral 0 since that time? 24 No. G Have you done any studies on the behavior of Boral 31 in relation to stainloss stual? 12 a Only in examining the materials that have been 13 available in connection with this hearing, but as a separate 14 research project, no. 15 Q Dr. Draley, have you ever inspected a spent fuel 13 pcol? 17 Tes, I've looked at a few. A 18 Can you tell me where they ware? 19 0 Well, I've seen the pools at a number of research 3 20 reactors and have, I think, seen the pool at Sion prior to 21 the time it was operating. 22 2 Have ou done any research into the behavior of 23 materials in spent fuel pools? 22 A Not research that was done for that purpose, no. 25 2326 211

Q Have you done other research that relates to the behavior of materials in spent fuel pools?

A Yes. I think much of the research that I have done in pure water and in water to which small amounts of chemicals were added is pertinent.

Q Dr. Draley, appended to your testimony there is an attachment which is called "Neutron Absorber Sampling Plan -In Pool." Correct?

A Yes.

eb7

1

2

A

3

3.

2

3.

3

10

11

12

13

1.1

13

18.

17

18

10

20

21

22

23

2.1

25

Q This was the plan to which you just testified there were some amendments and changes? Is that correct?

A Some omission.

Q There was a change on -- I just want to make sure I have this correct. On Figure 1 attached to that you deleted the words "and bottom."

A Yes.

Q Otherwise this plan, which includes a procedure 1 through 12, and then Table 1, which is a schedule, and Figure 1, which is a diagram, is the total plan that was included? I'm not missing any page.?

A That's right.

Q Is this the same plan that was submitted by Commonwealth Edison in response to the Nuclear Regulatory Commission question number 5 in their first round of questions and answers, the question being:

"For the proposed type of racks, a surveillance program is required to show the continued presence of boron throughout the life of the racks. PRovide a description of the boron surveillance program that you will perform."

And then there was an Attachment A that had a neutron absorber sampling plan in pool.

Are you familiar with that? It was submitted last
 Pebruary.

A I know this was prepared by the Commonwealth Edison
Company, and I think that you've identified the question for
which it was prepared, but I'm not positive.

Q Did you prepare that answer for that question?
 A No.

15 Q How does the answer to the question as it was pre-16 pared differ from the sampling plan which is attached to your 17 testimony?

A I'd have to look to see the differences.

10 Q I can show you Attachment A that was submitted on 20 12 February and a copy of your- Do you have a copy of your 21 own plan?

A

Yas.

23 There is some material added to the end of the text 23 or what is labeled attachment 1, or the title is "Attachment 23 A, Neutron Absorber Sampling Plan - in Pool."

1298

2326 213

eb8

2

3

5

7

13

1.3

13

What is that addition?

0

A There are nine items on Attachment A, and there are now 12 items on the May 25th Reference 5 of my testimony.

Q Were you responsible for these additions? A I can't answer that question cleanly. There was some discussion between me and people from Commonwealth Edison, and a decision was made to add those materials. I didn't decide it; they decided it.

9 Q After consultation with you it was decided to amend 10 the plan to add those parts?

A It is my understanding that the answer to your quastion is yes. If there had been a decision to make that change prior to the discussion I didn't hear it.

Q Could you read the three additional statements that were added, or actually it should be procedures.

A Number 10 is:

"Should any adverse conditions be detected, the samples may be subject to a B^{10} loading analysis.

"11. Additionally, two full length vented fuel storage tubes will be suspended in the pool. They will be observed periodically for signs of swelling, and they will be opened and examined should the small specimens indicate any loss of absorber material below .02 grams per square 2326 214

eb9

8

2

3

3

17

3

11

12

13

14

百倍

17

181

19

20

25

28

2%

eb10

centimater of boron¹⁰."

2 Item 12 is: "Retain samples." 3 Did you review this entire plan? 0 A Yes. 5 Did you find it satisfactory? 0 3 A Yes. The original plan did not include a neutron 2 3 attenuation test, did it? 3 A 20. 10 Will neutron attenuation be practiced as part of 0 the new plan? 11 It isn't comm. ted that neutron attenuation be 12 A measured in the plan. They will be available for doing that. 13 It is committed that an indication of absorber 3.4 material concentration within the specimen be measured, and 15 it is possible that neutron attenuation will be the system 15 used to do so, but it isn't specified in the plan. 17 Do you know what method of testing would be used Q 13 if a neutron attenuation plan were used? 19 If it wore used, or if it were not used? 20 A 0 If it were used? 21 If neutron attenuation were used, then that would A 22 be the test to be used. I'm a little confused. 2.3 I'm afraid maybe I'm confusing you with my ques-0 24 ticn. 25

1300

Will you explain the test?

A One can pass a neutron beam through a specimen and measure the intensity of the neutron beam that penetrates. If this is done carefully one can tell how much absorber material is present in the specimen.

0 Would this have to be done prior to the installation in the pool?

3 MR. STEPTOE: Objection, Mr. Chairman. The question seems very vague to me. The test will be done to what? 3 MS. SEKULER: Would the test for neutron absorbing capacity as described by Dr. Draley in his answer to my last question be performed prior to the rack's immersion in the 20012

CHAIRMAN WOLF: Dr. Draley, can you answer the question, or would you like it restated?

THE WITNESS: I think I understand the question.

The answer is it depends on the sensitivity that you need in the result whether you should measure the attenuation before putting in. For the sensitivity that is needed for this case, I'm not sure I know the answer.

> My guessing wouldn't be useful I think. BY MS. SEKULER:

0 It would?

It would not be useful since I don't really know. A Q Oh, your guessing would not be useful.

2326 216

1301

ebil

5

2

3

5

3

Ť

10

11

12

13

13

15

113

17

18

463

20

21

22

23

24
eb12

1

2

3

3

5

-7

3

9

10

11

12

13

14

13

16

17

13

19.

20

21

22

23

23

215

Could you tell me, is a test underwater more or less sensitive -- to use your word "sensitive."

A Underwater would be less sensitive in general than testing out of the water. We're talking about neutron attenuation?

Q That's right.

Do you believe that the plan as presented in your testimony for neutron absorber sampling is complete and adequate?

A I think it is adequate. I don't know the definition of "complete." It is complete insofar as -- oh, the present commitment of the company.

In other words, it describes the present commitment of the company. I think in that sense it's complete.

2326 217

	1	1303
		Q What up you mean by the commitment of the company?
WRB/wbl	2	A I think the company will be committed by the plan
	3	that they have prepared.
	4	Q To?
	5	A To carry out the plan as it is written.
	6	Q Committed to the NRC?
·	7	A Yes.
27	3	Q Other than consulting with some of the Commonwealth
	0	Edison officials regarding those additions to the plan that
	10	we discussed just previously, did you have any other input
	11	into the development of the surveillance design for this pocl?
	12	A I don't think so. Because there's no wording
	13	changed in the document, other than that. And the document
	14	that was identified as Attachment A was prepared prior to the
	15	time that I had any connection with the case or discussion
	16	about them.
	17	Q Other than modifying the chart I think it's
*		

Figure A. --other than making the modification on Figure 1 18 1 where you indicated that the bottom hole would be deleted, 10 you had no responsibility for drawing up that chart or 20 designing that chart; is that correct?

> A That's correct.

25

22

23

24

25

What would be the effect of a significant loss---Q Excuse me; let me to back and ask a further question.

What would you define as a significant loss of

wb2

nautron absorber.

2	Q The term "significant" tends to be relative.
3	In the present context I would define "significant" as
4	indicating a risk that the polson properties of the neutron
5	absorber would not be as high as desirable for safe opera-
6	tion, with some safety factor, of the storage pool.
7	Q That would be the effect of having a significant
8	loss.
9	Can you define how much neutron absorber may be
10	lost prior to having that effect?
11	A No, I don't know that. That's a nuclear calcula-
12	tion, and was performed by someone who identified .02 as
13	the quantity that they thought was an appropriate one.
14	Q Regarding the test rods that are now going to be
15	included in the plan, it states that two full length vented
16	This is No. 11:
17	"Two full length vantad storage tubes
18	will be suspended in the pool and will be examined
19	should the sample program indicate any loss of
20	absorber material below .02 grams."
21	Will there be any examination of the full sized
22	test rods at any time other than then?
23	A I'm afraid I was reading a sentence, and I'm not
24	sure whether you read all of it or only part of it.
25	There's a sentence that says, "They will be observed periodically

1304

wb3

1

2

3

13

3

7

3

9

10

11

12

13

11

15

16

37

13

151

20

23

22

23

20

25

for signs of swelling, and they will be opened and examined,"

et cetera.

Q I don't have that on my copy.

A Oh, don't you, really?

Q No. 11?

Q

A

A Yes. Could I see your copy?

(Document handed to the witness)

I may have a copy that was handed to me previously. Is your copy the correct one?

A Yes. No. 11 reads:

"Additionally, two full length vented fuel storage tubes will be suspended in the pool. They will be observed periodically for signs of swelling, and they will be opened and examined should the small specimens indicate any loss of absorber material below .02 grams per square centimeter of boron-10.

Q The part that was missing from mine is, "They will be observed periodically for signs of swelling." And that answers the questions I was trying to ask.

Will this observation be visual?

DR. REMICK: Excuse me, Ms. Sekuler. I'm not sure now which is the version we should be looking at. I find that my two copies are also different, the one originally

wb4

÷.

2

3

3

6

7

8

3

10

11

12

13

12

15

16

17

13

19

20

21

in Mr. Draley's testimony and the one we received yesterday from counsel. So I'm confused.

MR. STEPTOE: The fault is ours, Dr. Remick. The first two pages of the Neutron Absorbing Plan which was filed, as filed, is the correct version, I believe. That is the version that was just read. The thing we supplied you with yesterday, the first two pages are wrong in that that minor change was made before we made the final draft which was filed. I apologize to the Board that we handed that out.

CHAIRMAN WOLF: Do you want to strike some of it from the record? We ought to have a definitive statement about the thing so that we know what we're looking st.

THE WITNESS: Now about the reading that I made a few minutes ago standing as the correct testimony, or the correct Item 11?

CHAIRMAN WOLF: Does your counsel agree to that? Are there any other changes which should be made? MS. SEKULER: Mr. Chairman, may I suggest that perhaps Dr. Draley read into the record his copy and make any corrections that must be made, and then we can all follow along and have a correct copy in the record?

MR. STEPTOE: I have no objection to that, Mr. Chairman. And, again, I apologize for this difficulty. Perhaps we could go off the record for a moment and I can point out to you what the change was.

2326 221

CHAIRMAN WOLF: On the record.

1

2

10

1

5

5

17

3

3

10

11

12

13

15

16

17

18

19

20

21

22

23

26

25

Q

wb5

MR. STEPTOE: Mr. Chairman, once again I apologize for this confusion. The correct description of the neutron absorbar sampling plan in pool, which --

CHAIRMAN WOLF: Dated May 25, 19797

MR. STEPTOE: Yes -- which Commonwealth Edison plans to use includes the -- the first two pages of that plan are the pages that you have in your testimony as filed. The last two pages are a Table 1 and a Figure 1 which were handed to you yestarday.

CHAIRMAN WOLF: Thank you.

14 MS. SERULER: I have one or two more questions along this line.

BY MS. SERULER:

If, in testing, it was discovered that the B-10 0 content of the samples fell below the range of criticality and inspection of the tubes also indicated some neutron attenuation, are there any plans to empty the fuel out of the existing racks and inspect those racks also?

It is the intent to make a judgment on that when A the results are in. And I don't know if there are any detailed plans, I haven't discussed them.

Do you know if it would be possible for that to be

dona if the necessity arose?

1

2

2

is.

5

6

7

3

9

10

11

12

13

12

15

15

17

13

19

21

To produce a plan to do so, you mean? A

0 Well to move the fuel.

A As a generality, yes. What individual complication there might be because at a particular time the racks are nearly full, I can't address. But as a general statement, it would be possible.

> 0 All right.

Let's lock at your testimony on pages seven and eight, please.

> CHAIRMAN WOLF: What is the page, please? MS. SEXULER: Saven, going over to page eight. BY MS. SEKULER:

0 You state there that swelling should not occur because the only known causes of swelling are entrapped gas, which should be alleviated by venting, and the creation of corrosion products with greater volume of metal from that which it was produced which "should not reach serious proportions."

20 Are there tests and surveillance plans and procedures to monitor the production of gas in the tubes? 22

A . Not to my knowledge.

23 0 Are theer tests to monitor the creation of 24 corrosion products to see if they do in fact, attain greater 25 -- "reach serious proportions?"

wb7 If the -- the coupons, the small specimens, will A be examined periodically destructively, which means they'll 3 be taken apart and examined, and the formation of quantities 3 of corrosion products that are deemed objectionable or serious 5 will be observable. And in the event that it becomes necessary 8 or desirable, then the full-sized ones can be taken apart and 7 examined in the same way. 8 But there are no procedures to monitor the actual 0 9 creation of corrosion products within the tubes that are being 10 used, is that correct? 17 That's correct. By being used, I presume you mean A 12. to store fuel. 15 0 To store fuel, yes. 10 Is there any way to determine the size of corro-15 sion products within the tubes being used to store fuel, 16 which might be flaking away -- corrosion products being the 17 one that were flaking away? 18 I have a little difficulty with the question. A 19 Lot's see if I can ---20 I'll rephrase it and break it up. 0 21 Are there any tests for the size of -- excuse me, 22 strike that. 23 Are there any tests planned to measure the size 24 of any corrosion product which might flake off within the 25 tubes being used to store spent fuel? 2326 224

A I don't think so. That would be difficult. Q Are there any tests proposed or devised to monitor the accumulation of crud and/or corrosion products around the vent holes on the tubes?

A I don't think there is a plan to monitor that. I haven't discussed it, anyway.

Q You state in your testimony on page eight that the sample specimens are "expected to behave in the same way as the actual tubes." What is the reason for this expectation?

A I'm trying to find the place where it says that.

If it refers to the full-sized tubes, it is because they are in all respects that we know identical to the tubes that are used to store fuel and they are immersed in the same water and in the presence of nearly everything at the same level. Some tubes have fuel in them and some don't, and these will not have fuel in them.

2326 225

2

3

4

5

6

3

3

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

and2B

fls WRB 1311 AWEL/wel 1 That refers, then, to the full size tubes? Q 1 I'll have to find it, to see what we were talking 2 A about. 3 0 Okay. Second paragraph, page 8. 2 "To assure that unexpected dange is not occurring, 5 the surveillance program that will be put into effect 6 when the new racks are installed ... " 7 That sentence is intended to refer generally to A 3 both the small ones and the big ones. The small ones should 9 be similar in type of behavior, and the big ones should be 10 essentially identical in behavior. 11 Have any differences been considered between the Q 12 small vented tubes and the large tubes that will be used to 13 store fuel? 14 MR. STEPTOE: Objection, Mr. Chairman. The question 15 is vague. I don't understand what is meant by small vented 18 tubes. 17 MS. SEKULER: I'm quoting from his testimony. 18 CHAIRMAN WOLF: Do you understand the question, 19 Dr. Draley? 20 THE WITNESS: I think I understood what she 21 meant by small and large, but I didn't get the --22 MS. SEKULER: "Small vented specimens," is what's 23 in the -- I'm sorry. I skipped a line in the testimony. 28 BY MS. SEKULER: 25 0 The question I'm asking is if you have considered

wel 2	. 1312
	what types of differences there might be between the small
	vented specimens and the actual tubes used for storing the
	fuel in the pool?
	A We have thought of some differences, yes, related
	to the difference in size. There is a kind of difference
	in the mechanical properties of the stainless steel cladding
	with respect to how much distortion there will be from
	pressure differences.
	We have considered the fact that the vent hole
	is a different size and whether that would make a difference
	in the way they behave.
	And, in particular, we certainly considered the
	facts in which the small specimens are the same, namely the
	same materials and in the same general arrangement with
	respect to each other.
	We have concluded that the behavior will simulate
	the big ones adequately to be safe in the identification of
	any unexpected swelling or problem that occurs.
	Q So for that reason you have decided that it's
	not necessary to make regular inspections of the large test
	tubes?
	A We have decided the opposite to that, that large
2	tubes should be inspected regularly, but we think a visual
2	inspection is adequate.
	Q Just for clarification, since we have been given

wel 3	1.313
1	several different numbers, do you happen to know what the
2	size of the vent hole will be on the racks being used to
3	store fuel?
۵	A That's shown on the drawing as a quarter of an
5	inch in diameter.
5	Q Is that for the rack itself, or for the sample?
7	A That's for the rack, or the tubes in the rack.
3	Q I see. The tubes in the zack.
é	That's a quarter inch, is that what you said?
10	A Yes.
11	Q And will the dummy cells or large tost cells
12	have the same size vent holes?
13	A Yes.
· +4	Q And what will be the size of the vant hole on the
• 15	smaller specimen?
16	A As it shows in Figure 1, it's about a sinteenth
	of an inch.
18	Q Is that representative to scale determined by the
19	size of the small specimen in relation to the size of the
20	larger specimen?
21	A I don't know. But if so, that's not the reason
22	for selecting it.
23	Q What was the reason for selecting th?
24	A I didn't really get into that is detail with
25	them. In fact, it would be a little closer simulation to
	2326 228

B

wel 4

2

3

4

1.5

药

7

3

9

10

11

25

performance, I think, if it were a little bigger. I didn't think it was essential to reproduce it. It's conservative in the sense that it is -- if

the small one does well, there's a higher probability than otherwise that the big ones will do well.

0 Will the welded seams of the coupons experience the same stress conditions as a full-size rack tube?

A That question is difficult. Evidently you mean in the event something happens will they undergo the same stress conditions?

MR. STEPTOE: For the record, Mr. Chairman, I object to this. I don't think there's any foundation to 12 13 assume that there will be any stress conditions on the large racks, and therefore it's causing the witness confusion. 14

CHAIRMAN WOLF: What is your response to that, 15 Ms. Sekular? 16

MS. SERULER: Whatever normal stresses would be 17 in the pool is what we're interested in. 18

MR. STEPTOE: Well, Mr. Chairman, perhaps crunsel 19 should then ask what would be the normal stresses on the 20 walds in the spent fuel pool. 21

MS. SEKULER: I'll be happy to do so. 22 CHAIRMAN WOLF: I think the witness can handle 23 the question. 24

THE MITNESS: The strasses on the wolds in the

1314

re1 5	. 1315
i	specimens and in the full tubes will be related to the
2	fasion in which they're prepared and to possible stresses
3	related to the weights of material that apply stresses while
4	they're in place.
5	I haven't made an analysis, but by analogy with
6	systems similar to that, if the welds are not stress relieved
7	after the production then the biggest stresses that are
3	residual after welding will be as a result of the welding
9	and cooling itself, rather than as a result of the stresses
10	imposed by the parts of the system.
11	And in that event, the stresses on the little
12	ones will be very similar to the stresses on the big ones.
13	BY MS. SEKULER:
14	Q I think you've answered my guestion, "yes."
15	They will be very similar?
16	A I think so. I haven't been told whether they're
17	going to be stress relieved, but I imagine not.
18	Q According to the schedule on Table 1, the first
19	sample will be tested 90 days after the coupon is placed in
20	the pool. Will this be adequate to datact problems prior
21	to 90 days?
22	A In my judgment it will be, in that, in my
23	judgment, the probability of a problem that one would need
24	to take any corrective action for would be very small prior
25	to 90 days, and, in fact, I think it's small at 90 and
	2326 230

wel

11

5	1310
1	subsequent as well.
2	Q In your opinion is it possible there could be a
69	significant amount of swelling in a vented design?
4	A To answer that, I'd have to know the meaning of
5	significant as I might use it or as you might, but in my
6	opinion it is possible that there will be measureable
7	swelling.
3	Q Now would you quantify that swelling?
9	A By that, you mean how big is it likely to be?
10	Q Yes.
11	A Well, there's a range of possibilities. My
12	judgment is that it is not likely to be in excess of perhaps
13	a tenth of an inch, and that is as high as I expect to see
14	any.
15	In my testimony I estimated that from local
16	corrosion it would not be expected to exceed the number that
17	is calculated, of .234 inch.
18	Q It will not exceed .234 inch over the lifetime
19	of the tube? Is that what you
20	A Yes.
21	Q What would be the cause of that swalling?
22	A If that were to occur it would be because at some
23	time the Boral were completely - the thickness of the Boral
24	would be completely corroded, to form corrosion product and
25	the remaining boron carbide, which would not be corroded.
	2326 231

1	
wel 7	1317
1	Q I'm not quite sure I understand that answer.
2	What do you mean by the thickness of the Boral
3	would be completely corroded? Do you mean the clad?
4	A I mean it would be corroded all the way through
5	the Bozal, the cladding and the core material if that
8	happened, which I said I thought was not likely to occur,
7	the maximum swellings that I estimated would be about .234
5.	inch. And I don't expect that to be exceeded.
9	In fact, I don't expect it to be reached, either,
10	as I said a little while ago.
11	Q If such an event occurred, and the Boral were
12	completely corroded, why would the swelling be limited to
13	a small amount such as .234 inch?
14	A That's based on a change in volume of the aluminum
15	content of the Boral when it is converted to a corresion
16	product. The predominant corresion product at the temperatures
17	that will be in the pool nearly all the time goes by the
18	mineval name of Bayerite, and from a knowledge of its density
19	it can be calculated the extent to which swelling will occur.
20	In fact, my calculation is slightly more complex
21	than I indicated, since not all of the material in the
22	thickness of the Boral will corrode, some of it being boron
23	carbide, and not necessarily a perfect packing of the corresion
24 .	product will exist. And those two effects have opposite
25	effects. I have estimated that, on the conservative side, my

el S	1 maximum is still correct, in considering those two.
	2 Q Now, your assumption is based on a vented tube,
	3 is that correct?
	A It wouldn't matter whether it were vented or not.
	5 if I'm only talking about the corrosion product swelling.
	6 My assumption, in answering your question, was
	7 based on a vented tube.
	Q If the tube were not vented, would your answer
	9 change?
1	A If the tube were not vented, then experience at
1	Monticello indicates that it might swell more in the event
1	2 that there is a leak in an unfortunate location.
1	2 If a vented tube were to be partially closed up
1	by having the vent hole clogged, would that simulate a
• 1	5. situation similar to Monticello, where the tubes were not
1	6 vented?
1	A I don't believe so, no.
1	Why is that?
1	A Because it doesn't take a very big hole to let the
2	gas out, and partial plugging wouldn't prevent the gas from
2	escaping.
2	2 Does it make a y difference in your analysis
2	whether the vents go all the way through the tube, top and
2	bottom, or if they are c by vented at the top?
2	A You said all he way I missed what you meant
	7776 777

wel 9

1

by that.

21.11	
2	Q I have been told that the vent hole there would
3	be holes at the top and bottom. There would be kind of a
а,	space that went from the top to the bottom.
5	Let me rephrase the question.
6.	Would it make any difference if there were vent
7	holes at top and bottom, as opposed to only having the tube
81	vented at the top?
9 ·	A With respect to release of the gas I don't think
10	it would make any difference.
11	Q Would anodizing the aluminum in the Boral, or
12	the Bozal clad, reduce the amount of corrosion?
13 .	A My judgment is that it is not likely to make any
14	difference in the 40-year lifetime. I'm not certain about
15 .	that, though, because it would depend on whether the
16	electrical contact between the stainless steel and the Boral
17	were impeded significantly for a long period.
18	Simply in terms of corrosion, I don't think it
19	would matter, because the anodized coating doesn't last that
20	long. That is, its corrosion resistance doesn't last that
21	long.
22	But if it in a sense accidentally retained an
23	insulating layer between the alumunim and the stainless
24	steel, then it is possible that it would have an effect.
25	Q Regarding the timing of the sampling of the test
	2724 071

wel	10	1320
	1	coupons and specimens, do you know who determined the schedule
	2	for sampling?
	З	A The technical staff of Commonwealth Edison. If
	4	you want to know an individual, I'm not sure that I do know.
	5	2 You were not responsible for that determination?
	6	A No, I was asked if I would look at it and give
	7	them any objection I might have.
	8	Q Do you know why it was decided not to test more
	9	often after year-1 than every five years?
	10	A I haven't discussed it with anybody. I can
	11	speculate with you, in terms of the number of specimens
	12	that would be required, since specimens are destroyed when
	13	they are taken out and examined.
	4	Q Well, do you know what would happen between
	15	year-1 and year-5 if some type of unexpected event took
41	16	place? Would there be apy mechanism by which Edison would
1	17	be alerted to inspect those coupons?
	18	MR. STEPTCE: Objection, Mr. Chairman.
	19	"Unexpected event" in this context seems very
2	20	vague to me.
2	1	CHAIRMAN WOLF- Can you rephrase that, Mo. Setuler?
2	22	BY MS, SERULER:
2	23	Q Is there any way in which Commonwealth Edison
2	24	can let me start that again.
2	25	Should a change occur on c. of the test coupons
		2326 235

el 11	1321
1	between year-1 and year-5 which had not been predicted,
2	would there be any way of knowing, then?
З	A It's still difficult to answer, "Would there be
4	any way."
5	There isn't a provision in the plan that says they
6	will detect this.
7	Q There's no alarm
6	A but it's perfectly obvious that if someone
9	elected to change the plan and look at it more frequently,
10	then he could.
11	Ω Do you think that it would be advisable to change
12	the plan so that more frequent inspections were made?
13	A I don't believe that it's necessary. That's
14	the reason I didn't advise them that I thought they should
. 15	do it more often.
16	Ω Your testimony on page 8 indicates:
17	" the surveillance program that will be put
18	into effect when the new racks are installed "
19	Do you know if all the elements necessary for
20	the test program will be ready at that time?
21	A To my personal knowledge, I don't know, no. But
22	it was intended to commit them by writing it in the
23	testimony.
24	Q Do you know if there are plans to delay reracking
25	until the surveillance program will be ready?
	2326 236

1

W

wel 12	A I don't know if there is any problem in having
2	the surveillance program ready on time, and I don't know of
3	any possible plan for delay.
4	Q Do you know how accurate the test program would
5	be if it were to be done after the racks were installed?
6	A I guess that depends on how much after. I think
7	it would probably be fine if it were a small fraction of the
8	first exposure pariod.
9	Q What is the margin of error?
10	MR. STEPTOE: Objection, Mr. Chairman. I don't
11	understand the use of the term "margin of error."
12	MS. SERULER: Could you read back the answer to
13	the previous question?
14	(Whereupon, the Reporter read from the record, as
. 15	requested.)
16	BY MS. SEKULER:
17	Q Can you define a small fraction of the first
18	exposure period?
19	A The first exposure period is 90 days, and in my
20	judgment a small number of weeks of delay would not be an
21	undue risk of any kind.
22	2 Turning to page 2 of your testimony, you state,
23	under your general statements concerning corresion,
24	A. Boric Acid Solution, in the first paragraph, about
25	midway down, this is talking about the method by which the
	2326 237

The summer

1.322

1	solution used in the Zion spont fuel storage pool is purified.
2	"This purification process has not been run
3	at all times and the concentration of the boric acid
4	has not been constant." .
5	As the boric acid content varies, does the pH
G	vary in the pool?
7	A Usually it does, yes.
3	Q Do you know how it varies, what levels it varies
9	co7
10	A Well, the range that I have given here is a
11	pretty accurate statement of a period of about a year, and
12	for the year or two prior to that I guess I'd have to consult
13	to see if there's any error in it, but it isn't far off, for
14	certain.
15	G So the one period you refer to in the statement
16	from 4.7 to 5.5 in one period, that or a period is a year?
17	A Yes, it was approximately a year. I'm not sure
18	if there's a month or so deviation from that.
19	Q Do you know of any times when the pH in the
20	spent fuel pool has fallen below a pH of 4.72
21	A That's a matter of my recollection. I think
22	there probably were times that they were analyzed below 4.7.
23	And if one consulted the data, that answer would be
24	available.
25	Q On page 2 you make the statement, at the end of
	2326 238

wel 14 1 the second paragraph, 2 "A significant adverse effect on the aluminum corrosion can be predicted if the pH is below about 2 4, depending on the temperature, the presence of 5 other sclutes, and the rate of flow of solution past the metal surface." 5 7 Is that based on your own research? 8 A Yes. Can you tell me what the temperature would have to 9 0 be to make a significant adverse effect possible? 10 That also depends on the solution flow rate. A 11 At flow rates of the order of 9 feet per second or greater, 12 then at temperatures of the order of 70°C. at pH 4 there 13 would be a high corrosion rate, an objectionably high 14 corrosion rate. 15 At a lower flow rate, or in nearly stagnant 16 circumstances, such as in the tubes in the storage pool, 17 the corrosion rate would increase at that pH, but it would 18 not become very large in terms of short exposure creating 19 much of a problem. 20 I haven't really made an estimate of how low a 21 pH would be tolerable for how long, but I don't think a 22 pH of 4 for a short time would be cause for concern. 23 Should a problem in the spent fuel pool cooling 0 22 system cause evaporation of several fast of water, although 25

wel 15	1325
1	it might not be sufficient to uncover the fuel, would that
2	cause some change in the pH?
3	MR. STEPTOR: Objection, Mr. Chairman. I really
4	don't understand. There has been no basis for this question.
5	I don't know what Counsel is referring to by a "problem."
0	MS. SEKULER: Mr. Chairman, we have already
7	submitted in direct testimony some testimony by another
8	witness who will appear next week regarding the possibility
9	of boiling in the pool.
10	It is my intention to just elicit from the witness
11	some small amount of information regarding his interpretation
12 \	of the possibility of some corrosion at the higher tempera-
13	tures in the pool below 176, which the Applicant has conceded
14	is the temperature that may be reached in the pool with one
• 15	train of the cooling system shut off.
16	CHAIRMAN WOLF: Do you expect to tie this
17	testimony in with testimony next week?
18	MS. SEKULER: YES, I do.
19	CHAIRMAN WOLF: You may go ahead.
20 .	THE WITNESS: The answer to the question, as you
21	asked it, is:
22	I believe that the concentration of the boric
23	acid will increase in the pool, but it will not significantly
24	increase within the tube where the concentration is likely
25	to be lower than it is in the pool anyhow.
11	. 이는 사람이 있는 것은 이야기 이는 것은 것은 것은 것을 하는 것은 것을 가지 않는 것을 것을 수 있다. 것은 것은 것을 하는 것을 가지 않는 것을 가지 않는 것을 가지 않는 것을 수 있는 것을 가 하는 것을 수 있다. 것은 것을 가지 않는 것을 가지 않는 것을 수 있다. 것은 것을 가지 않는 것을 수 있다. 것은 것은 것은 것은 것을 수 있다. 것은 것은 것은 것을 수 있다. 것은 것은 것은 것은 것은 것을 수 있다. 것은 것은 것은 것을 수 있다. 것은 것은 것은 것을 수 있다. 것은 것은 것은 것은 것은 것을 수 있다. 것은

1 16	1326
2	BI M5. SERULER:
-	Ω Why would that be?
3	A Because some of the acid will have reacted with
4	the aluminum to yield solution whose hydrogen ion concentra-
5	tion is lower, and that means a less concentrated acid
6	solution.
7	Q Would you then say that the lower pH in the pool
8	would have no effect on the metals within the tube?
8	A If the time were long enough, it might have an
10	effect. That is, if the level in the pool ware low for a
11	long enough time it might have an effect.
12	But for a short time of the order of a week or
13	two, I think it would not.
14	Q Would you define a time as longer than two weeks
15	a long enough time?
16	A I'd have to reflect on that a little. To make up
12	a number that
18	Q I'm using the numbers that you're giving me.
19	A Two weeks is in the safe area. I haven't said
20	what is the borderline between safe and unsafe, with respect
21	to changing the concentration.
22	It's a natter of estimating how much mining there
23	is between the solution in the pool and the solution within
24	the
25	Q I realize, without giving you substantially better
	2326 241

			2	-
W	8	1	Δ.	1

1 numbers, I'm asking for some speculation. 2 A I think it is likely that a month or so would be 3 enough to show a significant difference in concentration 4 within the tubes. I haven't said enything to the effect of 5 whethar you care. õ Q . When you're making these assumptions about the 7 effect of lower pH on the tubes, are you making an assumption that the bottom of the tube is or is not vented? 2 9 A The bottom -- I'm assuming the bottom of the tube 10 is not vented. 11 0 Thank you. 12 CHAIRMAN WOLF: May I inquire if you have 13 considerably more? 14 11. MS. SEKULER: This might be an opportune time to take a break. I have about another half hour or 45 minutes 15 worth of questions. 16 17 CHAIRMAN WOLF: Let's take a ten-minute break. 12 (Recess.) 2326 242 19 20 21 22 23 24 25

BLOOM flwsLandon	. 1328
2C agb1	CHAIRMAN WOLF: We'll be back on the record.
61	Ms. Sekuler, are you ready to go forward?
3	MS. SERULER: Yes, Mr. Chairman.
2	At this time, I have some proprietary documents
5	with which I would like to examine the witness.
6	CHAIRMAN WOLF: Do counsel have any objections
7	to the use of these documents?
8	MR. STEPTOE: No, we do not.
9	CHAIRMAN WOLF: ARe you familiar with it,
10	Mr. Steptos?
11	MR. STEPTCZ: Yes, I believe I am.
12	CHAIRMAN HOLF: And are you, Mr. Goddard?
13	MR. GODDARD: I'm vaguely familiar with them.
14	We have no objection to their use at this time.
. 15	CHAIRMAN WOLF: When the Board takes up pro-
16	prietary matters - I'm speaking to the people in the
17	audience here now under the rules, it's necessary to
18	clear the courtroom until we complete the questioning on
19	the proprietary matters, and only counsel and their experts
20	who assist them are permitted to be in the courtroom.
21 -	So I'd like to ask the audience if they would
22	withdraw until we finish with these two documents. Under
23	the rules, we have to make a separate transcript of the
24	testimony that is heard in connection with them. And the
25	rules require that we ask everybody to leave during the time
	2326 243

(interest agb2 that the proprietary matter that is under discussion. I'm sorry to inconvenience you. Counsel suggests it will take about a half an hour. If you're going to be up in the lobby, we'll ask somebody to go up and announce that we're through. (Whereupon, the hearing was receased to in camera sassion at 2:55 p.m.) (IN CAMERA session: pages 1330 - 1354) 2326 244

ebl 1	(The afternoon session was resumed in open session)
2	(3:40 p.m.)
3	Whereupon,
4	JOSEPH E. DRALEY
5	resumed the stand on behalf of the Licensee and, having
6	been previously duly sworn, was examined and testified
7	further as follows:
8	CROSS-EXAMINATION (Resumed)
9	BY MS. SEXULER:
10	Q Dr. Draley, I just want to ask one more question
11	for clarification purposes.
12	Will the tubes in the spent fuel pool at Zion be
13	vented from the top and closed at the bottom?
14	A Yes.
. 15	Q And did you have any input into making that
16	decision?
17	A Yes.
18	2 And how were you involved in making that decision?
19	A My opinion was asked, whether it would be desirable
20	to close the bottom tubes for reasons related to corrosion
21	and electrochemical corrosion, and then decisions were made.
22	I didn't make any recommendations, but I told then my opinion.
23	Q And what was your opinion that you told them?
24	A My opinion was that with the tubes vented at the
25	bottom, I thought the performance would still be satisfactory.
	2326 245

eb2 In other words, I thought the performance inside the tubes i 2 in the storage canal would be better than the particular specimens that Mr. Karzmar had tested, and secondly, that 3 the performance, that is, the amount of galvanic or electro-4 chemical corresion would be less if the bottom were vented, 5 and therefore, there might be some advantage. 5 That was the general thrust of my comments. 7 Were you concerned at all with the possibility 3 Q that there might be some bulging of the tube near the bottom 9 due to internal hydrostatic when the tuck was not submerged :0 if the tube was not vented at the bottom? 11 A discussion of this was held in my presence and A 12 I didn't have any comment to make about it. 13 14 2326 246 15 16 17 18 19 20 21 22 23 24 25

1355

2đ

2E wbl 1

2

11

12

13

1.1

12

20

21

22

23

24

25

Q Do you have any knowledge about that particular issue, the bulging?

A Only generally; knowledge of materials. And my general conclusion is that the strength of the tube toward bulging from an internal pressure is greatest near the ends, near where the edges are welded, and that it would be readily possible for some engineer to calculate the strength with fairly good accuracy.

9 Q You do not think there is any danger from bulging 10 at that point?

A I didn't calculate it to confirm it, and I wasn't a party to making a decision whether it was strong enough. MS. SEKULER: I have no more questions at this

time.

MR. GODDARD: The Staff has no cross-examination for this witness.

MR. STEPTOE: Mr. Chairman, I just have a couple of questions by way of redirect.

CHAIRMAN WOLF: Very well.

REDIRECT EXAMINATION

XZXZXZX

10.250

BY MR. STEPTOE:

Q Dr. Draley, can you estimate the likelihood that corrosion products might become detached from the boral and float up and plug the holes in the top of the stainless steel racks?

1 wb2 I think the likelihood is very small. First of A 2 all, the amount of corrosion product that detaches is small. 3 It tends to be nearly zero in the early stages of corrosion 4 and to remain that way for a long time. And then one gets 5 sporadic bits of product that come loose. The density of the G product is greater than the density of the solution in which 7 they will find themselves. There isn't any -- By the time 8 that any oxide comes loose there isn't any force that I know 9 of that will tend to make them rise to go to the hole. 10 The amount of hydrogen bubbling which will occur 11 early in the exposure of the boral to the water that leaks inside the tubes, that hydrogen bubbling will have diminished 12 to such an extent that I don't believe it will have a signi-13 ficant effect by the time the corrosion product starts to 14 come off, with the possible exception of tiny bits that are 15 16 a rare phenomenon. So I don't believe that there is any significant 17 probability that the hole will be reduced in size from that 18 scurce. 19 Dr. Draley, in view of the monitoring program as 0 20 described in your testimony, do you believe it is necessary 21 to conduct tests of the corrosion effects which may be taking 22 place in actual tubes used to store spent fuel in the Zion 23 spent fuel pool? 24

25

A

No, I don't think so. I think the probability is

2326 248

wb3

1

2

3

4

5

6

7

3

9

10

11

12

13

14

15

15

17

18

19

20

21

22

23

25

low that there will be an effect great enough to create a problem, and that the presence of full size tubes that can be pulled apart when there is other indication, as by the smaller specimens, that there might be a problem will be enough to satisfy the need.

A storage pool is not a place where you cannot do experiments and examine things at a later time. The general condition is that it will be possible to change plans and to do other things if it becomes necessary.

Q Dr. Draley, to your knowledge has the pH of the Zion spent fuel pool ever fallen below 4?

A No. I have seen a series of pH values recorded that I believe are all of the pH values recorded for the past three years, and none of them is as low as 4.

Is the pH scale logarithmic?

BY DR. LITTLE:

to see if any weeks were missed.

Yes.

MR. STEPTOE: I have nothing further. CHAIRMAN WOLF: Thank you, Mr. Steptoe.

EXAMINATION BY THE BOARD

XZXZXZX

0

A

Q

Q

A

pool?

24

1

T hat's one of the weekly tests that they perform

Dr. Draley, how often is the pH menitored in the

Weekly is the norm. And I didn't look carefully

wb4

1

2

3

Ž.

5

7

8

10

11

12

with the grab sample that they take?

I presume that's the same sample. A

0 Thank you.

BY DR. REMICK:

5 Dr. Draley, back at the early part of cross-0 examination Ms. Sekuler asked you about the size of the hole, I believe, in the storage racks and in the specimens that are part of the currosion surveillance program, and you made an 5 answer that they were quarter inch holes, and I think you said "as shown in the drawing," or "figure." But I don't think you gave is a reference to that drawing or figure. Do you happen to remember what that is?

13 The drawing that I had access to some weeks ago A 14 was an engineering drawing of the racks. And I believe that 15 Nuclear Services prepared it for Commonwealth Edison, and I 16 assume that it's available for inspection, although I don't 17 know if it has been offered in any case.

18 DR. REMICK: The reason I asked that, I agree 19 with Ms. Sekuler that we have conflicting testimony I think in 20 the record about the size of those holes, and we should clarify it, and I thought this might be the time to do it. 21 22 And I thought this perhaps was the witness to do it through. But at some time I think the record needs clarifying, because 23 I think we have testimony that they were three-sixteenth of 24 . an inch and--25

2326 250

wb5 MR. STEPTOE: Yes, sir, we'll supply that next 14 week. We don't need this witness to do that, Dr. Remick. 3 BY DR. LITTLE: 1 0 I have one other question: 5 Is the dissolved oxygen level monitored in the 6 pool? 7 A I don't think so. I'm not absolutely certain that it's never measured, but I don't remember seeing any 3 9 results. 10 So the discussion about oxygen levels would be 0 theoretical based on the conditions in the pool rather than 11 based on known oxygen measurements in the pool? 12 Yes. I don't think there is really much doubt 12 A 14 that the oxygen content of the water in an open pool exposed to the air above it is a significant -- some significant 15 fraction of the concentration that would be in equilibrium 16 with the air, not necessarily exactly equal to it. That's 17 because the air will tend to dissolve in the pool and the 13 ion exchange resin that is used to purify it does not take it 18 up very much. 26 The pertinent oxygen concentration is the concen-21 tration of the oxygen inside the stainless steel tubes. 22 And it would not be easy to measure. Q 23 A And I think I said in testimony that the concentra-24 tion of the boric acid in that area would be lower than in 25 2326 251

35

1 the pool. It will also be true that the concentration of 2 oxygen in that area will be lower than it is in the pool. 3 There is an opportunity to speculate about whether the difference between performance in deaerated vorsus 4 aerated is related to cuygen or related to the concentration 5 of the acid, and one doesn't have enough information to draw 6 positive conclusions on that. In any case, the difference in 7 experiments is clear. 3 0 In the experiments I presume oxygen levels ware 5 10 measured? I taink not. 11 A It's such an easy measurement to do. 0 12 Thank you. 13 CHAIRMAN WOLF: Any further questions? 1h MR. STEPTOE: I have nothing further, Mr. Chairman. 15 MR. GODDARD: Nothing further. 16 MS. SERULER: No further questions. 17 CHAIRMAN WOLF: Thankyou, Dr. Draley, you may 18 be accused. 15 (Witness excused) 20 CHAIRMAN WOLF: Do we have any matters we should 21 take up before we adjourn? 22 MR. MILLER: I think just one, Mr. Chairman, and 23 that has to do with the proposed schedule for next week. 20 I believe that there is agreement among counsel 25 2326 252

wb6
wb7

2

3

13

5

3

7

8

0,

10

17

12

12

23

24

25

subject to the approval of the Board that the sequence of witnesses will be as follows:

Mr. Minor, who is the State of Illinois' witness on corrosion will lead off, followed by the witnesses who have prepared testimony with respect to Contention 2(g) on possible pool boiling. And it is expected that if the Board will sit that evaning -- this would be Wednesday evening -- that we could also deal with the testimony of the State's witness Feter Cleary on Board Question 4(b), which is Emergency Planning. Mr. Cleary is available only, we understand on Wednesday and Saturday. We thought it was desirable to have him testify on Wednesday in the event that we finish otherwise on Friday.

14 On Thursday it's the parties' expectation that we'd be dealing with Contention 2(f) and its subparts, and 15 18 that we would deal with all outstanding Board questions except Board Questions 4(a) and 4(b), that that would carry over --17 that process would carry over on to Friday, if necessary, 18 And we would then have argument on Contention 2(n) which was 19 stricken as a result of the Board's summary disposition order, 20 and that we would have the staff and licensee testimony on 21 Board Questions 4(a) and 4(b). 22

I should state that we are, of course, prepared to stay on into Saturday, should that become necessary. CHAIRMAN WOLF: That schedule you've outlined.

1363

2326 253

wbg	1	Mr. Miller, will be acreeable with the Board, and we'll be
	2	Mit Mixiel, will be agreeable with the sould, and we li se
		prepared to start at 9:00 a.m. on the 20th, that's Wednesday
	3	the 20th. And if you want the Board to sit, if it is helpful
	4	we'll sit that night.
	5	MR. MILLER: Thank you, Mr. Chairman.
	6	MR. GODDARD: Mr. Chairman, excuse me; we'd like
	7	a clarification as to whether Mr. Cleary will be available
	8	Thursday in the event his testimony runs over?
	9	MS. SEKULER: No. Mr. Cleary has informed me
	10	that Thursday and Friday he is occupied elsewhere. He said
	11	it would be impossible for him to be here.
	12	MR. GODDARD: The reason for this request,
	13	Mr. Chairman, is, during the conference call between all
	14	parties and the Board last week Ms. Sekuler indicated that
	15	the Staff's original schedule as set forthin the motion was
	16	satisfactory to her. And there has been no showing, on the
	17	record at least, as to why Mr. Cleary has become unavailable
	16	at this point.
	19	MS. SEXULER: Mr. Cleary informed me when I had
	20	set him up to be here early this waek, not knowing whether
	21	he'd be able to whether testim ould be required. He
	22	informed me at some point in time I don't really remember
	23	when that he would not be available other than Tuesday of
	24	this week and then, perhaps at a later time, Wednesday and
	25	Saturday. But it was my impression that 4(a) and (b) would

2326 254

1364

	1365
wb9 1	go on last, and that if he was not taken early in the week
2	we could put him on on Saturday. I didn't inquire any further
3	into it. I was informed that he would be unavailable.
4	CHAIRMAN WOLF: Well, you know, the Board will be
5	willing to sit late on Wednesday night if need be, if his
G	testimony can't be had earlier in the day.
7	I think we can work it out.
9	MR. GODDARD: Very well, sir.
ŷ	CHAIRMAN WOLF: Anything else we should discuss?
10	(No response)
11	CHAIRMAN WOLF: If not, we'll adjourn now until
12	next Wednesday, the 20th, at 9:00 a.m.
13	(Whereupon, at 4:00 p.m., the hearing in the
14	above-entitled matter was recessed, to reconvene
. 15	at 9:00 a.m., Wednesday, 20 June 1979.)
16	2724 000
17	2326 255
15	
19	
20	
21	
22	
23	
24	
23	