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# OFFICIAL TRANSCRIPT OF PROCEEDINGS

## NUCLEAR REGULATORY COMMISSION

### ADVISORY COMMITTEE ON NUCLEAR WASTE

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UNITED STATES NUCLEAR REGULATORY COMMISSION'S

ADVISORY COMMITTEE ON NUCLEAR WASTE

OCTOBER 18, 2000

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This transcript had not been reviewed, corrected and edited and it may contain inaccuracies.

1 UNITED STATES

2 NUCLEAR REGULATORY COMMISSION

3 ***

4 ADVISORY COMMITTEE ON NUCLEAR WASTE

5 ***

6 122nd ACNW MEETING

7 ***

8 Room T2-B3

9

10 Two White Flint North

11 11545 Rockville Pike

12 Rockville, Maryland

13

14 Wednesday, October 18, 2000

15 The Committee met, pursuant to notice, at 8:30

16 a.m.

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1 MEMBERS PRESENT:
B. John Garrick, Chairman
2 George W. Hornberger, Vice Chairman
Raymond G. Wymer, ACNW Member
3 Milton N. Levenson, ACNW Member

4 ALSO PRESENT:
Amarjit Singh, ACRS/ACNW Staff
5 Howard J. Larson, ACRS/ACNW Staff
Lynn Deering, ACNW Staff
6 Richard K. Major, ACNW Staff
Martin J. Steindler, ACRS Consultant
7 William J. Hinze, ACRS Consultant
Paul G. Shewmon, ACRS Consultant
8 Maury Morgenstein, Geoscience Management Institute, Inc.
Don Shettel, Geoscience Management Institute, Inc.
9 Robert W. Staehle, Adjunct Professor, University of
Minnesota
10 Aaron Barkatt, Professor, Catholic University
April Pulvirenti, Catholic University
11 Geoffrey A. Gorman, Dominion Engineering, Inc.
Chuck Marks, Dominion Engineering, Inc.
12 Gustauvo Cragnolino, Center for Nuclear Waste
Stephanie Bush-Goddard, Office of Regulatory Analysis,
13 Nuclear Materials Safety and Safeguards, NRC
Jim Lieberman, Office of General Counsel, NRC
14 Paul Genoa, Nuclear Energy Institute
Michael Webb, Office of Nuclear Materials Safety and
15 Safeguards, NRC
Allen Howe, Office of Nuclear Materials Safety and
16 Safeguards, NRC
Bret Leslie, Office of Nuclear Materials Safety and
17 Safeguards, NRC
Tae Ahn, Office of Nuclear Materials Safety and Safeguards,
18 NRC
John T. Larkins, Executive Director, ACRS/ACNW
19 Andrew C. Campbell, ACRS Staff [via speakerphone]

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1 P R O C E E D I N G S

2 [8:32 a.m.]

3 DR. GARRICK: Good morning. Our meeting will now
4 come to order.

5 This is the second day of the 122nd meeting of the
6 Advisory Committee on Nuclear Waste.

7 My name is John Garrick, Chairman of the ACNW.
8 Other members of the committee include George Hornberger,
9 Ray Wymer, and Milt Levenson.

10 We also want to recognize our consultants today,
11 Drs. Steindler, Hinze and Shewmon.

12 This entire meeting will be open to the public.

13 Today, the committee will discuss recent tests to
14 explore the specific aspects of the corrosion resistance of
15 alloy-22 material. We're going to hear a presentation from
16 the staff on its rulemaking plan addressing the entombment
17 option for power reactors and hear comments from consultants
18 and members on recent relevant activities and continue our
19 discussion on planned activities, including the entombment
20 option for decommissioning power reactors, and letter and
21 report preparation.

22 Amarjit Singh is the designated Federal official
23 for the initial portion of today's meeting. Andy Campbell
24 was supposed to be in that capacity. He is home recovering
25 from a back problem. I think we will be connected in with

1 him by telephone. I think that I have his number here
2 somewhere, if somebody can do that. He's standing by,
3 expecting that.
4 MR. SINGH: They're on.
5 DR. HORNBERGER: He went to get a telephone.
6 DR. GARRICK: I see. This meeting is being
7 conducted, as usual, in accordance with the provisions of
8 the Federal Advisory Committee Act. We've received no
9 written statements from members of the public regarding
10 today's session. However, should anyone wish to address the
11 committee, you can do so by making your wishes known to one
12 of the committee staff.
13 As usual, it is requested that each speaker use
14 one of the microphones, identify themselves, and speak with
15 clarity and volume so that you can be heard.
16 We have a lot of material to cover today. This is
17 a very important topic, as you all know. We have a lead
18 member on the committee that's been our cognizant person on
19 this topic, and that's Ray Wymer. I will ask him to take
20 over and lead the discussions.
21 DR. WYMER: Thanks, John. It finally has
22 happened. Chemistry has finally reared its ugly head. As
23 the few, the proud chemists among us knew, it had to happen
24 sooner or later.
25 DR. GARRICK: This is your day.

1 DR. HORNBERGER: Make the most of it.

2 DR. WYMER: It may never happen again. But the
3 importance that we attach to this topic, as indicated by the
4 amount of time that's devoted to it, we're going to be on
5 this until noon, which will give us ample opportunity for a
6 lot of good discussion, I hope, from anybody and everybody
7 who wants to comment on it.

8 This morning we have some formal presentations by
9 several consultants that were brought in specifically for
10 this purpose. As you all know, the issue of the corrosion
11 resistance of the C22 alloy, which is the outer layer of the
12 waste container for the bulk of the waste that will be in
13 the Yucca Mountain repository, if we have one, is a central
14 issue.

15 And within that issue, one of the central issues
16 is whether or not the conditions that have been studied so
17 far that have shown rather severe corrosion attack on this
18 alloy are realistic conditions within the repository
19 environment itself, and I hope we'll hear something about
20 that.

21 We have Bill Hinze here, who will be able to give
22 us a little insight into some of the geology that will have
23 a bearing on this.

24 So we'll start out by -- I'll introduce Maury
25 Morgenstein, who will then introduce the subsequent speakers

1 for the rest of the morning. Take it from there, Maury.

2 MR. MORGENSTEIN: Thank you. My name is Maury

3 Morgenstein. I want to briefly go over who we are.

4 Essentially, we're working for the State of Nevada. It's a

5 team approach.

6 We have essentially three tasks that we're working

7 on. We're going to report to you today on one of those

8 tasks, which is the C22 oversight assessment.

9 I'm not going to go through reading everyone's

10 name.

11 Our preliminary scoping studies on C-22, as

12 oversight, should not be confused with site characterization

13 activities. This is strictly oversight and I wanted to

14 underline that, because there is a big difference between

15 how one proceeds.

16 We have three presentations today. The first is

17 on natural lead and mercury values at Yucca Mountain, the

18 second on our scoping experiments, and the third on

19 essentially the waste package environment and waste package

20 concepts.

21 We will start out with Don Shettel, who is sitting

22 next to me here, with our first presentation.

23 The main issue of this morning and the

24 environmental assessment of lead and mercury, and I want to

25 start out here and stress the fact that we are only talking

about lead and mercury in this particular case.

There is a host of transition metals, other trace elements that are important in our overall discussions concerning C-22 in the natural environment. We are going to only concentrate on two of these at this point in time.

We're going to present to you information on fault and fracture carbonates and silicates that form at the surface of the ground as evaporates, that form in fault zones, such as trench-14, and we're going to take a look at the hydro geochemistry data available for the Yucca Mountain area, and the data on hard rock, whole rock tufts in the area.

So there are three different activities dealing with chem.

For the first, this is a -- and I'm going to turn this in a minute so, actually, we can look at it stratographically -- a shot, a stratographic run for mercury, for core hole, 3D, from Nye County. It's a Nye County core, Nye County early warning drilling project. And I want to show you the distribution of mercury in the tufts and sediments from the core.

At around 500 feet below surface, we have a uranium deposit in this particular core and that was the purpose behind our activity here. These data were not developed for C-22 project. We were looking at mercury.

1 You will note that there is a marked peak, mercury
2 peak associated with essentially the uranium peak and it's
3 probably a uranium roll front hydrothermal oriented. It's
4 not a very strange thing. We see these elsewhere in Yucca
5 Mountain area and they're probably related to normal gold
6 type mineralization that we see in Nevada, low yield. In
7 this case, we just don't have a lot of gold.
8 The point is here, we do get some reasonably high
9 mercury values. That's running about 199 PPM. And they are
10 associated with unique deposits, but at the same time,
11 there's a general background.
12 In the same hole, we take a look at lead, and,
13 again I'm going to go stratographic. I'm sorry. Turn that
14 so we can look stratographically.
15 DR. HORNBERGER: Where did that deposit occur in
16 the section, in the stratographic section, the uranium?
17 MR. MORGENSTEIN: The uranium deposit?
18 DR. HORNBERGER: Yes.
19 MR. MORGENSTEIN: That's in the tuft.
20 DR. HORNBERGER: It is in the tuft.
21 MR. MORGENSTEIN: It's in the tuft, just above the
22 sediment horizon.
23 We have a discontinuous data section here on lead.
24 I apologize, but, again, our purpose was not to look at lead
25 in this case and we had already used up the samples for

1 other purposes in the uranium area.

2 But the point I would like to make here is that

3 there's essentially no pattern on lead. It's all over the

4 place. There's a large number of samples that are below

5 detection limit, but at the same time, we have samples, for

6 example, at the surface with eight PPM and at depths with

7 six or seven. So there's no pattern at all associated with

8 lead.

9 We do see, in this particular hole, when we look

10 at the uranium section, we do see galena, which is a lead

11 sulfide. So there is some mineralization, lead

12 mineralization coming along with the uranium and it doesn't

13 show on this particular analysis.

14 But at the same time, we don't think, from our

15 other looks in the literature, we don't think that the

16 sulfide type deposits have exorbitant lead concentrations in

17 them. We see, most of the time, just normal background.

18 In fact, I will show you a little bit later the

19 tufts not associated with sulfide enrichment seem to have

20 higher values of lead than those associated with sulfide.

21 I'd like to transfer our attention to the surficial

22 sediments, the authogenics, those that are formed by

23 essentially precipitation, and we have -- this shows

24 minimum/maximum values, looking at carbonate, silicate

25 veins, fracture fillings, on other words, looking at

1 calcretes, which are soil horizon evaporates, and looking at
2 rhizoliths, which are also up in the soil horizon.
3 And the point I would like to make here is that we
4 have fairly significant lead concentrations -- this is only
5 lead that we're looking at right now -- running from a
6 couple of PPM to about 150 PPM in some cases, and this shows
7 around 64-65 PPM for trench-14A.
8 This is broken down into silicate and carbonate
9 fractions. This work is done by the USGS.
10 In the same paper, they looked at isotope ratios,
11 lead isotope ratios, in an attempt to source the formation
12 of the carbonates and silicates in the veins in trench-14 to
13 address the question of whether or not we're looking at
14 meteoric water, down-flow water, or something that was
15 up-welling.
16 And it was very clear from the isotope ratios that
17 this is meteoric water origin deposits. This is a down-flow
18 situation, and at the same time, we have relatively high
19 concentrations of lead and the origins of the lead was
20 thought to be, for the most part, as a function of aerosol
21 dust hitting the surface of the ground, rainwater dissolving
22 it and moving it through the system and evaporating.
23 If this is the case, and we believe that it is,
24 since we see these low to moderate background values all
25 over the place and certainly at the surface sediments, one

1 can presume, I think very confidently, that down-flowing
2 fracture water, especially in fracture zones and fault
3 zones, contains a general background value of someplace --
4 of lead. I won't give you a concentration, because I don't
5 know.
6 But what I can say is if we had that water
7 dripping on a canister and that water was to go to
8 vaporation, the calcite, silicate, opaline product just
9 prior to or at solidification, crystallization, would
10 contain values very similar to the surface. That would be
11 somewhere between two and about 150 PPM, because it's
12 essentially the same waters that we see depositing these
13 deposits on the surface.
14 Other analysts, other papers in our references
15 have looked at, for example, trench-14 and here is that 150
16 PPM. So what we have done is we have not developed in this
17 analysis any unique or specific analytical numbers
18 ourselves. These are all out of the Department of Energy
19 literature existing today.
20 Again, lead PPM values are all over the place.
21 There's just a general background. I can answer the
22 question that's running through your mind of why are the
23 values so different. That's because essentially, when
24 you're precipitating stuff, it depends upon how much you get
25 in that particular -- how much water is going through that

1 system at that point or how active that area is.

2 We cannot get back to the water concentration

3 values using this analysis.

4 IF we ere to look at mercury values for veins,

5 pyretic and non-pyretic tufts, trench-14, we see that

6 there's a fairly distinctive variance, again. Veins seem to

7 be, of course, higher and these are probably associated, in

8 this particular case or in these cases, with some

9 hydrothermal activity, and that's why those numbers are

10 higher.

11 These are not necessarily the same as we just

12 looked at for lead.

13 I want to bring to your attention the basic

14 background numbers that we're getting for a regional vadose

15 water chemistry on lead as a product from that water

16 vaporation as a function of the USGS analyses and work.

17 We have a specific -- I have a little diagram

18 here, where -- once again, the surface waters are running

19 general meteoric and aerosol lead concentration, which is in

20 low PPM values, drips down a fracture zone and if that were

21 to contact the waste canister, the deposits formed that we

22 see in trench-14, for example, or, I'm sure, if we analyzed

23 some of the vein fillings at the Ghost Dance fault, we would

24 see the same kind of numbers.

25 We expect to see the same kinds of things

1 precipitate in the near field and a general feel for that is
2 anywhere around three to 150 PPM values.
3 I would like to turn this over to Don at this
4 point.
5 DR. HORNBERGER: If you had to put a pH value on
6 that cartoon --
7 MR. MORGENSTEIN: Eight.
8 DR. SHEWMON: You have a water level table in
9 here, wells, where, in those columns, would they be? Below
10 1,000 feet?
11 MR. MORGENSTEIN: Yes.
12 DR. WYMER: Before we go on, are there any other
13 questions on this presentation?
14 MR. MORGENSTEIN: Okay, this part of it, the first
15 half.
16 DR. WYMER: Any additional questions?
17 DR. GARRICK: You have given us some indication of
18 distributions and concentrations. What about time
19 dependencies, time information?
20 MR. MORGENSTEIN: Anywhere from the tertiary to
21 present day. I can tell you -- the only thing I can tell
22 you about time is if we go into the uranium deposits,
23 because we did run a uranium series run on the 3D uranium
24 deposits, and those were 180,000, 182,000, and they're, of
25 course, sitting in tertiary lava. So that's kind of cute

1 and it's of interest.

2 But my sense is that we're looking across the

3 board. I don't think it matters what time.

4 DR. GARRICK: I guess the question is what are the

5 dynamics over a three or 400,000 year timeframe of the

6 distribution and concentrations. What evidence do you have

7 that might suggest what the dynamics might be?

8 MR. MORGENSTEIN: Almost nothing. We have a

9 miniscule amount of data coming into us that we can find in

10 the literature. Remember, we're not out there analyzing

11 anything ourselves. We're in an oversight capacity.

12 DR. GARRICK: Right.

13 MR. MORGENSTEIN: So looking at the distribution

14 of these numbers through time, we don't see any patterns at

15 this point in time. But at the same time, there isn't

16 enough material data, authogenics data, at least well dated,

17 that we could feel confident in even reporting to you, if we

18 had some numbers.

19 Roger, did you have something to say?

20 MR. STAEHLE: Roger Staehle, I'm with the State of

21 Nevada. Just to possibly anticipate some of the questions

22 I've been hearing here, the amount of lead it actually takes

23 to crack this material, if you use the analogy of alloy-600,

24 which is the only really super-available analogy, it's only

25 about one to ten parts per million over the pH range from

1 about three to 13.

2 So we're not looking for a lot of lead here, just

3 to get that framework straight.

4 DR. STEINDLER: I guess I'm confused. We're

5 talking here about the lead content in solids. You've not

6 addressed, I believe, in any of these data, the lead content

7 in solution.

8 MR. STAEHLE: That is correct.

9 DR. STEINDLER: Thank you.

10 MR. MORGENSTEIN: The solids that we are talking

11 about in the case of trench-14 type solids were solids that

12 were deposited from vadose solutions as evaporates. So in

13 order to get where they are, they had to go through a

14 solution.

15 One of the unique problems at Yucca Mountain is

16 that if we go to, and I'm sort of stealing some of Don's

17 stuff here, but I'll let him get to it, if we go to looking

18 at water analysis, that is, saturated zone water, vadose

19 pore water and vadose fracture water for trace elements, we

20 are going to -- we have an extremely hard time in the

21 databank. There is hardly anything of value there. This is

22 a problem of characterization.

23 I'm going to go to Don and then if there are any

24 questions that pertain to the whole, we'll go back over

25 those. Don Shettel.

1 MR. SHETTEL: I will try and use this microphone,
2 although I think Maury just gave my talk. It will be rather
3 brief, which will become apparent.
4 Starting out with the USGS database, put out by
5 Perfect in 1995, this is a compilation up to 1994 of over
6 3,000 water analyses in the vicinity of Yucca Mountain,
7 three degrees of longitude by three degrees of latitude,
8 which is about 100 kilometers in north-south-east-west
9 direction, and this is a histogram of the data we get
10 ranging from almost down to one parts per billion up to over
11 a PPM, and these values actually are not necessarily
12 natural.
13 They're evaporative ponds sitting in buttes and
14 fall-out hills. So they've been evaporatively concentrated
15 and the range for natural lead in water is more in this
16 vicinity here.
17 DR. SHEWMON: That X axis is hard to see.
18 MR. SHETTEL: This axis is -- this is log --
19 DR. SHEWMON: Ten-to-the-minus-one?
20 MR. SHETTEL: This is log parts per billion. If
21 you look up here, I have it thousand parts per billion,
22 hundred, ten and one part per billion. This is log PPM lead
23 down here. Does that help?
24 DR. SHEWMON: Yes.
25 MR. SHETTEL: That's all the data that's available

1 to date, other than some more recent data, which I'm going
2 to show next. In the vicinity of Yucca Mountain, this is
3 most saturated zone water, spring deposits, and well water,
4 and, like I said, there's some artificial pond water here
5 that's been concentrated on the test site.
6 Now, if we move in closer to Yucca Mountain and
7 look at some individual data that we have, and most of this
8 is from the Nye County early warning drilling program that I
9 personally sampled. The only data we had from the USGS is
10 well J-13 and J-12 here. This is dissolved lead up to 16
11 parts per billion.
12 These wells are arranged from west to east. The
13 Bond gold mining well is on the western side of the Amargosa
14 Valley and the Funeral Mountain is on the boundary between
15 Amargosa Valley and Death Valley.
16 As we come across Amargosa Valley, to the first
17 western-most site of the early warning drilling program, 1D
18 site, we have this value. As we come down Highway 95 a
19 little more, we have the next well is 9SX. Then we have a
20 few values from here from Site 3. These are sampled at
21 different times and different depths during the drilling
22 process. There's at least two or three holes at this site.
23 2D is directly south of Yucca Mountain, along 95,
24 Highway 95, and then the wells on the test site, J-13 and
25 J-12, are in 40 Mile Wash, directly east of Yucca Mountain.

1 Finally, the well 5-S is southeast of Yucca Mountain, in
2 Oasis Valley, and this is all the data that's in the
3 immediate vicinity of Yucca Mountain.
4 Now, what you should note from this is there is
5 nothing vadose or these are all saturated zone samples.
6 There's nothing in the vadose zone or saturated zone in the
7 repository block.
8 DR. SHEWMON: Nothing, meaning no measurements,
9 not no lead.
10 MR. SHETTEL: No measurements of lead.
11 DR. HINZE: Let me understand. You're looking at
12 mercury and lead because of their potential corrosive
13 qualities and because you have some data. Is that correct?
14 MR. SHETTEL: I'm concentrating a lot in mercury
15 because that's what our consultants have done in the lab,
16 experimenting with the alloy.
17 DR. HINZE: Do you have information on any other
18 elements that are potentially corrosive or that might be --
19 MR. SHETTEL: I think there's -- the data that
20 I've shown is going to be typical of what's available for
21 anything else that you might want to consider, cadmium,
22 arsenic, antimony.
23 MR. MORGENSTEIN: And there are other values that
24 do exist for other things, and we're not presenting those
25 today.

1 MR. SHETTEL: But the lead is typical.

2 DR. HINZE: Is that because you haven't put them

3 together yet?

4 MR. MORGENSTEIN: We have not put them together

5 yet.

6 MR. SHETTEL: We're just concentrating on lead and

7 mercury today.

8 MR. MORGENSTEIN: As we maybe in the future

9 present findings of significance for other trace element

10 values in the laboratory, we will present their natural

11 background concentrations.

12 DR. HINZE: So what you're getting to, if I -- let

13 me make certain I understand -- is that there are a dearth

14 of measurements and that you would like to see additional

15 measurements.

16 MR. SHETTEL: Yes.

17 MR. MORGENSTEIN: Yes.

18 DR. HINZE: And can you tell us a little bit more

19 about what you think should be made available to properly

20 evaluate the corrosion properties of the vadose water, for

21 example?

22 MR. SHETTEL: Yes. I'll get into that.

23 DR. HINZE: Okay. Sorry.

24 MR. SHETTEL: Now, when we come to mercury,

25 there's even less data. We have one value from the

1 literature here, from Castor, which is half a part per
2 billion. Location unknown. It's from some EPA database
3 which we haven't traced down yet. It may be NURE data,
4 which would be the National Uranium Resource Evaluation
5 data, it might be from there, we're not sure yet.
6 In the Perfect database, which is the USGS
7 compilation, there's almost 100 values, but they're all
8 zero, which I don't know if that's analytical property or
9 what. But out of 3,500 analyses, less than 100 are listed
10 as not missing, but they're all zero. So you'd have to dig
11 back.
12 And then the one conclusion we can make from all
13 this is that the site characterization of Yucca Mountain, in
14 terms of trace elements in vadose and saturated zone water
15 within the repository block is incomplete and essentially
16 unfinished.
17 And this may be a shortsightedness or an oversight
18 on the part of DOE, not looking forward to what might come
19 up, such as what you're going to see later this morning, and
20 may be the result of their -- well, I don't know how to say
21 this, but bias or preconceived notions about what's going to
22 be important, the data that they need to collect during site
23 characterization.
24 DR. WYMER: Would you go as far as to say that
25 there's so little data available on dissolved mercury and

1 dissolved lead that you can't really draw any conclusions
2 about the corrosion that might take place in the repository?
3 MR. MORGENSTEIN: No.
4 MR. SHETTEL: Well, I think we have enough data in
5 the area to say that it is certainly present in the system
6 and if they had analyzed it in at least the saturated zone
7 water, they would have found it.
8 So I don't think there's any question that it's
9 there or not. They just haven't done the analyses for trace
10 elements in the waters.
11 DR. WYMER: So you don't really know.
12 MR. SHETTEL: We don't really know, but judging
13 from the data that's in the immediate vicinity of Yucca
14 Mountain, it's there, so I don't think there's any doubt
15 that they'll find it, if they analyze for it.
16 DR. WYMER: Okay.
17 MR. SHETTEL: I don't think that's a question at
18 all.
19 MR. MORGENSTEIN: Let me speak to that for a
20 second. What we don't have information on, from an aqueous
21 geochemical point of view, is any reasonable set of
22 analytical figures for Yucca Mountain and precisely Yucca
23 Mountain and precisely the individual types of water that
24 exist.
25 It's not sufficient to talk about the hydrogeology

1 of Yucca Mountain with respect to any of these trace
2 elements, unless we distinguish if they are coming from the
3 saturated zone, which is a really poor choice of target
4 water to look for.
5 DR. WYMER: That's right.
6 MR. MORGENSTEIN: But seems to be the choice --
7 MR. SHETTEL: I'll get into that here.
8 MR. MORGENSTEIN: -- at hand. We really are
9 interested in vadose water.
10 DR. WYMER: Sure.
11 MR. MORGENSTEIN: And we're interested in fracture
12 flow vadose water as opposed to just pore water, vadose pore
13 water. We need to know actually both.
14 Those numbers aren't there. We do have enough
15 information to know that lead and mercury exist in the
16 system in the aqueous phases and in the solid phases. We
17 don't have a way at this point in time to look at how much.
18 DR. WYMER: Okay. Thanks.
19 MR. SHETTEL: Oh, good, you just finished my talk
20 for me.
21 MR. LESLIE: Ray, this is Brent Leslie, from the
22 staff.
23 DR. WYMER: Yes.
24 MR. LESLIE: Can I ask a question?
25 DR. WYMER: Yes.

1 MR. LESLIE: Don, what is the minimum value of
2 water that you need to do these lead analysis, since you've
3 been doing them for the Nye County wells? This will help me
4 understand whether that volume of water is available, for
5 instance, in the thermal test.
6 MR. SHETTEL: Well, I use a leader, but that is --
7 we use that for lead analysis, as well as lead isotopes,
8 uranium isotopes and strontium isotopes, and those are all
9 done at MIT.
10 MR. LESLIE: Thank you.
11 DR. WYMER: Marty, did you have a question?
12 MR. STEINDLER: Yes. You indicated that, I guess,
13 most of your lead data in solution comes from USGS.
14 MR. SHETTEL: Well, in that 100 kilometer region
15 around Yucca Mountain, yes.
16 DR. STEINDLER: Right. Is there any information
17 on what else is in the water?
18 MR. SHETTEL: Yes. They have a whole series of
19 all the major analyses, cations and anions, as well as trace
20 elements. I've only shown you the lead and mercury.
21 DR. STEINDLER: So you know what the pH is. What
22 else?
23 MR. SHETTEL: If they've measured it, it should be
24 in the database, yes.
25 DR. STEINDLER: If they measured it. I guess I'm

1 asking is --

2 MR. SHETTEL: This is a compilation of literature

3 data that the USGS put together. Mostly, their data -- I

4 haven't gone over the whole database to show everything

5 that's in there. I just pulled out the lead values.

6 And, finally, a little digression on the use of

7 J-13. DOE has historically used it as reference water in

8 all experiments. However, as Maury pointed out, there

9 really is no vadose zone water sample from within the

10 repository block.

11 In other words, collecting a sample of dripping

12 water from a fracture. They have pore water that they

13 squeezed out of the rocks, again, the USGS has done this.

14 This is not necessarily an appropriate water to use to

15 represent water that's flowing in the fractures.

16 It may be more appropriate, as Brett mentioned,

17 from the thermal test, if it's determined that the canisters

18 are going to leak early on during a thermal pulse, then the

19 composition of the water that's been refluxed and circulated

20 above the drifts will certainly have a different and evolved

21 composition due to the refluxing and boiling and condensing.

22 And to further complicate problems, the

23 experiments that use -- they use synthetic J-13, they only

24 use major cations and anions in the water and they leave out

25 all the trace and minor elements, which you will see later

1 on this morning that these may be important for the
2 stability of the canisters.
3 So I have some conclusions here about -- mainly in
4 reference to water, vadose and saturated zone water within
5 the repository block, that the site characterization is
6 essentially incomplete, and that because of their
7 shortsightedness or however you want to put it, they may
8 have to go back and reanalyze samples or even re-collect
9 samples.
10 I pointed out above, experiments are missing
11 important components, major -- not major, but minor and
12 trace elements in the water, although they're starting to
13 add some of the elements that we're concerned about into
14 their alloy tests now, I believe.
15 But the bottom line is they're not using a
16 realistic aqueous environment in any of their experiments,
17 especially as it refers to canister materials.
18 DR. WYMER: By environment, you're talking about
19 concentrations of --
20 MR. SHETTEL: Talking about the -- yes, the --
21 DR. WYMER: Not temperature, pressure, anything
22 like that, because you haven't discussed that yet.
23 MR. SHETTEL: No, I'm not going to discuss
24 temperature. I'm really just concerned about the
25 concentrations of elements in the aqueous solutions.

1 DR. SHEWMON: It bothers me some --

2 DR. GARRICK: Paul, can you move your mic closer?

3 Thank you.

4 DR. SHEWMON: To rephrase that last statement, I

5 would prefer to say that it's unrealistic to talk about an

6 aqueous environment for these casks, but then that's --

7 MR. SHETTEL: Why is that?

8 DR. SHEWMON: Because there's no -- you said the

9 water level was down a thousand feet or more. They aren't

10 submerged in water, are they?

11 MR. SHETTEL: No, but there's water that flows

12 through the fractures and can drip onto the canisters. The

13 unsaturated zone is almost 80 percent saturated by water.

14 DR. SHEWMON: That's not an aqueous environment.

15 It's sort of running through in --

16 MR. SHETTEL: Once you heat up the rock and drive

17 the water out of the rock, you could have water, more water

18 dripping into the drifts.

19 DR. SHEWMON: It's dripping on. It's not an

20 aqueous environment. Well, you can call an aqueous

21 environment parts per million --

22 MR. SHETTEL: Well, it's certainly a human

23 environment and with the water dripping -- no, you're right,

24 it's not going to be necessarily submerged in water, but

25 they can have water dripping on there, the water can

1 evaporate and build --

2 DR. SHEWMON: If that's what you mean by an

3 aqueous environment, that's fine.

4 MR. SHETTEL: Well, but in the lab, they do their

5 tests in an aqueous environment.

6 DR. SHEWMON: I know. I think that --

7 MR. SHETTEL: They submerge the sample.

8 DR. SHEWMON: -- makes them largely irrelevant,

9 but it's the only place, the only light we can look under.

10 MR. SHETTEL: No, I don't think that I'd say that

11 it's irrelevant.

12 MR. GORMAN: Can I make a comment, please? Jeff

13 Gorman, Dominion Engineering, with the State of Nevada team.

14 You should remember that the most aggressive corrosion for

15 carbon steel piping in PWRs occurs when you have dripping

16 borated water dripping onto the carbon steel and staying a

17 little bit wet, but being concentrated to a high

18 concentration.

19 You can chew through the carbon steel at an inch a year and

20 that's widespread occurrences and we have to watch for that

21 in plants, because of this dripping concentrating to near

22 draw-out, but not drawing out, is a very aggressive

23 condition and that seems like a possibility with these

24 canisters.

25 DR. WYMER: Is that equally aggressive -- let me

1 ask you a follow-on question. Is it equally aggressive in a
2 totally emerged environment of the same material?
3 MR. GORMAN: No. If you're totally emerged --
4 well, boric acid solutions are aggressive if it's also
5 oxygenated. And so if it's -- the boric acid inside the
6 PWR, that solution is not aggressive against carbon steel
7 because it's fully de-aerated with a hydrogen over-pressure.
8 Many cases, when it leaks onto really hot pipe and
9 it dries quickly and stays dry, you don't get corrosion.
10 You get the worst case when you have enough dripping to keep
11 it at about 200 to 250 Fahrenheit and moist and then you get
12 very aggressive -- truly you chew big holes in pump flanges
13 and in vessel walls and the like.
14 DR. WYMER: This line of reasoning suggests that
15 tests in total immersed solutions are not necessarily
16 appropriate.
17 MR. GORMAN: That's correct. We'll be discussing
18 that. We'll talk about that, some improved ways of testing.
19 DR. WYMER: Okay.
20 MR. AHN: Ray, we have -- there are a couple of
21 questions here.
22 MR. CRAGNOLINO: This is Gustauvo Cragnolino. I
23 only want to provide two pieces of information. One is in
24 response to the question of Dr. Steindler regarding the pH.
25 Typically, the pH for the solution that he described within

1 dissolved lead concentration going from one PPB to one PPM
2 is ranging from 7.5 to, at the most, 8.5. This is the range
3 of pH for the solution that he was describing.
4 The second one refers to the speciation of lead when you
5 have borated water. We tried to do some very simplistic and
6 preliminary analysis by running the GWB code using, as a
7 baseline, the concentration of anionic and cationic species
8 that you have in J-13 water.
9 But doping the water with the maximum value, both
10 the lead concentration that he has in solution, is about 3.1
11 milligram per kilogram of water, three PPM.
12 When you remove the water by this process of
13 evaporation in the code, you come out with the conclusion
14 that mostly lead is either precipitated, a cerrusite, that
15 is lead carbonate, and the remaining solution is the
16 dissolved form of lead carbonate, with a concentration on
17 the order of 1.2-ten-to-the-minus-three molar.
18 There is an ion pair association between lead plus
19 two and carbonate in the aqueous phase to this
20 concentration, while free lead, two plus is the order of
21 ten-to-the-minus-14 -- minus-12, I'm sorry.
22 DR. WYMER: Pretty insoluble.
23 MR. CRAGNOLINO: The concentration on the other
24 side reaches the range of the order of 1.4 molar. Then we
25 are getting close to saturation to the concentration

1 solution.

2 But this is only to give you a framework. It

3 doesn't mean that these are experimental data, by any means.

4 It's a simplistic calculation with a code in order to seek

5 out the operation process to lead to the concentration of

6 lead in the water.

7 MR. AHN: One more question here. Tae Ahn, of NRC

8 Headquarters. Have you considered the current design of the

9 EBS system including a drip shield, that blocks the water

10 drip during the thermal pulse period?

11 MR. MORGENSTEIN: Have we considered that? We

12 will be talking about that later, and, yes, it's been

13 considered.

14 DR. WYMER: And along these lines of this general

15 conversation, have you considered the effect of sulfide on

16 reducing the --

17 MR. MORGENSTEIN: Yes.

18 DR. WYMER: -- free ion -- I mean, that really

19 knocks it down.

20 MR. MORGENSTEIN: Yes.

21 DR. WYMER: We'll hear about that?

22 MR. SHETTEL: Yes. You'll hear about possible

23 effects of sulfate.

24 DR. WYMER: Sulfate.

25 MR. SHETTEL: Being reduced on the canister

1 surfaces.

2 DR. WYMER: Then being sulfide and then

3 precipitating into the lead and the mercury.

4 MR. SHETTEL: Well, it has other effects, I

5 believe, other than that. Roger Staehle will talk about

6 that.

7 DR. WYMER: Of course, effectively removing the

8 lead and the mercury is another whole area of consideration.

9 You're going to get into that.

10 DR. STEINDLER: Can I prolong this discussion just

11 a little?

12 DR. WYMER: That's what we're here for, Marty.

13 DR. STEINDLER: The conclusion I guess I come to

14 is that in solution, which is what you were talking about,

15 the variability of the lead content of the various samples

16 that you get are what you call all over the map.

17 MR. SHETTEL: In a sense, yes, but they are within

18 a fairly restricted range. I mean, they fall within the

19 part per billion range, yes.

20 DR. STEINDLER: In the aqueous phase.

21 MR. SHETTEL: In the aqueous phase, yes.

22 DR. STEINDLER: There seems to be no systematics

23 which would allow you to predict where you would find high

24 or low concentrations, even in that part per billion range

25 that you're talking about.

1 MR. MORGENSTEIN: That is correct. What we can
2 tell you is probably what the range is. So we have bounding
3 ranges.
4 MR. SHETTEL: You have bounding ranges.
5 MR. MORGENSTEIN: That could be used at this
6 point. But as you could tell, we're not feeling very
7 comfortable. We would like to have a lot more information.
8 MR. SHETTEL: You can also use a geochemical
9 modeling program, such as EQ36, to evaluate the chemistries
10 of the solutions, if things are in equilibrium or not. I
11 mean, we haven't gone that far yet. That certainly could be
12 done.
13 DR. STEINDLER: The level of uncertainties at
14 those concentrations strikes me as being excessive in terms
15 of being able to predict your concentrations, particularly
16 the --
17 MR. MORGENSTEIN: We have no argument with you.
18 We totally concur.
19 MR. SHETTEL: Yes. You have to know something
20 about the geology, as well.
21 DR. STEINDLER: The other point then is in the
22 case of mercury, you're totally without information. Is
23 that right?
24 MR. MORGENSTEIN: From an aqueous phase, that's
25 totally correct.

1 DR. STEINDLER: Don't have a clue.

2 MR. MORGENSTEIN: Don't have a clue.

3 MR. SHETTEL: We know it has to be fairly low and

4 probably lower than lead.

5 DR. STEINDLER: Yes. We know it's there.

6 MR. MORGENSTEIN: I think you now it's there.

7 MR. SHETTEL: You know it's there as a solid

8 phase.

9 DR. STEINDLER: I'm talking about solution.

10 MR. MORGENSTEIN: In the solution, we have not a

11 clue.

12 MR. SHETTEL: That's right. But if you're going

13 to heat up the repository and reflux water in there, the

14 increasing temperature is probably going to increase the

15 lead concentration in the water.

16 DR. STEINDLER: I'm sorry. I moved to mercury.

17 MR. SHETTEL: I mean mercury, yes. We're still

18 talking about the same thing.

19 DR. STEINDLER: But since you don't know whether

20 there is any mercury in the solution, you can't --

21 MR. SHETTEL: We don't believe that that's

22 important whether or not it's actually in the solution right

23 now.

24 DR. STEINDLER: How would it get to the --

25 MR. SHETTEL: The important point is that --

1 DR. STEINDLER: -- if it isn't in solution?

2 MR. SHETTEL: If you heat up the repository and

3 start circulating hot thermal water in there, you could be

4 drawing the mercury out of the rock.

5 DR. STEINDLER: Do you have any evidence to

6 substantiate that?

7 MR. SHETTEL: The hydrothermal deposits are

8 mercury. It happens in nature.

9 DR. STEINDLER: I'm talking about evidence that

10 relates to Yucca Mountain.

11 MR. SHETTEL: I'm going to be measuring mercury in

12 water. Next week I'm going to be sampling. So we will try

13 to get some mercury data in water. Not within a repository

14 block, but along Highway 95, where the Nye County early

15 warning drilling program is sampling next week.

16 DR. STEINDLER: What's your limit of detection in

17 the case of mercury?

18 MR. SHETTEL: I think it's below a part per

19 billion.

20 DR. STEINDLER: Below the part per billion.

21 MR. SHETTEL: Yes.

22 DR. STEINDLER: Do you have any idea how far below

23 the part per billion?

24 MR. SHETTEL: Not at the moment, no.

25 DR. WYMER: I don't want you to answer this

1 question now, but to alert you to the question so you can
2 talk about it later.
3 Do you have any idea, with respect to the
4 characterization that you're going to need, you need a lot
5 more data from the mountain, so that you really can pin some
6 of these things down. You need more characterization
7 information.
8 MR. MORGENSTEIN: We would not even consider that
9 characterization has taken place yet.
10 DR. WYMER: That's what I was going to ask you
11 later on and maybe you people can't answer the question,
12 maybe DOE has to answer it.
13 MR. SHETTEL: Yes. We think DOE needs to
14 characterize the mountain in a more thorough fashion.
15 DR. WYMER: What I was concerned about out was the
16 time in which this characterization can take place and then
17 when the characterization results will come out with respect
18 to the licensing process.
19 MR. SHETTEL: That's a question for DOE.
20 DR. WYMER: That's a question for DOE, I realize
21 that, but I thought you might want to kick it around a
22 little bit later on.
23 MR. MORGENSTEIN: We obviously have the similar
24 concern.
25 DR. WYMER: Okay.

1 MR. MORGENSTEIN: Unless there are further
2 questions --
3 DR. WYMER: We've got one.
4 DR. HORNBERGER: Don, I can infer from your last
5 slide the criticism that no dripping fractures have been
6 sampled in the ASF and that that's part of the
7 characterization that you're talking about.
8 MR. SHETTEL: Yes.
9 DR. HORNBERGER: Would you suggest that what has
10 to be sampled is water from the seepage tests in the cross
11 drift or water from the thermal test that's in progress?
12 MR. SHETTEL: I believe the thermal test does have
13 some water analyses and I just got a copy of one of their
14 reports.
15 DR. HORNBERGER: But my point is that you --
16 MR. SHETTEL: The seepage tests in the drifts --
17 DR. HORNBERGER: -- want to collect water from the
18 fractures.
19 MR. SHETTEL: Yes. That would be one -- we feel
20 that that's one part of the characterization of the mountain
21 that should have been performed.
22 DR. HORNBERGER: Right. But I guess I would
23 probably argue that you are going to -- if you sit out there
24 and wait for a naturally dripping fracture to give you a
25 liter of water, you might be characterizing for a very long

1 time. That is, you don't see water dripping from those
2 fractures. It's not like the Stripa Mine and --
3 MR. SHETTEL: Not in the ventilated parts of the
4 repository, you don't. You'd have to sit in a part that's
5 closed off to ventilation, yes.
6 DR. HORNBERGER: So, again, you're saying that
7 what should be sampled is if they do get water, and that's
8 not clear yet, in the sealed-off drift, number one; number
9 two, in the thermal test, which is --
10 MR. SHETTEL: I believe the thermal tests have
11 been sampled, yes.
12 DR. HORNBERGER: Okay. And then would you
13 consider data from leaching from a seepage test useable?
14 MR. MORGENSTEIN: Let me speak to that. We're
15 sitting with hardly anything now.
16 DR. HORNBERGER: Yes, I know.
17 MR. MORGENSTEIN: Everything at this point in time
18 is useable.
19 DR. HORNBERGER: Okay.
20 MR. MORGENSTEIN: A window of information is
21 better than a closed door.
22 DR. HORNBERGER: I'm just trying to put the
23 criticism that we don't have vadose zone water dripping from
24 fractures to characterize in perspective.
25 MR. SHETTEL: They do have UZ14, which is the

1 perched water, which they sample.

2 DR. HORNBERGER: Sure.

3 MR. SHETTEL: Although that's --.

4 DR. HORNBERGER: So you would consider perched

5 water to be --

6 MR. SHETTEL: -- not necessarily exactly the same

7 as the fracture water.

8 MR. MORGENSTEIN: Certainly.

9 MR. SHETTEL: But on a seepage test, you mean with

10 artificial recharge? Well, that's data. It's not

11 necessarily the natural system, but it is data.

12 MR. MORGENSTEIN: It would be better than what we

13 have.

14 MR. SHETTEL: Better than nothing.

15 DR. WYMER: Better than nothing, yes.

16 DR. HORNBERGER: Again, Brett asked you how much

17 you wanted and you wanted a liter of water per sample.

18 MR. SHETTEL: Well, that's just what I collect,

19 but that sample involves a lot of other things, as well.

20 It's not the minimum amount necessarily.

21 MR. LESLIE: Brett Leslie, from the NRC staff. I

22 mean, one of the places where potentially DOE has 35,000

23 liters of water is alcove-1, where they've forced

24 infiltration and have collected that water, and I guess the

25 question I would kind of toss back to you is the transit

1 time is a couple days to a couple weeks, is that useful
2 information. That's water that's flowing down fractures and
3 dripping and --
4 MR. SHETTEL: Did they use J-13 water for that,
5 Brett?
6 MR. LESLIE: Yes, they did.
7 MR. MORGENSTEIN: One of the things that you have
8 to recall is that the lead signal, the background lead
9 signal is a surface expression and so that if you take J-13
10 and inject it into the system, you may not be dealing with
11 reality.
12 But at the same time, you may be. We'd have to
13 keep that an open issue. But, yet, any activity that would
14 produce any numbers at this point in time would be welcome
15 and the more, the better.
16 MR. LESLIE: Are you saying that bad data is
17 better than no data?
18 MR. MORGENSTEIN: I wouldn't call it bad data.
19 MR. LESLIE: But that's in essence what you've
20 said. You said any data.
21 MR. MORGENSTEIN: Well, any reasonable decent
22 data.
23 DR. WYMER: These are literalists.
24 MR. MORGENSTEIN: I apologize. If there are no
25 further questions, we'd like to go to our next presentation

1 from Jeff Gorman and Ronnie Barkatt.

2 DR. STEINDLER: Ray, are we going to get copies of

3 the viewgraphs?

4 DR. WYMER: Yes.

5 DR. STEINDLER: It would be useful.

6 DR. SHEWMON: We have them, I think. Some of us

7 do.

8 DR. GARRICK: Well, our designated Federal

9 official got to supply it.

10 DR. WYMER: Would you introduce yourself, again,

11 please?

12 MR. BARKATT: Dr. Morgenstein already introduced

13 the team in general. The consulting group that we are

14 involved with consists of personnel from Catholic University

15 here in Washington, D.C. and Dominion Engineering of McLean,

16 Virginia.

17 My name is Aaron Barkatt and we have several other

18 members of the team, Dr. Pulvirenti is here in the audience,

19 Dr. Chuck Marks from Dominion Engineering works with Dr.

20 Geoffrey Gorman, and Dr. Geoffrey Gorman will give the other

21 half of the presentation, and, again, there are several

22 other people at Dominion working within this group.

23 Catholic University has been working for several

24 years with Dr. Morgenstein for the State of Nevada, mostly

25 on glass issues, and the project that we started here on

1 C-22 is evaluation to development, this whole effort only
2 started in the spring, several months ago, and the results
3 that we have got are necessarily just preliminary in nature.
4 We should also reemphasize that we have -- we are
5 making no effort here to compete with or to overlap the DOE
6 efforts. Our mission, as we see it, is to supply the State
7 of Nevada with information as to whether, in our opinion,
8 the DOE program adequately addresses all the significant
9 issues related to the waste package alloys and,
10 specifically, the C-22, or whether the other aspects, in our
11 opinion, that we think ought to be considered further.
12 In that context, the aspect that we started
13 addressing at the beginning of the program was the effects
14 of minor species and trace species which may have a
15 significant effect on corrosion.
16 This concern is the result of Dominion
17 Engineering's experience, as well as own experience in the
18 nuclear industry, but as Dr. Staehle will detail in his
19 talk, this is not by far the only issue and may not even be
20 the most important issue to address with respect to the
21 C-22, where we think that further consideration, further
22 study may be merited.
23 Many others, the nature of the heated concentrated
24 surface that we are dealing with, and he will speak to that
25 point. But I would think that one reason why we started

1 with aggressive species is it's easy to do preliminary
2 experiments and, of course, our purpose is to go into more
3 systematic studies that allow us to judge better the
4 relevance of our results to the expected repository
5 conditions.
6 So what we are doing here is exploring acid and
7 caustic environments with and without, so far, lead and
8 mercury. We've just scratched the surface with respect to
9 arsenic and sulfides.
10 Most of the tests were done with U-bends mostly at
11 the temperature of 250 degrees Centigrade, as well as disks,
12 unstressed disks at 160 degrees Centigrade, but, of course,
13 a much milder condition.
14 The base medium which we were looking at is J-13,
15 and, again, you heard at length the concerns about the fact
16 that J-13 may be not the most appropriate water for testing
17 relevant to repository conditions, and I think that's an
18 understatement.
19 This water is concentrated by a factor of a
20 thousand and that, again, is a an arbitrary number. We use
21 it because for DOE or Lawsonberg and coworkers analyzed the
22 one thousand concentration factor extensively. That's not
23 the maximum concentration that may occur.
24 Again, we are planning to use geochemical codes and if I may
25 add, in digression to an issue which was brought up in

1 response to the previous presentation, things can really get
2 complex -- excuse the bad pun -- with regard to lead
3 solubility, because, for instance, we know that there are
4 carbonates, we know the limitations on solubility in
5 carbonate systems, but there, again, it has been published
6 that in systems exposed to radiation, formation of organic
7 acids, formic acid, acetic acid and so on is observed, so
8 that situation may be very complex.
9 So what we tried to do here essentially is to take
10 a first cut at looking at wherever potentially aggressive
11 species, such as lead and mercury, may have significant
12 effects on C-22 corrosion.
13 MR. GORMAN: I'm Jeff Gorman, of Dominion
14 Engineering. We started the -- did this series of tests
15 with U-bends, which we'll show a picture of in just a
16 minute, and so you can see the size and shape. This is of a
17 flat sheet of C-22 and then was stressed with a nut-and-bolt
18 kind of thing, squeezing it.
19 We chuck the strain that we estimated was about 25
20 percent on the OD surface. So highly, highly stressed
21 U-bend samples and put in static autoclaves and in a variety
22 of environments.
23 Let's see. I think that I should use this. Here
24 is essentially all of the tests at 250, except one at room
25 temperature, and with rather a range of pH, some very acidic

1 at room temperature, not quite so acidic up at as calculated
2 pH at the 250 C, and some of the samples had wells in them
3 and some did not, and some we added samples of tuft material
4 in them and those are marked "yes." And then the
5 accelerants is with sulfuric acid. One test had applied
6 potential of 200 millivolts and these were short duration
7 tests, generally in the neighborhood of a month.
8 And in some of these environments, we saw no
9 results, nothing either visual or in terms of cracking or
10 pitting and the like, no -- while others, we saw definite
11 signs of chemical attack, ranging from tarnishing to slight
12 pitting, to very severe pitting, and then one specimen, this
13 one here, specimen number 12, cracks through wall.
14 We'll show a picture and we can pass the pieces
15 around. In quite a short time. We saw the crack in the
16 first inspection after one week, and fully fell apart after
17 two weeks. So then this is at an elevated temperature, 250,
18 but it's a very short time, and the question is, as you
19 reduce temperature towards more realistic, how long does
20 that time become.
21 DR. STEINDLER: Were these solutions de-aerated
22 before you used them?
23 MR. GORMAN: Chuck, no, they were not.
24 DR. STEINDLER: Do you have any idea of what the
25 oxygen content was?

1 MR. GORMAN: Well, it's starting in seven PPM
2 range, but the acidic ones probably the oxygen was consumed
3 very quickly, I would assume.
4 DR. STEINDLER: What was your free board volume on
5 your autoclave?
6 MR. GORMAN: Chuck, what's the volume in the
7 autoclave? It's, I think, listed.
8 MR. MARKS: Chuck Marks, also at Dominion
9 Engineering. The liquid volume in the autoclave was about
10 150 mils and the head space above that, which was air, was
11 about 100 mils.
12 DR. STEINDLER: So it's about one-to-one.
13 MR. MARKS: Just about, yes.
14 DR. SHEWMON: One other question. At 250 C in
15 that, the pressure is 1,000 PSI?
16 MR. GORMAN: No. Let's see. A thousand PSI is
17 288 C, so my guess is something in the 600 PSI, something
18 like that. There's further results are shown here and the
19 main -- the main point on this -- these are the same test
20 samples. The main new information or the concentrations of
21 the elements showing that a fair amount of dissolution of
22 some of the elements took place in these environments,
23 showing some chemical activity going on.
24 Again, in the same ones, the same general ranking,
25 with this number 12 being the most severe and then the very

1 severe pitting one being the next most severe, one with lead
2 and the other was mercury.
3 DR. WYMER: Why did you go to such high acidities?
4 That seems very unrealistic.
5 MR. GORMAN: The reason was is we only had a very
6 short time to do some tests and --
7 DR. WYMER: You wanted to see something.
8 MR. GORMAN: We wanted to see something and we
9 realize that these are rather -- these are aggressive
10 environments and the intent is then to, first, find out
11 where things happen and then start working in a systematic
12 way towards service conditions, allowing us to extrapolate
13 to longer and longer times.
14 Let's see. I think this is the time to the now
15 fractured pieces around. I'm going to pass it in the
16 envelope, so you can take it out and look at it. These are
17 this sample here. We'd like these -- oh, if anybody wants
18 to see a U-bend, we can pass that around, but it's not very
19 exciting.
20 DR. WYMER: Do you think that the stress that you
21 got there is anywhere close to what would be present in a
22 container?
23 MR. STAEHLE: Yes.
24 MR. GORMAN: Roger will discuss that. This was at
25 a -- we didn't quantify the stress. It would be up over the

1 yield stress, whatever level cold work would occur getting
2 to 25 percent strain.
3 So it would be at a high stress, but you could get
4 to such surface stresses at a damaged area on the surface of
5 a canister, for example.
6 More pictures of cracks, which I guess are not
7 terribly --
8 DR. GARRICK: You're going to have to install the
9 microphone on your --
10 DR. STEINDLER: While you're doing that, let me
11 ask a question here. You mentioned the pH at room
12 temperature. In some cases, you're up at 250. Do you have
13 any clue as to what your pH is at 250, especially in the
14 acidic solution?
15 MR. GORMAN: We show the calculated pH there, if
16 you look at the table, the next column over. It's
17 calculated room temperature -- I mean, calculated at
18 temperature pH.
19 DR. STEINDLER: And that took into account that
20 you've got an air over-pressure.
21 MR. GORMAN: No, I don't think it did.
22 DR. STEINDLER: I'm trying to figure out what that
23 means.
24 MR. GORMAN: I don't think we -- we did not take
25 into account the -- any effect of air.

1 DR. STEINDLER: Okay.

2 MR. GORMAN: I guess I'm going to flip through a
3 lot of cracks. You can see it, it's in the handouts.

4 Now, we also see a fair amount of evidence of
5 under the washer, which was isolating the nut-and-bolt from
6 the U-bend. We also see a fair amount of sort of crevice
7 attack, pitting kind of crevice attack.

8 DR. WYMER: What was the washer made out of, same
9 stuff?

10 MR. GORMAN: It was Teflon. Oh, no, excuse me.
11 Chuck will come up and --

12 MR. MARKS: The bolting mechanism was a similar
13 alloy to C-22, but there were Teflon liners in between the
14 bolts and the washers and the sample itself.

15 So there was no metallic contact with the bolting
16 mechanism.

17 DR. WYMER: What was the ionic strength of these
18 solutions, roughly, do you have a feel for that?

19 MR. GORMAN: Chuck, the ionic strengths? It's
20 listed, I think, on the --

21 MR. MARKS: We have a listing of the specific ion
22 parts per million. We don't have a molarity or anything
23 like that concentration. The autoclaves were also
24 Teflon-lined. So there was -- so the samples were isolated
25 completely, except for the solution contact.

1 MR. GORMAN: Just to show some more details of the
2 cracking. You can see sort of general pattern of
3 intergranular attack occurring. The sample -- the crack
4 growth direction is in this direction. This is the OD
5 surface. This is the ID, transgranular to about sort of
6 approximate midpoint, and then intergranular thereafter.
7 So transgranular in the higher stressed area, then
8 the final propagation at lower stress in the intergranular
9 mode, with lots of little intergranular starts along the
10 surface at other locations.
11 So the lead environment, the acidic lead
12 environments are quite aggressive against this material.
13 DR. WYMER: Were there some cracks before you ever
14 put it in the autoclave?
15 MR. GORMAN: Not as could be seen under visual
16 examination. We didn't do metallography beforehand.
17 DR. WYMER: Under the same condition that you saw
18 those cracks, you did not see cracks before.
19 MR. LEVENSON: They didn't do that.
20 MR. GORMAN: Let's see. In visual examinations
21 like this and some visual examinations under a
22 stereomicroscope, we don't see any cracks in the surfaces of
23 any of the samples, except for this one after test.
24 DR. WYMER: Okay.
25 MR. GORMAN: The only cracks that we have seen.

1 DR. STEINDLER: Excuse me. I'm slowly catching up
2 to you. Your sample 12, which was -- you don't need to go
3 to it, but which was the lead --
4 MR. GORMAN: That was the lead acid.
5 DR. STEINDLER: The lead acid, had a significant
6 amount of what looks like either deposits or whatever around
7 where that Teflon --
8 MR. GORMAN: Washer was.
9 DR. STEINDLER: -- washer must have been. Did you
10 look at that to see why that was there and whether it
11 indicated the thing that I think Ray was driving at, whether
12 you had electrolytic reaction?
13 MR. GORMAN: I'm not sure. I don't think I
14 understand your question, but, Chuck, let's get up to the
15 microphone? Because he's the one who actually looked at
16 these in greatest detail as he took them out. So repeat
17 your question again.
18 DR. STEINDLER: In that sample, in the lead acid
19 sample, it looks like there's a fairly non-uniform reaction
20 layer which surrounds what apparently was the location of
21 your Teflon.
22 MR. MARKS: Yes. Why don't you put up the slide
23 of sample 12, showing the --
24 MR. GORMAN: Yes, just a second.
25 MR. MARKS: -- bolting location?

1 MR. GORMAN: Right. Just a second.

2 DR. STEINDLER: Sorry about that.

3 MR. GORMAN: That's fine. I don't think these are

4 deposits. I think that's pitting, isn't it?

5 MR. MARKS: Yes. Basically, what you see is there

6 is a smooth circular region around the hole where the bolt

7 went through and then just beyond that, there is some severe

8 pitting in the location that was essentially a crevice

9 formed by the Teflon liner and the U-bend sample.

10 So we're looking at some accelerated corrosion

11 there in a crevice type region. In this particular picture,

12 you don't see any deposits. They've been washed off. There

13 was, because the J-13 water concentrated by 1,00 times did

14 have some precipitates in it, there were salts located on

15 the sample immediately after the test, but in this

16 particular picture, they have been washed off and what you

17 see there is pitting.

18 DR. STEINDLER: I guess all I want to do is draw

19 attention to the fact that there seems to be something going

20 on in the area of that magic nut and bolt.

21 MR. GORMAN: We were attributing it to crevice

22 effects, but I couldn't swear that it isn't due to something

23 from the Teflon.

24 MR. MARKS: Most likely it's a crevice effect.

25 The Teflon is supposed to be non-reactive in these

1 conditions and the bolt was an alloy C-276, which is
2 actually very similar to the C-22 and we would not expect
3 any kind of chemical reaction to be accelerated to this
4 extent by the differences between those.
5 DR. STEINDLER: Those of us that have had to do
6 MCC-1 tests will tell you that Teflon is not inert and you
7 can get a significant amount of fluoride out of it,
8 especially at the temperatures and conditions that you were
9 using.
10 MR. MARKS: Our conclusions about this particular
11 sample and the pitting that you see there are also based on
12 the fact that the same bolting assembly was tested in other
13 environments and, specifically, the lead acid is associated
14 with this phenomenon, as well as the mercury samples.
15 DR. SHEWMON: Did you do any of these experiments
16 at pH .5 without the lead?
17 MR. GORMAN: Yes.
18 DR. SHEWMON: I don't see any in the tables.
19 MR. GORMAN: The other ones, like this one here.
20 DR. SHEWMON: That's got sulfur.
21 MR. GORMAN: It's got sulfur in it, but the -- go
22 ahead, Chuck.
23 MR. MARKS: But at that pH, most of the sulfur
24 that was originally put into the solution is volatilized
25 during the pH adjustment. So the amount of sulfur there is

1 --

2 DR. SHEWMON: This is a closed autoclave, isn't

3 it?

4 MR. MARKS: Yes, but the pH adjustments are made

5 before the autoclave is closed and before the sample is

6 added. So there are certain adjustments made to what we

7 call the 1,000 X J-13 order.

8 MR. GORMAN: The answer is we didn't do any tests

9 without any additives and only the acidic, which would be

10 interesting to do. We haven't done that, but our thought is

11 that this one is pretty close to that condition.

12 DR. SHEWMON: We aren't sure whether it's the lead

13 or the conditions yet.

14 MR. GORMAN: But we're pretty confident that it's

15 the lead.

16 MR. CRAGNOLINO: This is Gustauvo Cragnolino, from

17 the Center for Nuclear Waste Regulatory Analysis. I was

18 precisely going to ask the question that Dr. Shewmon asked,

19 because I think that it is very important to have a blank

20 test under the same conditions with the absence of lead.

21 When we reviewed the literature on these subjects

22 several years ago in handbook on the stress corrosion

23 cracking, we found out data precisely produced at that time

24 by Haynes and Judy Kolls, showing that the alloy-22 is

25 susceptible to stress corrosion cracking, one weight percent

1 hydrochloride, hydrochloric acid, the pH is about .5 at room
2 temperature, when you test this at 232, using a U-bend
3 sample without lead.
4 I don't deny that it could be an important
5 accelerated effect of lead, but it has to be clearly
6 demonstrated here and I think that the way to sort out this
7 situation will be to have a blank test in which you are
8 completely sure that you don't have lead.
9 MR. GORMAN: And in the test program, we would
10 expect to do so. So this is suggestive, but not conclusive,
11 is our position at this stage.
12 If you go to that last sample we were just looking
13 at, which did not -- let's see. Had I -- let's see. I
14 wanted to -- I think I may have passed over that in response
15 to a question. This was the mercury acid, where no cracking
16 occurred, but we still saw some pretty severe pitting and
17 crevice kind of attack.
18 Then the one with the sulfur, where we think most
19 of the sulfur was removed, also saw some crevice attack.
20 DR. WYMER: What is chemically, sulfur acid, what
21 does that mean?
22 MR. GORMAN: It's on the -- earlier in the table,
23 it gives the environment. Chuck, do you want to answer that
24 in more detail?
25 MR. MARKS: Yes. Specifically, what we did was to

1 the 1,000 X J-13 water, we added sodium sulfide, NA2S, at
2 3,200 PPM sulfur. But upon acidification, there was a high
3 degree of volatilization of the sulfur, even through the
4 hood.
5 So the speculation is that sulfur levels in that
6 particular sample were not necessarily higher than any
7 others.
8 MR. GORMAN: This, we are now to disk tests.
9 Ronnie, if you're going to stand up, you're going to want
10 this on.
11 DR. SHEWMON: Will you have on your slide
12 something, what the concentration is in C-22 before the
13 test? I don't carry that around with me somehow.
14 MR. BARKATT: The C-22 composition --
15 MR. STAEHLE: The average compositions are nickel
16 56.5, chromium 21, this is all weight percent, molybdenum
17 13.5, tungsten 3, iron 4, and cobalt 2.
18 DR. SHEWMON: Thank you.
19 MR. BARKATT: The tests that you heard described
20 before were done, as you heard, under fairly severe
21 conditions, because we wanted to start under accelerated
22 test conditions and then start working backwards towards
23 milder conditions.
24 And the second series of tests which was done, it
25 had significant distinction from the first one. First,

1 instead of using stressed U-bends, these tests were done
2 with unstressed static disks of alloy C-22.
3 Secondly, the temperature, instead of being 250
4 degrees Centigrade, was about 160 degrees Centigrade. And
5 thirdly, when you look at environment, we used the J-13
6 water concentrated by a factor of 1,000, without attempting
7 to acidify it in the first eight rows of the table, and then
8 we also did acidified tests, but we acidified only to pH .5,
9 not all the way to .5.
10 I should also note, in passing, that in these
11 tests, we used the Teflon vessels, where very, very aged,
12 had been used at elevated temperatures in water for a long,
13 long time, and I would expect that based on previous
14 experience, by that time, the fluoride extraction from the
15 Teflon was not a significant factor.
16 Anyhow, we'd like to take a look at the chemical
17 analysis of the solutions after contact with the C-22 and at
18 least at the high pH region, we have a case where we had no
19 additives, so that can serve as a baseline, and this was
20 really a preliminary scoping test and please remember that
21 we are talking here about very preliminary work.
22 So we threw in everything that we could think of,
23 a lot of it, additives that have been suggested, as a result
24 of the DOE program. And I would like to direct your
25 attention particularly to two lines, one of them is the

1 lead, where we added, admittedly, a high concentration of
2 lead, but you can see here that with respect to chromium and
3 molybdenum, at the high pH, you have an enhancement by a
4 factor of about -- oh, I'm standing right in front of the --
5 DR. SHEWMON: You said high pH and pointed at 2.5?
6 MR. BARKATT: No, no, no. I was pointing to these
7 top nine lines, the pH at room temperature is about 13 all
8 the way down to here.
9 DR. SHEWMON: You said you singled out two of
10 them.
11 MR. BARKATT: I singled out -- let me single out
12 three. No, which is a mark to one, no additives, which
13 serves as our baseline. The row marked lead, introduced as
14 lead acetate, the second row, and you can see here an
15 enhancement in the concentrations of chromium and
16 molybdenum, which may or may not be significant.
17 At this stage of the program, it's premature to
18 ask about uncertainties and standard deviations and so on,
19 but there may be some enhancement here by about a factor of
20 two.
21 But when you go to the ninth line, the last line
22 of the pH results, with mercury, you have enhancement in the
23 concentration of these two dissolved elements, the chromium
24 and molybdenum, by about a factor of 30 and that is even
25 more likely to be significant.

1 With regard to the pH 2.5 experiments, here, of
2 course, you see larger amounts of the solution, higher pH,
3 you will notice, for instance, within the case of mercury,
4 you have what appears to be a significant enhancement of the
5 dissolution of molybdenum.
6 Now, again, admittedly, we don't have a line here
7 which says none, but we did do the test with no additives
8 and, again, because of the preliminary nature of the test,
9 we did not, in that case, analyze the concentrations, but we
10 had the samples and we could examine them.
11 DR. STEINDLER: I'm sorry. I don't think I've got the
12 picture yet. This is the concentration in the residual
13 solution.
14 MR. BARKATT: This is the concentration in the
15 residual solution.
16 DR. STEINDLER: So these are comparable because
17 the sample size surface area and the volume of the liquid
18 were the same --
19 MR. BARKATT: Were the same in all cases. Let me
20 start by discussing --
21 DR. STEINDLER: I'm just trying to make sure that
22 what I'm comparing is apples and apples.
23 MR. BARKATT: Apples and apples. All these disks
24 came from the same lot. I may have misunderstood the
25 question. Jeff, would you mind passing these along? One

1 comes from the blank test, the other comes from the
2 lead-containing test. And the pictures that we have here are
3 even worse than the ones -- the ones which you saw before
4 were really good. These ones were done, again, pretty
5 hastily and with less than optimum equipment.
6 But the one thing that we saw in the
7 lead-containing sample was an obvious evidence, clear
8 evidence of pitting, plus we saw a lot of the position of
9 corrosion products.
10 The case of mercury is peculiar. The case of
11 mercury, we have one sample that I think we didn't
12 characterize too much, because the filter won't let us get
13 it out, it's too much, with a reasonably deep pit, which
14 shows layers of chromium oxide and what may be molybdenum,
15 but this is -- these tests, again, need to be reproduced,
16 continued and the conditions need to be specified to the
17 extent that we can clearly distinguish why, in one case, we
18 did get a deep pit in the presence of mercury and in other
19 cases we got a multiplicity of shallow pits instead.
20 So we are not -- we cannot talk about the mercury
21 effects conclusively at this stage.
22 When we look at the main findings --
23 MR. GORMAN: You might as well go ahead. Why
24 don't you go ahead on this one, Ronnie.
25 MR. BARKATT: When we look at the main findings on

1 the U-bend tests that you saw before, what you can see here
2 is that in an acidified solution without additives, and so
3 to resolve the current contradiction, when you introduce
4 sodium sulfide into a solution at room temperature that
5 contains acid at the pH .5, practically all the sulfur is
6 driven out as hydrogen sulfide, and that's why we can talk
7 about that.
8 Without additives, the corrosion is mild and
9 involves shallow general corrosion and pitting, possibly
10 with some deposition, and, specifically, in the stressed
11 region along the apex of the U-bend, we see very, very
12 little alteration. I should say we don't see significant
13 alteration of the sample at all.
14 In the presence of mercury, we see general
15 corrosion, pitting, and deposition of corrosion products.
16 All these modes.
17 Now, there is something peculiar about the
18 mercury, which may have to do with our analytical
19 techniques. We tried to use EDX on these samples. Again,
20 that was preliminary, with obsolete equipment, and we have
21 not observed mercury accumulating on the corroded surface.
22 DR. WYMER: Why did you go to 1,000 full
23 concentration instead of, say, 100 or 10,000?
24 MR. BARKATT: Again, there is a recent paper by
25 Lawsonberg, I think at Lawrence Livermore, which

1 characterized at great length the 1,000 concentration factor
2 and related it to EQ, for EQ6 modeling results and there is
3 where we felt comfortable that we had a solution which is
4 pretty well characterized.
5 But, again, in all reality, there is no reason
6 that the concentration would stop at the factor of 1,000.
7 DR. WYMER: Yes, that was my point.
8 MR. BARKATT: And we'll try to do something about
9 that, which we'll talk about in a moment.
10 Okay. With acidified solution in the presence of
11 lead, we see the cracking occurs at first in the
12 transgranular mode. It may even start as pitting, going
13 transgranular, and then follows and intergranular mode as
14 the stress is relieved as a result of the cracking.
15 We see numerous secondary cracks, mostly
16 intergranular. The corrosion part of deposition is
17 observed. Pitting may proceed with transgranular cracking
18 and a large amount of lead concentrates at the crack
19 surface.
20 EDX results show between six and 11 percent
21 concentration of lead on the surface of the C-22.
22 DR. WYMER: Would you repeat that? I'm sorry.
23 MR. BARKATT: The EDX measurements show that
24 between six and 11 percent lead on the surface of the C-22
25 after it's been removed and washed.

1 DR. WYMER: Percent with respect to?

2 MR. BARKATT: In EDX, you get the top few microns

3 of the sample.

4 DR. WYMER: So it's that percent with respect to

5 the alloy.

6 MR. BARKATT: With respect to the composition of

7 the surface, that's the composition of the surface.

8 MR. GORMAN: It would be with respect to sort of

9 the average penetration depth of the --

10 MR. BARKATT: Of the EDX, which is a few microns,

11 five microns. The top five microns of the surface, and

12 somebody may want to correct me, to two microns.

13 DR. WYMER: Okay.

14 DR. STEINDLER: But it's uniform across that

15 surface.

16 MR. BARKATT: Again, it's not uniform. It varies

17 between five or six percent and 11-12 percent, but it's high

18 in all cases because we measured in a few spots, yes. I

19 think we had three or four independent measurements.

20 DR. STEINDLER: These samples were used as cut.

21 MR. BARKATT: These samples were used as cut,

22 after washing, yes. They were removed, thoroughly washed,

23 and then cut. Yes.

24 DR. STEINDLER: And the cutting was done with a

25 cutting fluid?

1 MR. BARKATT: The cutting -- no, no, no, no, no.
2 That was the experiment -- I'm trying to recall. I think --
3 DR. SHEWMON: If you look at the back of the
4 sample, it looked like a hacksaw. I mean, the fracture
5 surface wasn't damaged, but it was made small enough to put
6 in these EDX machines, with a saw.
7 MR. GORMAN: I seem to recall she talked about
8 dry-cutting. I don't know.
9 DR. SHEWMON: Keep going.
10 MR. BARKATT: Do you remember if she used cutting
11 fluid or not?
12 MS. PULVIRENTI: April Pulvirenti, Catholic
13 University. Even if she used a hacksaw, she wouldn't be
14 cutting on the surface that was cracked. The cracked part
15 was already open. She wouldn't have cut that, and I thought
16 the SEMs were on the crack surface, the inner surface of
17 that.
18 MR. GORMAN: Yes, they were on the crack surface.
19 MR. BARKATT: Okay. The disks. In the case of
20 these disks, what we saw in the case of the disks was strong
21 pitting on the surface of the specimens that were exposed to
22 lead. We saw extensive deposition of corrosion products.
23 A very large amount of lead concentrated on the
24 pitted surface. And now I think that I caught myself with a
25 major boo-boo. The 11 to 12 percent we observed on -- no.

1 Okay. Take it back, and I'm sorry about this.

2 On the crack surfaces of the U-bends, what we saw

3 was five to six percent of lead accumulation. On the disks

4 which were exposed at 160 degrees, we observed up to 11 or

5 12 percent of lead, again, in the top few microns of the

6 disk. Again, in this case, no cutting at all was done, just

7 washed them and we did run the analysis.

8 And ongoing tests indicate that in the case of

9 these disks, to mercury pitting, and, again, I would like to

10 emphasize that in the case of these unstressed disks, we did

11 run blanks. The blanks did not show any evidence of

12 corrosion at all under microscopic examination.

13 DR. WYMER: What was the lead chemical species on

14 the surface?

15 MR. BARKATT: Acetate. Yes, we introduced it as

16 acetate.

17 DR. SHEWMON: When you do your EDX analysis,

18 you're washing, as you phrase it, and it takes off the salts

19 and what you're analyzing is lead deposited on the fracture

20 surface.

21 MR. BARKATT: Yes. All in the case of the disks,

22 the surface of the disk.

23 DR. STEINDLER: How do you know it was acetate?

24 MR. BARKATT: What we added was acetate. That's

25 how we put it in.

1 DR. WYMER: That's what I was after.

2 MR. BARKATT: What was it after? We don't know.

3 DR. SHEWMON: But on the surface, there was

4 metallic lead.

5 MR. GORMAN: You get a lead signal from the EDX,

6 but you don't know --

7 MR. BARKATT: The EDX cannot tell you which

8 species it is.

9 DR. WYMER: That was my question.

10 MR. BARKATT: So the main findings on the

11 unstressed disks, the acid pH, pH room temperature of 2.5,

12 both lead and mercury caused extensive dissolution of the

13 C-22 ingredients.

14 In the pH 13 samples without acidification,

15 mercury, and here I would have to modify, I shouldn't say

16 but not lead, but I should say much more than lead, because

17 lead, again, may have a moderate enhancement of corrosion,

18 caused a moderately significant dissolution of chromium and

19 molybdenum.

20 IN general, the surface characterization and wet

21 analysis both agreed with respect to specifically lead

22 concentrating on the surface of the exposed surfaces.

23 Now, we tried to follow up --

24 DR. WYMER: If lead was on there as lead acetate,

25 it's hard to think of a mechanism that would cause

1 preferential precipitation on the surface, which gets back
2 to the significance of what actually was the lead species on
3 the surface.
4 It seems to me that's fairly important.
5 MR. BARKATT: Let me try to address it in the
6 following --
7 DR. WYMER: Okay. Please.
8 MR. BARKATT: So the question is really whether,
9 if lead and mercury are present in the repository water,
10 they could have, in fact, and all we are saying at this
11 point is that that possibility needs to be explored. But
12 coming back to the specific question of what happens to the
13 lead when C-22 is present, we are concerned that just
14 looking at concentrations by themselves may not be
15 sufficient, because if there is lead in solids surrounding
16 the C-22 containers and water gets into the system, the
17 concentration in this water may be very, very low, maybe
18 very, very low, but this water still can communicate with
19 other solids in the repository environment.
20 In that case, our concern is whether it's only the
21 concentration which is important or the total quantity of
22 lead that is available, that is around, and may end up in
23 full migration with the water acting as an intermediary,
24 interacting with the C-22 surface.
25 The question is whether C-22 actually absorbs,

1 reactors, we are not sure of all of the mechanisms at this
2 point of time, with lead and other aggressive species.
3 Of course, we have indications, as you heard in
4 the previous talk with Dr. Morgenstein, that lead is present
5 in solids, in natural solids in the repository environment,
6 and even more lead may be introduced as a result of human
7 operations, construction and operation of the repository, as
8 components of various metals that would be present during
9 these operations.
10 Now, if we are dealing with water that contains
11 lead and the only important effect is concentration, it
12 means that only the lead present very close to the surface
13 will interact with the C-22 and the rest will remain in the
14 solution and eventually find its way out without ever
15 interacting with the C-22 surface.
16 If, in the other hand, we have a mechanism that
17 provides for adsorption or chemical reaction between that
18 lead in the water and the C-22, causing the lead to be
19 scavenged by the C-22, then we may need to consider a much
20 broader availability of lead because as lead concentrated on
21 the C-22 surface, it may be replenished from other available
22 solid sources in the environment.
23 And so what we tried to do in these experiments
24 going on right now, these are experiments in progress,
25 again, we are using those disks, again, the J-13 water at

1 temperature of 160 degrees, we are looking at a variety of
2 pH. Again, we are limited -- our experiments so far have
3 been limited to ten to 14 days.
4 We are looking at various levels of lead
5 introduced into the system and we are measuring the lead in
6 the original solution and in the solution after contact with
7 the C-22, to verify the fate of the lead.
8 We are also starting to do acid etching on the
9 C-22 surface of the disks after they have been removed from
10 the solution and in one case, we have what looks like an
11 initial rough materials balance with respect to the lead.
12 Again, these results are very, very, very recent.
13 DR. WYMER: What acid?
14 MR. BARKATT: Dr. Pulvirenti?
15 MS. PULVIRENTI: This is April. These were nitric
16 acid.
17 DR. WYMER: Thank you.
18 MS. PULVIRENTI: At pH of 2.5.
19 MR. BARKATT: So we have a table here, we have one
20 more data point which hasn't even found its way into the
21 table yet, but I will give it to you orally.
22 What you see here is that we start with lead
23 concentrations ranging between 35 to 125 to 275 PPM before
24 contact with the C-22, and after contact with the C-22, we
25 end up with five or one or 14. In other words, we have

1 somewhere between about 87 and 95 percent removal of the
2 lead from the solution onto these C-22 disks.
3 Now, the extra data point, because lead
4 concentrations may be very low, is at one and a half PPM, I
5 think, to be exact, 1.4 PPM, initial lead, we ended up with
6 0.03 PPM of lead in the solution after removal, so that's,
7 again, about 98 percent removal.
8 And in this case, we had an acid etch and the acid
9 etch did account -- again, we had a rough materials balance,
10 but it did look as if the lead coming off the surface of the
11 C-22 in the acid etch accounted for most of the difference
12 between the initial solution and the final solution.
13 DR. WYMER: Did you analyze the solution for any
14 of the constituents of the alloy?
15 MR. BARKATT: The solution has been analyzed for
16 constituents of the alloy, as well.
17 DR. WYMER: Did you look for a relationship
18 between the amount of lead deposited and the amount of alloy
19 dissolved?
20 MR. BARKATT: These are ongoing experiments.
21 MS. PULVIRENTI: Do you mean the initial and final
22 of chromium and molybdenum? We have that. As yet, we don't
23 have a materials balance. We have numbers, but I don't
24 believe that they're accurate, because in addition to these
25 results, we also see some chromium oxide type deposits.

1 So the numbers would be less than what we would
2 expect if any of those alloys originally dissolved from the
3 disk would be trapped within those deposits.
4 DR. WYMER: I was looking for sort of a stochimetric
5 equivalence between the amount of lead deposited and the
6 amount of alloy dissolved.
7 MS. PULVIRENTI: We didn't see it. Now, we saw --
8 in all cases, we did see quite a high -- yes, I would say
9 quite a high concentration in inventory of dissolution of
10 chromium, molybdenum and nickel, but we didn't quite see --
11 we didn't see a nice linear increase as a function of
12 initial lead concentration.
13 DR. SHEWMON: This was done at room temperature?
14 MR. BARKATT: No.
15 MS. PULVIRENTI: This was done at 160 degrees
16 Celsius.
17 MR. BARKATT: All these experiments are at 160
18 degrees. Again, in response to a comment that was made
19 earlier, we are not looking only at aqueous environments.
20 We have an ongoing experiment with wet pate, as well, where
21 we went to the concentration limit.
22 MS. PULVIRENTI: We have that. Do you want to see
23 it? No. Okay.
24 MR. BARKATT: Do you want to talk about that? I
25 mean, it's really preliminary. These are experiments which

1 have come out in the last two or three days and we really
2 need more time.
3 This is about time for a break. So I think we'll
4 go, while this is still fresh on our minds, I'll ask for
5 questions, additional questions from anybody.
6 MR. AHN: Tae Ahn of NRC Staff. In actual
7 scenario analysis, they considered drinking water rather
8 than static water. That's my question, have you considered
9 adsorption under the dripping water conditions? That's one
10 question.
11 The second one, again, DOE, in the EDX design,
12 included drip shield that preclude dripping water. Can you
13 comment on that?
14 MR. BARKATT: Again, we apologize for the
15 preliminary nature of the experiments at this point. These
16 experiments under dynamic conditions are certainly being
17 planned and Dr. Staehle may address that.
18 But at the present time, again, we tried to answer
19 a question more qualitatively.
20 MR. CRAGNOLINO: I have a general question. My
21 name is Gustauvo Cragnolino, Center for Nuclear Waste
22 Regulatory Analysis.
23 I notice that most of the tests tend to be done at
24 low pH or at high pH. Do you plan to do sensing in the pH
25 in which, for instance, species like carbonate, many people

1 agree completely with what was said before, that J-13 cannot
2 be, by any means, representative of the water that comes
3 into contact with the waste package.
4 However, the main anions are there. If you go
5 very acidic pH, you're removing the C02 from the system.
6 That means that you don't have this species that is very
7 important in controlling the precipitating process. And if
8 you go to alkaline, you end up with species like this.
9 I think my question is, do you have plans to do
10 the study of these type of impurities in the intermediate pH
11 range?
12 MR. BARKATT: Experiments in the intermediate pH
13 range are going on right now, in progress, and we plan to do
14 many more.
15 MR. STAEHLE: Gustauvo, the data for alloy-600,
16 just as a possible paradigm here, shows that cracking occurs
17 readily at about a PPM to ten in neutral solutions, just
18 absolutely pure water, with lead oxide. So the pH is a
19 non-issue here, the first approximation.
20 DR. HORNBERGER: Does that include carbonate
21 species?
22 MR. STAEHLE: No. This is just pure water with
23 lead oxide.
24 DR. SHEWMON: As you know, the stress corrosion
25 cracking of these nickel-based alloys has been aggravated by

1 the chloride, and it just dawned on me, the only one of your
2 tests that has a very high chloride concentration is the one
3 where you found stress corrosion cracking, is that right?
4 You added HCL to this stuff to get the pH down to
5 .5.
6 MR. GORMAN: But there were a couple other tests
7 with the same HCL, but other additives where we didn't get
8 cracking.
9 DR. SHEWMON: But they weren't at .5?
10 MR. GORMAN: Yes, they were at .5. I think there
11 were three different tests at -- two tests at .5 and one --
12 I guess it was the W15 did not crack, while 15 did crack.
13 DR. SHEWMON: Fine. Thank you.
14 DR. STEINDLER: Just a comment. If your lead
15 absorption proposal holds water, then you should be able to
16 soak up essentially all the lead in the solution if you dip
17 some lead into it. Does that make sense?
18 MR. BARKATT: What we know, and I think Dr. Gorman
19 might be able to comment on this much better than I do, but
20 if we take a look at industry experience, then concentration
21 of lead on crack surfaces is a well known phenomenon. It
22 eventually should be able to remove all lead from the water
23 phase.
24 MR. GORMAN: Just to cite an example, which I
25 happen to have been working on recently for once-through

1 steam generators. The lead in the feedwater, it's very
2 difficult to measure at low levels, but it's estimated with
3 reasonable reliability at being ten PPT in the feedwater
4 coming into the bottom of the steam generator.
5 Up in the upper part of the steam generator, where
6 it's boiled dry and the super-heated region, recent tests
7 with sensitive XPS methods and with ATM methods have shown
8 that lead in the percent levels of three, four, five percent
9 is detected under the oxide layer on the tube surfaces and
10 in crack faces.
11 So this coming in at ten PPT, it's the Inconel-600
12 in this case, is able to absorb and concentrate lead on
13 surfaces and it appears to be having -- it's thought to have
14 an effect on the cracking that's being experienced in this
15 upper bundle region of these generators.
16 So that's -- and fairly often, in other steam
17 generators, recirculating steam generators, we find lead on
18 crack surfaces, even though the lead in the feedwater is
19 typically -- and in the blow-down water is thought to be in
20 the ten to 30 PPT range.
21 You find it in the percent range on fracture
22 surfaces.
23 DR. WYMER: We do have one ACNW -- oh, I'm sorry.
24 MR. MORGENSTEIN: I just wanted to reiterate the
25 fact that we believe that there is a general lead

1 concentration in the vadose water coming from the
2 dissolution of surface aerosol material and although we
3 could not, at this point in time, give you what the
4 concentrations are, we believe that you could get as much as
5 between three and five PPM solid product from waters in the
6 vadose.
7 And if that is a general background number out
8 there of some, say, one PPB or .1 PPB, and we do have a
9 surface sorption characteristic for C-22, this is a fairly
10 serious situation.
11 DR. WYMER: Well, we do have perhaps one ACNW
12 staff member on the telephone. He's home ailing with a
13 strained back. Andy, are you there? Andy's laying down.
14 MR. CAMPBELL: Can you hear me?
15 DR. WYMER: Yes, we can hear you. Do you have any
16 questions, Andy, or anything you want to add?
17 MR. CAMPBELL: I guess that the real issue, in my
18 mind, is I'd be surprised if any natural water or even
19 static water of any sort did not have lead in it at some
20 level. What that level is, as was pointed out, an open
21 question for things like the vadose zone water, and in the
22 experiments that DOE and other people have done, it hasn't
23 been measured, but there may be lead concentrations in those
24 waters of some unknown amount and whether or not they're
25 relevant, without those measurements, it's hard to say.

1 But the other issue, in my mind, is the speciation
2 of the lead under the various conditions and what is the
3 important lead species that, if there is a relationship to
4 this stress corrosion cracking, what is it.
5 And then if you know what that speciation of lead
6 is in the water, you do you get this cracking, then are you
7 going to get some sort of intersection of conditions you
8 might expect in the Yucca Mountain repository environment
9 with the kinds of experiments done in systems where this has
10 occurred, and anybody can answer that, if they want.
11 DR. WYMER: Or address it.
12 MR. GORMAN: Can I make one comment on it? With
13 regard to autoclave testing of lead and its effect on
14 alloy-600, tests have been done with lead metal, lead
15 sulfide, lead chloride and lead oxide, and all have been
16 approximately as aggressive.
17 It hasn't been -- the additive species to the
18 autoclave has not had any significant effect on the results.
19 So there's no particular speciation as far as for
20 600 mil annealed. Related to that, in pure ACD -- that's
21 all volatile treatment water, which would -- at temperature,
22 would be essentially near neutral, at 320 Centigrade, 4,000
23 hour C-rings at 25 percent of stress, low stress, .1 PPM of
24 lead can cause cracking of 600 mil anneal and one PPM, quite
25 clearly, but down to about a tenth of the PPM in just pure

1 water won't crack it.

2 MR. CAMPBELL: And, again, the question at had is

3 depend -- I mean, you can add all kinds of different sources

4 of lead, but the question is what is its speciation once

5 it's come to some sort of equilibrium in the water where you

6 are seeing the cracking, and then are you going to see that

7 kind of speciation under various repository types of

8 conditions.

9 MR. STAEHLE: One possible answer to that, if

10 you're looking, as Jeff pointed out, that whether it's lead

11 or PVS or PVO, when those dissolve in water, you end up with

12 PV-double-plus. So essentially, from a speciation point of

13 view, you're looking at lead-double-plus and also in that

14 range of oxidizing potentials, that's always possible.

15 So the options you have is either lead metal, the lead metal

16 to lead oxide equilibrium is about the same place as the

17 standard hydrogen equilibrium.

18 So there is actually some mechanistic question

19 about whether you've got lead metal or lead plus two, and

20 that's a mechanistic issue that has yet to be resolved.

21 So, anyway, I think that maybe partially answers

22 the question.

23 DR. WYMER: I think it's a very important

24 question.

25 DR. STEINDLER: But I think the chances of you

1 ending up with lead-double-plus in the solution that's got a
2 tenth of a percent chloride in it is very small. This 1,000
3 X J-13, in a sense, screws up the standard chemistry.
4 MR. STAEHLE: Sure. But let's start with
5 something simple. This experiment is just one set of
6 experiments and if you look at the broad set of data that
7 are available for alloy-600, exposed to lead, and start with
8 something simple, like PVO, forget the chloride, just PVO
9 and water, that's a place to start and that is quite
10 sufficient to produce all the cracking you would see here.
11 So then if you then expand that -- one of the -- I think the
12 implication of the question that you just asked, and I'm
13 sorry, I forgot your name, but the implication of the point
14 is that, in fact, in operating steam generators, you
15 sometimes see a lot of lead in deposits and you don't see
16 any cracking.
17 Wait a minute. Why is that? Well, probably
18 what's happening is, in fact, the lead is reacting to form
19 some -- more in soluble compound. You just lower the
20 activity of the lead.
21 So there is an issue here about equilibrium with
22 other lead activity affecting systems, and I think that's
23 certainly relevant to the point you made.
24 MR. CAMPBELL: That is basically the point I'm
25 making, is that until you get a handle on the speciation,

1 and I will say, at 320 degrees C, under some equilibrium
2 vapor pressure, you may very well have -- in fact, you
3 almost certainly have different speciation than you would at
4 25 or 30 C under atmospheric pressure.
5 And you'll get pressure/temperature changes with
6 speciation. So that seems to me to be the key here to
7 getting the handle on this, is how is the lead speciation
8 changing under these various conditions in terms of
9 relevancy to corrosion, stress corrosion cracking in steam
10 generators versus conditions in Yucca Mountain.
11 Anyhow, yes, that is the point.
12 MR. BARKATT: If I may add one comment. With
13 regard to lead, again, at the present time, we don't have a
14 handle on the speciation. With regard to mercury, recent
15 observations showed information of mercury metal, metallic
16 mercury, in contact with the C-22 under these conditions.
17 DR. WYMER: I think we probably need to declare a
18 break. The break was scheduled for 15 minutes. Let's get
19 back no later than ten minutes till 11:00, if you will.
20 [Recess.]
21 DR. WYMER: It's ten of 11:00. Let's go ahead and
22 get started. We do have a cutoff time of noon. So we're
23 going to have to move along.
24 Let's go ahead and get started, whoever is next
25 here.

1 MR. GORMAN: I think I am. The purpose of this
2 next section was we were asked by the State of Nevada just
3 to review the history of material selection and material
4 problems in nuclear power plants to get some ideas as to
5 what sort of problems we ought to stay alert to when looking
6 at the engineered barrier system.
7 And so I've not tried to be exhaustive. I've
8 picked some of the ones that are most significant to the
9 industry and ones which I happen to have worked on, so knew
10 the situation pretty thoroughly, without a great deal of
11 work.
12 And what they show is that despite good intentions
13 having been involved in the selection of the materials,
14 there have been lots of problems, which has made a nice
15 living for me for 40 years, but nevertheless.
16 DR. WYMER: Not 40 certainly.
17 MR. GORMAN: Well, since '59. So 41.
18 DR. WYMER: You're aging well.
19 MR. GORMAN: No. Okay. First example is BWR
20 stainless steel cracking, with the -- in piping and
21 internals. Piping was the original one. Currently, the
22 main problem is with the internals, where the stresses are
23 lower and the cracking growth rates are lower.
24 But people are wrestling with it. And the main
25 causes -- the material was selected because of its good

1 general corrosion resistance.
2 What seems to have been ignored or not enough attention paid
3 to was the effect of sensitization at wells, the effects of
4 the oxidizing potentials caused by radialytically produced
5 oxidants, and effect of residual stresses and cold work due
6 to grinding on accelerating crack initiation.
7 By the way, Roger is going to be talking about
8 many of these subjects in some more depth in a little bit,
9 and so I am going to whip through this so as to not steal
10 his time, because we're getting limited on time.
11 Inconel-600 or alloy-600 used for steam generator
12 tubes has experienced very widespread cracking. Many of the
13 steam generators made with the 600 mil annealed material
14 have had to be released, and lots of money and lots of plant
15 downtime.
16 The reason Inconel was selected was primarily
17 because of its good general corrosion resistance and
18 resistance to chlorides, because if you remember, back in
19 the '50s, there were cases of cracking of the stainless
20 steel tubes due to the chlorides and testing showed that the
21 higher nickel alloys were resistant to that kind of chloride
22 induced stress corrosion cracking.
23 What that selection seems to have failed to
24 consider was a very large range in susceptibility as a
25 function of the processing history and minor compositional

1 varies, at least a thousand times in some tests in pure
2 water, in primary water environments.
3 So very large range in susceptibility as a
4 function of rather minor changes, seemingly minor changes in
5 how the material was made and its composition differences,
6 like trace levels of boron, for example, have a big effect
7 on the resistance to caustics.
8 The effects of low potentials, cold work and
9 residual stresses on primary water stress corrosion
10 cracking, on the other hand, the effects of oxidizing
11 potentials and the concentration of impurities under boiling
12 conditions, which can lead to high or low pH and to
13 aggressive -- high conductivity solutions and can
14 concentrate aggressive species, such as lead, to
15 intergranular attack and secondary and stress corrosion
16 cracking from the secondary side, which is the current main
17 biggest problem in the still operating steam generators,
18 with 600 mill anneal.
19 And as I already mentioned, the effect of minor
20 elements in the metal, particularly boron, its resistance to
21 stress corrosion.
22 Most of these high strength materials or at least
23 some of the high strength materials, I think X750 and A286,
24 both precipitation hardening austenitic alloys, this one
25 being nickel-based, this one being steel -- iron-based, were

1 selected primarily for their high strength and were from
2 aerospace applications.
3 There have been a lot of failures of those two
4 and, also, 17-4 pH and martensitic stainless steels, with
5 lots of bolting having been replaced, expensive repairs in
6 reactor internals and the like.
7 They were selected based on their general good --
8 their good corrosion resistance in terms of general
9 corrosion resistance, but sufficient attention wasn't paid
10 to the possibility of stress corrosion cracking in long-term
11 exposure in reactor environments for material that was
12 actually in the actual heat-treated condition.
13 Again, effects of local residual stresses in cold
14 work were commonly not given enough attention and in the
15 case of particularly 17-4, the effects of time at
16 temperature on its embrittlement and susceptibility to SEC
17 wasn't taken into account.
18 It's now pretty well shown that at over 500 F, the
19 17-4 in a long period of time, after several years, will
20 start to degrade, and that wasn't recognized back in the
21 early days.
22 And then a big point on particularly the 17-4 and
23 the martensitic stainless steels, you can meet specified
24 mechanical properties, the kind of things you see on your
25 mill cert, but have very poor stress corrosion cracking

1 resistance as a result of thermal mechanical heat
2 treatments, not following the prescribed sequence.
3 So there was the need for much tighter quality
4 control in the fabrication to make sure that the materials
5 actually saw the times and temperatures specified.
6 DR. SHEWMON: Before you change that, was most of
7 this in PWRs with the hydrogen over-pressure or was it also
8 in BWRs?
9 MR. GORMAN: On the X750, it's more a -- well,
10 it's both BWR and PWR. Both, both. I mean, like the BWR
11 jet pump beams and in the core bolting at shoes, for
12 example, of the PWR, so it's both. The A286 is all PWR.
13 The 17-4 pH is a mix of both and martensitic is a mix of
14 both. A286 was early identified as being a problem with the
15 oxidizing environment in BWRs and wasn't much used.
16 Ziracalloy cladding, chosen for its good corrosion
17 resistance and its low neutron cross-section. The main
18 thing that wasn't identified was its susceptibility to
19 stress corrosion due to fission products such as iodine and
20 cesium and when stressed, after the clad creeps down and
21 then you get pellet-clad interaction, leading to the stress
22 corrosion. So that's been a big problem over the last 20
23 years or so with zircalloy clad fuel.
24 Sort of trying to summarize, what lessons should
25 we learn with regard to thinking about choice of alloys for

1 difficult applications. You got to have a full range of
2 realistic crevice environments and with all of the
3 parameters, the potential, the pH, and aggressive species.
4 You have to have the full range of realistic
5 material conditions and compositions, including things like
6 welding and stress relief operations and local surface
7 damage is often a big effect.
8 So realistic range of total stresses, especially
9 including residual stresses and from things like surface
10 damage or from fabrication operations.
11 You've got to test for long times in realistic
12 environments, with accelerated methods, and then work
13 towards ever more realistic, but longer term tests to try
14 and predict to the total service conditions that you're
15 trying to protect against, the long times at lower, less
16 aggressive conditions.
17 I had mentioned this, the aggravating effects of
18 the fabrication details and surface damage, and I guess you
19 can't over-emphasize that, because lots and lots of cracks.
20 On steam generator tubes, for example, many times, the
21 cracks are at surface scratches made during tube insertion.
22 And long-term material aging has to be considered,
23 because material properties can change with time.
24 DR. STEINDLER: Would you agree that the results
25 that we've heard so far do not include attention to some of

1 these parameters that you were talking about here?

2 MR. GORMAN: Yes. That's the next slide.

3 DR. STEINDLER: Oh, sorry. The main lesson is

4 you've got to consider all of those factors. You can't

5 afford to neglect any of them, and some of them may not have

6 been -- we're being very cautious. I'd say clearly have not

7 been, but for written things, we'll say may not have been

8 suitably addressed.

9 DR. SHEWMON: Could you tell us where the C-22

10 alloy has been tested out, where it was developed for what

11 kind of service?

12 MR. GORMAN: I'll let Roger address that. Roger,

13 development of C-22, what kind of service? I think it was

14 for acid chemical service, primarily. But I haven't studied

15 that in great depth. Go ahead.

16 MR. MARKS: Basically, when you look at the alloy

17 chemistry, with the molybdenum and tungsten and chromium,

18 it's basically an acid service alloy and it's basically not

19 developed for neutral or alkaline environments.

20 I'm going to talk about that in some detail in a

21 minute.

22 DR. SHEWMON: Fine.

23 DR. HINZE: When you talk about long-term tests,

24 give me an idea of what you're talking about.

25 MR. GORMAN: I think we can start getting a feel

1 for it in tests within about two years. But I think for a
2 10,000 year application, getting to tests that can last five
3 or ten years is not unreasonable to try and --
4 fundamentally, what you do, let's take just temperature as
5 the aggravating factor.
6 Probably, you'd also use stress, too, but you do
7 tests, first, up at a high temperature where you see some
8 effect, and then you reduce the temperature, say, by 50
9 degrees C and then see how long it takes, and then you go
10 another step temperature lower and you then start getting
11 results that you can extrapolate on a log-log plot,
12 basically, developing an arrhenious activation energy.
13 But since we haven't done the tests at the lower
14 temperature, we're not sure how long we're going to have to
15 go for any given temperature.
16 DR. SHEWMON: And you also have to bet that the
17 mechanism doesn't change fundamentally when you change
18 temperature, which this test won't show you.
19 MR. GORMAN: Right, you have to take an estimate
20 on that.
21 DR. HINZE: Is there experience with C-22 in terms
22 of these long-term tests?
23 MR. GORMAN: Not that I know of. Talking about
24 the status of testing of C-22, we've been through the
25 literature to some extent and not as thoroughly as we intend

1 to in the next few months, and it looks like they haven't
2 addressed trace aggressive impurities, such as the lead
3 arsenic, mercury and sulfides on SEC and other modes of
4 corrosion, such as the crevice corrosion and pitting.
5 They don't seem to have addressed the range of
6 water chemistries and concentrations that occur,
7 particularly under heated crevices and deposits. You sort
8 of envision -- you have this canister that's going to be at
9 pretty high temperature, initially, I think, as high as 200
10 C, but up over 120 C, at least, for significant periods of
11 time.
12 You have some deposit, either rust or tuft or some
13 kind of material on it. You have a drip on it that
14 concentrates. It can go -- it's like a steam generator
15 crevice. It can go from pH of two to pH of 12, depending on
16 the mix of species. So those kinds of conditions haven't
17 been tested.
18 I think they've started looking at some material
19 composition variations, but I haven't seen any systematic
20 work on trace deleterious species, such as boron and carbon
21 and this sort of thing, and the various conditions that
22 might occur as a result of the fabrication route that they
23 use.
24 So we are intending to start a more extensive and
25 systematic test program. We're going to try and identify

1 the mechanisms that we got to pay attention to, pitting,
2 crevice corrosion, intergranular attack and stress
3 corrosion, and then determine the effect of crevices and
4 deposits, the pH, aggressive species concentrations and
5 potentials, and the resultant effect of these chemistry
6 changes on the corrosion phenomena; in other words, a
7 systematic set of tests.
8 DR. WYMER: Let me ask you. Presumably, in order
9 to get at this alloy C-22, you've got to go through the
10 titanium drip shield. Is there any reason to believe that
11 you ought to be looking at either of the states of titanium
12 on any of these tests?
13 MR. GORMAN: I haven't considered that at this
14 stage. I think Roger has got the task of trying to consider
15 the overall thing, so I'll leave it to him to address when
16 he gives his talk in just a minute here.
17 Let's see. My last slide is -- so our objective
18 is to develop a scientifically based way to predict the
19 long-term performance of C-22 using accelerated experiments
20 with -- as time goes on -- progressively less accelerated
21 conditions and looking at the ability of the C-22 to
22 scavenge and concentrate aggressive species, such as the
23 lead, as we were talking about, the mercury and others, and
24 determine how do you determine -- how do you assess what
25 level of aggressive species, is it the total quantity in the

1 inventory in the world around the container or is it the
2 concentration in the water, what is the important parameter.
3 We really don't know the answer to that yet.
4 So I know turn it over to Roger, unless there are
5 questions for me. No questions.
6 DR. WYMER: Well, now, let's not be too fast here.
7 MR. GORMAN: Roger, are you going to be standing?
8 Then you will want this.
9 DR. WYMER: An awful lot of questions got shoved
10 down to your end of the table, Roger. We're going to see
11 here.
12 MR. MARKS: You know what they say about what
13 rolls downhill. Some years ago, I think in 1992, I was on
14 the same program with a friend of mine, Bob Way, who some of
15 you know, at Lehigh, a very fine guy, and he at -- we were
16 at the point where we were talking about predicting things
17 and he was saying, well, you just absolutely can't make a
18 prediction until you understand absolutely the atomistics of
19 the problem.
20 And later, after his talk, I said, Bob, not in
21 your lifetime or your children's lifetime or their lifetime
22 will you know the atomistics of the problem, and so you have
23 to deal with kind of what's in front of you in the best you
24 can do doing intelligent experiments.
25 And we're kind of in that framework, where there's

1 a lot of things we'd like to know, but maybe we have to use
2 a lot of judgment here and a lot of analogies.
3 Now, just to point out where we're all at here,
4 this is not -- this is out of the DOE report, we're
5 basically talking about this container wall here and the
6 C-22 is on the outside surface, fuel is on the inside
7 surface, the titanium drip shield is on the outside.
8 So for those of you who need some refresher,
9 that's essentially the framework that this discussion is in.
10 Now, I have some number of slides and they're all
11 in my pass-out and I'm not going to talk about all of them,
12 because I know that, first of all, you all read very well
13 and some of these things don't need to be said particularly,
14 and I'm going to start with this idea about maybe we could
15 learn something from history.
16 For those of you who are unfamiliar with this
17 technology, this is a steam generator in a pressurized water
18 reactor. The hot water comes in the bottom, in the bottom
19 plenum, goes through a tube, exits through and goes back to
20 the reactor to be heated. The inlet temperature is around
21 320 to 330 Centigrade, the outlet temperature is around 395
22 or so.
23 Steam exits here around 290 Centigrade. Now, the
24 reason this is a useful set of ideas for discussion is that
25 we're going to be interested particularly in the crevices

1 between this Inconel or alloy-600 tube and these tube
2 supports.
3 And we're a little bit more interested in this
4 joint here, because the -- it's an analogy for concentrating
5 surfaces. It's also an analogy for a surface which is not
6 otherwise stressed, except for fabricating stresses. And
7 there is an issue here about -- the question was raised,
8 well, what's the stress and what's the relevance of a
9 U-bend.
10 What I want to point out is that the as-fabricated
11 tubes, as I will show you shortly, cracked just fine as
12 fabricated, as mill annealed. So we don't really need to
13 have an enormous set of stresses to make cracking occur.
14 So this particular joint is relevant for two reasons. One
15 is the concentration that occurs under heat transfer
16 conditions and the second is the fact that the tube is not
17 seriously stressed, except for an internal pressure, which
18 is about net 1,000 PSI, and there's a little bit of thermal
19 stress, there's a drop of about ten degrees Centigrade
20 across the wall.
21 That's not as much as the drop across the waste
22 package container, but anyway, so it's not a bad analogy and
23 so we can learn something from this and I would like to lean
24 a little bit on that as a basis for my discussion.
25 Now, in the beginning, I mean, in the beginning

1 was different times for all of us. My beginning was about
2 1957, when I first joined the Naval Nuclear Program and I
3 have been thinking about reactors ever since.
4 Let me compare something. I'm going to compare
5 the steam generator with the waste package and, for example,
6 there are four areas where there are interesting
7 comparisons.
8 One is the appearance of an adequate test
9 environment. In the early days of the steam generators, it
10 was thought that a fossil water chemistry of in excess of
11 100 parts per million was an okay water chemistry. Today,
12 just for sake of comparison, the EPRI standard is around ten
13 parts per billion.
14 It was thought that the alloy-600 was an immune
15 alloy and for those of us who worked for Rickover many years
16 ago, it was said that actually God himself created this
17 alloy and God himself was, of course, Rickover.
18 If you don't believe that, you should have worked
19 for him. Anyway, and here we have C-22, which is, again, to
20 quote DOE, is a corrosion-resistant alloy. And the third
21 area of comparison is the heat through crevices,
22 concentrating impurities, as I mentioned, and here is the
23 heat through the surface, this surface also capable of
24 concentrating impurities.
25 In this case, the early design objective was a

1 40-year life based on fatigue. Here, it's a 10,000 year
2 life based on what I'll tell you later is basically a BWR
3 stress corrosion model.
4 So that's a little bit of analogy about the reason
5 there is a reasonable comparison here from which we can draw
6 some understandings.
7 Now, just to make the point here, this happens to
8 be capacity loss in BWRs, capacity loss in PWRs, and the
9 point is virtually all this capacity loss was due to
10 corrosion.
11 So despite the fact that there's some wonderful
12 engineers working on this, the fact is that we still had
13 lots of problems.
14 Now, in terms of the idea, essentially the analogy
15 for prediction, again, in the DOE prediction discussions,
16 they're talking what essentially is about a predictive model
17 that comes out of the BWR technology, where we're talking
18 about oxygenated water exposed to weld, whereas in the PWR
19 analogy, we're looking at the condition where we concentrate
20 impurities and I have the residual stresses on this side,
21 which is, I believe, are much more analogous and useful idea
22 than the BWR example.
23 Now, I'm going to use a framework for my
24 discussion which I call the corrosion-based design approach.
25 It's a general way of approaching a design problem from a

1 corrosion point of view.

2 I'm not going to belabor it, just except to say

3 that I'm going to emphasize the discussion on environmental

4 definition, material definition, mode definition,

5 super-position. I won't talk about the failure definition

6 or statistical framework and a little bit about prediction.

7 Now, when we think about designing environments

8 that are relevant, the environment that's relevant here is

9 the environment on the surface of the metal. It's not the

10 environment out someplace. It's what actually ends up on

11 the surface of the metal.

12 So that's where our focus has to be. The next

13 point in defining environment is the heated surface produces

14 a totally different environment than an isothermal surface.

15 And the third point I want to make is -- this is

16 for those of you who are geologically inclined -- it may be

17 an overstatement, but the entire -- from the point of view

18 of thinking about chemistry on surfaces, you've got to start

19 with the bounding condition that the entire surface and the

20 mountain is relevant to the heated surface.

21 I realize that sounds like a stretch, but you have

22 only to look at what I'm going to show you in a minute about

23 what ends up in the crevices of steam generators.

24 You think, well, this is really pure water. I

25 will show you in a minute what ends up in these crevices.

1 It's like the thiosulfate in TMI-3. How could
2 this thiosulfate ever get into the steam generator and
3 produce all those cracks? Well, it did and it wasn't
4 supposed to. It's like the sea water leakage at Millstone.
5 It wasn't supposed to get in, but it did. It's like the
6 sodium that cracked some of the LFBMR technology. It was
7 supposed not to get outside, but it did.
8 So while this is clearly a hand-waving argument, I think we
9 have to be sensitive to the idea that when something is an
10 environment of some impurities, things do have a way of
11 getting there somehow. And so while it's logically a little
12 bit hard to argue with, it is nonetheless something you've
13 got to start with.
14 Now, the other problem we have, of course, is no
15 feedback control here on environmental contamination.
16 There's no conductivity meters, there's no local chemical
17 analysis. So we have a problem that we don't have in other
18 technologies.
19 Then, of course, the thermal gradients in the
20 Yucca Mountain site produce flows we hadn't expected and
21 another aspect of the environment is that the highest
22 concentrations, like chloride, which is the dominating idea
23 in the DOE work, are not always the most aggressive
24 conditions.
25 I mean, it would seem like chloride is always the

1 most aggressive thing. Wrong. Chloride is not always the
2 most aggressive environment.
3 And then we do have to think about environments in
4 not only molecular chemistry, but the stress and
5 temperature, I'll touch on that shortly, and then there is
6 also a slightly heated surface on the drip shield. It's not
7 quite as severe.
8 I have a picture showing something about
9 thiosulfate I'm going to pass over, you can look at that,
10 and let me now emphasize this or push this analogy a little
11 bit.
12 What my hypothesis is here, which I think is a
13 reasonable hypothesis, is that the surface of the drip
14 shield is, first of all, going to be hot. We know something
15 about the temperatures, we can calculate those.
16 And furthermore, that on the surface of this drip
17 shield, there's going to be dust, which will form
18 eventually, it will build up, and this will interact with
19 the chemistry that's around and eventually we will build a
20 deposit on the surface and this deposit now will begin to
21 change the nature of the thermal condition at the interface
22 and will be -- will approach the analogy of this crevice.
23 Now, to give you some idea about what happens to a
24 concentrated crevice, just to give you some reality about
25 what is actually observed in a steam generator, this is a

1 pulled tube from Beaver Valley and it shows you something
2 about the kinds, the extent of the cracking in a
3 concentrating environment.
4 Now, the detail what the chemistry, the causative
5 chemistry has a range that I will discuss shortly, but there
6 is a reality in the cracking that does occur that you should
7 appreciate.
8 Now, the next idea, again, I want to emphasize or
9 take further is the idea that in the beginning, from the
10 point of view of thinking about performance, you really do
11 have to think about the available elements.
12 And so far as I can tell, from Maury Morgenstein's
13 work and others, including DOE's, that this is the set of
14 species in some form that has to be considered, not just
15 lead. We're talking about a lot of other species. And that
16 this somehow can find its way to a heated surface.
17 Again, I realize this is an argument, it's a
18 hypothesis, but it's a bounding condition that we've got to
19 start with.
20 Now, to look at this in a little bit more detail,
21 I think an approach to thinking about this surface is that
22 first of all, we have dust deposits. These deposits will
23 probably harden under the reaction of chemicals.
24 The surface is going to be hot. This hot surface
25 will become hotter because of the thermal resistance.

1 These chemicals are maybe available, and then in
2 this kind of a structure, we're going to also form sets of
3 cells which will have alternately hydrolysis and
4 alkalization effects, and how that will play out isn't
5 actually all that clear to me.
6 So that's sort of a place to start thinking about
7 a structural mechanistic picture.
8 DR. HORNBERGER: Roger, do you have any guess as
9 to the time scale for the evolution of this dust layer?
10 MR. STAEHLE: Well, no, I don't. I mean, I think
11 that, again, we're not talking about a 40-year nuclear
12 plant; we're talking about longer times.
13 And I think the question of dust buildup deposits,
14 I think once you've been to Chion and seen the dust that
15 built up on the soldiers, these things happen, you know, and
16 those of you who are in the rock business probably know that
17 story better than I do.
18 DR. SHEWMON: But the heat does decay, and that's
19 over decades to 100 years.
20 MR. STAEHLE: Yes, so, if we're looking, say, at a
21 hundred years, we still have a big thermal resistance here.
22 I mean, this is not going to go away quite that
23 quickly. If you look at the DOE -- the
24 temperature-dependent concentration, they show a peak that's
25 over 100 years from now.

1 But I think the problem here is that what -- my
2 sort of perspective for a model needs some quantification to
3 it, and that's something that I'm not here to talk about,
4 but I will eventually.
5 But I'm portraying something which I think is a
6 reasonable hypothesis for a model which has, I think --
7 obviously needs some work on it, including Paul's thermal
8 thought.
9 Now, let me show you sort of the general panorama
10 of a crevice in this heat transfer condition in the steam
11 generator. What you've got is a hot -- this is 320, 325
12 Centigrade. Out here it's about 290.
13 This is the tube wall, this is the tube support.
14 And what you've got in here is, you've got a two-phase water
15 steam system; you've got capillarity effects; you've got
16 deposits; you've got corrosion of this side occurring.
17 And these species are all available, and then
18 you've got gradients in the system. You've got
19 electrochemical potential gradients, temperature gradients,
20 concentration gradients, fluid density gradients, that do
21 things that are certainly analyzable, but a little bit
22 complex.
23 Now, this is a real crevice. This is from a paper
24 by Combrade, et al, in 1995. This happens to be a -- this
25 vertical is a thickness dimension.

1 This is the location where the tube support is,
2 and this is outside the tube support. So this tells you the
3 thickness of the deposit, 100 microns for the outside
4 deposit.
5 And simply having thought the water was a fairly
6 pure water, having quite an array of compounds including
7 calcium, silicon, or course, iron makes sense, molybdenum,
8 aluminum, and then farther down inside, looking at arsenic,
9 antimony, barium, believe it or not, and then some organic
10 species that will form, presumably because of the carbon
11 present and the temperature. You may get organic species of
12 various kinds, and also the hydrazine gives you some
13 nitrogen.
14 So, you know, in these heat transfer crevices, a
15 lot goes on. And this isn't to say it's perfectly
16 analogous, but it is to say that this kind of complexity
17 needs to be considered.
18 Now, I won't cover the stress issue. The stress
19 issue, at least to me, is pretty self-evident; that in the
20 mill-annealed surface of the tube in the steam generators,
21 the cracking occurs just fine.
22 That rate of cracks I showed were from something
23 that was not a U-bend. It was mill-annealed surfaces.
24 So, to me, you really get -- and the stress,
25 contrary to the DOE thought, is not just at the welds. The

1 stress is over the whole surface. When you make a metal
2 surface, you've got to grind it, you've got to bend it,
3 you've got to do things to it.
4 And that surface will be stressed unless you
5 figure out a way to globally heat treat it, and when you
6 globally heat treat it, you change the metallurgy and you
7 make a bigger problem.
8 Now, so I'm going to take the next step and talk
9 about material deformation. What I've just done is sort of
10 painted a picture of what I call environmental deformation.
11 It clearly has some argument to it, but that's a picture.
12 Now, let's talk about defining the material. Paul
13 asked a little bit about this during the previous
14 discussion. I'm going to hopefully answer some of those
15 questions, maybe.
16 But the essence of C-22 is that it's prone to be
17 less stable and neutral to alkaline environments. The
18 alloying additions are basically additions that are used for
19 acid resistance.
20 The second point is that for lack of data, C-22 is
21 a lot like 600 or a cross between Alloy-600 and 690. I
22 think these data are applicable to a first order, not
23 perfectly, but I think that what's available in 600 needs to
24 be considered.
25 Third is that there is a very broad range of

1 effects of metallurgical structure on Alloy-600. We're not
2 talking about a metallurgical monolith in terms of
3 composition.
4 This has all the variability that occurs and
5 structure property relationships. I'll illustrate those a
6 little bit.
7 If we move to global stress relief, we're going to
8 change the structure and the proneness to corrosion. We
9 need to pay a lot more attention to grain boundary
10 composition. I won't say much about that at the moment, but
11 I think it's pretty obvious.
12 As far as I know, there is no prototype that's
13 been fabricated that even tells us what this animal looks
14 like. And so to some extent, we are kind of talking about
15 something that hasn't been done yet.
16 Now, let me give you some metallurgical
17 perspective, or a an alloy perspective. This is the Ternary
18 diagram for iron, chromium, nickel. This is iron, nickel,
19 chromium; this is a 400 C isotherm.
20 And these are the classic stainless steels, the
21 410, the 430, the Type 304 stainless, and at least the
22 stable alpha-gamma region; the Alloy-800, 825.
23 Now, the alloy we're specifically interested in
24 comparing with Alloy-600 has been for years, the standard of
25 steam generators, and now the Alloy 690 is the standard of

1 steam generators.

2 The C-22 Alloy fits about right in here, from the
3 point of view of iron, chromium, and nickel, but in
4 addition, there is 13 percent molybdenum, some tungsten, and
5 cobalt, so that, you know, stretches a little bit the
6 comparison, but this is a place to start.

7 Now, the molybdenum, tungsten, and cobalt,
8 metallurgically will affect the precipitation of carbides in
9 the boundaries, and probably minimize the so-called
10 sensitization effects that sucks the chromium out of the
11 grain boundary area. Chemically, I'll talk about that in
12 just a second.

13 So I think there's some argument to be made that
14 the large amount of data that are available on Alloy-600 is
15 relevant, although may be somewhat imperfect, but it
16 certainly is a good place to start.

17 Now, here I'm showing the potential pH diagrams
18 for the main alloying species in C-22. The main alloy
19 element is nickel, and what I have in these diagrams, this
20 lower line is the standard hydrogen equilibrium; this is the
21 standard oxygen equilibrium; these are all at room
22 temperature.

23 And this is the -- this hatching in each case is a
24 pure metal. The other hatching here is the sequence of
25 various oxides, depending on the oxidizing potential.

1 And you can see that, of course, the big advantage
2 of nickel is not so much the fact that you've got passive
3 films; it's the high solution potential which slows down the
4 reactivity.
5 Now, there is some film here. The film that
6 actually shows up on these alloys is not so much a nickel
7 oxide but a nickel-chromium oxide, which as a slightly
8 broader stability that I'm showing here.
9 With 21-percent chromium, the CR-203 stability has
10 this range; it gets it acid benefit from the fact that
11 phenomenalogically you can extrapolate this CR plus three to
12 CR 203 line in this direction, and it seems to preserve a
13 metastable stability and gives you acid protection.
14 Molybdenum is a largely misunderstood material
15 from the point of view of corrosion resistance. It's sort
16 of like, wow, I have molybdenum, therefore, I'm somehow
17 great.
18 The fact is that molybdenum is absolutely soluble
19 in water. And molybdenum is only useful in the relatively
20 acidic environments and in the very acid environments where
21 you have a MO3 stability.
22 And so molybdenum is not a great addition,
23 especially for neutral to alkaline environments.
24 Tungsten has a passive range below about pH 3, and
25 above that range, tungsten is soluble in water. And then

1 this is the well-known iron diagram which has a fairly broad
2 alkaline stability, but unfortunately there's no much of it,
3 and chromium or cobalt looks very much like nickel, and
4 there's not much of that, either.
5 So that's kind of the picture, but the sort of
6 thing you come away with the in C-22 Alloy is the material
7 is basically a lot like Alloy-600, possibly a little bit
8 like 690, with chromium and tungsten, but the chromium and
9 tungsten don't help you in neutral solutions.
10 So, it's not -- there is some question about it,
11 okay.
12 Now, we had this -- I had several questions about
13 metallurgy. Let me show you two things quickly: This plot
14 is percent of affected tubes versus heats.
15 Now, let me tell you what was done here: This
16 work from Peter Scott at Framatome. The French,
17 fortunately, know for every steam generator, the heat of
18 material used in ever tube.
19 Now imagine the possibility then of taking each
20 tube that's plugged or cracked and relating it to a heat and
21 being able to say what fraction of that heat cracked. So
22 you've got 35 tubes made out of heat one, and, you know, 20
23 of them crack, then you know that you've got about 65
24 percent tubes cracked from that heat.
25 So this is now 40 percent up here, so one heat

1 cracks a lot, fractionally. There are 25 or 30 heats here
2 in one steam generator. There are 4,000 tubes in the steam
3 generator, so it's reasonable there should be several heats.
4 Several other heats crack at the ten, or
5 five-percent level, but over half of these heats hardly
6 crack at all.
7 This tells us something about thinking about alloy
8 development; that we need to think about in developing an
9 engineering framework, about something about the
10 structure/property relationships and the effect on the
11 corrosion processes.
12 This is the induction time or initiation time for
13 cracking in pure water environments, essentially pure water
14 environments as a function of grain boundary carbides within
15 the specified carbon in the alloy.
16 So, for essentially the same carbon, same nominal
17 heat treatments, depending on the carbide distribution at
18 the boundaries and away from the boundaries, there's an
19 enormous difference in the proneness to cracking.
20 So this is not to make an argument in too much
21 detail, but simply to point out that the structure, as those
22 of us who have been in metallurgy a long time know, is a big
23 issue.
24 Let me say just a word about the Grade 7. Grade 7
25 titanium, for those of you who are unfamiliar with it,

1 basically has about two to three-tenths palladium in it.
2 Now, why palladium?
3 What palladium does, kinetically, is that it
4 accelerates the reduction of the water, that is, the water
5 at the hydrogen reduction. That's the so-called exchange
6 current electrochemistry, and by doing that, it raises the
7 open circuit potential on the surface and keeps it away from
8 the low potential range for hydrogen or where titanium has
9 its greatest vulnerability.
10 But in terms of our interests here, it actually
11 hasn't been very well characterized, and I make a couple
12 points there.
13 Now, let me tell you a little bit about the
14 material selection for Alloy-600 as maybe a
15 history-repeats-itself kind of story here.
16 Alloy-600 was initially selected, based on its
17 great nominal corrosion resistance to chlorides, based on a
18 boiling magnesium chloride test. That was the total basis
19 for the choice of that material.
20 This work was first presented in 1957 by Copson,
21 later presented again in 1959 by Copson, and that's the
22 total basis for the choice of this material.
23 Now, it turns out, as I will show you in a minute,
24 that the failures that have occurred have had nothing to do
25 with chloride, and not only that, but the basis for using

1 chloride as a criterion is just wrong, because this alloy
2 cracks just fine in chlorides; it's just never been studied
3 very well.
4 Now, the Alloy-690, the higher-chromium alloy, was
5 again basically selected based on a 1972 work by Flint of
6 INCO in the UK, where he showed that this kind of
7 composition was nominally resistant to cracking in lead, and
8 also was resistant to cracking in oxidizing crevices. The
9 detail is not so important here, but I'll show you how in
10 both case those criteria were fallacious.
11 These are Copson's data. This is breaking time
12 versus nickel for a 20-percent chromium composition. The
13 point is, above about 50-percent nickel, the cracking stops.
14 Now, 42 percent boiling magnesium chloride is a
15 fairly aggressive environment. Anyway, so this is not a --
16 but there is something of a fallacy in using some aggressive
17 environments, and I think you all know that very well, but
18 this is a good example.
19 So these were his data which stood some test of
20 time for awhile. In 1981, two EDF people, Berge and Donati,
21 published a paper showing, in fact, that Alloy-600 cracks
22 just fine at about the same pH with small amounts of
23 chloride in a boric acid solution with the same
24 transgranular cracking, and later then published about three
25 years ago, the full set of data.

1 But the fact is that what that shows you is this
2 assumption, presumption, is just wrong, and, second, that
3 the alloy in service wasn't a chloride problem in the first
4 place; it was a problem with alkaline cracking, acidic
5 cracking, lead cracking, low potential cracking, and some
6 copper problems and so on.
7 So, the test that was done to qualify the material
8 was largely irrelevant. With respect to the lead issue in
9 qualifying Alloy-690, this is chromium concentration versus
10 iron.
11 These were exposed to high purity water with a
12 lead oxide in the environment. And this shows a region of
13 cracking.
14 Alloy-600 is about -- this is 18 percent.
15 Alloy-600 is about right in here. Alloy-690 is up here at
16 30 percent of chromium, about 10 percent -- this should be
17 over a little bit, incidentally -- and nominally it was in
18 the region where lead did not cause cracking.
19 However, again, I have a photomicrograph here
20 which some of you metallurgically inclined people might
21 enjoy. This shows the effect of an aqueous lead
22 environment, the specimen was exposed in the steam phase
23 above an environment containing lead oxide in an alkaline
24 solution of one molar sodium hydroxide solution.
25 And I don't know about you, but this is the worst

1 cracking I've ever seen. And this is purely a lead oxide
2 kind of environment.
3 The point is that the early work, again, by
4 International Nickel on this subject, produced an alloy for
5 which it was just an incomplete evaluation of the
6 properties.
7 So, the qualification of some of these materials,
8 even with extensive testing, is something that maybe needs a
9 little -- leaves something to be desired.
10 Now, the third step in making predictions,
11 corrosion-based predictions, is to figure out what the
12 framework is for where certain kinds of corrosion occur with
13 respect to some reasonable variables.
14 And the variable I'm going to use here for this
15 discussion, the main framework variables I'm going to use
16 are pH and potential.
17 Now, rather than going through this, I think I'm
18 going to show you the pictures . You can read this. One of
19 the first very useful frameworks that was developed was
20 published from the work of Parkinson and Congleton at the
21 University of New Castle.
22 This is a potential pH diagram for iron. This is
23 work that was done in a variety of aqueous environments,
24 including phosphates and carbonates and nitrates, showing
25 that there was a range of cracking, essentially along the

1 axis of the FE-304, FE-203 line; that the minimum in
2 cracking occurred at the minimum insolubility for the iron
3 oxide.
4 And then as you moved to more alkaline, you get
5 alkaline cracking.
6 This line shows that below this line, the alloy
7 cracks again in hydrogen environments, and so what you end
8 up with is a framework for low alloy steel, which looks
9 schematically like this.
10 This is the hydrogen line, the oxygen line, and
11 these other lines are the main phase ranges for iron
12 compounds. You have a hydrogen region below this value, you
13 have an anodic, mildly acidic region here that cracks,
14 alkaline region here that cracks.
15 Now, this framework that I'm showing you here, the
16 results from Parkinson and Congleton's work, actually
17 applies in the broad range of iron -nickel-chromium alloys
18 with variations which are more or less slight, and I'll show
19 you that in a minute.
20 So it's possible to dope out the framework. I
21 mean, this is not necessarily magic. It can be doped out.
22 And let me show you now, something that we
23 published in 1989 for the occurrence of cracking of
24 Alloy-600. This is, again, the potential pH framework.
25 This is a diagram at 300 Centigrade. or calculated at 300

1 Centigrade.

2 These are the iron lines; these are the nickel,
3 plus two, nickel oxide, lines. Now, what I've shown here by
4 the crosshatching are four regions where cracking occurs, no
5 unlike what we just saw for the iron.

6 You have alkaline cracking, and I'm going to show
7 you in a minute, how well defined this actually is. There
8 is acidic cracking, cracking of low potential regions. This
9 used to be called PWSCC, but that meant that it had to be
10 occurring in the primary system, which doesn't make any
11 sense, and so I've relabeled this as low potential cracking,
12 which it really is.

13 Then there's a high potential cracking range which
14 occurs in BWRs, and this is the thing that has caused the
15 cracking in the BWR technology until it was fixed by
16 changing the alloys.

17 So, this is essentially what the data tells you.
18 This is based on real data, where I have actually taken all
19 the world data and plotted it and come up with these regions
20 where cracking has actually been observed to occur in this
21 particular alloy.

22 Now, to show you that this is, in fact, based on
23 some pretty solid data, let's take, for example, this
24 transition here from the cracking region to no cracking
25 here.

1 We look at these data from Smialowska, and this is
2 amount of cracking versus potential, and the change from a
3 lot of cracking to no cracking occurs about over 100
4 millivolts, just right about the standard hydrogen line
5 which also happens to lie at the same place. This should be
6 NOI right here, how that happened.
7 Anyway, so, this change from no cracking to
8 cracking has been very well defined by a lot of people,
9 which is this situation here.
10 These boundaries can be defined. The alkaline
11 region, which is this region here, has also been very well
12 defined by many investigators. This happens to be
13 Mitsubishi work for Alloy-690 and 600, showing that the
14 potential dependence of that region of cracking covers about
15 300 millivolts and starts essentially at the D-area of open
16 circuit potential.
17 So, it is possible then to dope-out the regions of
18 a given material where cracking does occur. And it doesn't
19 necessarily have to be all that obscure.
20 Now, an interesting test, set of tests was done.
21 I mean, can we do this today on some material? The answer
22 is yes.
23 This was a set of experiments that was done by
24 Mitsubishi and reported in 1994. Again, this is
25 electrochemical potential versus pH. Actually the reference

1 here is a horizontal reference.

2 What the did is, they did a bunch of experiments

3 and then checked out these regions and so this was a

4 coherent set of experiments.

5 You get the same result that I got from patching

6 together everybody's data.

7 Now, what I've show here are what I call the major

8 submodes of cracking. The reasons I call them submodes is

9 that the principal mode here is a stress corrosion cracking

10 mode, but a submode really is an occurrence which as

11 different pH potential, temperature-dependencies. So each

12 of these has different dependencies. They're still all

13 stress corrosion cracking.

14 Now, let me show you then some minor submodes

15 which are maybe pertinent to this discussion, and I'm going

16 to show you a region of this diagram here and look at some

17 minority points.

18 This is what I call the set of minor submodes

19 which occur in Alloy-600 and 690. Our discussion of lead,

20 for example, the data on lead show that cracking due to lead

21 mainly is lead oxide added to these environments.

22 And, incidentally, there's this question about

23 chlorides that's interesting because a lot of this work has

24 been done down around the pH-3 range, with chlorides and

25 lead. It cracks just fine.

1 So the range of cracking of the lead is a little
2 bit difficult to see, because I've got a lot of stuff on top
3 of each other. But lead produces cracking that has been
4 verified over a full range of pH.
5 In addition, when the sulfur is in some lower
6 valence form -- don't ask me in detail what it does,
7 although I published a big paper on this last year -- but
8 when sulfur somehow gets into a lower valence, a plus-2, a
9 minus-2 valence, it causes all these alloys to crack fairly
10 rapidly.
11 Unfortunately, this work hasn't been extended
12 beyond the basic region, but it I am sure is an issue over
13 this whole pH range, of course depending on the stability of
14 the pH dependence of the stability.
15 Now there are some other species here that are
16 important in the presence of alluminates and silicates. the
17 alkaline cracking occurs at the lower values of pH and the
18 acid rains, the presence of copper in the environment
19 accelerates the occurrence of cracking. Chloride produces
20 cracking we know now in the pH 3 range. This has not been
21 studied at higher pHs, and so there is an array of sort of
22 miscellaneous things that people have done that are in
23 frankly not very great shape but nonetheless are out there.
24 Just to illustrate one of these, these are data
25 and it's a little bit complex and I won't bore you with it

1 too much. This is Alloy 600, Alloy 690. These are in
2 solutions of varying -- and I have the solution basis
3 here -- medium acidic environments.
4 Now the difference here is that one set of alloys
5 was exposed in autoclaves without copper oxides in the
6 autoclave and the other with. What does cooper oxide do?
7 For those of you who know the thermal on this it gives you a
8 potential that is the thermodynamic potential is about 500
9 millivolts above the standard hydrogen potential but the
10 mixed potential won't be that high.
11 Now they have also added with hydrogen, without
12 hydrogen. What does hydrogen do? Hydrogen lowers the
13 potential and so what that means is that without the
14 hydrogen leaving the potential probably a couple hundred
15 millivolts above the standard hydrogen electrode it cracks
16 both Alloy 600 and 690 very rapidly.
17 Now that is just one of the multiple submodes and
18 this is due to an acid copper system which we could discuss
19 later if you wish.
20 Now the point then I want to make relative to our
21 discussion, that having laid out what is a fairly extensive
22 definition of Alloy 600 right here, the question is, okay,
23 what about Alloy C-22, and Alloy C-22 has no definition at
24 all.
25 That is the alloy we are talking about engineering

1 with. We are talking about engineering with an alloy for
2 which there really is no panoramic definition. It's not
3 that there are not some very nice experiments that have been
4 done. Incidently, some very nice electrochemical work has
5 been done by Gustavo over here, Dr. Cragnolino, but the
6 point is that in this alloy that we are talking about
7 engineering with there is no basis for making judgments
8 about turning left or right. We don't know where to
9 engineer with this system.
10 Now a similar situation occurs in the Grade 7. I
11 won't discuss that. I have a few notes about the titanium
12 system, which I won't bore you with since it is not as
13 important here and let me move on now to some prediction
14 processes.
15 If you read the DOE analysis of how they predict
16 stress corrosion cracking, they essentially use the approach
17 that has been developed at the GERND, mainly by Andreson &
18 Ford. They have done a lot of very nice work on this, but
19 essentially what they come up with is that the crack
20 velocity relates to the crack tip strain rate and some
21 environmental exponent.
22 Then they convert this crack tip strain rate into
23 a stress intensity to the fourth power so you can substitute
24 stress intensity in here to approximately the fourth power.
25 Now the problem is this doesn't predict anything.

1 It doesn't tell you anything about the environments. It
2 doesn't tell you about mode diagrams. It just simply is a
3 way of plotting data and so this is not a basis really for
4 any kind of prediction nor is it a basis for if you take the
5 data -- this is work from Eason & Shusto in 1983, this is
6 their statistical analysis of weld failures in BWRs for
7 smaller pipes and larger pipes.
8 The discrimination actually isn't so important
9 probably and this is one percent failure, tenth of a
10 percent, hundredth of a percent. There were a lot of welds
11 in a lot of plants.
12 This is a Weibull plot. The slope here is a
13 little bit more than one, which means this is very
14 dispersed, very dependent on heat to heat variation of the
15 welds. Something has happening here -- so this formulation
16 doesn't predict this either, so we need something that is
17 just a little bit better than saying this is proportional to
18 something, to a power.
19 One of the points that's made in the DOE report is
20 the minimum stress intensity for cracking they find is
21 around 30 ksi root inches or greater. In fact, in alkaline
22 cracking the minimum S1 SCC is around 10. It's actually
23 lower than that, so that assumption I think is somewhat
24 questionable.
25 Now the next step, having gotten some sense of

1 environmental definition and again this was sort of an
2 argument about what the environment should look like on the
3 surface when you have a heated deposition. You define the
4 environment and you define the metals. We have discussed
5 it.
6 The next step, a little bit slanted here, is what
7 I call super position, and what is super position? The idea
8 is what you do very schematically is you are interested then
9 in comparing the mode definition -- this is where the cracks
10 occur, as we show in our mode diagrams -- with the
11 environment that you have, and I have shown these in
12 potential pH coordinates. This could be in any
13 coordinates -- and you find out where the overlap is.
14 Now the problem here is it means that you have got
15 to have some definition of mode. Where do these occur? For
16 C-22 you have absolution no definition of where cracking
17 occurs despite the fact it's pretty clear that it cracks.
18 We just don't know where.
19 With respect to the environment, the idea of
20 engineering in terms of a aqueous environment from J-13 when
21 you are thinking primarily about a concentrating surface, it
22 just frankly is irrelevant, and so the capacity then to make
23 a judgment about the inner section of modes and environments
24 I think is maybe somewhat difficult.
25 Now the next point I wanted to make -- I am almost

1 done but not quite -- is that the reality, the making
2 predictions has to be based not on just one set of
3 experiments that one guy or one lady ran in the lab, but in
4 fact is the result of work by a lot of people over some
5 length of time and even though if you don't like the data
6 and you would rather sensor it and just include your data,
7 the reality is you have got to deal with a set of data by
8 respectable people and this -- these are crack growth rate
9 data versus stress intensity.
10 This is from a collection by Jansson & Morin, but
11 the point is the crack velocity versus stress intensity, one
12 gets down to about 10 KSI root inches. The megapasal root
13 meter is virtually the same set as KSI root inches, not
14 quite.
15 This is what? Five, six orders of magnitude of
16 crack velocities. Some of this is pretty crappy data.
17 That's not a technical term, but --
18 [Laughter.]
19 MR. STAEHLE: -- but it is, and the same problem
20 with smooth surface data. I showed these the last time I
21 was here. They haven't changed very much.
22 This is time to failure versus 1 over T for
23 stainless steels and magnesium chloride. These are data
24 from about 20 different investigators which we have put
25 together.

1 I know every one of these investigators
2 personally. Unfortunately about half of them are dead now,
3 but what this shows again is that this is the reality of
4 data for a set which is done by people of some repute, and
5 so in making predictions we need to recognize that you don't
6 have the sort of monolithic single value kind of capability
7 but rather a somewhat more complex circumstances that you
8 need to pay attention to.
9 What I would like to do now is just conclude and
10 say just a few things here that -- this actually is in the
11 beginning of my notes -- that my first conclusion in looking
12 into this problem is that there's substantially inadequate
13 knowledge about the conditions under which C-22 or Grade 7
14 sustains cracks, i.e., there is no capacity to know whether
15 we go left or right with respect to an environmental
16 definition.
17 Second, I don't think there is any corrosion
18 testing of a real environment -- that is, the concentrating
19 surfaces. This just simply doesn't exist.
20 It is doubtful in my opinion that any of the work
21 that has been done under isothermal conditions is
22 substantially useful or substantively useful. There's a lot
23 of good work that has been done. It's not bad work it is
24 just irrelevant.
25 The residual stress issue on broad services is

1 quite adequate to produce cracking. The application of
2 global heat treatments to reduce surface stresses may
3 accelerate other problems. So far there is no evaluation of
4 the condition of manufactured prototypes. We don't know
5 what the prototype does in terms of surface stresses.
6 There is no prototype system for judging real
7 environments. Nobody has made -- for example, for those of
8 you who know this, recall in the early years the BWR people
9 made a quarter size BWR to evaluate certain heat transfer
10 and fluid flow things -- a wonderful system they had
11 built -- and the PWR people did equivalent things. There is
12 nothing like that here. There is no prototype facility that
13 you can go to.
14 Again, some of you historically may remember the
15 A1W and the S1W and D1W things and the whole tradition of
16 this industry was to build prototypes. There is no
17 prototype here for the environmental problem.
18 The next point -- this is the point Jeff made --
19 that I think there's a lot that can be learned in the
20 historical sense from looking at some of these analogies and
21 paradigms from the nuclear development and I am also
22 somewhat concerned that the same people that said there was
23 no water present or going to be present are the people that
24 are now making other predictions.
25 So maybe with that -- oh, one more thing I wanted

1 to mention here quickly -- the things that I think are
2 needed.
3 First, I think we need to develop a plan or
4 program or system for realistically testing heated surfaces
5 and I would be the last one to tell you, as I am sure Jeff
6 and Ronnie would be, that these experiments in autoclaves
7 are the perfect experiment. They are not. They just happen
8 to be a good place to start -- say do you have a problem,
9 are you worried or not worried, is this a perfect material,
10 what, and ideally these experiments should be done on heated
11 surfaces with grips or with something that is a better
12 approach to reality.
13 Second, I think we need to investigate this
14 question about just how much of the Yucca Mountain chemistry
15 is really relevant. Now I made this sort of bounding
16 statement that from the beginning you have got to start off
17 and say what's there, and it will get there. Now that is an
18 overstatement.
19 Then you have got to back off and say, well, now
20 how much of it can get there and how, and let's do some
21 prototypes and figure out just what really happens and take
22 some intelligence from the steam generator examples.
23 There is no mode diagram story for the C-22 or the
24 Grade 7. You simply don't know how these materials perform.
25 We need to assess stresses over whole surfaces for

1 manufacturing prototypes and we need to assess stresses over
2 whole surfaces for manufacturing prototypes, and we need to
3 get some kind of a prototype where we can deal with these
4 large-scale environmental problems. Okay?
5 DR. WYMER: Thank you very much. That's a lot.
6 Let me ask you a unscientific question and it is
7 just a matter of your judgment.
8 What is the likelihood of getting the essential
9 information to qualify C-22 in about six years?
10 MR. STAEHLE: That's why I showed this data from
11 Mitsubishi -- one chart showing this -- because that was
12 actually done in a couple of years.
13 Actually the guy that did most of that works,
14 former Ohio State guy, which Paul and I both expect --
15 [Laughter.]
16 MR. STAEHLE: The work that was done by Parkins
17 Congleton on their work was done by about four graduate
18 students over a period of five years, but in fact with an
19 organized effort I think the things that I think need to be
20 done here in that kind of time I think is reasonable.
21 Admittedly there is a problem of acceleration and
22 predicting, even if we had started the experiment today and
23 it went six years, there is always the question of just how
24 relevant is this but of course if it fails in six years then
25 you have got a big problem with 10,000.

1 I think that clearly we are not going to get to my
2 friend Bob Way's aspiration --
3 DR. WYMER: No.
4 MR. STAEHLE: -- of defining all the atomistics,
5 where I think we can get a lot smarter, there's a lot of
6 thermal around we can deal with. I mean there's a lot of
7 analysis we can do that I think is pretty intelligent and so
8 I think that a person could conceive of a reasonable program
9 in that kind of time to get a reasonable set of data.
10 I was afraid when we started talking you were
11 going to ask me about a year --
12 DR. WYMER: Oh, no.
13 MR. STAEHLE: -- and I thought, well, I've got a
14 problem with that, but a six year program done by good
15 people who have good leadership I think can do a good job on
16 this.
17 DR. WYMER: Thank you.
18 We need to take other questions, even though it is
19 Noon.
20 MR. STAEHLE: Sorry.
21 DR. SHEWMON: Let me make a couple comments.
22 One didn't come up in the discussion but I am sure
23 this C-22 was given us by Mike Stryker, who came out of
24 Dupont and did corrosion work for them for years, which
25 would fit in and he, when I last was involved in this 10

1 years ago, was on his horse to save the program by getting
2 rid of the stainless steel that they were talking about
3 then, probably a 316 or something and going across to this,
4 which just didn't stress corrosion cracking or much of
5 anything else.
6 I am not sure whether Mike is still with us or
7 not.
8 MR. STAEHLE: No, Mike is still around, and Mike
9 was one of the great people in the field.
10 His experience I think was basically in acid
11 corrosion. I mean that is where Dupont had a lot of their
12 problems.
13 DR. SHEWMON: The other thing, you raise an
14 interesting point that you can get lots of concentrations
15 with high heat fluxes. You talked earlier about getting a
16 temperature variation. Let me remind you of your original
17 premise and said it is the heat flux, not the temperature,
18 so the heat flux does dies down a lot in decades.
19 MR. STAEHLE: Well, Paul, you are right. It is
20 against though the framework that in any given day you could
21 run a crack all the way through this wall in about four,
22 five hours so we are not talking about -- if you get the
23 right galactic intersections this is not a great big
24 challenge to crack and so I think we need to sort of be
25 conscious of that framework.

1 The problem here is look, Roger, if you are so
2 clever what is the answer to this sort of question which I
3 think is an honest question to ask. The way the problem was
4 essentially solved in the nuclear technology was of course
5 by a process of evolution and that Alloy 600 had lots of
6 problems and eventually the 690 became a better material.
7 They redesigned the tube supports, reorganized the water
8 chemistry and so you have a system that behaves pretty well.
9 In fact, I want to Kansi Electric Power and they
10 wanted me to analyze the 690 future and I laid out to them
11 some of the problems that were potential problems and the
12 manager of the program said, well, you're right. We agree
13 with you that it has potential problems but in the field it
14 hasn't failed yet and so we can't justify any work.
15 Now the point I want to make here is that
16 basically the solution to corrosion problems is a design
17 materials interaction. To say that you can solve this
18 problem totally with one material is just a mistake.
19 There is not a material that exists today that you
20 can choose that is not going to crack in some framework of
21 these environments.
22 You have got to step back and say listen, we need
23 to look at this not as a material but as a design material
24 system so the solution is someplace like that.
25 This on the other hand means that we have got to

1 be intelligent about our understanding of C-22 because you
2 can't design with something that you don't know left, up,
3 right, or down, so you have still got to do that, but I
4 think to think that a C-22 is going to resist even the
5 reasonable environments that you can get there is just a
6 mistake.
7 If you go to some other material, well, if you are
8 so clever, let's think of a better material, I think the
9 answer is you have looked at some good ones. The steam
10 generator program has looked at some good ones by some very
11 good people and you are kind of where you are at.
12 So I think you have got to accept that reality and
13 say, look, maybe we have got to kind of rethink how we do
14 this.
15 DR. GARRICK: Well, isn't the opportunity even
16 greater for doing it systematically in the repository
17 application than it was for nuclear power plants simply
18 because most of the evolution you are talking about in the
19 nuclear industry occurred in the first and second generation
20 plants, rather than in prototypes.
21 There was some of it in prototypes but most of the
22 real problems with the BWR occurred after we had BWRs and
23 they were in operation and during the inspection and
24 surveillance.
25 Now in the case of the repository we have anywhere

1 from a 50 to 300 year operating period.

2 MR. STAEHLE: Yes.

3 DR. GARRICK: Which is unique in engineering of

4 systems, so maybe the opportunity exists to go much beyond

5 the prototype here and actually have a performance

6 confirmation program of an actual situation or an actual

7 waste package under its actual environment and make

8 measurements there and evolve in such a way that if things

9 really go bad there is the option of relatively easy

10 retrievability.

11 MR. STAEHLE: Well, that is kind of what I was --

12 I agree with that.

13 DR. GARRICK: We are not here to design the thing.

14 We are here to advise the Commissioners on how to reach a

15 conclusion on its safety.

16 MR. STAEHLE: Yes.

17 DR. GARRICK: But I am just picking up on the

18 comment about the evolution.

19 MR. STAEHLE: Well, you know, in the nuclear

20 program there were some interesting early things.

21 For example, in Dresden, which was the earliest

22 BWR, they actually saw cracking at room temperature in 1967.

23 DR. GARRICK: Right.

24 MR. STAEHLE: And people thought, oh, well, that's

25 a bad heat. That's always the answer to first cracks -- bad

1 heat.

2 The problem of alkaline cracking was clearly
3 evident in 1967 from Lindsay's calculations where he showed
4 the concentration of alkalinity in these crevices and from
5 the paradigms of the stainlesses, the cracking of Alloy 600
6 was actually demonstrated in alkaline solutions in 1965 by
7 Sedricks, so little things were out there but they say,
8 well, that will blow away -- it's a bad heat, something, but
9 in fact the things that were the beginnings of what
10 eventually became very big were already known before major
11 commitments were made. That is one thought.

12 The second thought is in fact what the nuclear
13 industry really did was to use the reactors for the model
14 boilers.

15 DR. GARRICK: Sure.

16 MR. STAEHLE: In a sense you can understand all
17 that in framework of the hurry and the sales and the
18 competition and all those things, but I think the argument
19 here is that maybe we need a more stepwise, thoughtful
20 approach to how to do this, and one of these has certainly
21 got to be some kind of a prototype. One is maybe a more
22 design materials interaction that has some reality to it.

23 There are some elements like that that we ought to
24 evolve and rather than just saying we have got to have this
25 tomorrow, we have got to pass a safety thing or an NRC thing

1 tomorrow, you know, I just don't think that is consistent
2 with the nature of this system.
3 DR. GARRICK: My point was that a lot of what we
4 discovered in the nuclear plant systems came considerably
5 later, such as the core spray nozzles on the BWRs.
6 MR. STAEHLE: Right, right.
7 DR. GARRICK: And I don't think we are in that bad
8 a shape here in terms of being able to come up with a design
9 and manufacturing strategy.
10 That is to say, there is a lot more opportunity
11 here for doing research than may be the first impression
12 would suggest.
13 MR. STAEHLE: I think if we could think in those
14 terms and a mature view of how things really are in
15 approaching that, I think this is quite an imminently
16 accessible, doable thing.
17 Excuse me, Morrie?
18 MR. MORGENSTEIN: I do have a concern relative to
19 this. If we are reading PMRs and AMRs that have start to
20 failure times at 10,000 years from now for everything in the
21 AMRs and PMRS no matter what the topic is and it is based on
22 our C-22 canister.
23 I am worried that the site as defined as a natural
24 barrier may not be as rigorous as we originally envisioned
25 and we are relying very heavily on C-22 as a containment

1 barrier.

2 We have pretty much agreed that there's some

3 problems with C-22. Are we willing to go for the next 300

4 years and investigate C-22 while loading the repository or

5 do we need some other kind of discussion?

6 DR. GARRICK: Well, I don't get the impression

7 that we need 300 years. I get the impression we can do it

8 in a much shorter period of time, but I am saying this as an

9 advantage that they have. They have a lot more time to do

10 more realistic in-place tests and prototype testing than we

11 had in the power reactor field.

12 MR. MORGENSTEIN: I concur. I would like to see

13 that before we start loading and licensing.

14 DR. GARRICK: And we have done a pretty good job

15 there. That is my point.

16 MR. MORGENSTEIN: My point is that I would like to

17 see us investigate C-22 before we agree on licensing or --

18 DR. GARRICK: I think that is correct, yes.

19 DR. WYMER: Any other comments?

20 MR. CRAGNOLINO: I have a comment and a question.

21 My comment regards something that was mentioned in

22 the past by Roger regarding the fact that we really look in

23 the resistance to corrosion of Alloy 22 and one of the main

24 reasons that was not mentioned for the large counting of

25 molybdenum and tungsten -- they seemed significantly

1 resistent to localized corrosion and in this sense this
2 alloy has been used not only for service in the chemical
3 industry acidic media but on a range of applications for
4 seawater and the demanding conditions for geothermal
5 application and a lot for replacement in the oil industry
6 for perforation and the conditioning -- I mean there are a
7 series of important aspects that have to be considered.
8 Roger is however completely right in this concern
9 about stress corrosion cracking that is one of the most
10 insidious forms of failure. It is a matter of important
11 consideration.
12 We have explored this in our work program, putting
13 a lot of emphasis in certain aspects. However, I think that
14 even though the framework that Roger presents in thermal for
15 pH is very important.
16 There is one other body of it that should be
17 included there, and this is my question -- temperature.
18 What happened with temperature and what happened with a very
19 large activation energy that this process has in particular
20 in the pressing of lead for Alloy 600 where we are talking
21 about 105, 125 kilogen or more.
22 Roger, I'm sorry, but I would like to ask these
23 types of questions.
24 MR. STAEHLE: No, no we are good friends. The
25 thing -- Gustavo has raised several important points here,

1 but the actual problem with the answer is in fact that the
2 data for the temperature dependence is not well established
3 except over a narrow range.
4 For example, alkaline cracking of infinel 600
5 occurs as low as 100 centigrade.
6 I showed you the data on the chloride cracking
7 which occurs at 100 centigrade from EDF work.
8 On the other hand, the cracking of the -- the pure
9 water cracking and the so-called low potential cracking has
10 a fairly steep activation energy and a long coefficient in a
11 sense and probably does not practically occur below probably
12 at least 200 centigrade and maybe more like 225 centigrade,
13 so -- but in fact the interaction -- I mean one of the
14 problems, for example, with this is a lot of the possible
15 interactions just have not been explored.
16 Potential dependence -- we had this discussion on
17 lead dependence -- and I think you have to step back a
18 little bit and say, you know, if it cracks here we better be
19 careful of there. It doesn't mean we can't do it. It just
20 means we have got to be careful to do the experiments and I
21 think short of having the kind of atomistic things that we
22 would all like to have, we have got to give things not a
23 super-wide berth but a wide enough berth to say at least we
24 do experiments that are intelligent -- I mean but that is a
25 good point.

1 DR. WYMER: Bill?

2 DR. HINZE: Roger, just a very quick question

3 based upon your experience.

4 Do you have any comments about the relative

5 advantages of lower high thermal loading of the repository?

6 MR. STAEHLE: Well, I think that is certainly --

7 the model I was suggesting here is sensitive to thermal

8 loading because it affects the heat flux and the

9 concentration and the length of time and I think in general

10 in the system --

11 DR. HINZE: And also the moisture.

12 MR. STAEHLE: Yes, and I think whatever you can do

13 to cut down the concentration on these surfaces is a good

14 idea.

15 That affects both heat flux and temperature on the

16 surfaces and length of time and those all sound like good

17 ideas in one framework of thinking.

18 There is a consequence in terms of how the water

19 moves and the rocks and those things and I think it is not

20 just sort of my reaction, it is kind of my reaction and your

21 reaction together.

22 DR. HINZE: It is a real coupled process.

23 MR. STAEHLE: Yes, and I think that, I mean this

24 is one of the wonderful interdisciplinary things where we

25 both speak the same thermodynamic language. We both speak

1 the same framework, but there's a lot of differences in how
2 we see things and understand things and there is certainly
3 room for a lot of interaction here.
4 DR. WYMER: Anything else?
5 [No response.]
6 DR. WYMER: Well, if not, this is has been a great
7 session from my point of view.
8 It's been very enlightening. We have a lot yet to
9 do but ostensibly we can do it, so with that I do thank you
10 all very much. We are adjourned.
11 DR. GARRICK: I want to indicate that we
12 anticipated that this might overrun a little and so we are
13 going to make arrangements to delay the start of the first
14 session this afternoon on entombment.
15 We are going to try to do that at 1:30 rather than
16 1 o'clock as shown on the agenda.
17 With that, we will adjourn for lunch.
18 [Whereupon, at 12:17 p.m., the hearing was
19 recessed, to reconvene at 1:30 p.m., this same day.]
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1 AFTERNOON SESSION

2 [1:34 p.m.]

3 DR. GARRICK: I'd like to call the meeting to
4 order. We're now going to get into the decommissioning
5 business.

6 This is Ray Wymer's big day because he's also the
7 lead member on this, so, Ray, do you want to introduce the
8 subject and speaker?

9 DR. WYMER: Yes, we're going to spend an hour till
10 2:30, so you've got your full time, practically, on looking
11 at entombment as an option for decommissioning reactors.
12 Entombment is sort of, as I understand it, has been added
13 formally to the SAFESTOR and license termination suite of
14 means of getting out from this reactor responsibility.

15 So, Stephanie Bush-Goddard is going to talk to us
16 this morning about the rulemaking activities associated with
17 entombment of power reactors.

18 Stephanie.

19 DR. GARRICK: Except that it's afternoon already.

20 DR. WYMER: Time flies when you're having fun.

21 MS. BUSH-GODDARD: Good afternoon. As he said, my
22 name is Stephanie Bush-Goddard. I am the Task Leader for
23 the entombment rulemaking.

24 I am here because the Commission has requested the
25 staff to consult with the ACNW on this issue. So my goals

1 or my objectives today will be first to give a regulatory
2 history.
3 Entombment falls under -- is a decommissioning
4 alternative, so I'll talk about the regulatory history of
5 decommissioning, and then I will go into what actually is
6 entombment, and some of the specific NRC activities related
7 to the entombment issue.
8 I'll go into the need for rulemaking and its
9 scope, and I'll also give you a current status of where the
10 rulemaking effort is, and then finally, I'll end up with
11 some of the guidance I'm asking for from the members.
12 As I said, entombment is a decommissioning
13 alternative. It falls under the decommissioning rule in 10
14 CFR 50.82. And basically this rule says that you have 60
15 years from permanent cessation of operations to
16 decommissioning.
17 The NRC will approve beyond the 60 years, only
18 because of public health and safety. Now, this rule was
19 written in 1988. At that time, we only had an unrestricted
20 release criteria.
21 That criteria was 25 millirem a year. Then in
22 1997, we published what you call the radiological criteria
23 for license termination. This also gave a restricted dose
24 criteria.
25 You could -- the criteria was 25 millirem a year,

1 and if institutional controls failed, you could go up to 100
2 millirem a year, and if justified, up to even 500 millirem a
3 year.
4 However, if you go up to 500 millirem a year, you
5 had to monitor the decommissioning site, and there had to be
6 surveillance every five years.
7 So, let's go into entombment. Entombment is a
8 decommissioning alternative, and basically it's where
9 radioactive contaminants are encased in a structurally
10 long-lived encasement such as long-lived materials such as
11 concrete.
12 The structure is maintained and surveillance is
13 carried out until the radioactivity decays to levels -- I
14 have permitting unrestricted release here because this rule
15 was made in 1988 with the decommissioning rule, but now we
16 also have the restricted release criteria, and that's
17 something to keep in mind.
18 DR. HORNBERGER: Stephanie, just a point of
19 clarification.
20 MS. BUSH-GODDARD: Yes?
21 DR. HORNBERGER: Who does the surveillance?
22 MS. BUSH-GODDARD: The licensee.
23 DR. HORNBERGER: So is the NRC involved
24 afterwards, in a restricted release with surveillance or
25 judging whether the surveillance is successful?

1 MS. BUSH-GODDARD: In the license termination
2 plan, I believe, the licensee has to prove that after the
3 facility is terminated, that they will be able to maintain
4 either the unrestricted or the restricted release criteria,
5 and this is even before the final license is terminated.
6 So, in 1997, when the license termination rule was
7 being published, the NRC also told the Staff to see if
8 entombment is viable, and if they determined that it was
9 not, to see what could make it viable.
10 So we published this information paper. I'm going
11 to talk a little bit about that.
12 After the paper was published, we had public
13 workshops, and actually we had a public workshop, and we
14 submitted the workshop findings and Staff recommendations in
15 a SECY paper.
16 From that, the Commission told the Staff to
17 proceed with rulemaking, and I'll go over each of those.
18 The first was a PNNL report, the Pacific Northwest
19 National Laboratory Report, and basically they first talked
20 about some entombment experience in the U.S. Currently, we
21 have three DOE reactors that are entombed.
22 They were entombed around the 1969-1970 timeframe,
23 and they were entombed by regulations under the AEC. These
24 were small demonstration power reactors.
25 The Hanford site is also going under some type of

1 entombment. They have eight former plutonium facilities,
2 and as we stand now, they're doing partial dismantlement,
3 and, subsequently, entombment.
4 Now, the Hanford site is different from the DOE
5 site in that they have characteristics similar to commercial
6 power reactors, in that I think they're near a large body of
7 water, they have low population density, and the residual
8 activity is more like commercial power reactors.
9 The PNNL report also did a study, not necessarily
10 an isolation assessment, but what an isolation assessment
11 would have to be done if a reactor would be entombed.
12 Basically you have to look at the radioactive inventory.
13 Now, they reference a pressurized water reactor
14 that's about 350 megawatt thermal, and what they said is
15 that you really have to have a great radionuclide inventory.
16 If you're only going to leave in the Cobalt-60, which has a
17 half life of about 5.27 years, then the radioactivity will
18 last as long as the structure would be able to maintain it.
19 If you have something like Cesium-137 at 30 years,
20 and I think Nickel-63 at 100 years, you need something on
21 the order of 130 to 300 years. And then if you have your
22 longer-lived radionuclides, I think, like Niobium, that's
23 like 20,000 years, and then you couldn't necessarily verify
24 that the containment would last.
25 They also looked at the transport through the

1 containment, and the long-term integrity, and they came up
2 with the conclusion that concrete can last about on the
3 average of about 500 years.
4 Now, this report was taken in 1993, and they took
5 data from the 80s, and they also looked at dispersal through
6 the environment, in that once the radioactivity left the
7 containment structure, what type of flow and what type of
8 pathways would it have to go through?
9 And they came up with conclusions. First of all,
10 there is no current isolation data, so you would have to do
11 a study, and it would probably have to be site-specific on
12 things like determining distribution coefficients and things
13 like that.
14 But the performance assessment could be similar to
15 the low-level waste disposal -- a low-level waste disposal
16 facility. So you could take some Part 61 requirements and
17 apply them to the performance assessment.
18 Did you raise your hand, sir? Okay.
19 Also, there is a difference. The performance
20 assessment could be similar to low-level waste facilities,
21 but there is a difference between entombment and low-level
22 waste, in that the source term is very much different, and
23 the site characteristics could be different.
24 They also did two types of entombment scenarios.
25 Say, if you had immediate entombment where you take out all

1 of the stuff in the beginning and in about five years you
2 seal and you monitor it until 130 years, and they're
3 assuming that at 130 years, you meet the unrestricted
4 release criteria.
5 Now, this would have to take all the spent fuel,
6 the GTCC out, basically everything except the Cobalt-60.
7 And then they also did a deferred entombment where you place
8 it in storage for 100-120 years, let things decay, and then
9 entomb.
10 And from that data, they came out with here I have
11 radiation dose. If you do immediate, delayed entombment and
12 to other decommissioning alternatives which are DECON and
13 SAFESTOR.
14 Of course, with DECON you have the higher amount
15 of person-rem, because you're decon'ing the material, the
16 equipment, but you also have a large generation of low-level
17 waste here in the red.
18 Immediate entomb -- and both of the entombed
19 produce the lowest person-rem here, and they are, each of
20 them except DECON, had similar low-level waste being
21 generated.
22 Okay, so from that PNNL report, the NRC conducted
23 a public workshop. This was in December of last year. We
24 took the workshop findings and Staff recommendations to the
25 Commission.

1 And I'll go over the workshop findings. In that
2 workshop in December, the first thing that they found was
3 that no attendees challenged the capability to construct a
4 viable, technically-viable entombment.
5 And we had seven states represented. They viewed
6 entombment favorably, but an issue that they had is that if
7 the license is terminated, then the responsibility might
8 fall back on them. I'm sorry, if the license is terminated,
9 and if there was entombment failure, that the cleanup and
10 mitigation might fall on the states.
11 There was agreement that the Low-Level Policy Act
12 was not working, and entombment seemed viable from an
13 economical standpoint.
14 They preferred excluding, rather than Class C
15 waste. They felt that if this was going into rulemaking,
16 the GTCC issue might hold up the entombment option.
17 And they also called for a need for a study
18 specific to NRC-licensed facilities. As I mentioned before,
19 the entombed reactors are basically DOE reactors, in that
20 the source term is lower than some of our commercial power
21 reactors.
22 From those workshop findings, the Staff
23 recommended that we do an Advance Notice of Proposed
24 Rulemaking, an ANPR to solicit comments in a regulatory
25 framework, you know, to get public comments, to get

1 Agreement State comments and what have you.

2 So in that Staff requirements memorandum, the

3 Commission told us to do a couple of things: First of all,

4 they did not object to a rulemaking plan. They told us to

5 coordinate the rulemaking plan with the generic

6 environmental impact statement, and to address the issue of

7 greater than Class C waste.

8 The workshop findings said we should not include

9 that issue, but they wanted us to put it back in, and

10 finally, why I am here today: To ensure that you all are

11 appropriately consulted.

12 So, now we're at the rulemaking stage. I have

13 here, going from current requirements. What we plan to do

14 is put the current requirements in the rulemaking plan, try

15 to provide different entombment option scenarios. I'll go

16 in that in a minute.

17 And then specify what we feel is our preferred

18 option.

19 As I also said, we're issuing an Advanced Notice

20 of Proposed Rulemaking, and here we just are telling the

21 public about the issues, the background of entombment, and

22 asking questions related to state issues, questions about

23 the technically-viable issues, the greater than Class C

24 waste, and what have you.

25 So, we have a couple of options: The first one is

1 just to maintain the status quo. We also have to put that
2 in for NEPA analysis.
3 A second option is to terminate the license,
4 amending the 10 CFR 50.82. You know, we have the six-year
5 requirement, and maybe modifying that requirement to make it
6 feasible for some power reactors.
7 And then also we're thinking about retaining some
8 type of license, maybe under Part 50, or under another
9 existing Part. You know, Part 50 is the utilization of
10 power reactors, and the power reactor now will be
11 decommissioned.
12 Or we are thinking about some other option, maybe
13 introducing a new Part under a new regulation, something
14 maybe similar to the Low-Level Waste Part 61 license,
15 similar in performance.
16 DR. HORNBERGER: Stephanie, let me ask a question
17 to try to overcome some of my ignorance here. So,
18 maintaining the status quo, just means that you would go on
19 a case-by-case basis; that is, a licensee could apply for
20 entombment and you would do the evaluation, and either
21 approve or not approve?
22 MS. BUSH-GODDARD: Yes, but that's not viable for
23 most entombment scenarios. Most reactors have things in
24 there that would let -- that you could not meet the license
25 termination rule in the 60 years.

1 Now, say, if they wanted an exemption, the
2 Commission will only approve an exemption for public health
3 and safety. So if you wanted to extend it to, say, 100
4 years based on economic reasons, as the rules are written
5 now, you cannot do that.
6 DR. HORNBERGER: I see. Okay, and the second
7 option, terminate the license, I'm not clear what that
8 means.
9 MS. BUSH-GODDARD: Okay
10 DR. HORNBERGER: Terminate the license for a
11 specific --
12 MS. BUSH-GODDARD: Okay, the difference between 1
13 and 2 is that you're terminating the license eventually, but
14 in Option 2, terminate the license, we would amend that
15 60-year requirement.
16 DR. HORNBERGER: Oh, I see.
17 MS. BUSH-GODDARD: Yes. Sorry about that.
18 So, ending with the other, like I said, it might
19 be under a new regulation.
20 So, the current schedule, right now the rulemaking
21 plan and the ANPR are in NRC Office Concurrence.
22 Hopefully, by next Friday, we'll send them to the
23 Agreement States for comment.
24 That will take about 30 days. We will get the
25 comments back, analyze them, resolve the issues, send out

1 another Office Concurrence, and hopefully by that time we'll
2 also have our paper from you guys, and then we'll send it to
3 the Commission.
4 Now, there are some issues, particular issues that
5 we would like to talk about, however, please feel free to
6 write down anything you feel would be relevant.
7 The first one is this issue of dose reduction
8 credit. Basically, there are some -- we're struggling.
9 When I say "we," the Working Group is struggling with this
10 issue of what dose reduction credit can be given for
11 engineered barriers in an entombed structure.
12 Basically, how long can we say the concrete will
13 last? Of if it's grouted and concreted, is there a specific
14 lifetime we may say that the grout remained -- will remain
15 effective to meet the dose criteria, which, again, is the 25
16 millirem a year, the 100 millirem, or the 500 millirem a
17 year.
18 And then the second big question is, what should
19 be the regulatory framework? If we do decide to go with an
20 entombment option, should it be still under Part 50 and just
21 be a decommissioning Part 50?
22 Should we develop a whole new Part and have the
23 performance assessment similar to low-level waste, do some
24 isolation assessments and things like that, and have that
25 criteria in the rule?

1 Or should it be under existing and existing Parts?
2 So those are the two questions that we're wrestling with,
3 we're struggling with.
4 We would appreciate your comments, and any other
5 comments that you will have. And that's it.
6 Are there any questions?
7 DR. WYMER: Thank you very much. Are there other
8 questions around the table?
9 DR. GARRICK: I was a little -- I was trying to
10 figure out the real merit of deferred entombment, as you
11 have described it, safe storage to 120 years. Why the
12 choice of that particular --
13 MS. BUSH-GODDARD: I guess, from an occupational
14 exposure basis, that it probably has more merit than, say,
15 immediate entombment.
16 DR. GARRICK: And it seems then to go to a sealed
17 entombment for another ten years, that seems a lot of work
18 for a short period of time.
19 DR. WYMER: There is a technical factor here,
20 Stephanie, if I can jump in?
21 MS. BUSH-GODDARD: Go ahead.
22 DR. WYMER: To plot the radiation level inside the
23 -- from the vessel, that is a function of time. There is a
24 sharp-kneed curve that's like a hockey stick and at about 70
25 years, it breaks very sharply.

1 MS. BUSH-GODDARD: And also this is some -- this
2 is the PNNL report that they just made up two different
3 scenarios. I don't think in the rulemaking plan stage,
4 we're actually looking at, you know, when will the license
5 be terminated, and even actually look at the different
6 scenarios of where it would be a delayed versus an
7 entombment scenario, and even if we would be that specific
8 in the regulations.
9 DR. GARRICK: How much has risk perspective been
10 built into the entombment approach?
11 MS. BUSH-GODDARD: Well, we're looking at RCRA,
12 the Resource Conservation and Recovery Act law. They give
13 some type of risk reduction credit to their institutional
14 controls, so we're trying to look at their model to see if
15 we can apply some of that to commercial power reactors.
16 DR. GARRICK: The other thing is, what are the
17 specifications for entombment beyond radiation?
18 MS. BUSH-GODDARD: Specifications beyond
19 radiation?
20 DR. GARRICK: Are there area limitations? Are
21 there structural integrity requirements? What drives the
22 qualification for entombment beyond radiation levels?
23 MS. BUSH-GODDARD: We're looking into that right
24 now, but I can say that in looking into that we are trying
25 to model some of the low-level waste criteria. I think

1 we're maybe trying to, if these options -- once we get a
2 preferred option, we're going to look at maybe putting
3 requirements in that if you're below a certain water table,
4 you can entomb your structure.
5 DR. GARRICK: Is there an area limitation?
6 MS. BUSH-GODDARD: No, not yet.
7 DR. GARRICK: Or height limitation? No spatial
8 language?
9 MS. BUSH-GODDARD: We haven't developed that yet,
10 no. We sure haven't.
11 DR. GARRICK: Okay, thank you.
12 DR. HORNBERGER: Stephanie, I have a couple of
13 questions on the same study that John started on, and the
14 immediate entombment versus delayed.
15 And in their PNNL, it also had a SAFESTOR option.
16 Does that mean safe storage in perpetuity? Is that how the
17 analysis was done? I just thought it was odd to contrast
18 SAFESTOR with decommissioning and entombment, which seemed
19 to me to --
20 DR. GARRICK: Yes, I was trying to relate it why
21 on earth would you not SAFESTOR through the whole period,
22 rather than --
23 MS. BUSH-GODDARD: Well, actually, entombment, if
24 you can look at it, it can kind of encompass the SAFESTOR
25 issue.

1 DR. GARRICK: Right.

2 MS. BUSH-GODDARD: In SAFESTOR, I think the end
3 point was to, after the dose has been reduced, to take that
4 and put it into an existing low-level waste depository, so
5 to move it away from the site.

6 The difference between SAFESTOR and entombment is
7 that in entombment you're having onsite disposal of that
8 waste.

9 DR. HORNBERGER: I see, okay, okay.

10 MS. BUSH-GODDARD: Yes.

11 DR. HORNBERGER: I missed that. That's, again, an
12 indication of my ignorance of how this works.

13 So, again, Ray's point was that of course, if
14 you're doing entomb immediately, the radiation, the
15 occupational exposure is higher because you're doing work
16 inside the containment.

17 And yet the PNNL study, the difference is between
18 800 person-rems and 300-plus-person-rems. It doesn't look
19 like a huge difference in exposure.

20 DR. WYMER: One of the things that came out of the
21 conference we attended last week was the fact that the
22 business of just waiting is one that's being seriously
23 considered. The British are saying, let's wait 75 to 135
24 years or something like that, and the Canadians say you're a
25 little bit out of your tree; we ought only wait about 50

1 years.

2 At any rate, they agree you ought to wait, maybe

3 seven years till you come to the knee in the curve.

4 So there are definite benefits to those, waiting.

5 DR. HORNBERGER: I mean, that stands to reason

6 because of the nuclides there. Stephanie, I think I heard

7 you say that the PNNL report suggested that concrete will

8 last 500 years?

9 MS. BUSH-GODDARD: Yes, they reference another

10 paper, and in the workshop, it was brought up that it could

11 last much longer than that. But I'm just --

12 DR. HORNBERGER: So going to the question, the

13 first question that you posed that you'd like some feedback

14 from us on is the life of, the potential life of engineered

15 barriers. You're just looking for us to again comment on

16 that?

17 MS. BUSH-GODDARD: Yes, just comment. You know,

18 in the end, we will probably do an assessment of different

19 types of concretes, and they will probably -- I'm not a

20 geologist or a geological engineer, but go through all these

21 criteria, and take data from that and decide.

22 So, just a general feeling of if dose reduction

23 credit should be taken.

24 DR. HORNBERGER: Should be taken. Finally, I just

25 have two other things, again related back. Part of what I'm

1 trying to grapple with, not knowing too much about 10 CFR
2 Part 20, Subpart E, but we heard a lot about West Valley
3 yesterday, and, of course, they're grappling with the
4 potential use of the license termination rule there, and the
5 policy statement.
6 And this issue of surveillance, let me come back
7 to that.
8 MS. BUSH-GODDARD: Okay.
9 DR. HORNBERGER: You said under the regulations,
10 surveillance would be carried out by the licensee; that's
11 the licensee's responsibility.
12 But I guess who looks over the shoulder of the
13 licensee when they're doing their surveillance?
14 MS. BUSH-GODDARD: The licensee has to have an
15 approved plan before its terminated.
16 DR. HORNBERGER: Right, so they come to you with
17 an approved plan, and you say, yes, this looks good. The
18 end then? We just trust them?
19 MS. BUSH-GODDARD: Well, no we don't. I think
20 that's when, say, for instance, if we have some type of
21 failure, then maybe one of the federal agencies, probably
22 the EPA, would have jurisdiction in that.
23 MR. LIEBERMAN: Stephanie, could I add something?
24 I'm Jim Lieberman from Office of General Counsel.
25 Under the license termination rule, when we're

1 dealing with a restricted release, the Commission makes a
2 determination based on the institutional controls that the
3 cap, the dose cap, if institutional controls fail, is below
4 either 100 or 500.
5 They terminate the license when they're satisfied.
6 If, after that point, something occurs, such that there is a
7 greater dose, the Commission has said in the regulations,
8 they will only get involved if they perceive significant
9 threat to the public health and safety.
10 They haven't defined in the regulations or the
11 statements of consideration, what that threshold is of
12 getting involved because they are seeking finality. But
13 they reserve the right to get reinvolved to deal with the
14 situation.
15 I presume somewhere in the 500 millirem --
16 somewhere between 100 and 500 millirem, the Commission would
17 probably get reinvolved.
18 Absent that, under the decommissioning plan that's
19 approved and the institutional controls, it provides for the
20 monitoring, the maintenance, and the surveillance.
21 And they have to have enforceable requirements but
22 enforced outside of the Commission's activities.
23 DR. HORNBERGER: Okay, so who looks at the
24 surveillance data, and who then does the enforcement? I
25 guess that's my question.

1 MR. LIEBERMAN: Okay, it would not be the
2 Commission, so that would be the state, whoever is the
3 steward, maybe the state or the Federal Government.
4 DR. HORNBERGER: And the steward would be
5 specified in the application for license termination?
6 MR. LIEBERMAN: Exactly. We have to approve the
7 steward. We have to be satisfied that there is sufficient
8 financial assurance, and that the relationship is
9 sufficiently enforceable so that it will be a workable
10 system.
11 In most of these cases involving the large
12 exposures, potential exposures, they have to have durable
13 institutional controls which would be more likely the
14 governmental entities.
15 DR. HORNBERGER: Okay, so it gets specified, and
16 that makes sense to me now.
17 The other thing that I was interested in was that
18 you mentioned that under the LTR, the exemptions beyond the
19 60-year period can only be for reasons of public health and
20 safety.
21 And as far as you know, that could have a fairly
22 broad interpretation, though, couldn't it? I mean, I guess
23 what I'm trying to grapple with is, in your case, suppose
24 the analysis came back that deferred entombment which went
25 beyond 60 years for reasons that Ray was saying,

1 substantially would reduce both occupational and potentially
2 dose to the public.
3 Wouldn't that be a reason for public health and
4 safety?
5 MS. BUSH-GODDARD: I will -- since OGC interprets
6 the rule, can you give us an answer to that also?
7 [Laughter.]
8 MR. LIEBERMAN: That is a very good question. In
9 fact, we're looking at that question.
10 The rule itself, I don't have the rule in front of
11 me, but the rule says something like the Commission --
12 approval of the Commission extended, based on a case-by-case
13 basis, based on health and safety. And then it has some
14 examples.
15 And I think one -- can you just read the rule,
16 Stephanie?
17 MS. BUSH-GODDARD: Yes.
18 MR. LIEBERMAN: This is 50.82, .83.
19 MS. BUSH-GODDARD: Okay, factors that will be
20 considered by the Commission in evaluating an alternative
21 that provides for completion of decommissioning beyond 60
22 years of permanent cessation of operations includes:
23 Unavailability of waste disposal capacity and other
24 site-specific factors affecting the licensee's capabilities
25 to carry out decommissioning, including presence of other

1 nuclear facilities at the site.

2 MR. LIEBERMAN: So we're still struggling with

3 what those words actually mean. So I really can't give you

4 a more detailed answer.

5 DR. GARRICK: If you're struggling, what's that

6 mean about the rest of us?

7 [Laughter.]

8 DR. HORNBERGER: So you're not surprised then that

9 we're struggling.

10 MR. LIEBERMAN: Exactly.

11 MR. LEVENSON: I have got sort of a followup

12 question: You said that the licensee is responsible for the

13 monitoring, imposes the LTR. But the draft policy statement

14 on West Valley specifically states that the responsibility

15 for the monitoring is not the licensee's, but will be a

16 responsible government entity.

17 Is that at variance with what's done in power

18 reactors?

19 MR. LIEBERMAN: No. During the period the license

20 is in effect, it's the licensee.

21 After the license is terminated, it's the function

22 of the termination plan. You have to have in the case of

23 West Valley, because of the size of the source term, durable

24 institutional controls, which the statement of consideration

25 addresses as basic federal, state, or governmental agencies.

1 This is a very complex rule, so let me try to
2 explain it a little bit here. You have to have
3 institutional controls.
4 You have to have an independent third party to
5 provide the monitoring, provide the capability for
6 monitoring and maintenance.
7 The licensee can do it, but if the licensee fails,
8 then the independent third party gets involved, which would
9 be the institutional controls that would be the federal or
10 state agency.
11 So, one scenario is, the licensee does it from
12 scratch, and that would continue until there is a failure
13 and then the institutional controls kick in.
14 Another situation might be the licensee gets out
15 at the very beginning, and the institutional controls would
16 begin early on.
17 MR. LEVENSON: Is the identification of the
18 responsible government entity something that is done in
19 advance then, when the -- I can't say when the license is
20 terminated, because West Valley license is already
21 terminated.
22 MR. LIEBERMAN: No, no. The West Valley license
23 is in suspension. It's going to be reinstated once DOE is
24 completed.
25 But in a typical case, yes, it is agreed to in

1 advance, because we want to make sure that the Government
2 agency, whoever is going to do the institutional controls,
3 will agree to do it.
4 It has -- and satisfied the financial resources to
5 achieve that, have been set aside in a trust or whatever.
6 So that when we're closing the site and terminating the
7 license, all these loose ends that we're talking about are
8 resolved.
9 And that may be easier said than done, and we
10 haven't yet released a license under restricted release.
11 But several licensees are getting into that
12 situation now.
13 DR. WYMER: Thank you. Is that all, George, that
14 you had?
15 DR. HORNBERGER: Yes, thank you.
16 DR. WYMER: I have one question: We may, in
17 deciding to respond to this, to comment on something having
18 to do with greater than Class C waste, Stephanie, and this
19 whole issue of whether or not you address greater than Class
20 C waste now or put it off into the future sometime, as has
21 been suggested by some of the people who have made comments
22 on it.
23 That brings it up as an issue. Can you say a
24 little bit more about the implications of deferring the
25 removal of greater than Class C waste and what this has to

1 do with the regulation, how you respond to it?

2 MS. BUSH-GODDARD: There is another

3 interpretation, and I'm going to have to call you up here

4 again, Jim. It's the issue that if we include greater than

5 Class C waste in the entombment structure, we can do what

6 they call volume-averaging, and if we volume-average it,

7 then we can classify it as less than greater than Class C

8 waste, and we can put it in the entombment structure.

9 If we cannot classify it as less than greater than

10 Class C waste, then to put it in an entombed structure as

11 greater than Class C waste would require modifying the

12 Low-Level Waste Policy Act, I believe.

13 DR. HORNBERGER: Don't go there.

14 [Laughter.]

15 MS. BUSH-GODDARD: Exactly.

16 DR. HINZE: It sounds like a good idea to me.

17 MR. LARSON: Remember, this was one of the

18 considerations in the Trojan Pressure Vessel disposal.

19 DR. WYMER: And there is the -- 94 problem that

20 you have, so that it never goes away. It seems to me that's

21 a pretty significant barrier to entombment, because it's

22 forever a restricted release.

23 DR. GARRICK: Sort of as a followup to why we're

24 where we are on this issue, where has the initiative for

25 entombment come from?

1 MS. BUSH-GODDARD: Well, back in 1998 when the
2 decommissioning rule was written, they gave basically three
3 alternatives, DECON, SAFESTOR, and entombment.
4 In the supplementary information, they did say
5 that they favored both DECON and SAFESTOR.
6 Now, since we have the license termination rule
7 with restricted release, some licensees might say, well, we
8 probably can entomb and meet the restricted release
9 criteria, hence the new involvement in entombment. That's
10 kind of the basis why it's being renewed.
11 DR. WYMER: It's a cheaper option than taking it
12 all offsite.
13 DR. GARRICK: I guess you got some feedback at the
14 workshop as to the public's reaction to the entombment
15 option?
16 MS. BUSH-GODDARD: Yes. Like I said, there were
17 seven states represented. And they looked favorable,
18 because one reason they realized that the Low-Level Waste
19 Policy Act was not working, and they didn't know where they
20 would put the low-level waste.
21 But there was also a concern, like I said, that if
22 the license terminated, who would assume cleanup and
23 mitigation expenses and liability if there was a failure.
24 Licensees would like to have entombment as another
25 decommissioning alternative that will give them a little bit

1 more flexibility in how they're decommissioning.

2 DR. WYMER: Can you give us a little feeling for

3 -- do you know how many utilities are considering

4 entombment?

5 MS. BUSH-GODDARD: No, I don't. In the workshop

6 -- right now I know of only one. I think that's Florida

7 Power, but that's not to say that there aren't more.

8 But I don't think I have that data, but I can get

9 that to you, if you'd like.

10 DR. WYMER: It would be interesting. It didn't

11 sound like it was a groundswell of the utilities, does it,

12 to go to entombment?

13 DR. GARRICK: Well, no. But the utilities have

14 been kind of frustrated on where to put the low level waste,

15 so it solves that problem to a certain extent.

16 DR. WYMER: There's a representative from NEI that

17 maybe would present the industry perspective on this, if

18 you're interested.

19 DR. GARRICK: Yes, that would be good.

20 MR. GENOA: Thank you, Mr. Chairman. My name is

21 Paul Genoa. I'm a Senior Project Manager at the Nuclear

22 Energy Institute, and one of my issues -- all of my issues

23 involve material disposition.

24 And one of them is the entombment option. The

25 industry is interested in entombment as an option.

1 At the workshop, we had members of our Task Force
2 On License Termination. Those members represented over 30
3 reactors that all said at that meeting, that -- well, they
4 showed up in December in D.C. for a meeting to show that
5 they are interested in the option, but not that they're
6 ready to move forward.
7 I believe the Commission was motivated to pursue
8 exploring the issue by a letter sent from the State of
9 Florida. It was a joint letter from the Department of
10 Health Services, if that's the right term Florida, but the
11 Agreement State agency, combined with the Public Utility
12 Commission, both showing interest in the entombment option.
13 But there are others as well, and clearly, as you
14 point out, the concern over future availability of disposal
15 -- we want to understand today, what it will take to safely
16 disposition these reactors after their useful life is done,
17 if we're forced to be in a situation where disposal is not
18 available.
19 As you know, spent fuel is facing that today. And
20 there is no regulatory structure in place to deal with that
21 crisis -- Yucca Mountain.
22 And so we don't want to be in the same situation
23 with low-level waste.
24 Further, there are economic and occupational
25 safety issues. Right now, in Connecticut Yankee, they are

1 segmenting the reactor internals. They're removing the
2 greater than Class C material.
3 It is a horrendous radiological exposure, about
4 140 man-rem are being expended today to cut that material
5 up, plus a lot of other industrial safety issues to involve
6 in a task that great.
7 I think you gentlemen have reviewed what happened
8 in Trojan, and I think any real valid environmental
9 assessment would find that the environmental impacts of
10 taking this material out of a very robust container, perhaps
11 have not been fully evaluated.
12 Entombment seems to provide some options.
13 DR. GARRICK: Are we going to run into the same
14 problems with entombment that we've run into with the states
15 and the public that we have with the low-level waste
16 Agreement State compacts? Has the NEI done any surveys or
17 public outreach projects to get a better assessment of how
18 this option would be received by them?
19 MR. GENOA: We certainly have not done anything
20 formal, but when we look to implement the Low-Level Waste
21 Policy Act, or the High-Level Waste Policy Act, our
22 opponents say leave it where it's stored.
23 So we're looking for a regulatory approach at
24 leaving it where it's stored.
25 DR. GARRICK: Near where the sites might be.

1 MR. GENOA: Generally not, actually.

2 DR. GARRICK: I guess we can't guarantee that we

3 won't have the same problem with the entombment.

4 MR. GENOA: I think that's an accurate assessment.

5 DR. GARRICK: Right, right.

6 DR. HINZE: John, thinking back eight, ten years,

7 the Committee spent a good deal of time discussing the

8 longevity of concrete.

9 And, in fact, I think we may even have a letter

10 that discusses that. You might want to go back and review

11 those topics and what was said and some of the germane memos

12 and so forth.

13 DR. GARRICK: Yes.

14 DR. HINZE: There is a good deal of information

15 residing on that point.

16 DR. GARRICK: Thank you, thank you for reminding

17 me.

18 DR. HINZE: The author is here of that letter.

19 He's not going to admit it.

20 [Laughter.]

21 DR. GARRICK: We don't want to press that too far.

22 Marty, yo had a question?

23 DR. STEINDLER: Let me just make a comment: It

24 seems to me that the long-lived activities essentially are

25 all in the reactor vessel. The rest of the stuff can be

1 packaged, if you can get it out of there, and shipped to
2 some low-level burial ground. At the moment, a lot of this
3 junk ends up in Utah.
4 So the issue, it seems to me, is not a waste
5 disposal issue, nearly as severely as one would believe.
6 The expenditures, as I think you pointed out,
7 George, the expenditure of over 150 or even 200 person-rems
8 to cut up a reactor vessel is to the industry, probably a
9 significant issue, as it should be.
10 But I would expect that it's a lot more expensive
11 than filling up a reactor vessel plus its surroundings with
12 concrete and letting it sit there. So there's an economic
13 issue.
14 I think the waste disposal issue is -- my sense is
15 that it's not real in the sense that there are currently
16 ways of alleviating that, albeit expensive. If somebody in
17 the East Coast wants to get rid of a reactor, they've got to
18 move a lot of concrete debris to Utah, which can't be cheap.
19 DR. GARRICK: Yes.
20 DR. HORNBERGER: Not only expensive in dollars,
21 but if you talk about real risk, the trucks running concrete
22 pieces to Utah run over people
23 DR. STEINDLER: Even if it's railroads. And it's
24 the regulatory nightmare that everybody has got to jump
25 through.

1 But I don't see how in the absence of addressing
2 the greater than Class C issue, I don't see how you can make
3 this work unless you operate on what I consider to be
4 numerology, and that is averaging the total waste content
5 from the fairly hot pressure vessel and piping over a very
6 large concrete enclosure. Something interesting, but not
7 really the way it was designed. Dilution is not really
8 allowed, usually.
9 But the --
10 DR. WYMER: It's not exactly dilution, Marty.
11 That's sort of a fictitious dilution.
12 DR. STEINDLER: Well, yes, that's right. But you
13 do have to run some kind of a performance assessment to
14 address the question of what happens? Supposing your
15 concrete last 1,000 years on a good day, but in the acid
16 rain that the Chicago area occasionally comes through with,
17 for example, 1,000 years is as optimistic as all get out.
18 Then what do you do with a reactor vessel that's
19 got a fair amount left of Niobium and nickel? So some
20 performance assessment has to address that issue.
21 DR. GARRICK: Yes.
22 DR. STEINDLER: It seems to me that that should be
23 the determinant.
24 DR. HINZE: You might also want to consider some
25 site characterization, because talking about Florida, you

1 have your potential for very fast pathways. We saw that
2 when we looked at the low-level waste siting in that state.
3 DR. STEINDLER: Yes. The thing that troubles me about this
4 particular approach is that this is almost setting aside of
5 what I guess I would call the normal approach to risk
6 assessment, the business of, the specialized business of
7 getting rid of a reactor.
8 I think the regulations have to be more coherent
9 than that in the overall.
10 DR. WYMER: Can you address the Maine Yankee case
11 in this context of their planning to leave something below
12 grade there. Aren't they?
13 MS. BUSH-GODDARD: Yes. I think -- I'm not an
14 expert in it, but I know that they are decommissioning, and,
15 yes, they do not have a place yet for their spent fuel, or
16 -- I'm sorry, you said they're planning on leaving something
17 below greater than Class C?
18 DR. WYMER: I think I remember from the conference
19 that they were going to go down to three foot below grade
20 and leave everything lower than that there; is that right?
21 MR. WEBB: Yes, Stephanie, maybe I can help a
22 little bit.
23 MS. BUSH-GODDARD: Please.
24 MR. WEBB: My name is Mike Webb, and I'm the NRR
25 Project Manager for Maine Yankee. And as you've said, what

1 they have proposed is to remove all the radiological
2 material above ground level, down to the three-foot level,
3 to retain the foundations in place. They will scabble
4 and/or otherwise remove surface contamination, but then
5 they'll backfill that space with clean soil.
6 DR. WYMER: That's not exactly entombment.
7 MR. WEBB: Correct. They will have removed large
8 portions of both concrete and all the other debris, the
9 metals that would be associated with entombment.
10 DR. GARRICK: Marty?
11 DR. STEINDLER: Just one other thing: This PNNL
12 report by Smith and Short, there's a disclaimer by the NRC
13 Staff in the front of it, which I thought was appropriate.
14 Then I read in the front that this report dated
15 May 11th, was revised by Carl Feldman of the U.S. Nuclear
16 Regulatory Commission.
17 Now, tell me what that's all about. Since when is
18 a contractor report revised by the NRC? And does that --
19 MS. BUSH-GODDARD: Would anyone like to help me
20 with that?
21 [Laughter.]
22 DR. HORNBERGER: Well said, Stephanie.
23 DR. STEINDLER: That's the first time -- I have
24 read a lot of NRC reports, and that's the first time I've
25 seen one where the Commission Staff admitted to revising

1 somebody's report.

2 DR. WYMER: I don't think you need to answer that.

3 DR. GARRICK: Howard, are you going to comment to

4 us about what they're expecting to get from us?

5 MR. LARSON: Well, Stephanie had -- her questions

6 that she asked for on concrete, and I guess the other thing

7 is whether the Committee had any thoughts as to whether or

8 not the ANVR should be issued, right? But you're planning

9 on doing it no matter what the Committee thinks.

10 MS. BUSH-GODDARD: No. In fact, we're taking it

11 to the Commission for approval to publish it.

12 And I'm sure that they will also look at what you

13 all have to say about it. If the Commission approves it to

14 publish it, then we'll go ahead and publish it.

15 DR. WYMER: Okay, any other questions?

16 MR. LEVENSON: I have one. You have suggested

17 that there are several possible regulatory frameworks in

18 which this might be issued.

19 Basically, what's really the difference? What are

20 the advantages or disadvantages of issuing it, either under

21 Part 50.82 or, say, maybe another existing regulation?

22 MS. BUSH-GODDARD: Well, I guess there are pros

23 and cons of both. Decommissioning of power reactors is kind

24 of a gray area, because it's -- actually, decommissioning is

25 under Part 50, which is the utilization and production of

1 power reactors. But actually you're not utilizing or it's
2 not producing anything anymore, so it goes into this waste
3 arena.
4 Low-level waste is under Part 61, and other
5 licensee-type Parts. I think material source licenses are
6 under Part 30 or whatever; I'm not sure. So we're trying to
7 write a clear regulation. Should it be now in a specific
8 race arena only, and say, for instance, leave 50.82 alone,
9 and say if you want -- you know, leave it as it stands, and
10 say, well, if you want to entomb, you have to go to this
11 whole entire Part because we realize that it's not a
12 production or utilization facility.
13 Or should we leave it under 50.82, because that is
14 where decommissioning of power reactors, you know, that's
15 where the regulations are.
16 So we're struggling with, you know, what, exactly,
17 is this entombment issue?
18 MR. LEVENSON: Where, for instance, is SAFESTOR
19 now?
20 MS. BUSH-GODDARD: SAFESTOR is not exactly in the
21 regulations, but the supplementary information to the --
22 okay, let me start again.
23 Yes, the supplementary information that talks
24 about SAFESTOR and DECON are actually located in 50.82. So,
25 you would go to 50.82 for guidance with SAFESTOR and DECON.

1 MR. LEVENSON: Do you think there is any advantage
2 in having it all in one place, rather than having to bounce
3 around the regulations?
4 MS. BUSH-GODDARD: I guess that's maybe an
5 administrative type choice.
6 MR. LEVENSON: Well, not so much that as that most
7 of the regulations have all kinds of supplemental stuff, and
8 if you're moving back from in between regulations, you can
9 have a lot of changes, whereas if they are all within one
10 regulation --
11 DR. GARRICK: I guess one of those options -- and
12 maybe that's what you were doing, talking about, because I
13 have been looking at some other stuff while you were talking
14 -- but one option would certainly be to remove the
15 decommissioning material from Part 50 and combine it with
16 the entombment and other things into a separate regulation.
17 MR. LEVENSON: My gut feeling, without thinking
18 about it extensively, is that it's all being in one place is
19 more important than where it is.
20 DR. GARRICK: Well, yes.
21 MR. LEVENSON: You have a speaker from NRR that
22 maybe would like to say something on that.
23 MR. HOWE: I'm Allen Howe with Industrial and
24 Medical Nuclear Safety, actually Stephanie's Section Leader.
25 I just wanted to provide a comment to you. Where we are

1 right now with the process, we're at the point of developing
2 a rulemaking plan for this.
3 Some of these questions that you're asking, we're
4 also trying to work out ourselves.
5 We are also in the process of developing an ANPR
6 and some of these issues, we want to explore as a part of
7 the ANPR.
8 In terms of what is the best option, we have not
9 concluded yet what is the best option for that part of we're
10 headed in trying to make that determination.
11 And part of what we're trying to do right now is
12 to keep you informed as to where we are, what kind of
13 options we're considering, and in terms of the pros and the
14 cons of locating the requirements in one part or another, it
15 certainly is an item of discussion. If we left it located
16 in Part 50, it would be subject to entombment of reactor
17 facilities.
18 If we looked at it for another part, it may be
19 that the scope is still defined for reactor facilities; it
20 may be that the scope would be broadened to other things.
21 But that is the question right now that is in the very
22 preliminary stages of consideration, and it is something
23 that will be a part of the information that we provide to
24 the Commission for their consideration.
25 MR. LARSON: To one of your questions, Milt, the

1 Commission did recognize that the Part 50 was written for
2 the design, construction, maintenance, and operation of
3 reactors, but they never looked at the back end of the
4 cycle.
5 So they did direct the Staff to take a look at the
6 regulations that might be associated with decommissioning,
7 and to look at putting those into one section.
8 I think they are also looking at the GIS.
9 Now, in regards to the first one, they've said,
10 well, we'll look at that, and the Staff did make a proposal,
11 and they said, okay, we'll defer looking at that for awhile
12 longer.
13 But the intent is to try and pull the applicable
14 regulations together, because as you say, right now, they're
15 here, there, and everywhere, and, you know, even today we're
16 talking Part 20, Part 50.82, and other facilities.
17 DR. WYMER: If I understand it, you just said that
18 you think entombment is enough different or has enough
19 different aspects to it that you might consider writing a
20 more broadly based regulation that includes not only
21 entombment but other things that might be similar but are
22 not necessarily reactor --
23 MR. HOWE: Let me just answer that question.
24 That is certainly an option that could be
25 considered. The charter that we currently have before us

1 right now, from the direction of the Commission, and
2 Stephanie, please assist me with this, is to look at the
3 entombment option for reactors
4 DR. WYMER: Okay, so that would rule out what I
5 just said.
6 MR. LEVENSON: No.
7 MR. HOWE: If we want to explore that, that would
8 have to be something that we would have to go to the
9 Commission to get their approval with.
10 MR. LEVENSON: But you have to go to the
11 Commission anyway.
12 MR. HOWE: Right. In terms of preliminary
13 thinking, yes, it has been an item that we have discussed --
14 what would be the applicability of this type of option to
15 other applications, other type of facilities.
16 DR. WYMER: Thanks. Could you hear that over
17 there, recording this stuff?
18 DR. GARRICK: Yes, he did.
19 DR. WYMER: Any other questions? We have run over
20 Stephanie's time here a little bit.
21 DR. LARKINS: Ray, I was just curious. What is
22 the Staff schedule for this ANPR and development of the
23 options, because a lot sounds very preliminary right now.
24 MS. BUSH-GODDARD: Well, we have a preliminary
25 package in office concurrence as we speak.

1 We are trying to get those comments resolved by
2 Friday of this week.
3 DR. LARKINS: When is your preliminary plan to go
4 to the Commission?
5 MS. BUSH-GODDARD: February, 2001.
6 I think ACNW will be on distribution for the
7 preliminary copies, even before they go to the Commission.
8 DR. WYMER: When do you need our input?
9 MS. BUSH-GODDARD: I would like to have it by next
10 ACNW meeting.
11 DR. WYMER: That will be in San Antonio.
12 MS. BUSH-GODDARD: Okay. I will fly there and get
13 it.
14 [Laughter.]
15 MS. BUSH-GODDARD: I don't know your schedule but
16 I think in talking to Rich Tortel he said that you could
17 possibly, if you decided to write something up I think
18 you're going to also send it to the Commission.
19 I was hoping to have something, you know if
20 possible, maybe by Thanksgiving in case there were some
21 comments that I wanted to incorporate into the plan before I
22 send it to the Commission.
23 DR. WYMER: You are likely to get a turkey if it
24 comes that soon.
25 [Laughter.]

1 MR. LARSON: Our next meeting is after that.
2 MS. BUSH-GODDARD: Oh, is it?
3 MR. LARSON: Our next meeting is that Monday,
4 Tuesday and Wednesday.
5 MS. BUSH-GODDARD: Okay -- early December, I
6 guess, if possible
7 DR. GARRICK: Well, we will talk about that later
8 in our reports session. Yes, thank you very much.
9 MS. BUSH-GODDARD: You're welcome.
10 DR. GARRICK: Thank you very much. Okay. We are
11 to what our agenda says is 2 o'clock and we are now going to
12 hear some reports from members and consultants.
13 You have the honor of hearing from Bill Hinze
14 first.
15 DR. HINZE: Well, prior to Stephanie's terrific
16 presentation there I was going to use some overheads, but I
17 have copies --
18 THE REPORTER: Do you want this as part of the
19 record?
20 [Discussion off the record.]
21 DR. GARRICK: I don't think we do. Who is our
22 designated Federal official?
23 All right. For this session he says yes.
24 [Pause.]
25 DR. GARRICK: Okay, Bill, tell us what you are up

1 to.

2 DR. HINZE: First of all I do want to thank you

3 for directing me and allowing me to attend these two

4 technical exchanges. I found them very interesting.

5 However, I want to say that I think that one of

6 the momentous affairs of my life occurred this morning, I

7 heard the first crack in the engineered barrier --

8 [Laughter.]

9 DR. HINZE: -- and so --

10 DR. GARRICK: Geology is back on the map.

11 DR. HINZE: -- this is a great day for the

12 geoscientists.

13 I think it is appropriate that I go immediately

14 after entombment because --

15 [Laughter.]

16 DR. HINZE: -- there seems to be some kind of

17 relationship there.

18 Despite the many excellent attributes of the Yucca

19 Mountain area, there are some negative aspects of the Yucca

20 Mountain area and certainly those that have the disruptive

21 events are very much a part of that.

22 The Yucca Mountain region has been tectonicly and

23 seismically and volcanically active for many millions of

24 years and we as geoscientists have nothing to do but to

25 assume that that is going to continue on for some period of

1 time.

2 In fact, within 20 kilometers of the Yucca
3 Mountain facility, as you well know, we have a 80,000 year
4 old volcano and we had a 5.6 magnitude earthquake which
5 occurred in '92 which caused damage, I am not going to say
6 how much damage, but damage to the FOC, the Field Operations
7 Center at the NTS. These are examples of the importance of
8 giving the disruptive events a very sharp look.

9 Disruptive events are not easy to predict in this
10 environment, as they might be in some other environments
11 because in terms of the volcanic activity it is sparse, it
12 is low-volume. There is little direct evidence and that
13 also is true of the seismicity, which is widely dispersed,
14 and generally low magnitude except for the occasional larger
15 magnitude like the Little Skull Mountain earthquake.

16 Incidentally, I couldn't help think about, as one
17 thinks about the Little Skull Mountain earthquake, that
18 shortly after that earthquake, if you will recall the ACNW
19 had a walk-through of what was it? -- the Y-Tunnel. I think
20 that was the name of it, the Y-Tunnel, immediately above the
21 epicenter of that earthquake, and it had recently been
22 painted white. The tunnel had recently been painted white
23 and one of the things that I remember so vividly of that
24 walkthrough is that we tried to find a chip of white paint
25 that might have popped off from the wall and despite going

1 through not with a hand lens but with pretty close scrutiny
2 we were unable to find any evidence of even something, a
3 little chip coming off the wall in an epicenter directly
4 above it, above the epicenter of that earthquake.
5 Well, in any event, disruptive events are very
6 important. They are hard to predict and as a result much of
7 what has been heard at the technical exchanges from the DOE
8 revolve around the evidence derived from the probabilistic
9 volcanic hazard analysis and the probabilistic seismic
10 hazard analysis plus its derivatives.
11 These basically form the meat and potatoes of the
12 response of the DOE to the NRC concerns.
13 In the disruptive events there are these two KTIs
14 that the NRC Staff has identified, the igneous activity and
15 the SDS, the Structural Deformation and Seismicity.
16 I was fortunate enough to attend both of those and
17 the SDS was just last week. I have prepared a trip report
18 on each of those and your quiz on those will not be until I
19 finish, but I hope that you will at least look them over.
20 I do want to point out though that these are meant
21 to supplement the NRC/DOE summaries that come out of these
22 meetings because I really think these go hand-in-glove. I
23 have made no attempt to do every -- to say everything in the
24 right words and the correct, exact verbatim of the
25 agreements between the NRC and the DOE.

1 On the next page I try to point out the objectives
2 and the basic results of the technical exchanges.
3 The NRC has identified in their KTI analyses
4 several concerns regarding both igneous activity and the
5 SDS. For example, in igneous activity they have identified
6 prior to the technical exchanges some 16 different concerns
7 of various significance, but concerns, and these then were
8 the subject of discussion in the presentations by DOE where
9 they have presented additional data and analyses on these
10 previously unresolved issues leading hopefully to the
11 closing of these issues.
12 This requires -- attendance at these requires a
13 very close attention to what is going on. Things go very
14 rapidly and particularly if you have not been doing this
15 every moment of your life.
16 I was sitting there feeling sorry for myself that
17 I couldn't daydream at all when I turned and looked at my
18 neighbor at the last meeting, and it was Jim Curtis, who you
19 will recall is a lawyer and a former Commissioner, and a
20 good benefactor of this committee, and he was staying right
21 with it, right with all of these things, so I figured if a
22 lawyer could stay with it --
23 [Laughter.]
24 DR. HINZE: -- that we could stay with it as well.
25 Another objective was to develop an action plan

1 leading to the closure of the KTIs. This has happened to
2 some extent but it has often led to new concerns.
3 This is not bringing me another rock, but further
4 clarification, need for additional data that has been
5 indicated by the NRC and its coworkers.
6 The results were these intensive discussions by
7 the DOE of the NRC concerns and I think that you will be
8 pleased to know that all issues except one concern in
9 igneous activity has moved to the closed or closed
10 pending -- in other words, the NRC feels that they have
11 enough information or that they see a proper path to obtain
12 the information.
13 That one issue relates to the intrusive scenario
14 in the igneous activity and the number of casks that would
15 be involved with that and what kind of disruption there
16 would be to those casks. That is the one remaining issue.
17 Now in view of the fact that you wouldn't give me
18 much time to do this discussion, I thought it would be best
19 if I started with some general conclusions and not only
20 about the technical aspects of it, but about the process
21 itself because this is a process that may be new to you.
22 So on the next page I have some bullets on general
23 conclusions and the first is that this is an efficient
24 process. I think this eyeballing, this sitting down and
25 actually looking at data together or maps together is a very

1 efficient process which will lead to a much improved,
2 enhanced site recommendation analysis and license
3 application, if we reach that point.
4 The discussions are very open and far-ranging, but
5 they are very much focused on the technical issues.
6 Both the DOE and the NRC Staffs are well prepared
7 and bring a lot of ammunition in the form of backup
8 expertise with various individuals that have discipline
9 experience.
10 The NRC, and here I am speaking about the NRC and
11 the Center, has done a thorough job of identifying points of
12 concern in the DOE's AMR, the FEPS, and the TSPA. It is not
13 immediately obvious that there are any holes in this.
14 The NRC -- I know one of the things that this
15 committee has been concerned about and rightly so is is the
16 NRC overly conservative in their concerns.
17 That would not be my feeling at all, at least on
18 the basis of these two. That goes even to igneous, the
19 probability of an igneous event.
20 I don't think they have been overly conservative.
21 The fact of the matter is I think in some cases DOE has
22 been, if you will, somewhat conservative, and frankly if I
23 were in their shoes I would probably do the same thing,
24 because they are covering themselves from the standpoint of
25 uncertainties in data and inadequate knowledge of some of

1 the events and so some of their assumptions are overly
2 conservative and you can talk about that in many ways.
3 For example, the number of casks that are damaged,
4 the set-back distance and so forth -- these seems to be
5 pretty conservative.
6 There is a general concern that the NRC has about
7 better documentation and I mention that as a general point
8 because it is pervasive throughout the entire discussions
9 and if you look at their summary reports you will see that,
10 maybe not ad nauseam, but you will see that quite often.
11 The DOE screens the basis of 63 and this is on the
12 basis of the individual features, events and processes, the
13 FEPs, for a 10,000 year period, but one of the questions
14 that you have to ask, and this was brought up by the NRC at
15 the technical exchanges, well, what is the impact of these
16 FEPs in the period immediately following the time of
17 compliance.
18 You don't want in 10,001 for something
19 catastrophic to happen and the fact of the matter is I think
20 Congress has already stated their concerns about that.
21 It isn't clear that even though their TSPAs, DOE's
22 TSPAs are extended beyond 10,000 years that they are
23 considering the FEPs that may have an effect after 12,000
24 years. An example of that might global change.
25 I would suggest that this is something that this

1 committee or some oversight committee needs to be on the
2 alert for.
3 DR. HORNBERGER: Change meanings going to pluvial?
4 DR. HINZE: A change in the infiltration, a change
5 in the water table, you know, et cetera.
6 DR. HORNBERGER: We actually have included that in
7 there, the TSPA --
8 DR. GARRICK: Certainly included it in their TSPA
9 dose calculations.
10 DR. HINZE: You know, I think you are obviously
11 right but you want to worry about things that are going to
12 happen after that 10,000 year period of time after 10,001
13 and whatever.
14 The 63 gives them a very definite date on which to
15 exclude by. One part in 10,000 and 10,000 years, okay? --
16 and so if something happens after 10,002 it may be of
17 importance.
18 It is not clear, and this goes back to your
19 thoughts, Ray, that DOE is -- it is not clear, as I put it
20 here, it is not clear that DOE is adequately considering the
21 effect of coupling the events in the exclusion screening
22 process -- this one part in 10,000 and 10,000 years.
23 We also, as I mentioned yesterday, have to be
24 worried about these events which cross over that may have an
25 effect upon two different KTIs and get lost in the middle.

1 There is -- you hear a lot of people saying, well, that will
2 have to be taken up in engineering design, but somebody has
3 to make certain that that really is taken up in engineering
4 design and oftentimes these things are extremely critical.
5 A couple of other items in general. Staff of the
6 Center I think have contributed greatly to the NRC's
7 response to the DOE. I think they have done a great job.
8 There is also a need to maintain a continuing technical
9 expertise as these things evolve and we are not through
10 seeing the igneous activity, even though this committee
11 might like to say that that is true.
12 [Laughter.]
13 DR. HINZE: Well, I put myself in that category
14 too.
15 Something that I don't have listed down here but
16 which is in the summary of my igneous activity trip report,
17 and I don't know exactly how to say this but the
18 documentation before -- let me start over again.
19 I think it is very important that as this
20 committee feels that stakeholders, public perception, be on
21 the side of good science and good engineering at Yucca
22 Mountain and part of that is taking part in these technical
23 exchanges because you hear a lot and you do a lot.
24 The problem is that except for the core group in
25 NRC and the core group in DOE which have had numerous

1 communications and which have access to all the reports and
2 all that there is somewhat inadequate documentation both
3 before and after the meeting for the stakeholder, for the
4 advisory committees, et cetera, and I think that it would
5 make life a lot easier.
6 Let me just give you a case in point and this is
7 not throwing rocks at anyone but I received through Len's
8 good graces the PMR and the AMRs the day I was leaving for
9 the technical exchange. You can understand that these just
10 then became available. It is essentially impossible to go
11 into that meeting, sit in that meeting and be a
12 knowledgeable observer -- all right, I've said enough. I
13 think you understand.
14 DR. HORNBERGER: You had enough time subsequently
15 to digest the AMRs and PMR.
16 DR. HINZE: Merry Christmas -- and seriously, it
17 is --
18 DR. GARRICK: He is our token earth scientist.
19 DR. HINZE: The fact of the matter is I don't even
20 have a copy of the PSHA and my PVHA has been pulled apart
21 and I think to attend these kinds of meetings that it is
22 extremely important if you are going to get the most out of
23 them that you have to have this kind of documentation not
24 only in your hands but under your belt.
25 John or George, I don't know how much you want me

1 to go on with these --

2 DR. GARRICK: I figure we'll be here till 7:30 in

3 the morning.

4 Which conclusion are we on?

5 DR. HINZE: Well, we have gone through the general

6 conclusions.

7 Should I just hit a couple of high points? Maybe

8 I'll try to just hit a couple of high points.

9 DR. HORNBERGER: Before you do that, you know, I

10 just am interested in following up on what you just said,

11 and I take your point that those of us who do this on a very

12 part-time basis, it is extraordinarily hard to keep even a

13 tenth of the relevant details in our minds and therefore to

14 be nearly as well prepared as Staff.

15 Now I would ask you though -- our hope is that

16 nevertheless it was worth our while having you go there and

17 write this report for us because you are technically capable

18 enough to at least assess some of these general things,

19 what's going on and whether the process itself is working,

20 and be able to warn us if there are any red flags that

21 should be raised.

22 Are we wrong in assuming this?

23 DR. HINZE: I think that you get that from my trip

24 reports.

25 DR. GARRICK: Right.

1 DR. HINZE: That is what I carried forward. There
2 are general observations but there are also specific
3 observations. I mean we all have our technical expertises
4 and our special interests and, yes, I think that standing
5 back may be -- you know, sometimes too much knowledge gets
6 you into the woods -- and you really need to get back there,
7 and that is what this committee has always done, I think,
8 and will continue to do, but it is helpful to be as prepared
9 as possible and so that's my point.
10 DR. HORNBERGER: Right.
11 DR. HINZE: One of the more contentious issues
12 which has consumed a lot of this committee's time is -- that
13 is between the DOE and the NRC, is the probability of future
14 igneous activity.
15 That contentious nature of that was not really
16 subdued too much at the technical exchange. It is still
17 there. It's clearly still there.
18 The DOE has done the PVHA. They have come up with
19 basically 10 to the minus 8th per year based upon the ages,
20 the distribution, and typography of the area.
21 In contrast to that, as you will remember, the NRC
22 Staff with the work of the Center have come up with 10 to
23 the minus 7th to 10 to the minus 8th and they have included
24 the tectonic controls much more than did the experts in the
25 expert elicitation.

1 Frankly, I think the NRC Staff is right on target
2 here because there is ample evidence that there are some
3 controls on particularly the more recent volcanic activity
4 of the tectonism so I think that that has to be given a
5 great deal of credibility. I mentioned that in the report
6 and so forth.
7 I think the key thing is "so what" -- you know,
8 what is the difference between 10 to the minus 7th and 10 to
9 the minus 8th. We were very interested to hear that the DOE
10 indeed has done the TSPA going to 10 to the minus 7th as
11 well as 10 to the minus 8th. Basically they end up with
12 about six times greater peak dose for the 10 to the minus
13 7th over the 10 to the minus 8th, but this peak dose is
14 really quite minimal.
15 I think, if my notes are right, for the eruptive
16 event the peak dose calculation shows .03 millirems per year
17 and for the intrusive, 1.2 millirems per year and this is
18 for 10 to the minus 7th.
19 DR. HORNBERGER: That's within the compliance
20 period.
21 DR. HINZE: Yes, surely within the compliance.
22 DR. HORNBERGER: No, no, I mean that is for the
23 compliance period.
24 DR. HINZE: Yes, that's right, excuse me. That is
25 for the compliance period.

1 There is some difference here about whether
2 intrusion, extrusion is important, earlier or later than the
3 10,000. I don't really think that is a real argumentive
4 point, a problematic point, but the interesting thing is
5 here that the DOE says okay, you know, now that they have
6 run the TSPA as they follow through with their subsequent
7 TSPAs they will provide 10 to the minus 7th plus their base
8 case and that's great. That is the kind of cooperation we
9 want to see.
10 The other --
11 DR. HORNBERGER: By the way, Bill, I totally agree
12 with you and that is when John asked me the question
13 yesterday about igneous activity. He was, of course,
14 chuckling, when he asked me the question but my response was
15 at least partially serious, and that is that I really think
16 that it is a great example of issue resolution because the
17 Staff and DOE really came to an accommodation that seems to
18 me to give satisfaction to both sides.
19 DR. LARKINS: I am glad to see that you were at
20 least partially serious.
21 [Laughter.]
22 DR. HINZE: We didn't reach agreement on numbers
23 but we reached agreement on action. That's the beautiful
24 part about this.
25 One of the things that enters into this also is

1 this, is the buried igneous features and this gets into an
2 old problem of events and the USGS has flown to new aeromags
3 and I have given you copies or where to get that as an open
4 file if you are interested in looking at it. I don't
5 suggest you do because it is kind of arcane but you can't
6 get the figures off of the website -- at least I was unable
7 to -- but you can get them from the USGS.
8 The new survey has really not found any new
9 events. They found a new magnetic anomaly near Lathrup
10 Wells. It probably is a lava flow that is associated with
11 Lathrup Wells.
12 DR. STEINDLER: You realize the implication of
13 what Bill said? Regulation by adjudication, you average.
14 DR. HINZE: That is not the case at all --
15 [Laughter.]
16 DR. HINZE: And to establish that --
17 DR. HORNBERGER: You tried to stuff those words
18 right into us now.
19 [Laughter.]
20 DR. STEINDLER: I have been trying for years.
21 DR. HINZE: I'd point out that you are --
22 DR. STEINDLER: Wrong as usual.
23 DR. HINZE: -- maybe this one time in error.
24 I will ask you to direct yourself to the -- we are
25 moving rapidly here -- to the second to the last page under

1 Structural Deformation and Seismicity KTI agreement, the
2 faulting.
3 This was one of the more interesting -- the second
4 bullet under Faulting.
5 The second bullet under Faulting is perhaps one of
6 the more interesting aspects of the technical exchange.
7 That is that the DOE is using the median of the
8 hazard as predicted by the probabilistic seismic hazard
9 analysis. There are further details in the material of the
10 report plus this and this is the post-closure period.
11 NRC says wait a second, you know, you should be
12 using the mean like you are using in the pre-closure period,
13 and DOE says no, we should be using the median as we do in
14 the siting of nuclear power plants. That is what I am
15 getting to -- your average.
16 This I think remains a very controversial point
17 and it not only deals with the faulting subissue but it also
18 deals with the seismicity and the ground motion, not only
19 with the displacement but the ground motion associated with
20 the seismic events.
21 DR. HORNBERGER: When you say it is a big issue,
22 is it going to matter? Is it going to matter in the bottom
23 line?
24 DR. HINZE: We don't know that from the materials
25 presented.

1 I did not hear that but the problem, George, is
2 that there were an expert or two that were way out on the
3 tail, way out on the tail, and as a result the median falls
4 beyond the 85th percentile, and so all of a sudden you're
5 bumping way over here and DOE says what we are doing is just
6 following the normal routine of the NRC and using the
7 median.
8 DR. GARRICK: The mean. The NRC uses a mean.
9 DR. HINZE: Well, as I understand it in the siting
10 of nuclear power plants that they use the median and this is
11 according to Carl Stepp, and I have not looked up the
12 regulation but Carl, you know, lived with these things
13 longer than I have.
14 In any event, as I say here, they have agreed and
15 I have abbreviated this, the longer expression of this is in
16 your report, document technical justification for the use of
17 the median or use of the mean or use of some other
18 statistical measure that you justify -- but this is one that
19 we should keep our eyes on very clearly because it may, it
20 really may have an effect.
21 Related to this, and I thought this may be of
22 interest to the committee because of your long-term interest
23 in expert elicitation, is that -- and it is the first bullet
24 under Seismicity in this --
25 DR. GARRICK: Bell, before you get on to that, do

1 you recall what they said the difference was between the
2 mean and the median?
3 DR. HINZE: No, No, and I don't -- it's not that I
4 don't recall. It's the fact that it wasn't given.
5 DR. GARRICK: I see, because if they have a median
6 they certainly have a mean.
7 DR. HINZE: There is a range of about 10 to the
8 minus 5th to 10 to the minus 8th for the post-closure
9 period.
10 DR. GARRICK: Yes, so if it is highly skewed then
11 the mean may be anywhere from two to ten times the median.
12 DR. HINZE: Yes, exactly.
13 DR. GARRICK: And --
14 DR. STEINDLER: That's what Bill is saying.
15 DR. HINZE: That is what I am saying. The median
16 is way out there.
17 DR. GARRICK: Of course the other thing that often
18 means, if that is as a direct result of an elicitation
19 process, that there's some inconsistencies in the
20 implementation of the elicitation activity.
21 DR. HINZE: Once again, you are right on target,
22 sir. That is the point that I was just bringing up here.
23 That is, the NRC has asked the DOE to document the feedback
24 to the subject matter experts following the elicitation of
25 their respective judgments.

1 This is to see what kind -- I have gone through
2 the elicitation process with the Eastern Seismicity and I
3 know once you give your results then all the calculations
4 are made and they you are faced with comparing your results
5 with what everyone else has done and why are you such an
6 outlier and so the NRC has appropriately asked that they
7 want feedback on what feedback was given to the subject
8 matter experts.
9 Now what DOE claims and I suspect correctly so is
10 that they followed 1563, the Branch Technical Position.
11 DR. GARRICK: Right.
12 DR. HINZE: And recalling from my own days of
13 going through this with the same group, you know, there was
14 a pretty fair discussion of that, but nonetheless that is
15 something to be -- it is the first time we have seen even a
16 question of a chink in the armor of the PSHA or the PVHA,
17 and so this would be an interesting one to keep very close
18 tabs on.
19 DR. HORNBERGER: I am still curious about your
20 assessment, because you started out talking about Little
21 Skull Mountain and looking for white chips of paint, and not
22 finding any, all right? -- and my question to you as an
23 expert, post-closure is seismicity a big issue?
24 DR. HINZE: No.
25 DR. HORNBERGER: Thank you. I thought I was

1 missing something.

2 DR. HINZE: No, but to me I don't think based upon
3 what I know of the issue that it is going to be a major
4 problem.

5 DR. HORNBERGER: Okay.

6 DR. HINZE: But we have to follow the rules and
7 standards.

8 DR. HORNBERGER: No, no, I agree, and I think that
9 the NRC Staff is absolutely correct for asking for
10 clarification and what-not, but I am just curious from our
11 standpoint if we look at risk as the bottom line, yes, we
12 should keep tabs on this but it is probably not going to be
13 a big red flag for us.

14 DR. LARKINS: Just for your information, this is a
15 reoccurring issue, even in the reactor side. We are looking
16 at the risk of spent fuel pool accidents, particularly spent
17 fuel pool fires and those are dominated by the seismic
18 events.

19 In trying to reconcile it, the Staff was looking
20 at the Livermore curves versus EPRI curves, which are about
21 a factor of 10 difference, and what they ended up doing --
22 they couldn't reconcile the difference -- was to do the
23 analysis, the risk assessment using both sets of curves and
24 in saying where they lay in terms of the safety goal, but
25 the expert elicitation process, if you are familiar with it,

1 was slightly skewed in one case versus another case.

2 DR. HINZE: I think there are some critical

3 elements going on here in the igneous activity and the SDS

4 and I think you ought to track them. I think they are

5 important.

6 I think the word on the street now is that the

7 most critical, from the standpoint of dose in the first

8 10,000 years, is the igneous activity and that is even with

9 the -- that is both with 10 to the minus 7 and 10 to the

10 minus 8. I think it is important to follow up.

11 DR. HORNBERGER: What is your assessment on the

12 open issue, the open issue having to do with dispersal?

13 DR. HINZE: That is a good point, George.

14 The DOE has assumed that the intrusion comes up,

15 it hits a cask -- a cask, because generally the orifices are

16 relatively small, a meteor -- and it hits a cask and then

17 they have arbitrarily selected, and I say arbitrarily

18 because I didn't hear any evidence -- that three casks on

19 either side in that drift are destroyed and the lids are

20 taken off from all of the so-called Zone 2, taken off all of

21 the rest of the casks.

22 It is rather -- it looked very arbitrary. There

23 needs to be a real documentation of the thermal, the nature

24 of the thermal event, the mechanical and also the shock

25 effect because if that magma comes up there's going to be a

1 quite disastrous shock and so we have the mechanical effects
2 of the magma on the shock wave as well as the thermal.
3 The other aspect of that is that the NRC, and I
4 think the NRC is right here again, is that the NRC states
5 that any intrusion that reaches the drift will also have an
6 explosion, an eruptive event, violent strombolian, okay?
7 I think that is very reasonable because that will
8 come up and the pressure differential will lift that
9 thousand feet, you know -- it will work its way up.
10 The DOE, in contrast to that, says no, that they
11 have these two separate events.
12 DR. HORNBERGER: Two separate events, right.
13 DR. HINZE: Right.
14 DR. HORNBERGER: Actually I thought that the NRC
15 Staff had agreed on separate analyses for the intrusion and
16 for the exposure.
17 DR. HINZE: Yes, they do, but they think they are
18 going to have both when they have an intrusion event.
19 DR. HORNBERGER: I see. You know, the only thing
20 that bothered me in looking at it fairly recently is that
21 the concern now, and I think it is a concern, is once you
22 get the ash plume out there, and Staff is now pretty happy
23 with the way DOE is doing the modeling of the ash plume
24 because they are basically taking the lead from NRC, but the
25 real question then is okay, this stuff gets out on the

1 ground.

2 Now a big issue is redistribution, post-eruption

3 redistribution, and we don't know how the hell to do that.

4 DR. HINZE: You know, this is discussed in the

5 report, my report, and --

6 DR. HORNBERGER: I know. I read your report, by

7 the way, and it was a good report.

8 DR. HINZE: It really worried me because, you

9 know, one of the real features of the Amargosa Desert are

10 the sand dunes.

11 DR. HORNBERGER: That is correct.

12 DR. HINZE: And that stuff is going to move, to

13 say nothing of the working of the soil. That is to enter

14 into it as well.

15 DR. HORNBERGER: Whatever happens there.

16 DR. HINZE: And I really -- the modeling is all

17 done with this ash plume, which is the Suzuki model, which

18 is strictly an empirical model.

19 I would feel much happier about it if we could go

20 back to first principles, mechanics and thermal, and have a

21 ash plume model that was based upon first principles rather

22 than empirical fitting.

23 It occurred to me that back in another world I

24 used to be involved in, cratering, in fact out at NTS, and

25 those days, which was long ago, we were working on models

1 for cratering and they were pretty primitive --

2 DR. HORNBERGER: Yes, but you were using modeling

3 clay, right?

4 [Laughter.]

5 DR. HINZE: The fact of the matter, I tested my

6 models in the sandbox, but that is another story -- out at

7 Fort Belvoir -- but it occurred to me that there probably

8 should be some pretty good models out of the cratering

9 people, and I know from the work that I was involved with

10 back in those days that we went back to first principles.

11 I mean we checked it but we really tried to do it

12 on a first principle basis, and I think that it would be

13 worthwhile for the -- for someone to look into that.

14 I think I would have a much better feeling about

15 it.

16 You know, along that same line, we can talk a lot

17 about this, but one of the concerns is the speed of the wind

18 and the direction of the wind, because currently the DOE is

19 cutting off their plume at 3.8 kilometers, which is low for

20 a violent strombolian, which may be conservative but we

21 should push that to a higher elevation, which means a higher

22 velocity and if you go to a higher velocity in the Southern

23 Nevada area you know what happens. You know that from the

24 radioactive spread from some of the vented nuclear weapon

25 features. It goes east.

1 So there is more work to be done in looking at
2 that whole biosphere issue including the remobilization.
3 I was really proud of the NRC and its Staff in
4 looking at these things.
5 DR. LARKINS: Bill, can I ask you a quick
6 question?
7 I notice on here you say "Address NRC concerns
8 with the assumption that inhalation of 10 to 100 micron
9 range particles is treated as additional" -- so ingestion --
10 DR. HINZE: The health physicist -- my
11 recollection of that, John -- is the health physicist from
12 the Center brought that issue up and felt that it could lead
13 to underestimation of the dose, which therefore really has
14 to be looked at.
15 There are a number of things in the mass loading,
16 in this --
17 DR. LARKINS: I was going to say there's a lot of
18 information available on the inhalation of aerosols in the
19 particle size range.
20 DR. HINZE: My guess is that it would be helpful
21 if DOE had a better connect with NRC on this and I think
22 that this agreement really spells that out.
23 DR. STEINDLER: Did you see any interest in the
24 chemistry of resuspension?
25 DR. HINZE: Resuspension?

1 DR. STEINDLER: Yes -- junk gets down through the
2 chemistry of transport to the water table, et cetera.
3 You have a lot of stuff -- lay it down -- then
4 what? The issue is not entirely due to inhalation.
5 DR. HINZE: That's right and that is one of the
6 things that the NRC asked for was there's concern about not
7 only the inhalation but also drilling down and using the
8 water that has gone down. Yes. That is part of it.
9 I think you want me to shut up.
10 DR. GARRICK: Well, no. This has been very
11 valuable.
12 DR. HINZE: But yes?
13 [Laughter.]
14 DR. GARRICK: There's a lot of issues with this
15 that I have struggled with, especially the igneous
16 probabilities.
17 The approach of separating the consequence from
18 the likelihood was very foreign to me as a practitioner of
19 risk assessment on the basis that the probability is very
20 much dependent upon the end state and the end state is a
21 variable and the end state is a consequence.
22 The justification for that seems to be that if you
23 get a partial intersection it is about the same as a total
24 intersection and so the variability that usually exists in
25 catastrophic events doesn't exist in this one, so that has

1 been the simple explanation.

2 DR. HINZE: Good point.

3 DR. GARRICK: And also the issue you bring up

4 about the median and the mean, that is a traditional one. I

5 thought it had been resolved.

6 If you really believe in uncertainty and you want

7 the central tendency parameter that best represents

8 uncertainty it has to be the mean, and so I am surprised

9 that there is a debate over that.

10 DR. STEINDLER: Well, isn't there always the

11 question of skewed distribution?

12 DR. GARRICK: When you calculate a mean, you

13 utilize the -- you calculate an expected value and that

14 expected value calculation embraces all of the

15 probabilities.

16 DR. STEINDLER: But for a skewed distribution --

17 DR. GARRICK: Well, yes -- but if the skewed

18 distribution is in fact as a result of a consistent

19 interpretation of the evidence.

20 DR. STEINDLER: Yes. That is the issue, precisely

21 the issue.

22 DR. GARRICK: And if it is not -- and that's where

23 I don't think it is, and so I would agree with you if

24 there's some high level of suspect on the distribution, but

25 that is not something we are going to --

1 DR. HINZE: One of the real problems there is that
2 the DOE is using the mean in the preclosure and the median
3 in the postclosure. You know, that smells like a day-old
4 fish.
5 I mean certainly the NRC's requests here --
6 DR. HORNBERGER: If they are doing it. If that's
7 correct then I would argue that at least they are doing it
8 the right way, because the mean will be conservative and
9 preclosure is when seismicity probably is important and you
10 probably want to be conservative and postclosure is probably
11 who cares.
12 DR. HINZE: Achh -- you can buy me a drink.
13 [Laughter.]
14 DR. GARRICK: That's very good, Bill, and very
15 helpful and your reports are comprehensive and enjoyable to
16 read. Okay.
17 Let's see -- Ray, do you want to make a few brief
18 comments about the decommissioning conference?
19 DR. WYMER: I can be very brief.
20 DR. HINZE: Excuse me. There was a good old guy
21 and he made copies of the attachments for this last report
22 on the SDS.
23 DR. GARRICK: Oh, good.
24 DR. HINZE: So these are for you. They are the
25 attachments and your quiz will be --

1 DR. GARRICK: Oh, my --

2 DR. HINZE: Seriously, there's a lot of

3 boilerplate in there but there's a lot of goodies too and

4 flick through them, okay?

5 MR. LARSON: You are getting even with us for the

6 PMRs.

7 [Laughter.]

8 DR. HINZE: Yes.

9 DR. GARRICK: Okay, Ray, and then we will take an

10 overdue break again.

11 [Whereupon, at 3:25 p.m., the recorded portion of

12 the meeting was recessed, to reconvene at 8:30 a.m.,

13 Thursday, October 19, 2000.]

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REPORTER'S CERTIFICATE

This is to certify that the attached proceedings before the United States Nuclear Regulatory Commission in the matter of:

NAME OF PROCEEDING: 122TH ADVISORY COMMITTEE ON NUCLEAR WASTE

PLACE OF PROCEEDING: ROCKVILLE, MD

were held as herein appears, and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission taken by me and thereafter reduced to typewriting by me or under the direction of the court reporting company, and that the transcript is a true and accurate record of the foregoing proceedings.

Mark Mahoney

Mark Mahoney
Official Reporter
Ann Riley & Associates, Ltd.

# YUCCA MOUNTAIN NATURAL LEAD AND MERCURY VALUES: THE NEAR-FIELD REPOSITORY ENVIRONMENT WITH RESPECT TO ALLOY C-22

**Maury Morgenstein and Don Shettel**
**Geosciences Management Institute, Inc.**

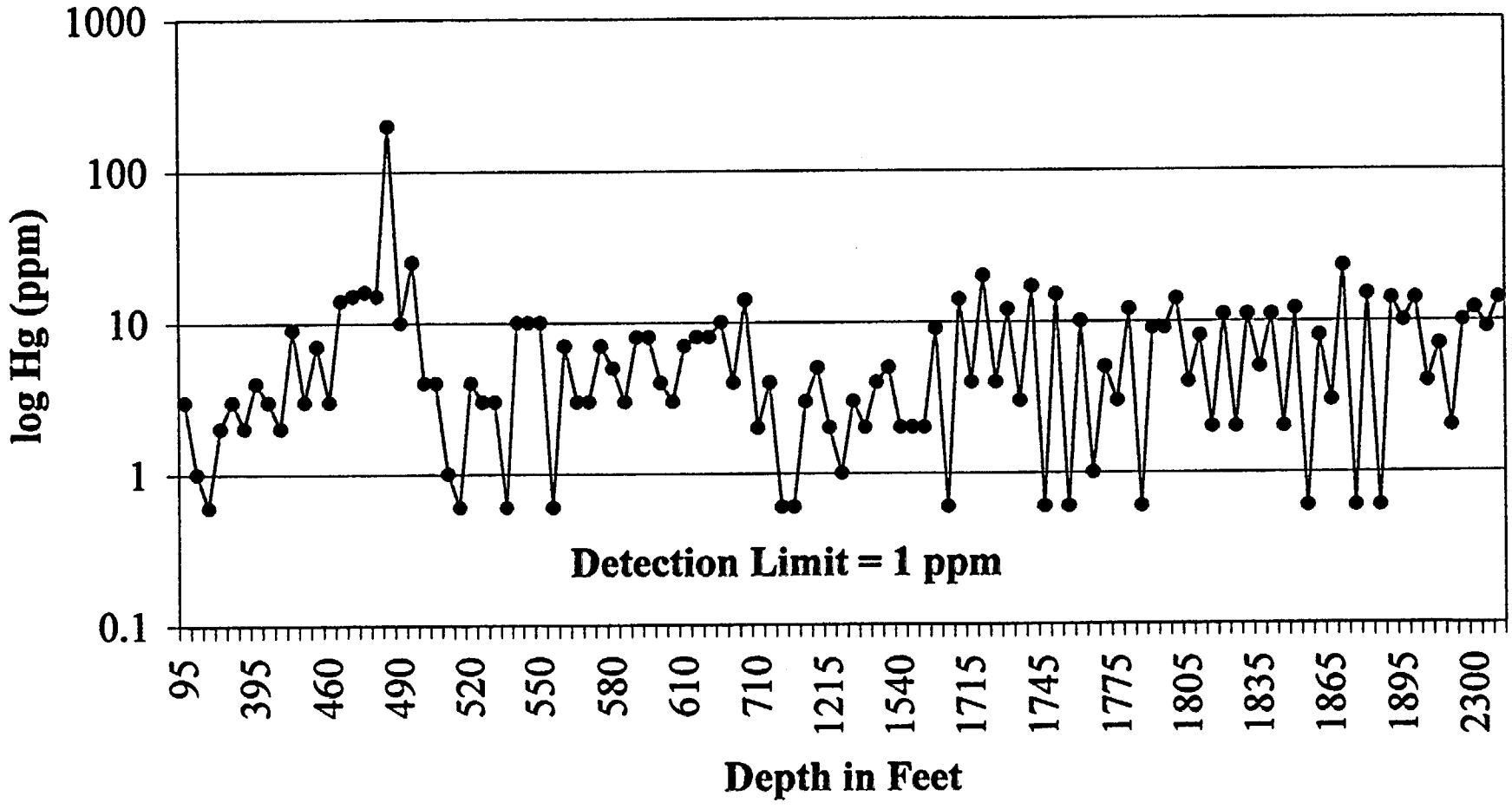
The issue:

Lead and mercury concentrations in the near-field

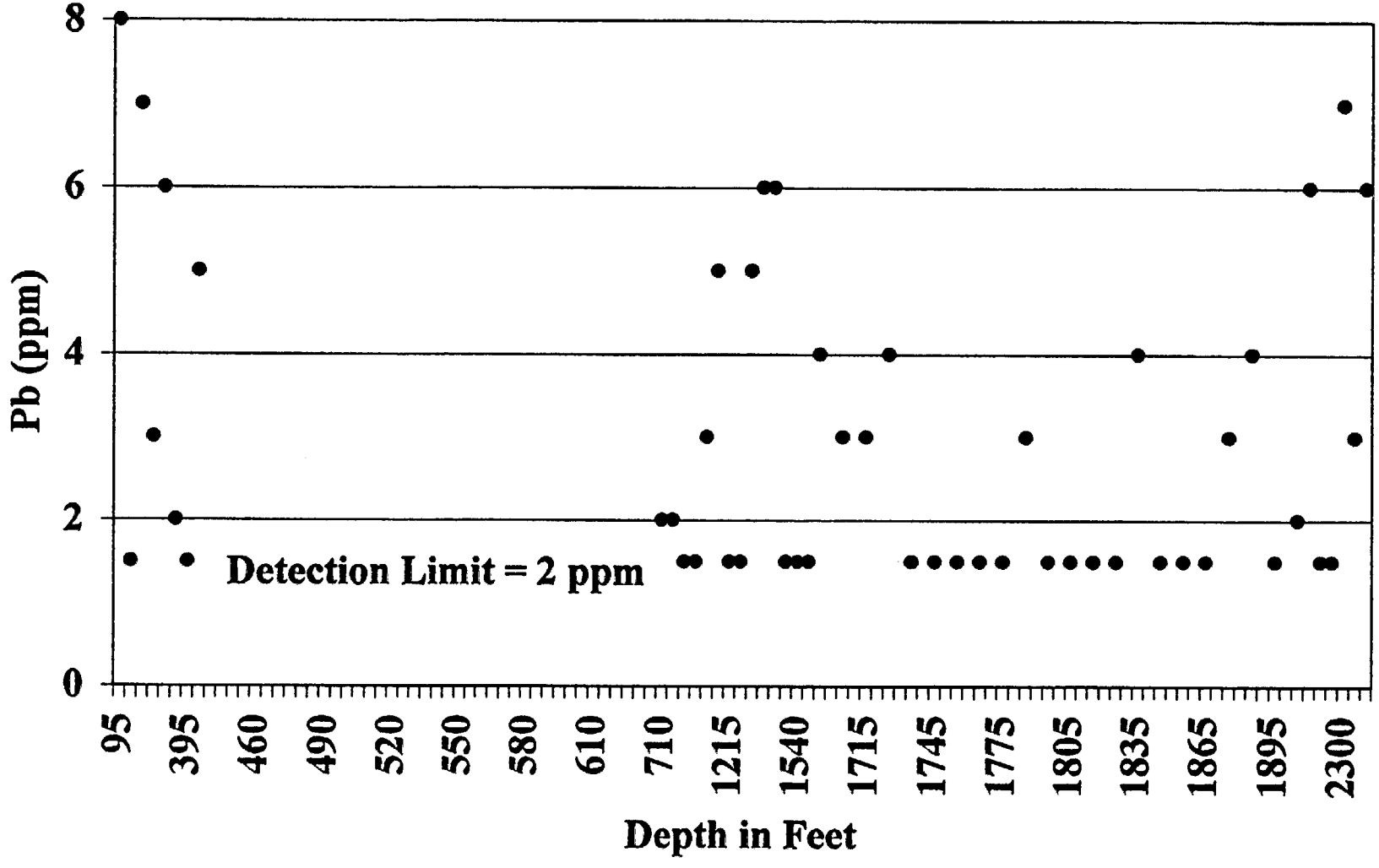
We present concentrations of lead and mercury in:

- Fault and fracture system diagenetic carbonate and silicate precipitates that are a function of meteoric down-fluxed water in the vadose zone (e.g. Trench 14);
- Yucca Mountain hydrogeochemistry; and
- Yucca Mountain tuffs and sediments (pyritic and non-pyritic).

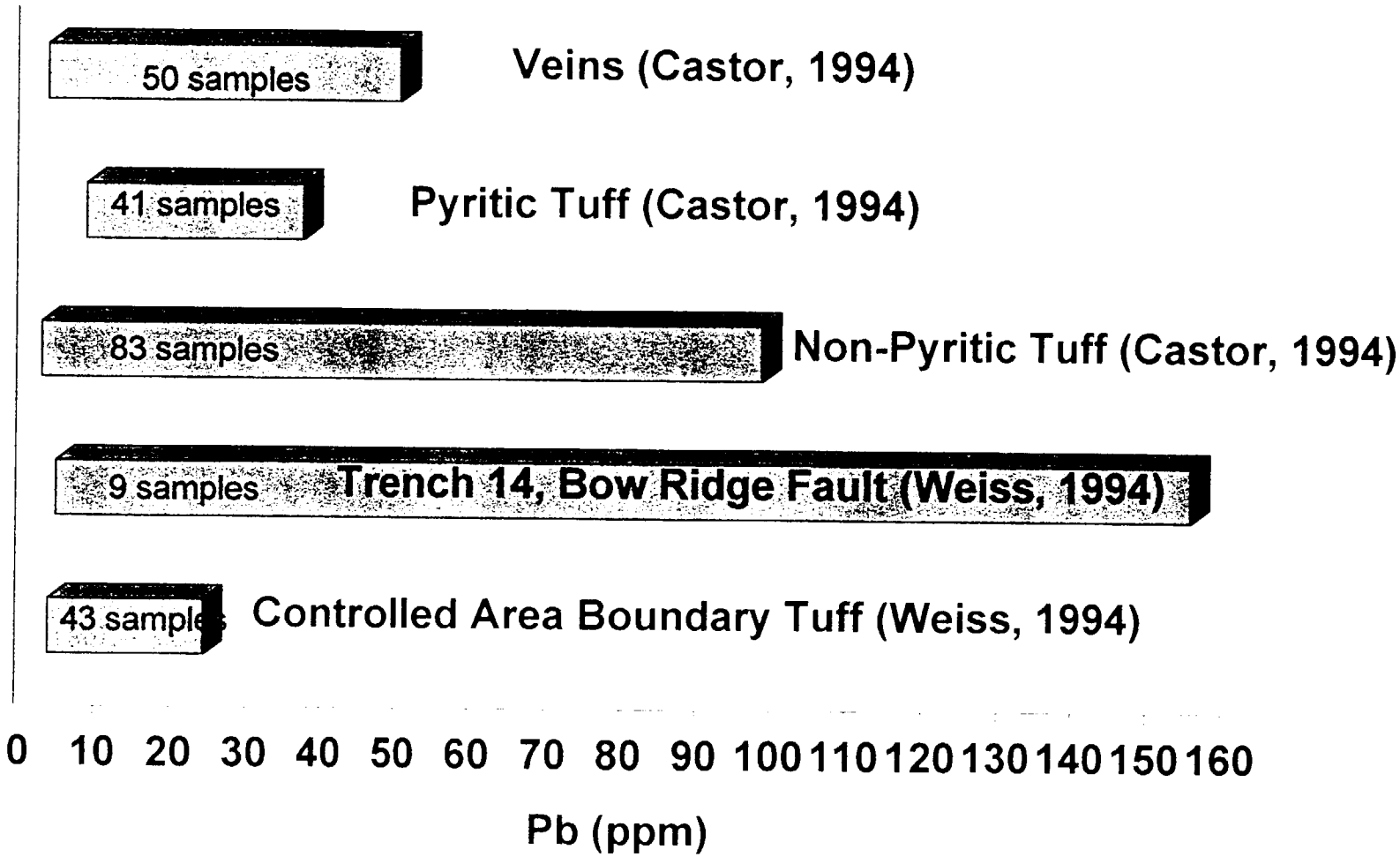
# NC-EWDP-3D Mercury with Depth by Neutron Activation Analysis



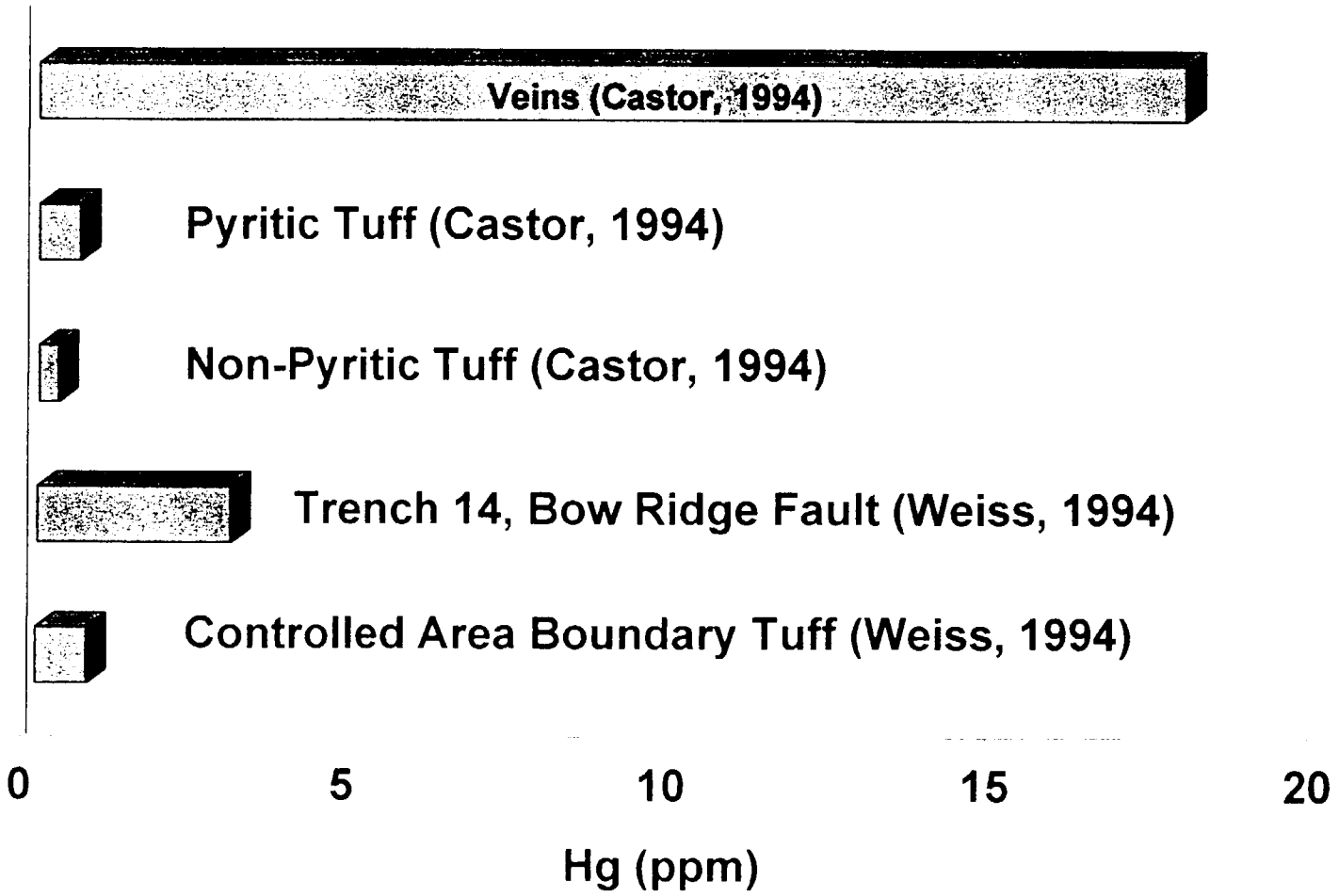
# NC-EWDP-3D Lead with Depth by Inductively Coupled Plasma (ICP)



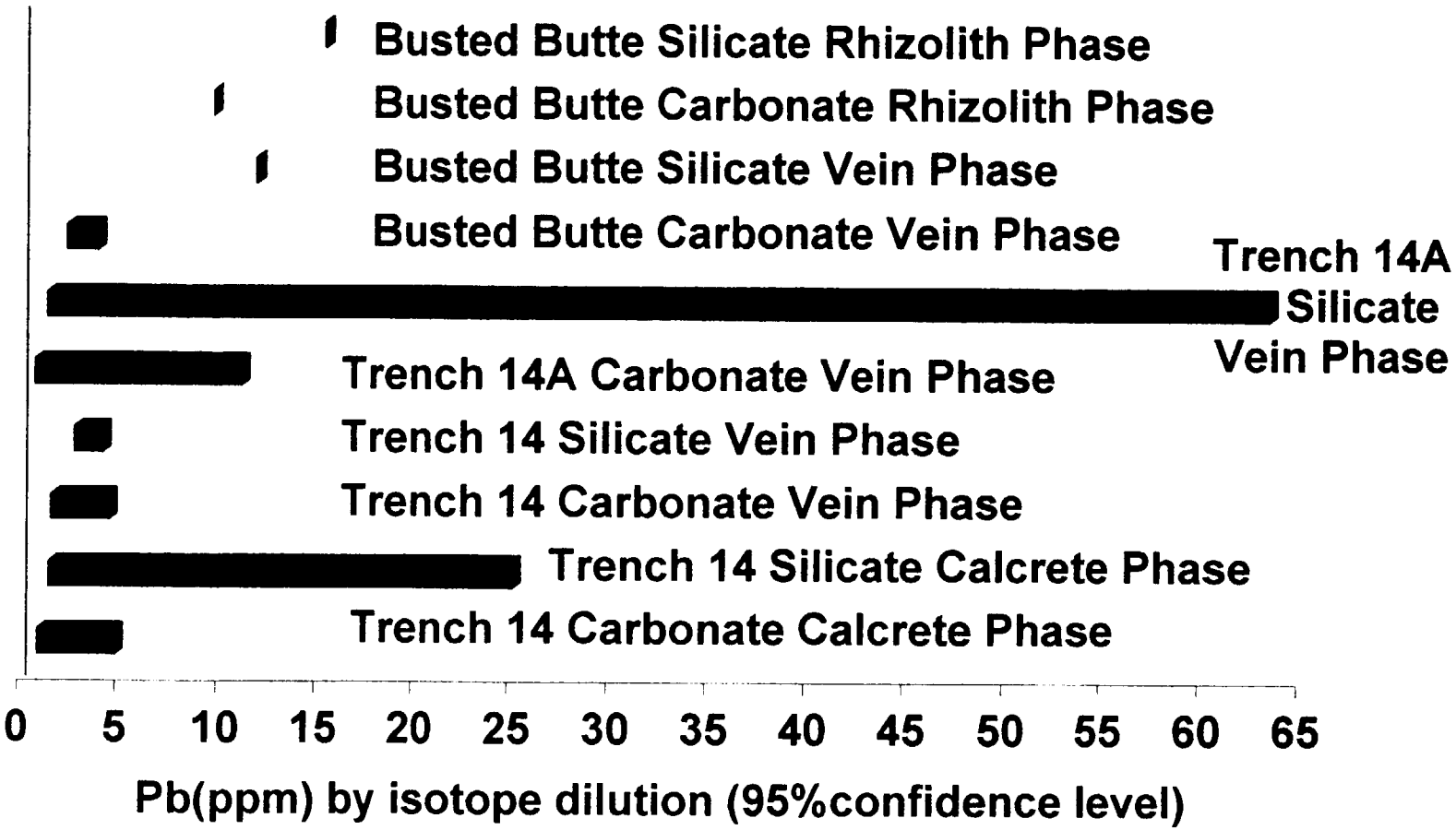
# Tuff and Vein Filling Lead Concentrations, Yucca Mountain



# Tuff and Vein Filling Mercury Concentrations, Yucca Mountain



# Lead Concentrations from Carbonate-Silicate Veins, Calcrete and Rhizoliths , Data from: Zartman and Kwak (USGS:OFR-93-690)



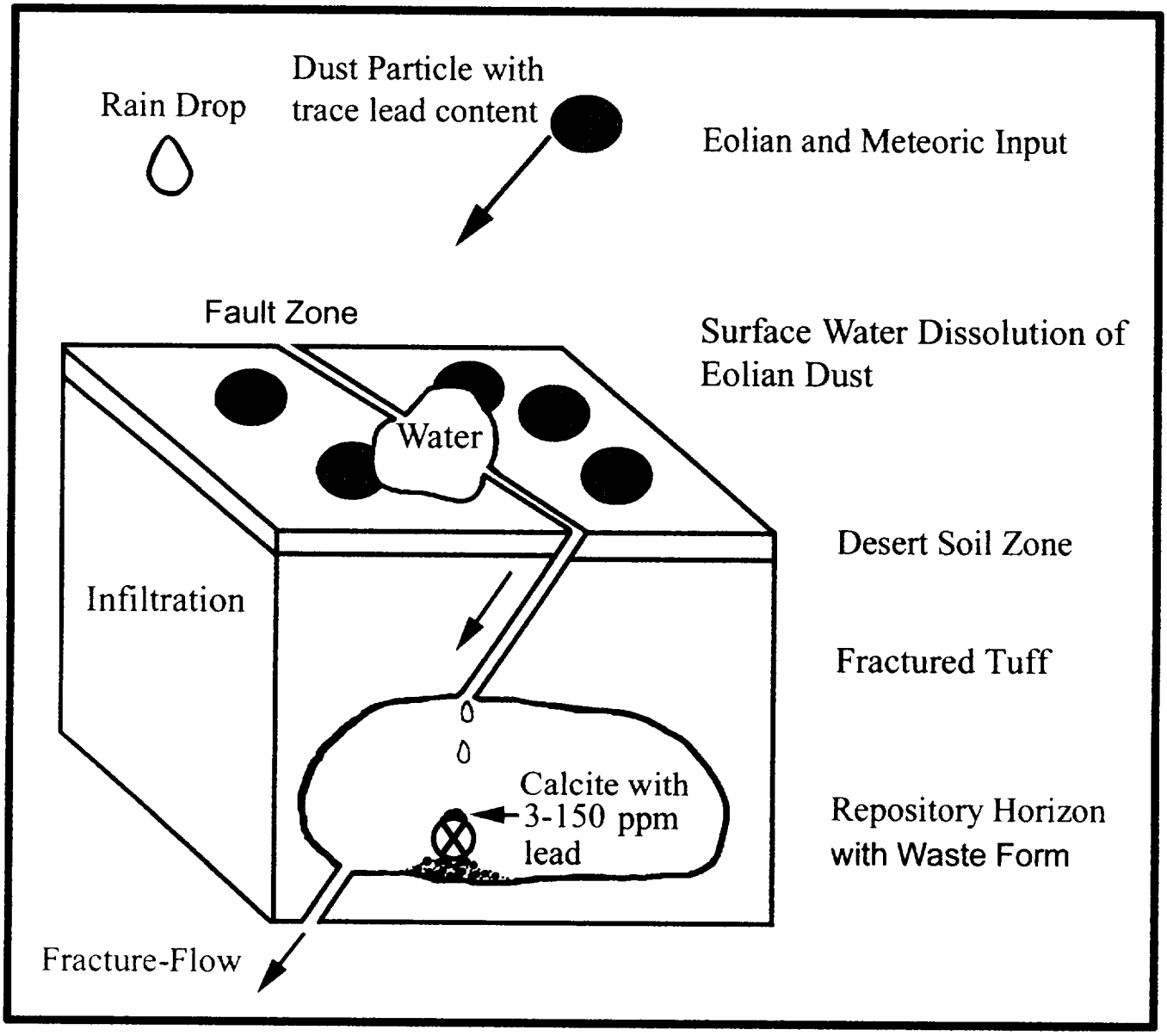
## A Regional Vadose Water Lead Signal

Zartman and Kwak (USGS-OFR-93-690) conclude from lead isotope studies that:

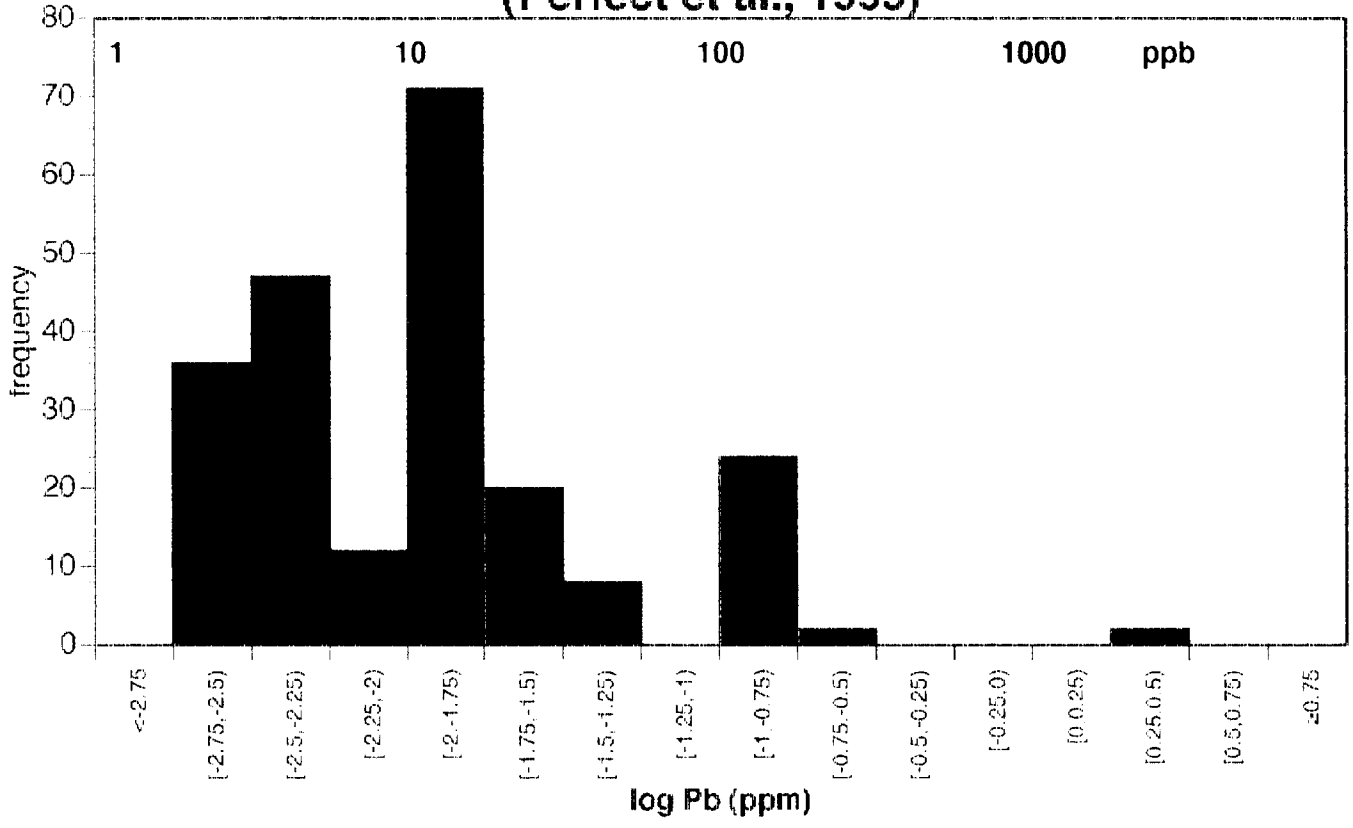
> "Because the lead isotope field defined by the vein material are virtually identical to those of soil calcrete, one need not look any further to explain the observed lead isotope data." page 10
>
> **Trench 14 and other similar carbonate and silicate vein fillings are precipitates from meteoric water.**
>
> "The ultimate source of this radiogenic lead is as yet unknown, but it may accompany an eolian contribution to the soils derived from exposed Paleozoic and Late Proterozoic carbonate rocks in surrounding mountains." page 9

These conclusions suggest that there is a regional background signal for lead values due to an eolian lead contribution to the soil horizon. With meteoric water dissolution of the regional eolian dust at the ground surface, the resultant vadose water background lead signal may be similar at most fault zones (e.g. the Bow Ridge and the Ghost Dance Faults). Transmissive fault and fracture structures supporting vadose zone infiltration to the repository horizon contains this regional $Pb_3(CO_3)_2(OH)_2$ lead fingerprint.

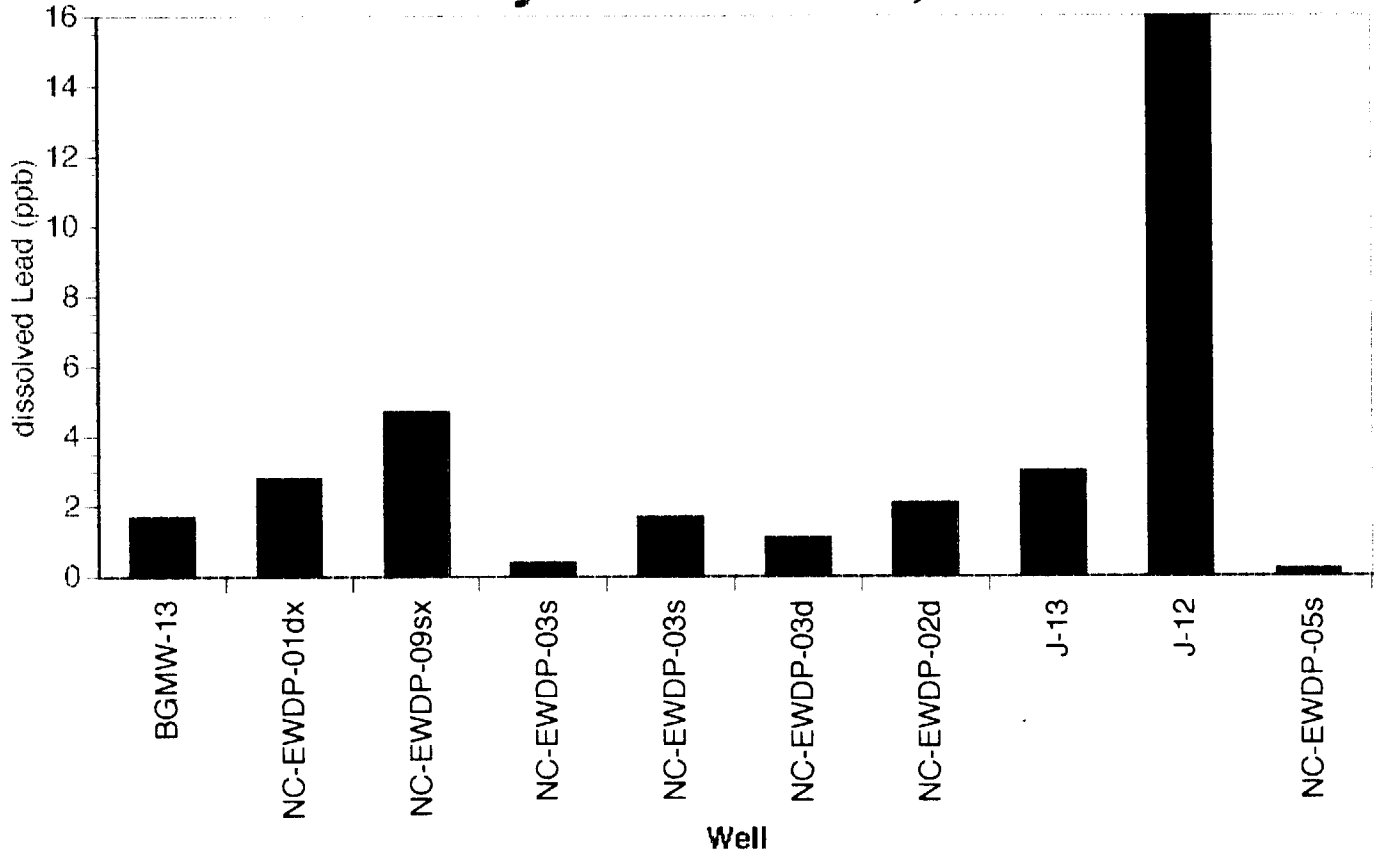
# A Regional Eolian and Meteoric Lead Signal at the Yucca Mountain Area, Nevada



# Dissolved Lead Values Around Yucca Mountain
## (Perfect et al., 1995)



# Dissolved Lead Concentrations in Immediate Vicinity of Yucca Mt., Nevada




GMII

# Dissolved Mercury Concentrations (near Yucca Mt., Nevada)

- Castor et al.: 1 value => 0.5 ppb, location unknown.
- Perfect et al. Database: less than 100 values, all zero.

CONCLUSION: site characterization incomplete & unfinished.

# Digression on Use of J-13 Water

- Currently J-13 is reference water for all experiments for Yucca Mt.
- No dripping fractures sampled in ESF that would represent vadose zone water
- Worse, experiments use synthetic J-13 (only major cations + anions), no minor or trace elements considered.

CONCLUSIONS:

- Site Characterization incomplete & unfinished
- Experiments missing important component
- Realistic aqueous environments not considered in experiments

## REFERENCES for Whole Rock Values:

Castor, et al., 1994. Pyritic Ash-Flow Tuff, Yucca Mountain, Nevada. *Econ. Geol.*, v.89, p. 401-407.

Morgenstein, M., in prep. Quaternary Epithermal Uranium Silicate and Trace Element Sulfide Mineralization in Tertiary Tuffs and Sediments from Drill Hole NC-EWDP-3D. *Environmental & Engineer. Geosci.* (Stellavato Memorial Vol.).

Weiss, et al., 1994. Evaluation of Mineral Resource Potential, Caldera Geology, and Volcano-Tectonic Framework at and near Yucca Mountain. Part II, Major and Trace-element Geochemical Data. *Econ. Geol.*, v. 90, pages 2081-2090.

Zartman, R.E. and L. M. Kwak, Preliminary study of lead isotopes in the carbonate-silica veins of Trench 14, Yucca Mountain, Nevada. *USGS-OFR 93-690*, p. 1-18.

## REFERENCES for Aqueous Values:

Castor, et al., 1996. Volcanic Rock-Hosted Uranium Deposits in Northwestern Nevada and Southeastern Oregon – Possible Sites for Studies of Natural Analogues for the Potential High-Level Nuclear Waste Repository at Yucca Mountain, Nevada, *NBMG-OFR 96-3*, p. 1-81.

Perfect et al., 1995. Hydrochemical Data Base for the Death Valley Region, California and Nevada. *USGS OFR 94-305.*

Shettel, D.L., in prep. Saturated Zone Hydrogeochemistry of the Early Warning Drilling Program, Nye County, Nevada. *Environmental & Engineer. Geosci.* (Stellavato Memorial Vol.).

# Bases for Prediction of Performance of C-22 and Titanium Grade 7 and Paradigms

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Meeting of ACNW-NRC
Rockwell Maryland

00-10-17 to 19

# Topics

1. Not a critique of AMR (Analysis and Modeling Report) nor PMR (Process Model Report).

2. Mainly, a review of framework for prediction of performance as applied to C-22 and Ti Gr7.

3. Identification of special concerns for storage of radioactive waste.

4. Use of paradigms from commercial nuclear power development

5. Framework of "corrosion based design approach" (CBDA) applied to performance and application of C-22 and Ti Gr7

# Conclusions about the Use of C-22 and Titanium for Yucca Mountain Application

1. Substantially inadequate knowledge about the conditions under which either C-22 or Ti-Gr 7 sustains SCC.

2. No corrosion testing of real environment on surfaces of engineering significance (heated surfaces with Yucca Mountain chemistries).

3. It is doubtful that any testing under isothermal conditions is substantively useful.

4. Residual stresses on general surfaces of as-fabricated containers are not known and are likely to be adequate for SCC.

5. Global heat treatments necessary to reduce surface stresses may accelerate corrosion.

6. No evaluation of manufactured prototypes.

7. No prototype system for judging real environmental and corrosion systems.

8. The development of materials and designs for the Yucca Mountain application could benefit substantially from considering the lessons to be learned from the development and application of commercial nuclear power.

9. Lack of early prediction of presence of water raises questions about other predictions.

# Need

1. Corrosion testing methods for realistically heated surfaces.

2. Consideration of full set of Yucca Mountain chemistries accessible to heated surface

3. SCC mode diagrams for C-22 and Ti Gr7

4. Assessment of stresses over whole surface

5. Manufacturing prototypes

6. System prototype where large system of environmental effects on movement of species can be assessed.

# Special Concerns

1. Long term performance objective without capacity for intermediate inspection.

2. Initial assumption of dry and now wet.

3. Lack of prototype for testing of environment-material interactions

4. Lack of manufactured prototype

5. Lack of perspective on performance of C-22; assumption of "corrosion resistant alloy"

6. Lack of perspective on performance of Ti-Gr7

7. Lack of appreciation for hot surface on container.

8. Lack of definition of chemical environment; Focus on J 13 well water as environment

9. Necessity to use "Guilty until proven innocent approach" -- opposite of justice

10. Metals are chemicals: surprise is not that they fail--surprise is that they work

# Paradigms from Commercial Nuclear Program

1. Enormous resources spent on SARs (Safety analysis reports) and ignore resources to prevent corrosion-related performance problems.

2. Large focus on magical alloy, Alloy 600, with little supporting data.

3. Dependence on "well established material" (Type 304) when large data base on deleterious effects of sensitization were well known.

4. Lack of environmental definition, especially in heat transfer crevices and oxidizing conditions.

5. Assumption that fossil water chemistries were applicable.

6. Selection of basis for assuring life prediction: 40 year fatigue life

7. Failure of fuel elements from inside: iodine SCC

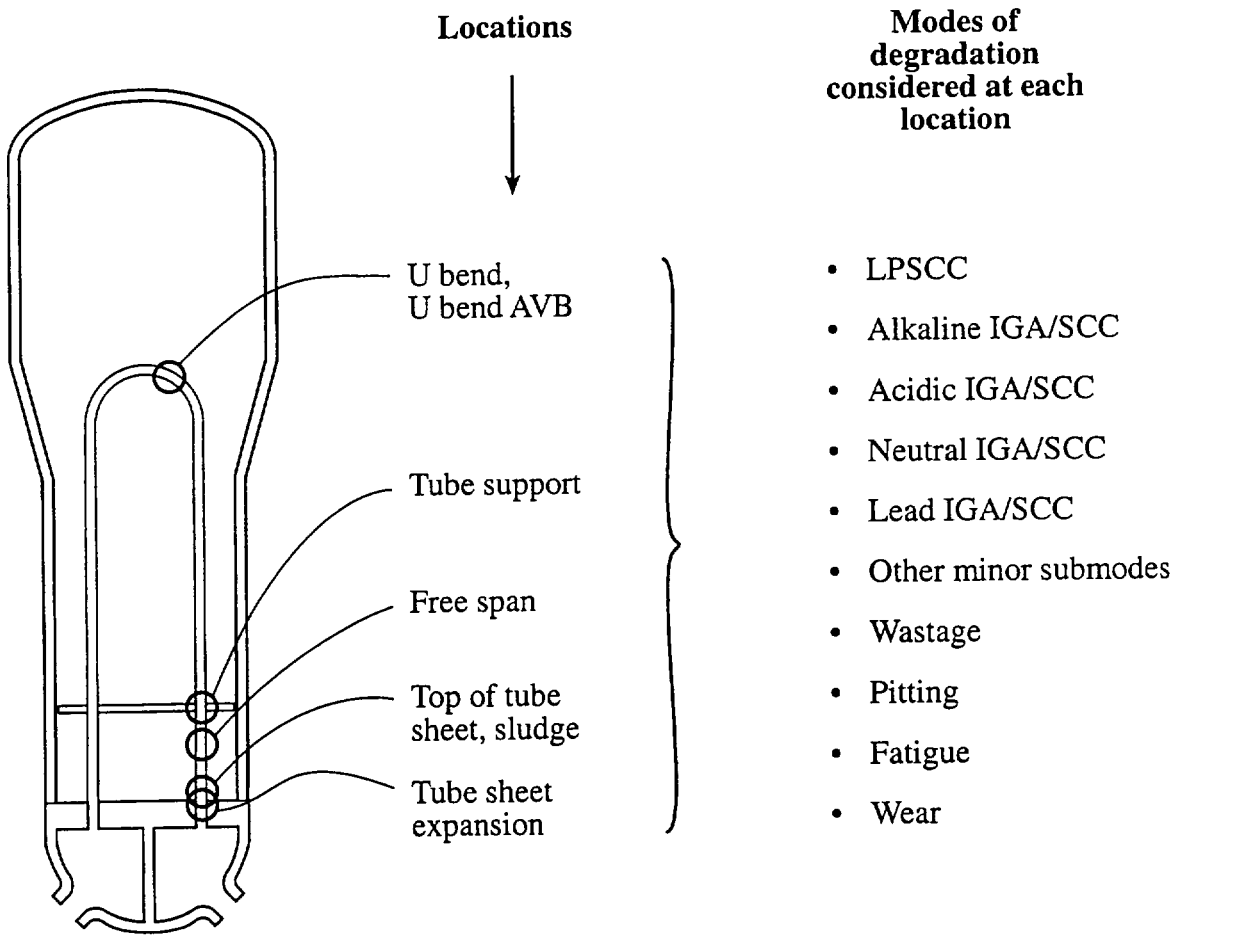
8. Decisions in a hurry (for sales) prevent orderly considerations of performance

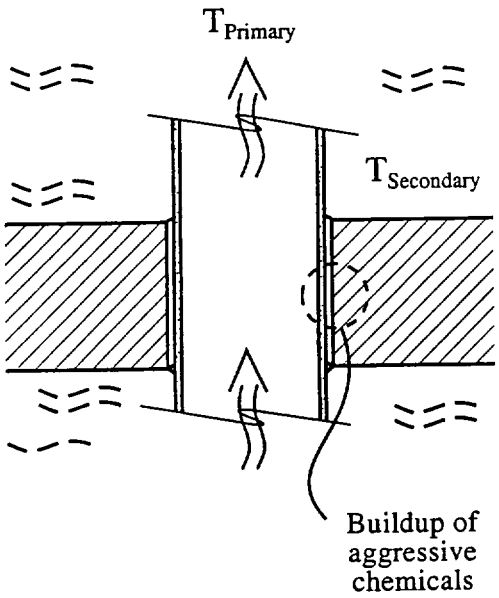
9. Use of model boilers and prototypes valuable (although never taken far enough)

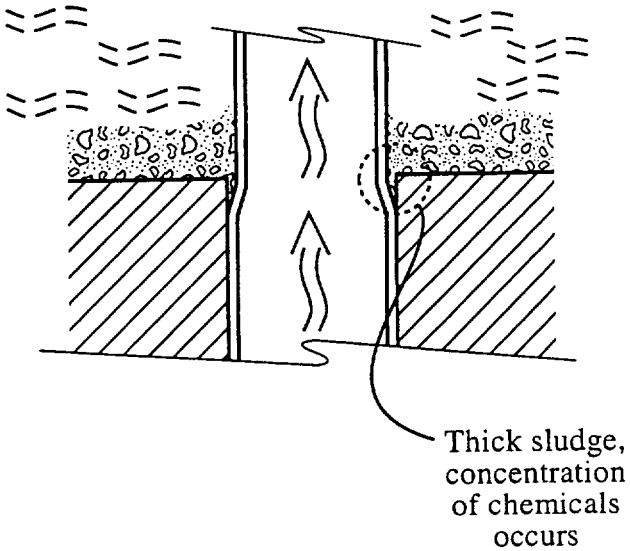
10. Global stress relief increases sensitivity to other SCC

11. Residual stresses in as-fabricated and non-welded locations produce SCC

12. Large differences in corrosion produced by slight changes in metallurgical structure


Locations
Modes of degradation considered at each location
U bend,
U bend AVB
Tube support
Free span
Top of tube sheet, sludge
Tube sheet expansion
• LPSCC
• Alkaline IGA/SCC
• Acidic IGA/SCC
• Neutral IGA/SCC
• Lead IGA/SCC
• Other minor submodes
• Wastage
• Pitting
• Fatigue
• Wear

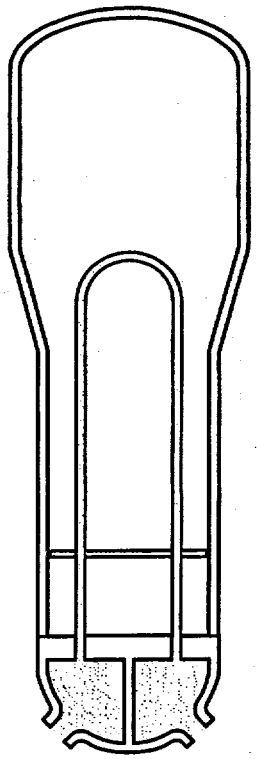

$T_{Primary}$
$T_{Secondary}$
Buildup of aggressive chemicals


Thick sludge, concentration of chemicals occurs

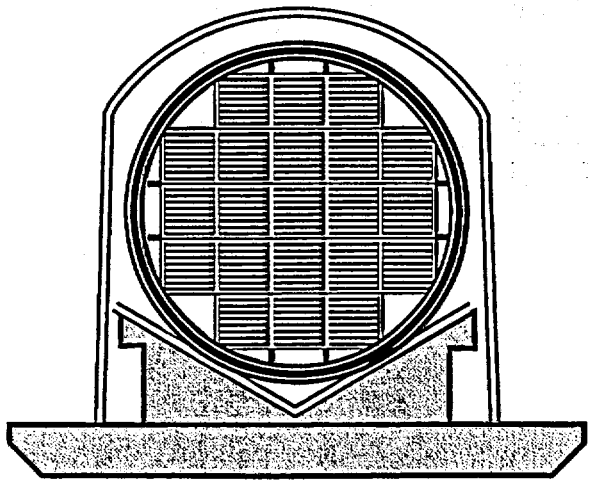
# Comparison of Early Designs: Commercial Nuclear, Waste Package

Paradigm:
- Appearance of adequate test environment
- Corrosion resistant material but not proven
- Heat transfer concentration
- Lifetime objective with questionable mode basis

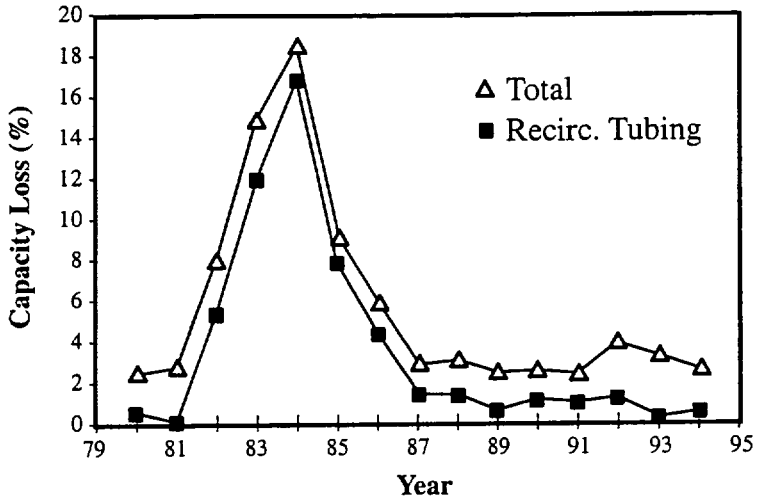
- Fossil water chemistry > 100 ppm solids
- Alloy 600, not susceptible to SCC
- Heat through crevices concentrates impurities
- 40-year life based on fatigue



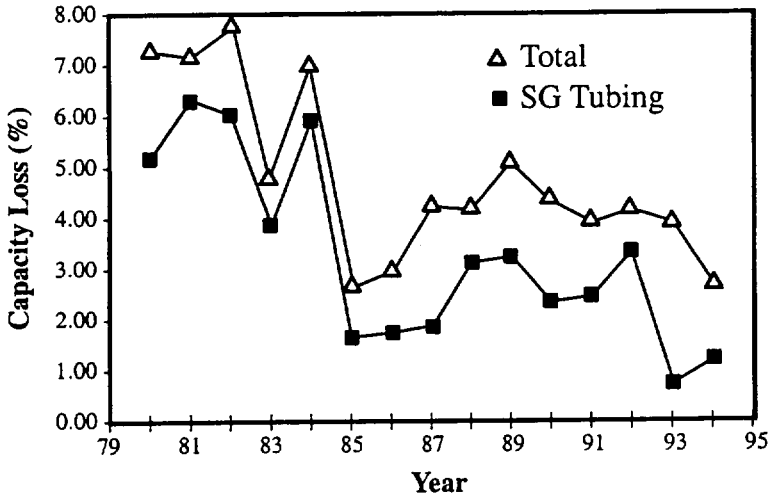
- J 13 well water with concentrations
- C-22, corrosion resistant
- Heat through surface concentrates impurities
- 10,000-year life based on BWR SCC Model



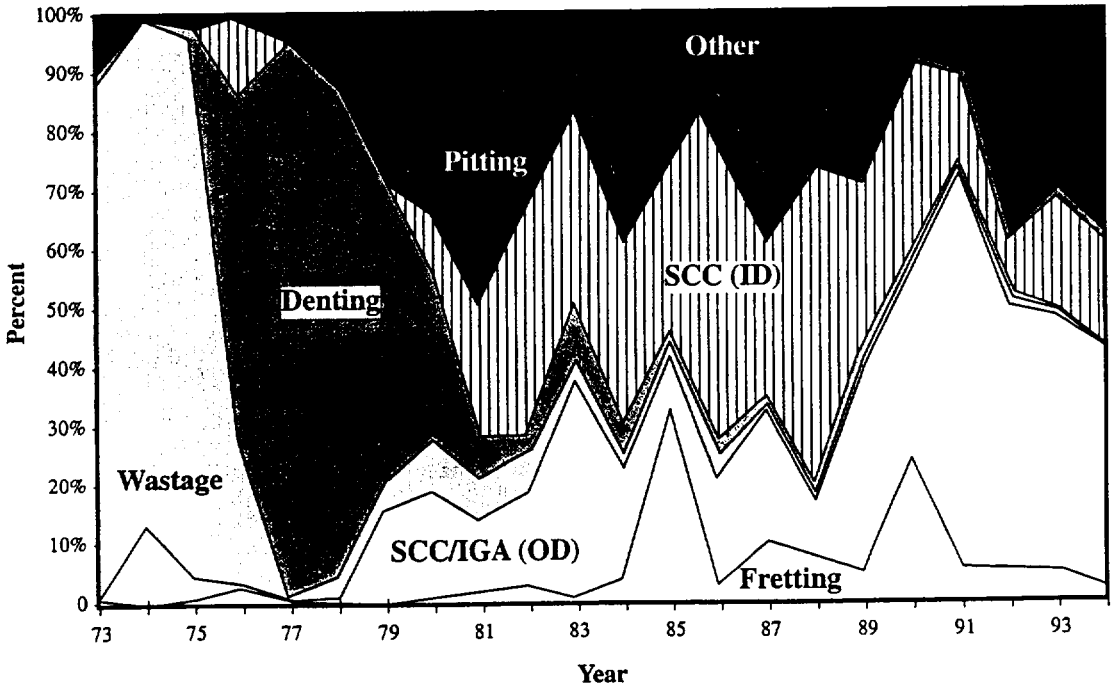
## Capacity Factor Losses in US BWRs Due to Corrosion




## Capacity Factor Losses in US PWRs Due to Corrosion

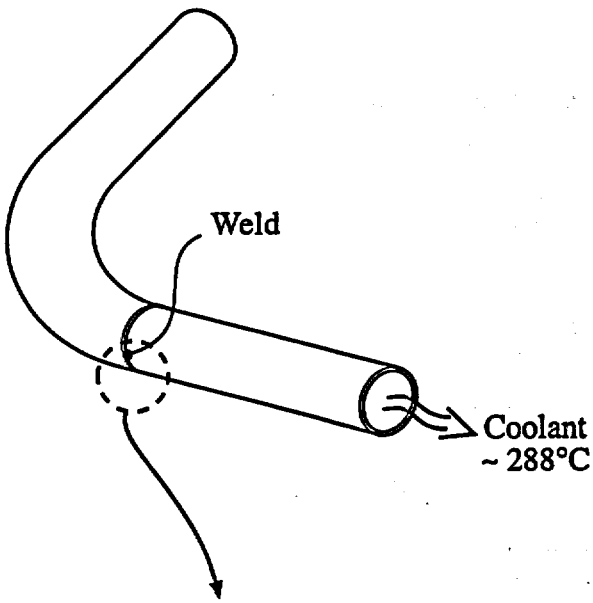


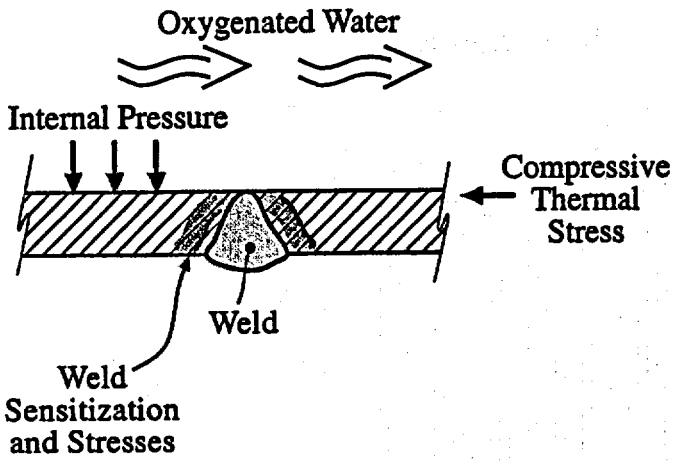

## Causes of Steam Generator Tube Plugging in US PWRs



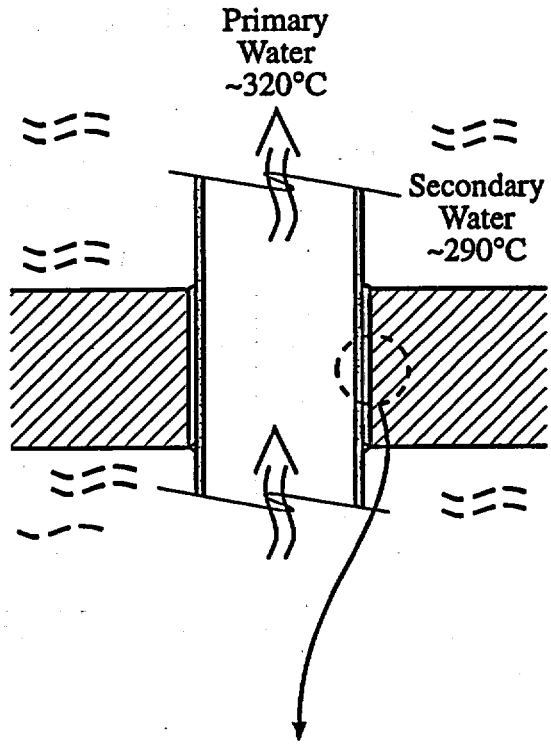
# Which Paradigm for Stress Corrosion Cracking?

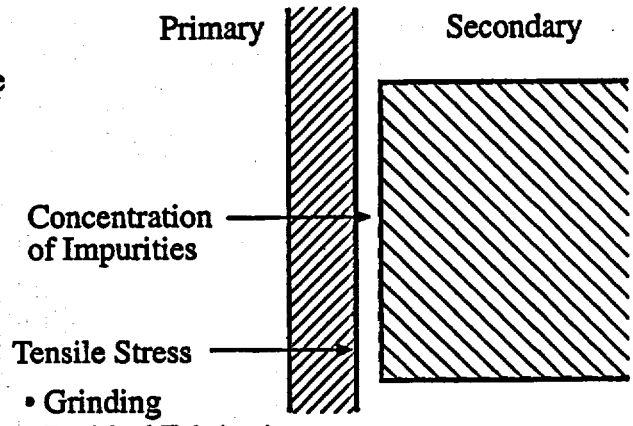
## BWR Piping




## PWR Secondary Side




- Grinding
- Residual Fabrication
- Pressure
- Thermal

# Corrosion Based Design Approach

1. Environment definition
2. Material definition
3. Mode definition
4. Superposition
5. Failure definition
6. Statistical framework
7. Accelerated testing
8. Prediction
9. Feedback
10. Fix

## CBDA: Environmental Definition-- Applied to YM

1. Chemistry directly on the surface is what produces corrosion.

2. Heated surface produces a totally different condition for corrosion than isothermal surface; heated surfaces are very efficient concentrators of impurities.

3. Entire chemistry in mountain is relevant to heated surface, e.g.:

   - Impurities in heated crevices of SGs
   - Thiosulfate in TMI-3
   - Sea water leakage at Millstone
   - Sodium in LMFBRs

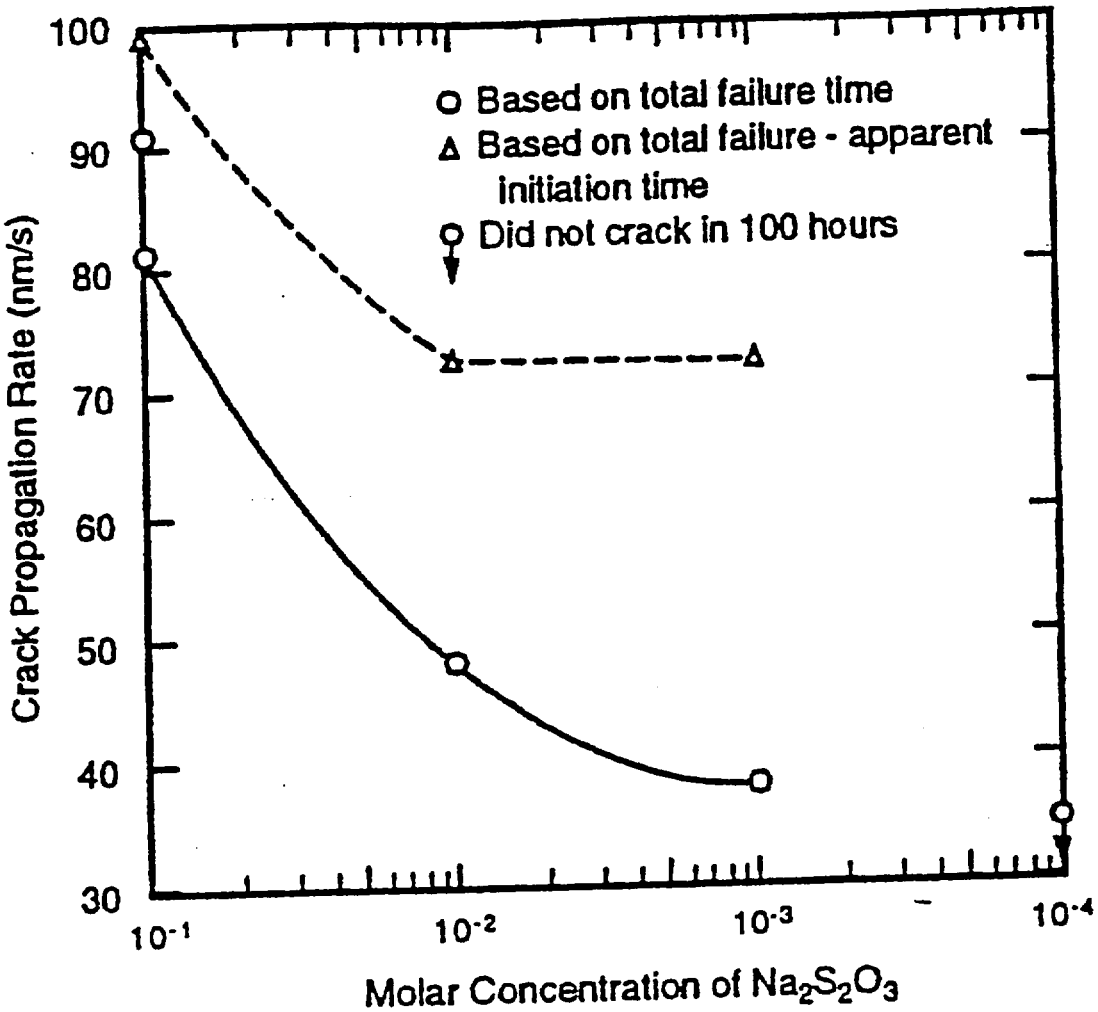
4. No feedback control on environmental contamination.

5. Thermal gradients inYM site produce new flows of water with new chemistries.

6. Highest concentration (possibly chloride) are not always the most virulent, e.g. lead effects. Other impurities.

7. "Environment" includes stress and temperature

8. Heated surface on outside of drip shield




Crack propagation rate for sensitized Alloy 600 as a function of concentration of borated thiosulfate at pH 3 based on two different considerations of crack propagation time; specimens held at an initial stress approximately the yield stress. From Bandy et. al.

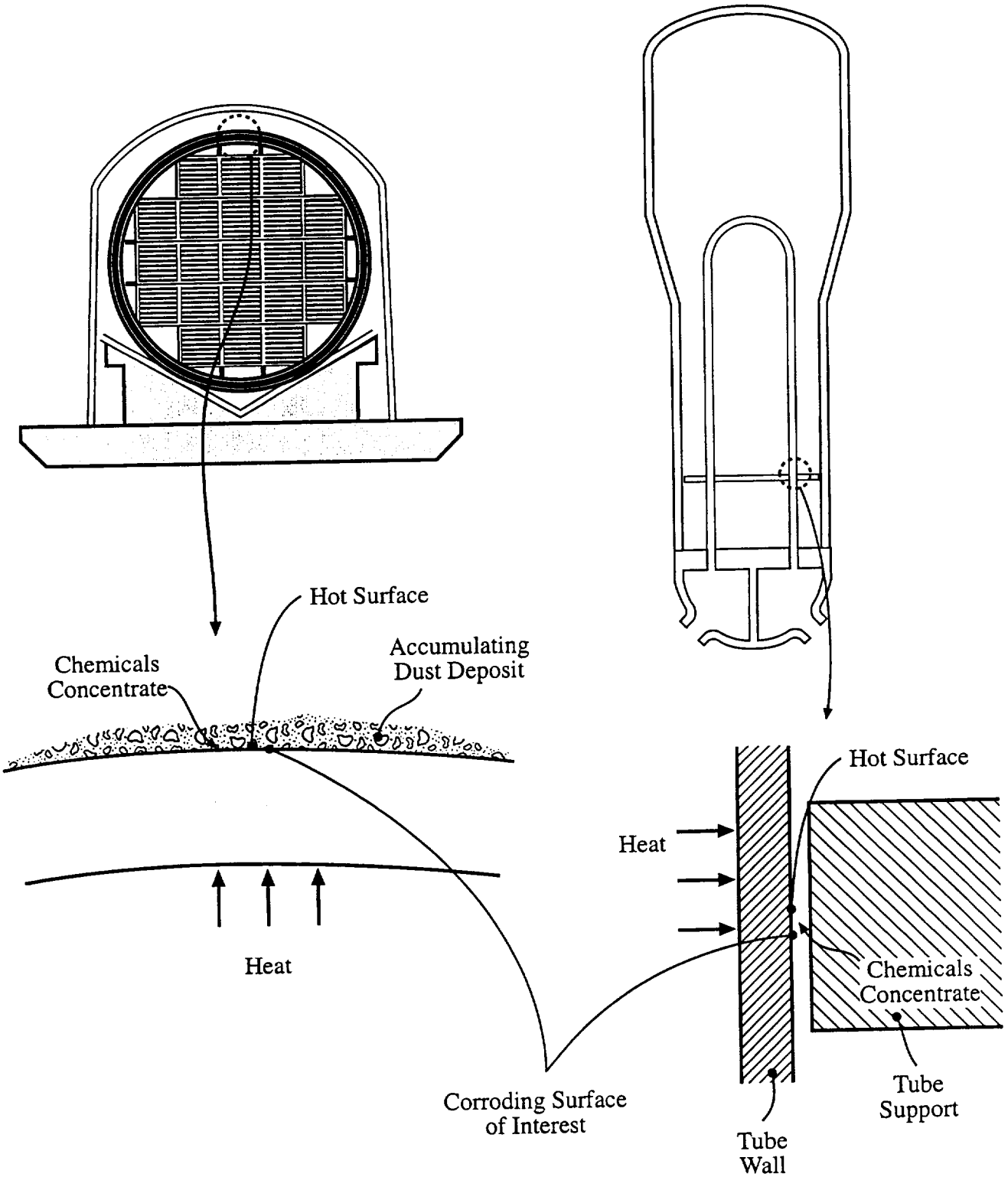
R. Bandy, R. Roberge, and R.C. Newman, *Corrosion*, Vol. 39, October 1983, p. 391.

R.W. Staehle, "Occurrence of Modes and Submodes of IGC and SCC," Control of Corrosion on the Secondary Side of Steam Generators, Eds. R.W. Staehle, J.A. Gorman and A. R. McIlree, Symposium held at Airlie, Virginia, October, 1995, NACE , Houston, 1996, pp. 135 - 208.

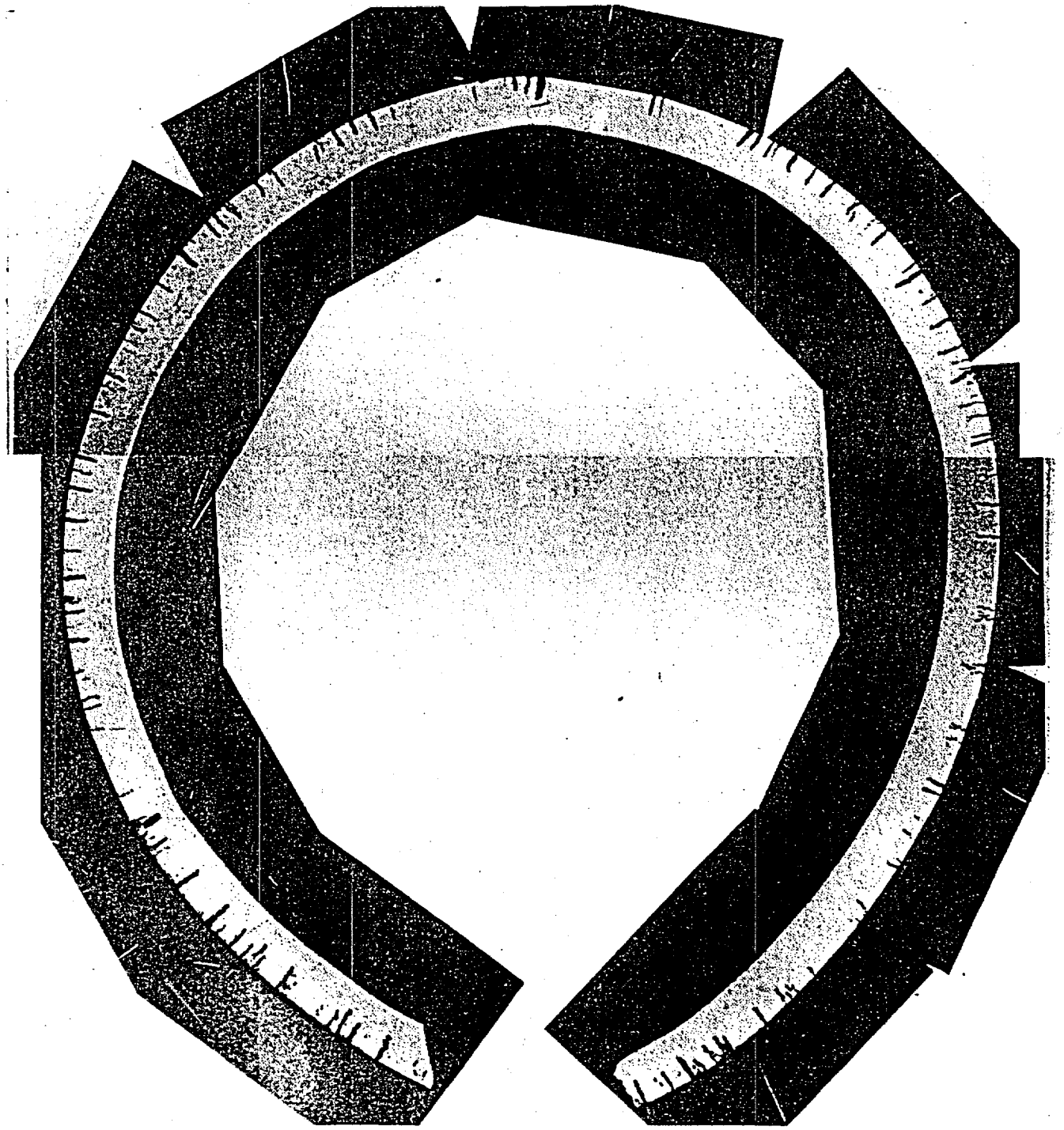
Table 25. The Composition of Several Aqueous Solutions used for Corrosion Testing (UCRL-ID-132285, UCRL-ID-132286, UCRL-ID-132287)

| | Concentration (mg/L) | | | |
|---|---|---|---|---|
| Ion | Simulate Dilute Water (SDW) | Simulated Concentrated Water (SCW) | Simulated Acidified Water (SAW) | Simulated Saturated Water (SSW) |
| | 60 & 90°C | 60 & 90°C | 60 & 90°C | 100°C |
| K | 34 | 3400 | 3400 | 141600 |
| Na | 409 | 40900 | 40900 | 48700 |
| Mg | 1 | <1 | 1000 | 0 |
| Ca | 0.5 | <1 | 1000 | 0 |
| F | 14 | 1400 | 0 | 0 |
| Cl | 67 | 6700 | 24250 | 128400 |
| $NO_3$ | 64 | 6400 | 23000 | 1310000 |
| $SO_4$ | 167 | 16700 | 38600 | 0 |
| $HCO_3$ | 947 | 70000 | 0 | 0 |
| Si | 27 (60°C); 49 (90°C) | 27 (60°C); 49 (90°C) | 27 (60°C); 49 (90°C) | — |

# Hot Surfaces Concentrate Chemicals



## Cross Section View of Tube R16C60 Pulled From Beaver Valley Unit 1 Steam Generator A

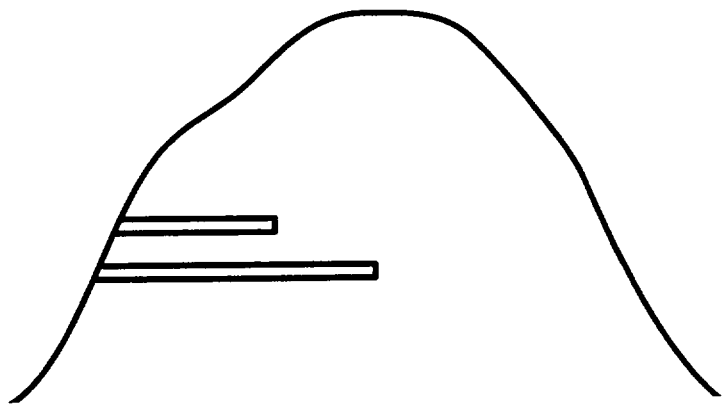


# Consider All Available Elements for Deposit Concentration

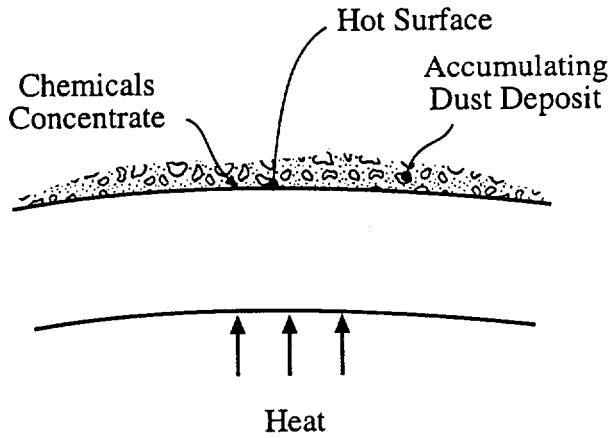
Water, Vapor, Gas Transport

| | |
|---|---|
| As | Mg |
| Bi | Mo |
| C | N |
| Ca | Na |
| Cl | Pb |
| Cu | S |
| Cd | Sb |
| F | Se |
| Hg | Si |
| K | Te |
| | Zn |

Yucca Mountain



Container Surface



## CBDA: Environ Definition #2, Heated Surfaces of Waste Container,-- Applied to YM

1. Paradigm is heated surfaces on secondary side of PWR steam generators

2. Very efficient concentrators even when solids are in range of tens of ppb.

3. Local steam phases possible

4. Change in local oxidizing condition to negligible oxygen at some locations

5. Unevenness produces cells

6. "Everything" seems to end up on heated surfaces: full chemistry of Yucca Mountain is accessible

7. Water currents when rock is heated produces different chemistry access

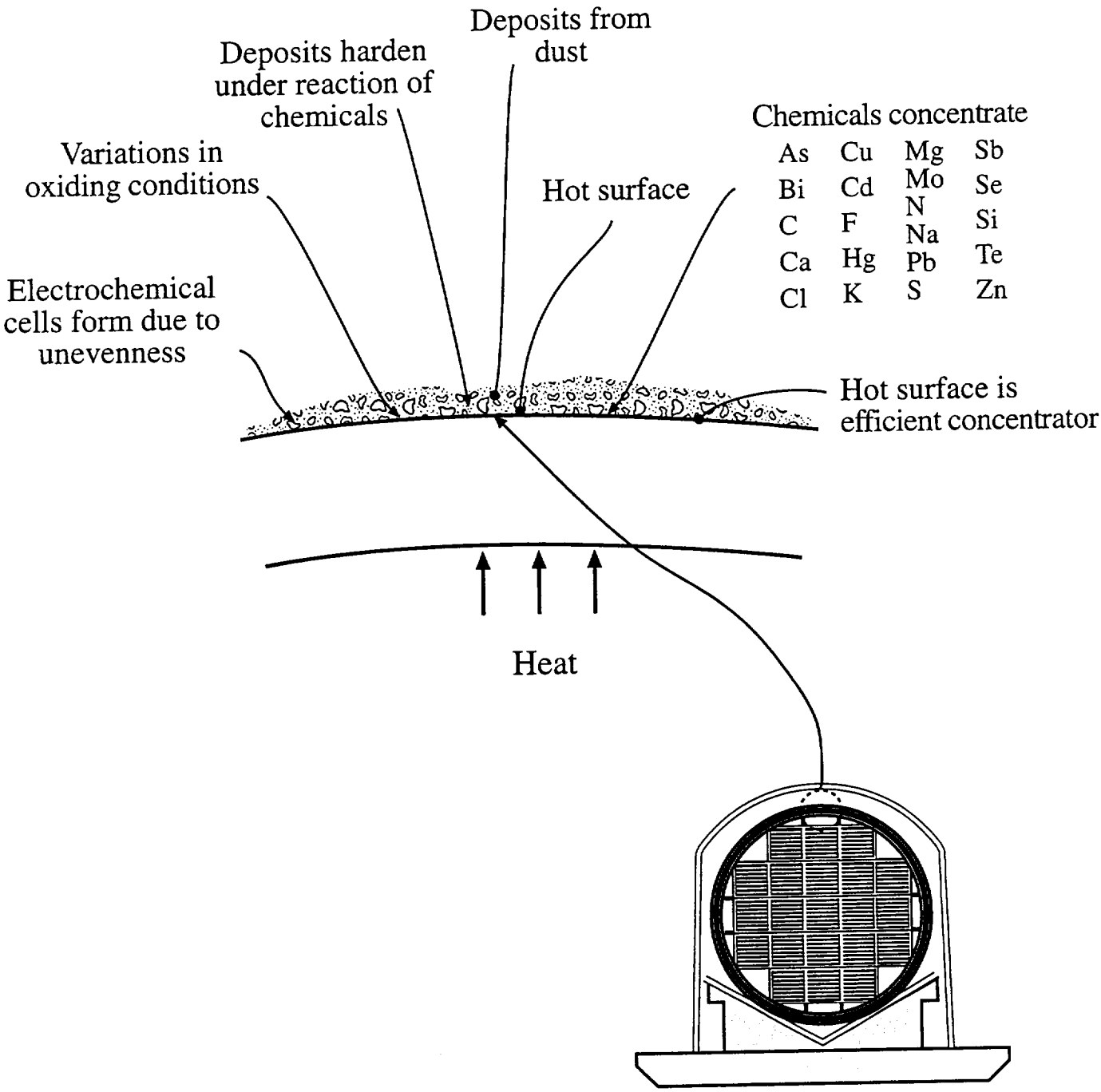
8. Dust deposits increase thermal resistance; also leads to gradients inside waste package

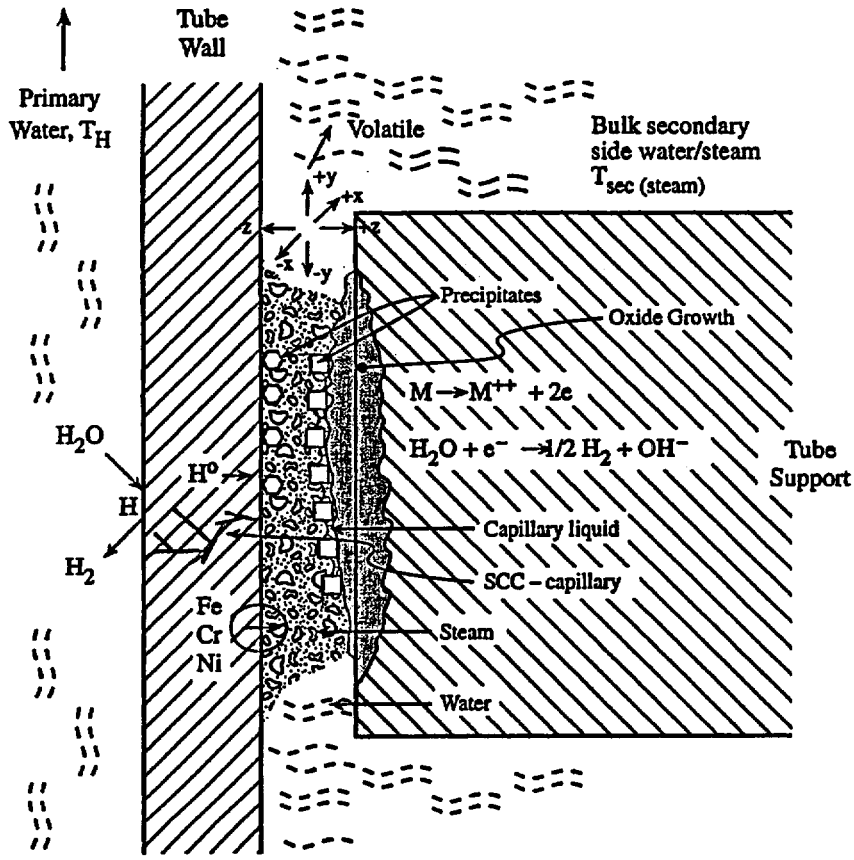
- Rate of dust deposition

- Chemistry of dust

9. Detailed chemistry of backfill

# Container Surface



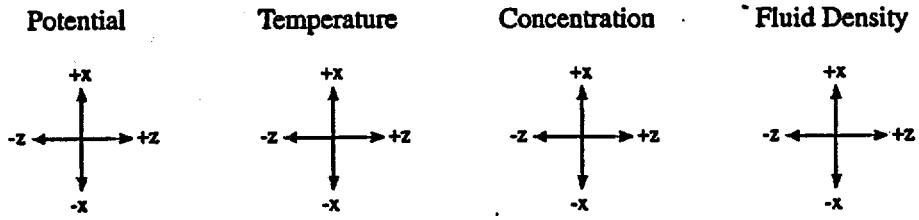



(a)

| | | | |
|---|---|---|---|
| Cl | ($Cl^-$, HCl) | B, Ti, Zn | (inhibitors) |
| $SO_x$ | ($S^{+6} \rightarrow S^{+4} \rightarrow S^{+2} \rightarrow S^o \rightarrow S^=$) | $O_2$ | ($H_2O$, compounds) |
| $SiO_x$ | ($SiO_2$, complex compounds) | $H_2$ | ($H^+$) |
| $AlO_x$ | ($AL_2O_3$, complex compounds) | $N_2H_4$ | ($NH_3$, $N_2$) |
| Cu | ($Cu^o$, $Cu^{++}$, CuO) | C | ($CO_3^=$, organic) |
| Pb | ($Pb^o$, $PbO_x$) | N | ($NO_x$, organic) |
| Na, Ca, Mg | (complex compounds) | Fe, Cr, Ni | ($Fe^{+2}$, $Cr^{+3}$, $Ni^{+2}$, complex compounds) |
| $Na_2HPO_4$ | (retrograde compounds plus $H_3PO_4$) | | |

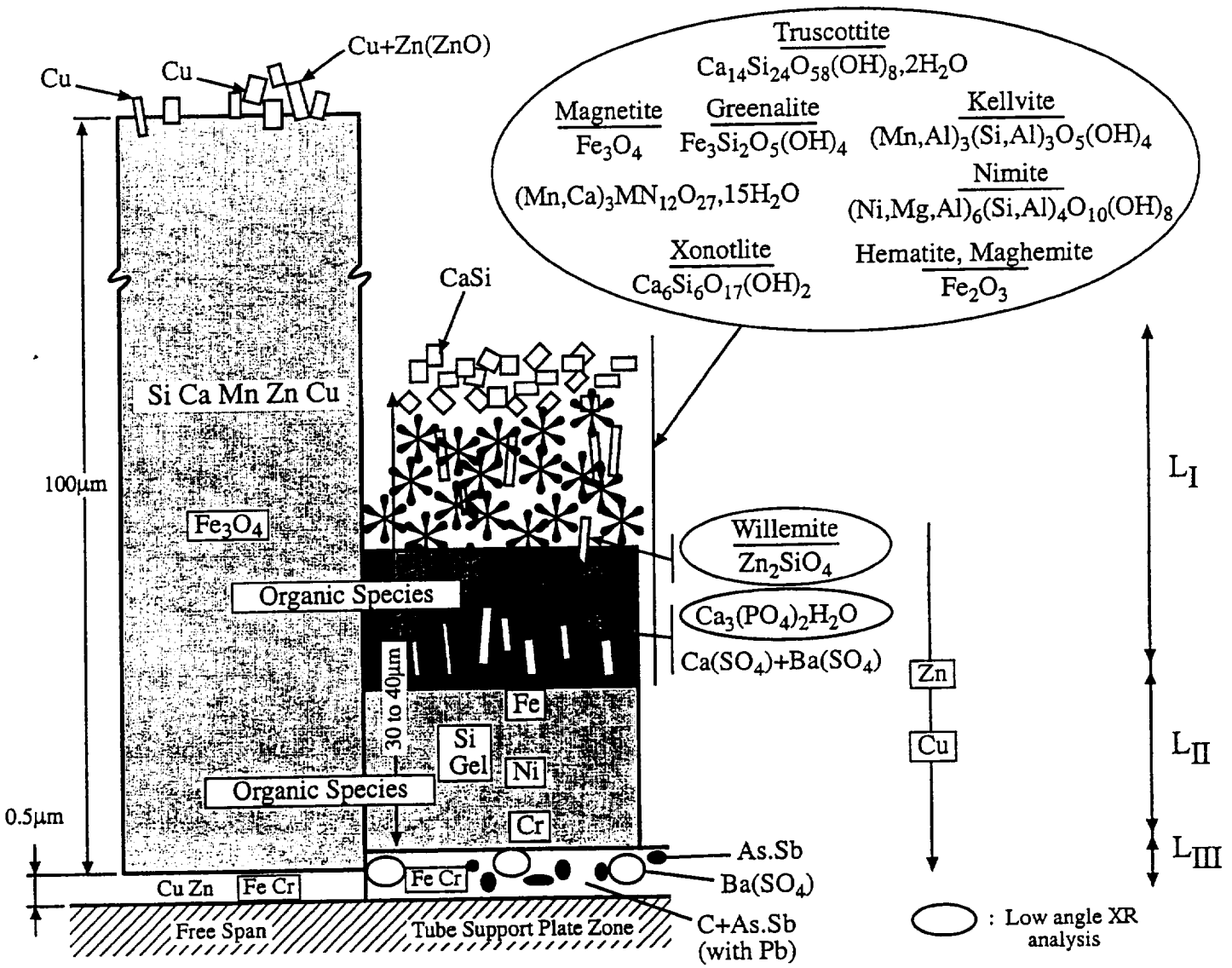
(b)

## Gradients




(c)

Schematic illustration of chemical processes which can occur in heat transfer crevices at the intersection of tubes and tube supports on the secondary side of steam generators used in pressurized water nuclear reactors. (a) The crevice geometry occurs between a tube with hotter water than the secondary side and a tube support which is cooler. (b) Chemicals concentrate and react in the sequestered geometry. Typical species of products are shown. (c) Inside the crevice, gradients in potential, temperature, concentration and density occur; these cause movements, further concentrations, and electrochemical cells.




Sketch of deposits and surface films observed on IGA affected tubes pulled from a French plant with copper alloy condenser and cooled by Loire river.

B. Sala, P. Combrade, A. Gelpi, M. Dupin, "The Use of Tube Examinations and Laboratory Simulations to Improve the Knowledge of Local Environments and Surface Reactions TSPs,"in *Control of Corrosion on the Secondary Side of Steam Generators,* Proceedings of meeting held in Airlie, VA, October 9-13, 1995. NACE International, Houston, 1996.

## CBDA: Environ Definition #3, Heated Surfaces of Drip Shield,-- Applied to YM

1. Impurities in backfill

2. Moderately heated surface

3. Crevices due to construction

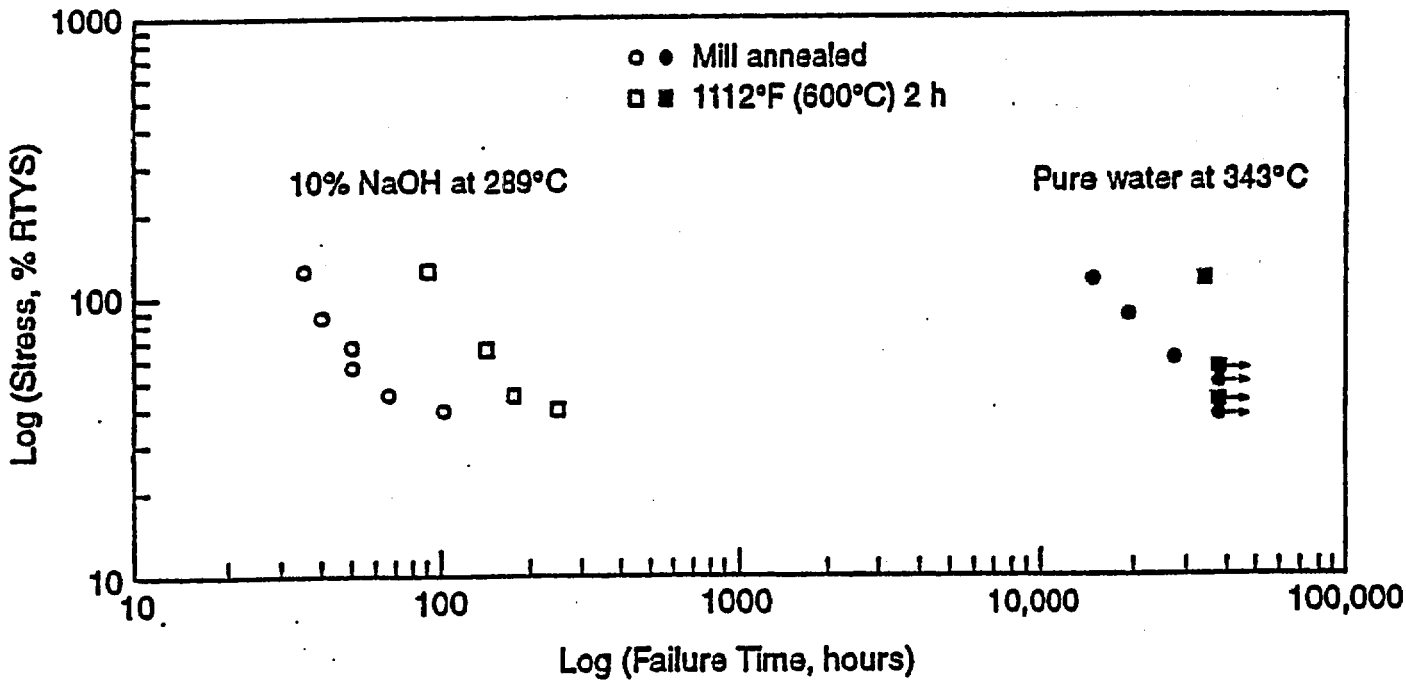
4. Residual stresses from fabrication

5. Access to mountain chemistry

## CBDA: Environ Definition #4, Stresses,-- Applied to YM

1. Internal heating produces tensile thermal stresses on outside heated surface.

2. Residual stresses from fabrication adequate to produce SCC anywhere on outside surface-- welds are not only sources of stress. SCC of SG tubing at tube supports is example




Effect of stress on time-to-failure for Alloy600 in (a) pure water at 343°C and (b) 10% NaOH at 289°C. Adapted from work by Theus.[68]

68. G. J. Theus, "Summary of the Babcock and Wilcox Company's Stress Corroson Cracking Tests of Alloy 600," EPRI WS-80-136, EPRI Workshop on Cracking of Alloy 600 U-Bend Tubes in Steam Generators, Denver, August, 1980.

| Main groups of residual stress | Sub groups |
|---|---|
| Machining residual stresses | Grinding, Turning, Milling, Planing, Drilling } Residual stresses |
| Joining residual stresses | Welding, Soldering, Brazing, Adhering } Residual stresses |
| Forming residual stresses | Rolling, Drawing, Forging, Pressing, Spinning, Shot peening } Residual stresses |
| Heat-treating residual stresses | Quenching, Transformation, Hardening, Case hardening, Nitriding } Residual stresses |
| Coating residual stresses | Cladding, Spraying, Electroplating, Plating, Galvanizing } Residual stresses |

Origins and types of residual stresses. Adapted from Macherauch.[46]

R.W. Staehle, "Combining Design and Corrosion for Predicting Life," presented as a plenary lecture at Life Prediction of Corrodible Structures, Conference held in Kauai, Hawaii, November 1991, NACE International, Houston, 1994, p. 138 - 291.

# CBDA: Material Definition for C-22 -- Applied to YM

1. Essence of C-22: alloy is prone to be less stable in neutral and alkaline environments due to high solubility of chromium, molybdenum and tungsten alloying elements with increasing pH.

2. C-22 is much like Alloy 600; in the absence of much data for C-22, the Alloy 600 data should be carefully considered.

3. Recall range of effects of metallurgical structure in Alloy 600:

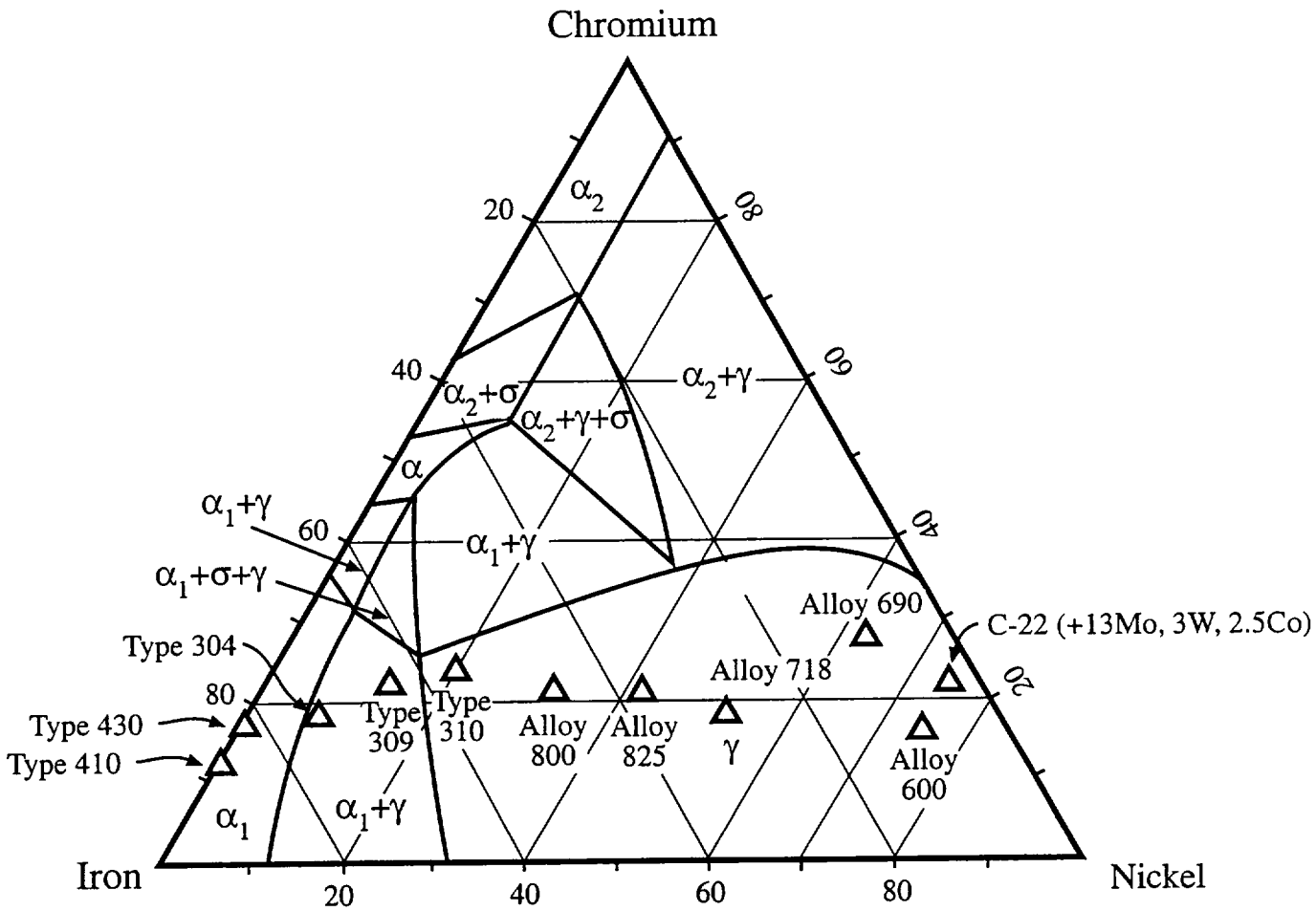
   a. Large difference in proneness to all submodes of SCC

   b. Testing of high susceptibility and low susceptibility heats provides misleading results.

4. If global stress relief used, will change structure and proneness to corrosion

5. Grain boundary composition as function of heat treatment affects SCC and IGC

6. Prototype fabrication is required to determine real conditions of residual stresses, material structures due to fabrication



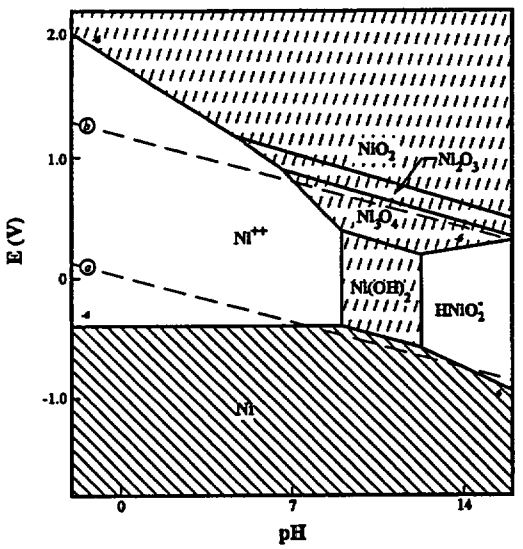

Notes:

- Ternary phase diagram for Fe-Cr-Ni Alloys at 400°C
- Compositions of commercial alloys show only Fe, Cr, Ni

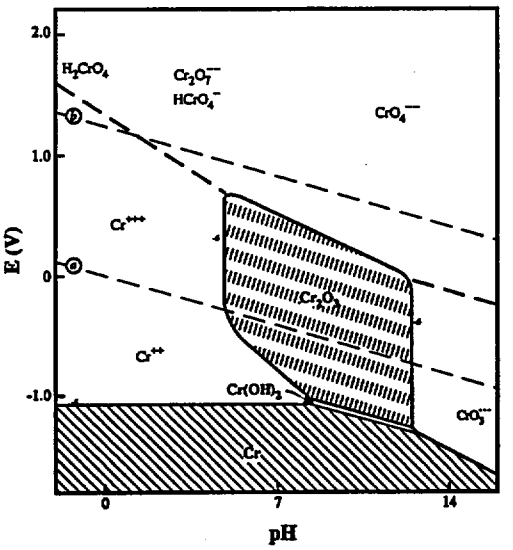
# Potential pH Diagrams for Alloying Elements in C-22

- Diagrams at 25°C
- Solubilities are at $10^{-6}$M concentrations

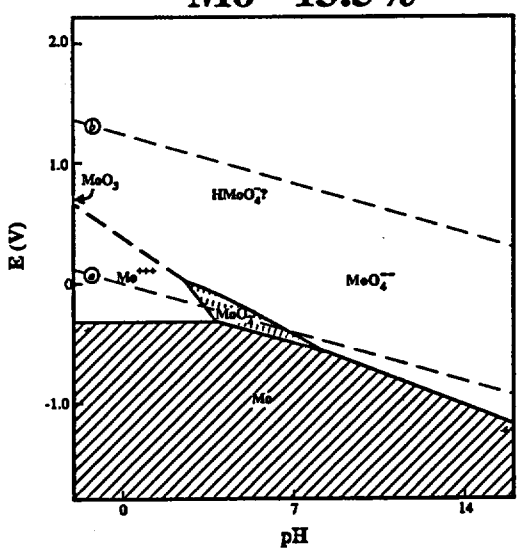
## Ni - 56.5%



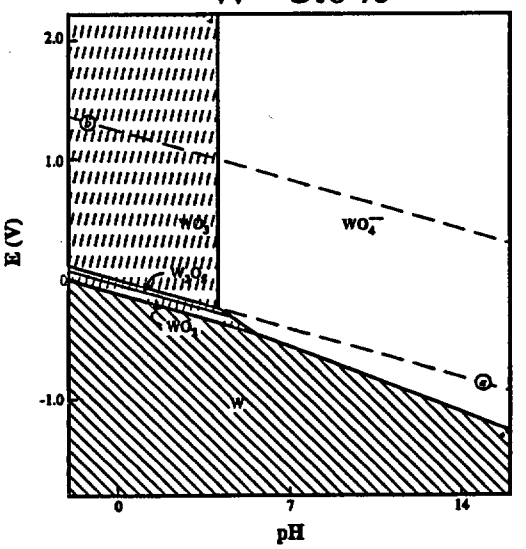

## Cr - 21%



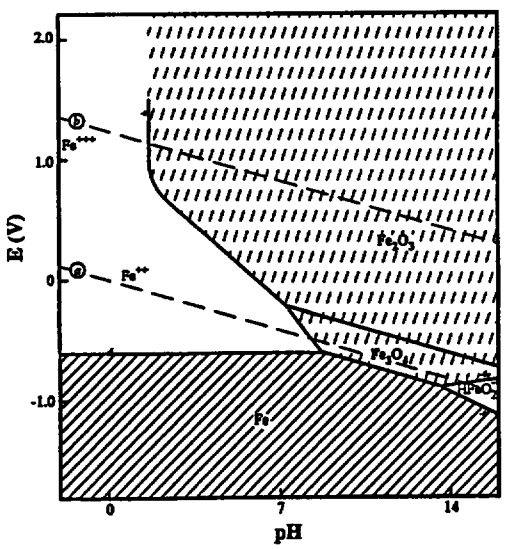

## Mo - 13.5%



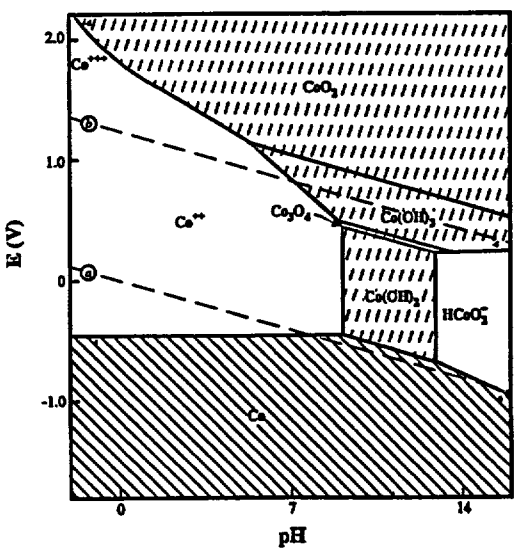

## W - 3.0%

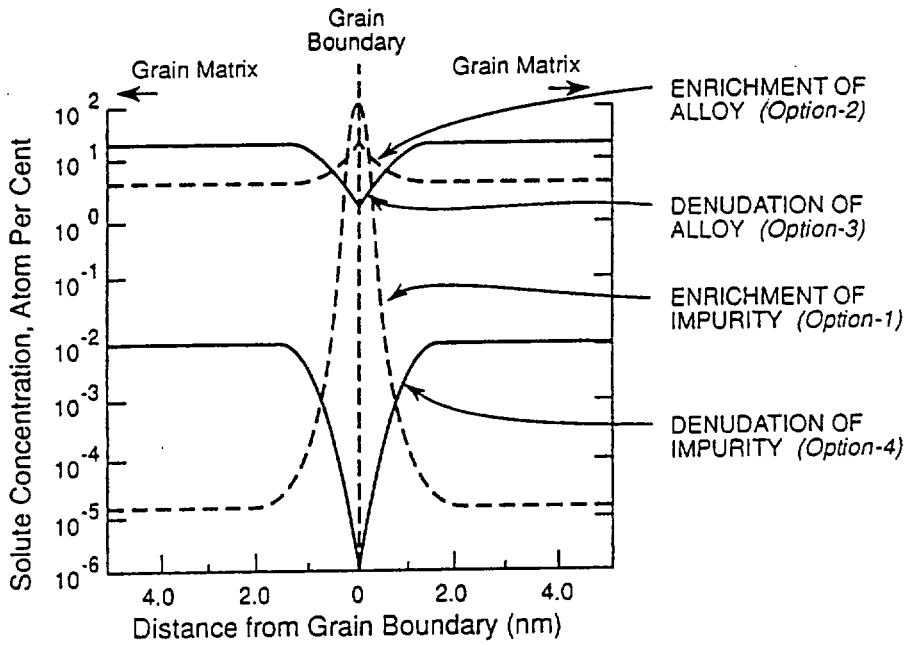



## Fe - 4.0%

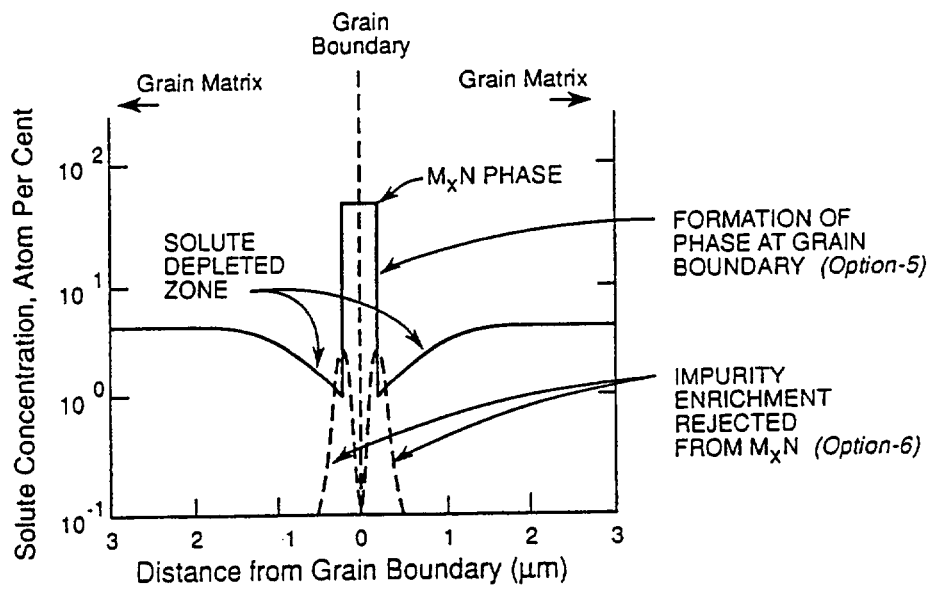



## Co - 2.0%






(a)




(b)

Distribution of chemical species at grain boundaries for the case of adsorption (a) and precipitate formation. (b) Various options for distributions of species are identified.

R.W. Staehle, "Understanding 'Situation-Dependent Strength' : A Fundamental Objective in Assessing the History of Stress Corrosion Cracking," Environment Induced Cracking of Metals, Proceedings of the First International Conference on Environment-Induced Cracking of Metals, October 2-7, 1988, Kohler, Wisconsin, NACE-10, National Association of Corrosion Engineers, Houston, Texas, 1990, pp. 561-612.

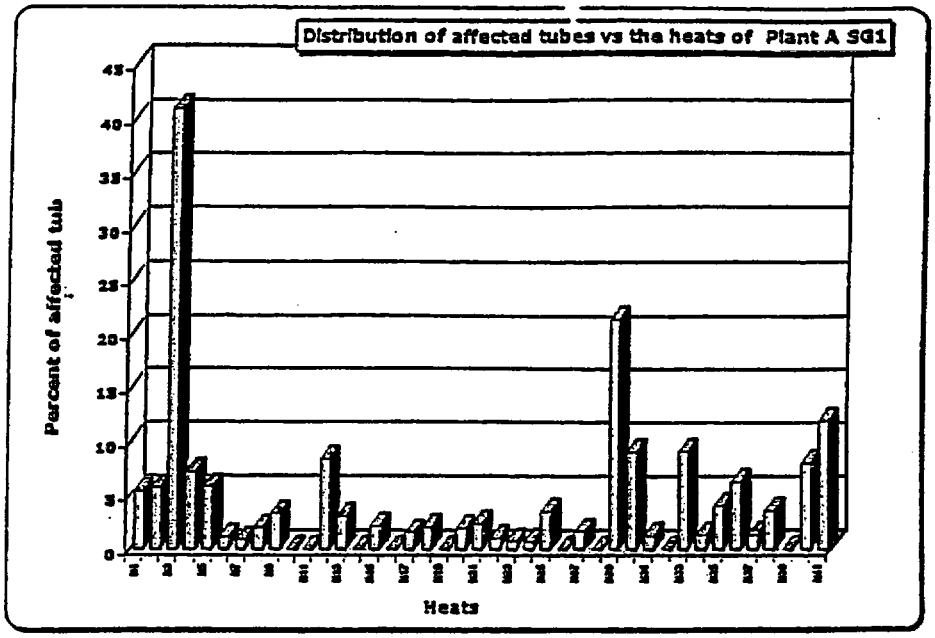



Figure 4: Histogram of fraction of tubes of each heat of alloy 600 affected by IGSCC on the primary side of the roll transitions in a steam generator tube bundle after ~40,000 hours in service.

P.M. Scott, "Stress Corrosion Cracking in PWRs— Interpretation, Modeling and Remedies," Speller Award Lecture, CORROSION 2000, NACE International, Houston, 2000.

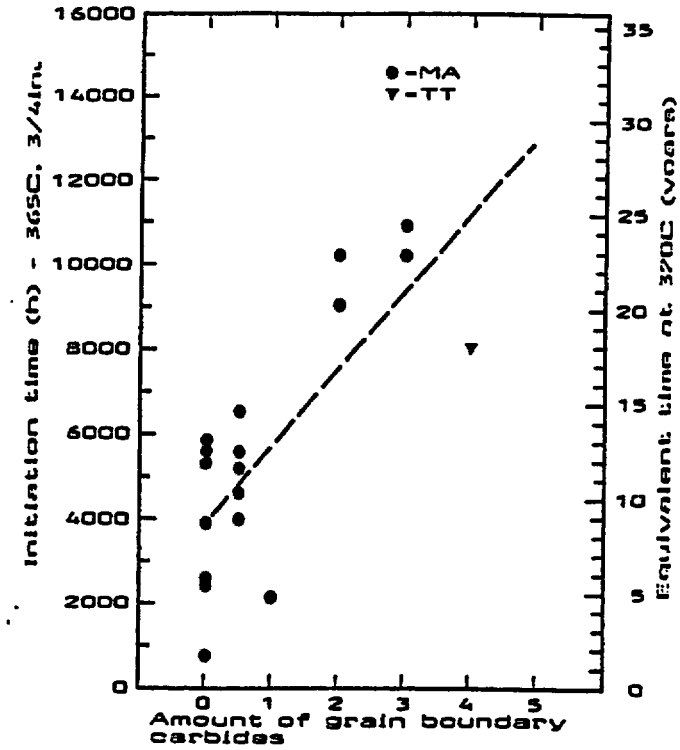
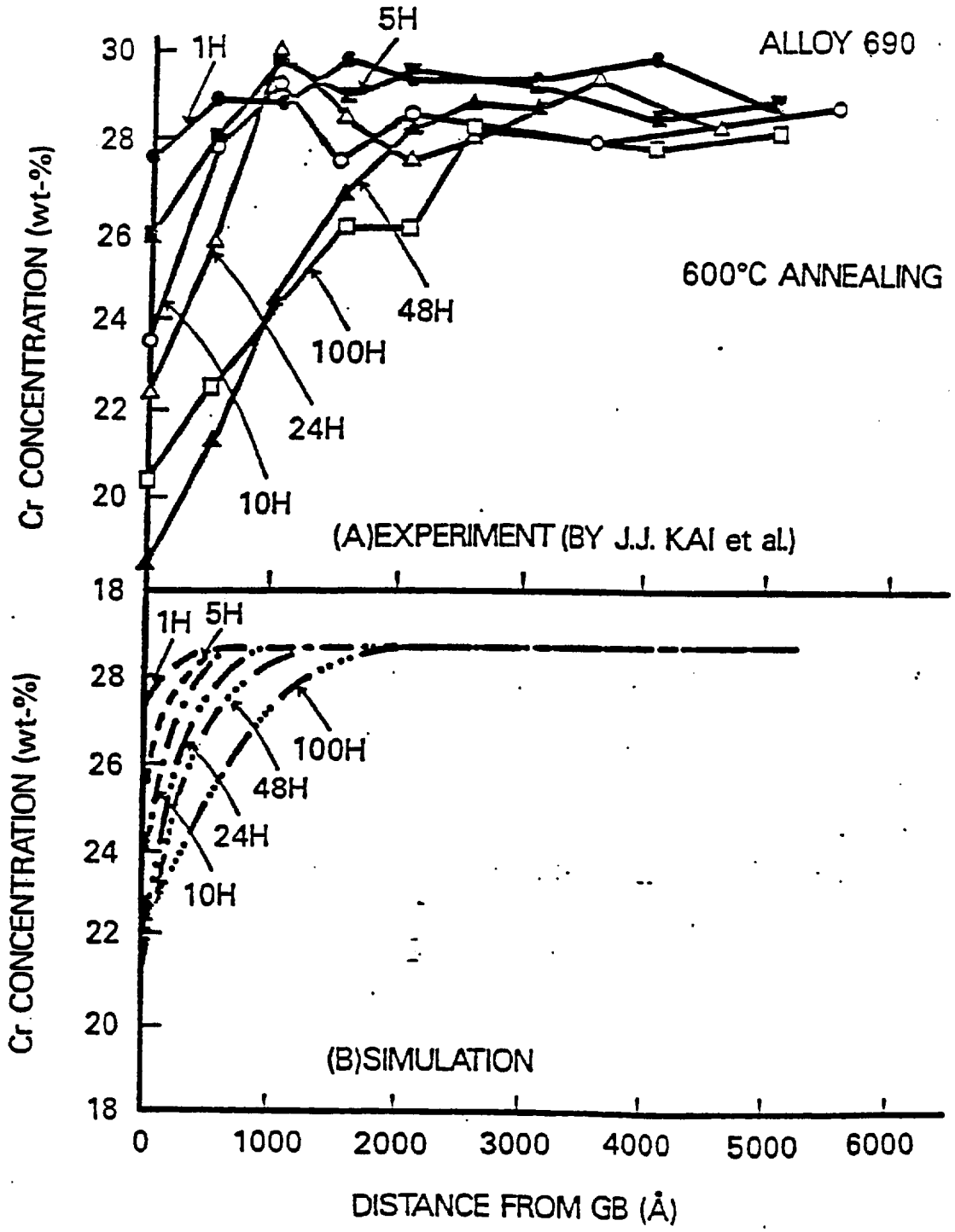



Figure 8 - Influence of grain boundary carbides on the crack initiation time (0 = no carbides at all; 5 = the grain boundaries are completely covered with arbides).

K. Norring, J. Engstrom and P. Norberg, "Intergranular Stress Corrosion Cracking in Steam Generator Tubing. Testing of Alloy 690 and Alloy 600 Tubes," *Environmental Degradation of Materials in Nuclear Power Systems— Water Reactors.* G.J. Theus and J.R. Weeks, Eds., The Metallurgical Society, Warrendale, PA, 1988.




**Experimental Measurements of GB Chromium Depletion for Alloy 690 at 600°C.**

**Simulation Results.**

C.F. Lo, W.E. Mayo, and S. Weissmann, "Computer Simulation of Grain Boundary Depletion in Alloys 600 and 690," Presented at EPRI Workshop on Alloy 690, New Orleans, LA, April 12-14, 1989.

# CBDA: Material Definition for Ti-Gr7 -- Applied to YM

1. Essence of Ti-Gr7 is the presence of 0.1-0.25%Pd. This produces persistently higher open circuit potentials owing to the high exchange current density on net Pd surface.

2. This alloy has been used generally in chemical environments for corrosion and hydride resistance. However, its general SCC behavior relevant to YM is not established.

3. The presence of the Pd surface will greatly accelerate any reduction of oxygen or water as well as any other species in a highly oxidized state. This tendency will place the alloy in a range of potentials that are not common to other titanium alloys.

4. The metallurgy of this alloy is not well defined.

# CBDA: Material Definition: Applicable Material Selection: Examples of Problems--Applied to YM

1. SCC of Fe-Cr-Ni alloys in boiling $MgCl_2$ as function of Ni concentration was basis for Alloy 600 and assumed immunity to all corrosion:

   a. Alloy 600 sustains SCC under mild conditions in chloride environments

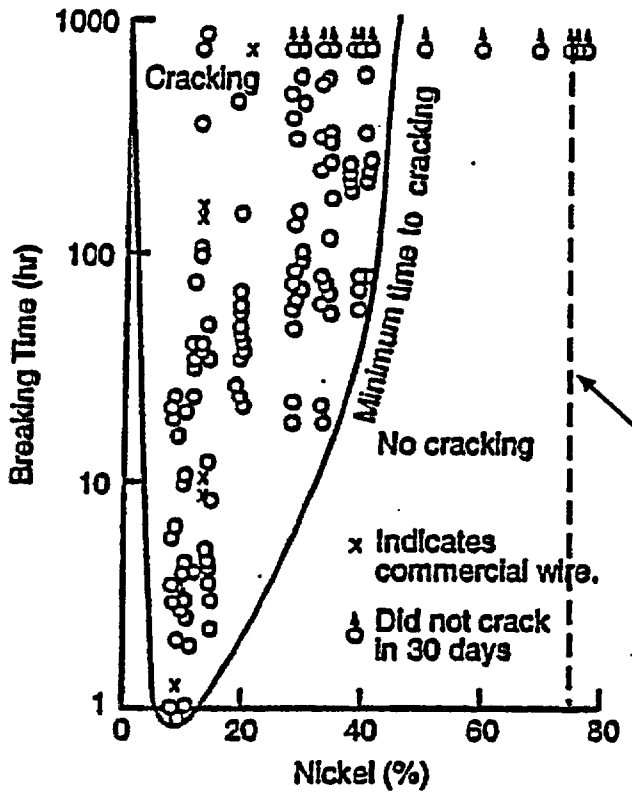
   b. Failures of alloy 600 occurred without presence of chloride in many environments in service--non-chloride

2. Alloy 690 was initially selected based on (a) resistance to SCC in lead and (b) resistance to SCC in oxidizing crevices, both criteria were erroneous:

   a. Alloy 690 sustains severe SCC in low concentrations of lead in liquid and vapor

   b. Alloy 690 sustains severe SCC in oxidizing acidic environments

# INITIAL DATA FROM COPSON (1957-59)




Effects of alloy composition on the stress corrosion cracking of Fe-Cr-Ni alloys exposed to boiling 42% $MgCl_2$. (Adapted from the work of Copson [17]

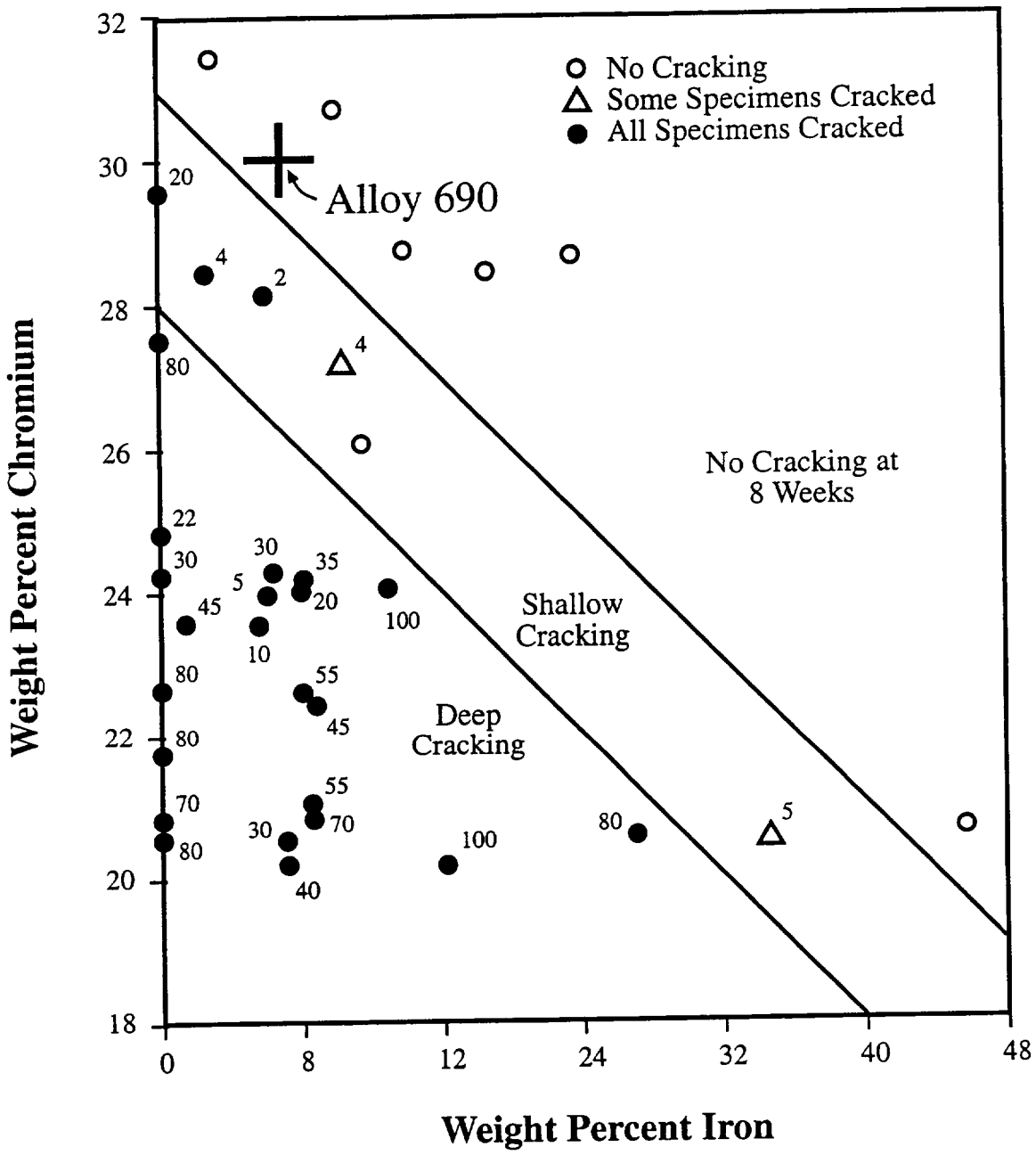
## BERGE & DONATI 1981 Show Cl SCC of Alloy 600

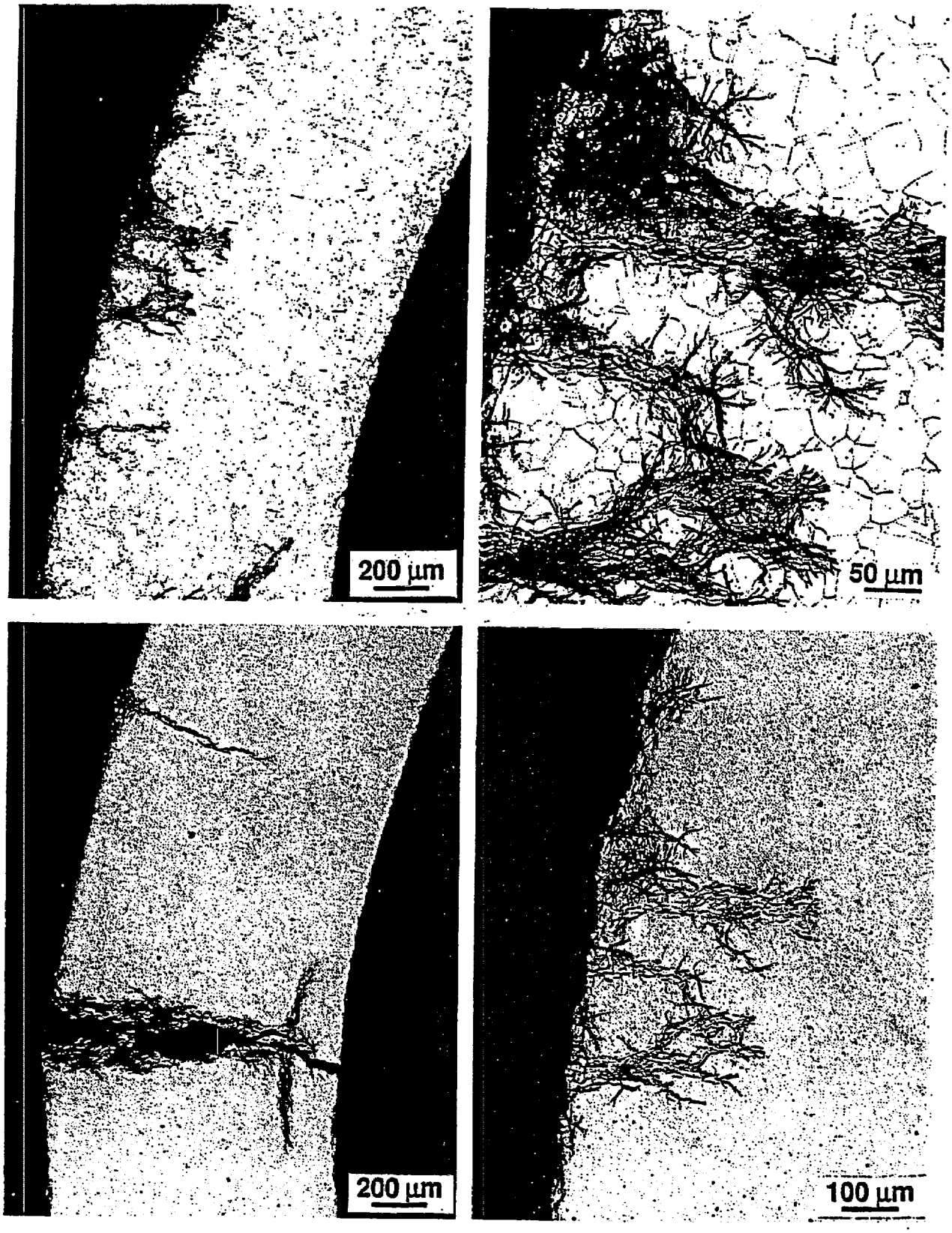
Stress corrosion cracking of Alloy 600 at 100°C in a solution containing boric acid (50 g/ℓ boron) and chloride (2 g/ℓ $Cl^-$). U-bend specimen after 800 h.

## ALSO

- Alkaline SCC
- Acid SCC
- Lead SCC
- Low Potential SCC
- Copper SCC
- Low Valence Sulfur SCC

# Maximum Depth of Cracking (in mils) of Ni-Cr-Fe Alloys after 8 Weeks in Deaerated Water + Pb






C-ring 8-196, Alloy 690, Heat 752469, TT, after 4073 hrs in vapor of Canister 9 (1.0m NaOH + 0.1m PbO); left photos unetched.

# CBDA: Mode Definition--Applied to YM

1. Modes of corrosion includes general, pitting, IGC, SCC, CF

2. Submodes of e.g. SCC include same modes with different dependencies upon principal variables.

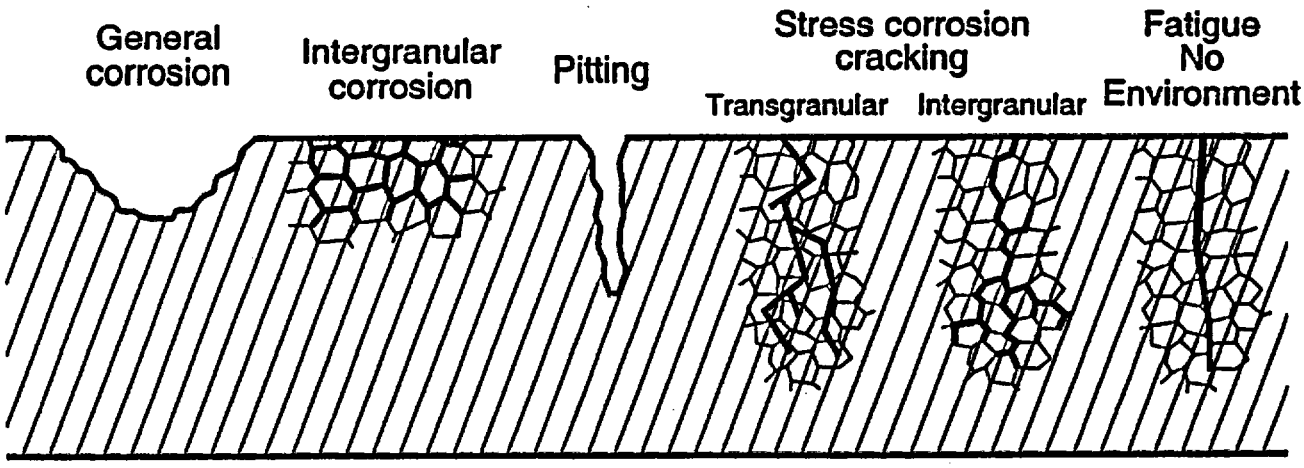
3. Defining regions in which corrosion (mainly SCC here) occurs that can be compared with possible environments.

4. Defining dependencies on principal variables: potential, pH, species, alloy composition, alloy structure, temperature, stress.

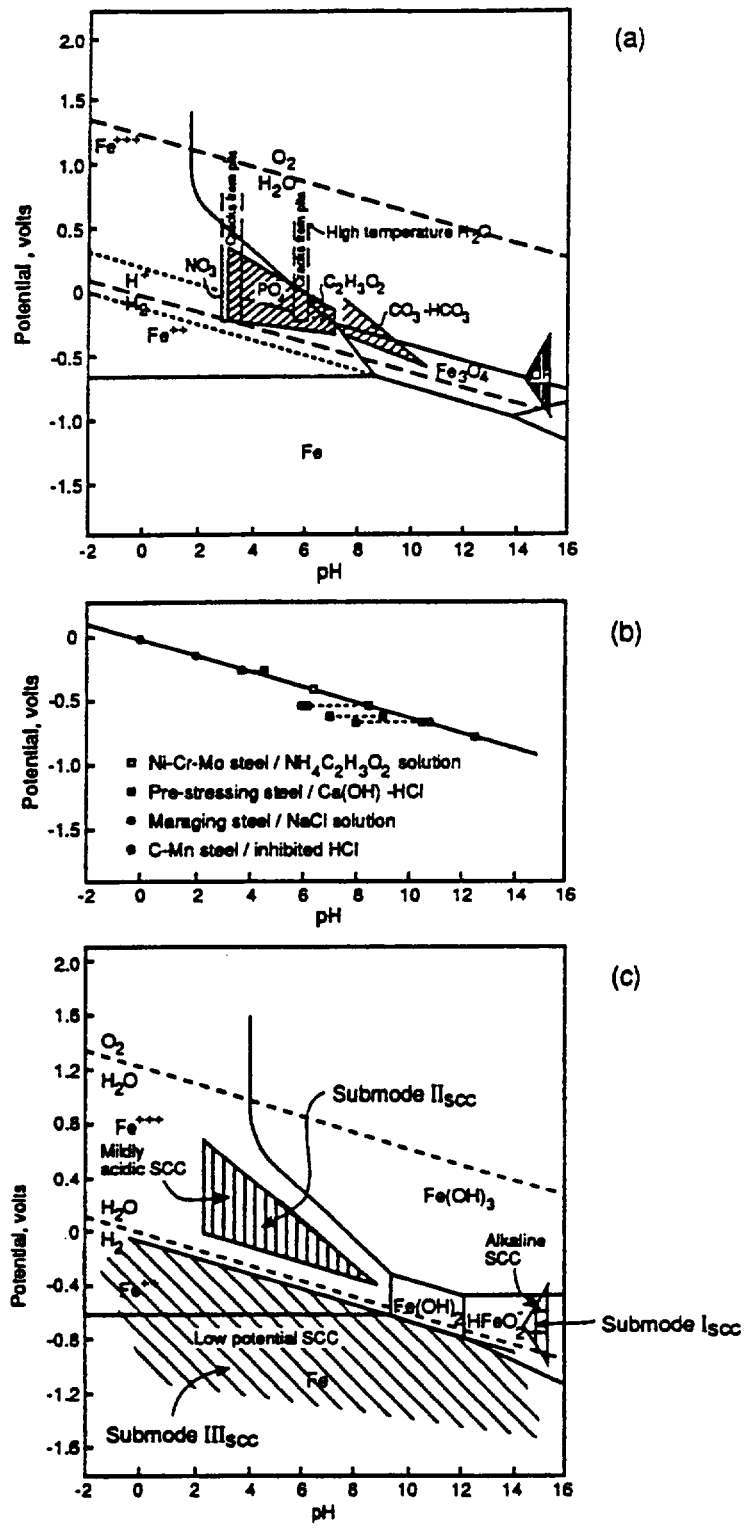
5. Specifying differences between initiation and propagation dependencies.

6. Occurrences of submodes of SCC are generally orderly and can be "guessed at" and determined on an orderly and rapid basis.

7. Correlation of submodes with locations on mode diagram privates qualitative insights to dependencies.




*Intrinsic modes of corrosion. (From Staehle [15].)*



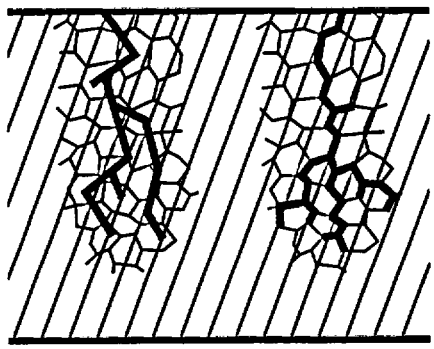

Regions of occurrence for different modes of SCC for low alloy steels exposed to aqueous solutions mostly at room temperature. Work shown is taken from studies in different environments and for different alloys. (a) Shaded areas show regions where SCC occurs. Adapted from Congleton *et al.*[143] (b) Line shows the potential below which hydrogen related SCC occurs. Adapted from Parkins.[144] (c) Schematic synthesis showing three submodes of SCC based on (a) and (b).

R.W. Staehle, "Combining Design and Corrosion for Predicting Life," presented as a plenary lecture at Life Prediction of Corrodible Structures, Conference held in Kauai, Hawaii, November 1991, NACE International, Houston, 1994, p. 138 - 291.

# Principal Variables Affecting Modes and Submodes of SCC

Stress corrosion cracking

Transgranular Intergranular



2. pH

3. Environmental Species

1. Electrochemical Potential

6. Alloy Composition and Environment

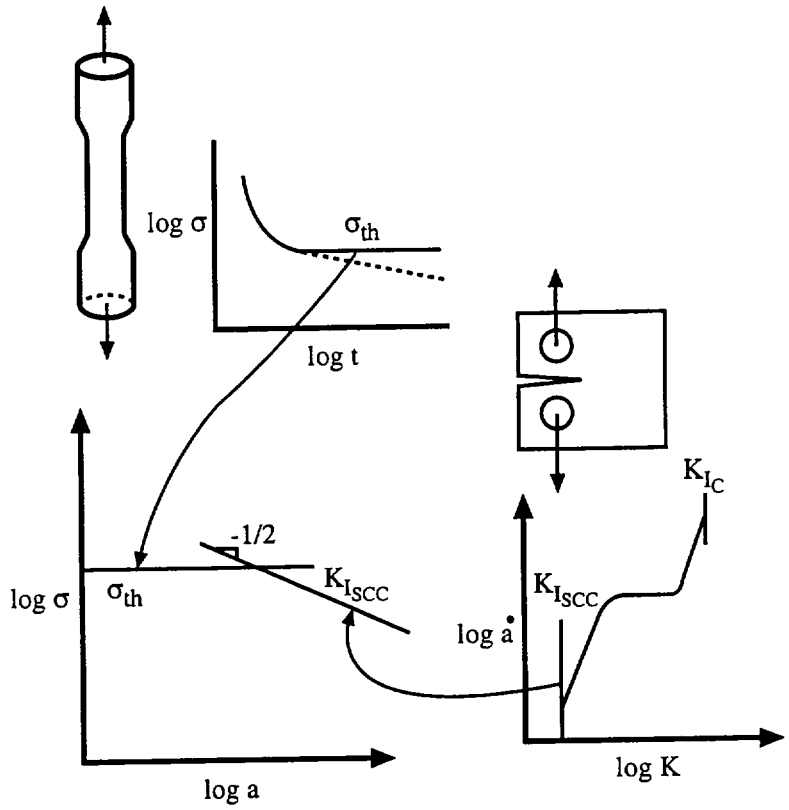
5. Temperature

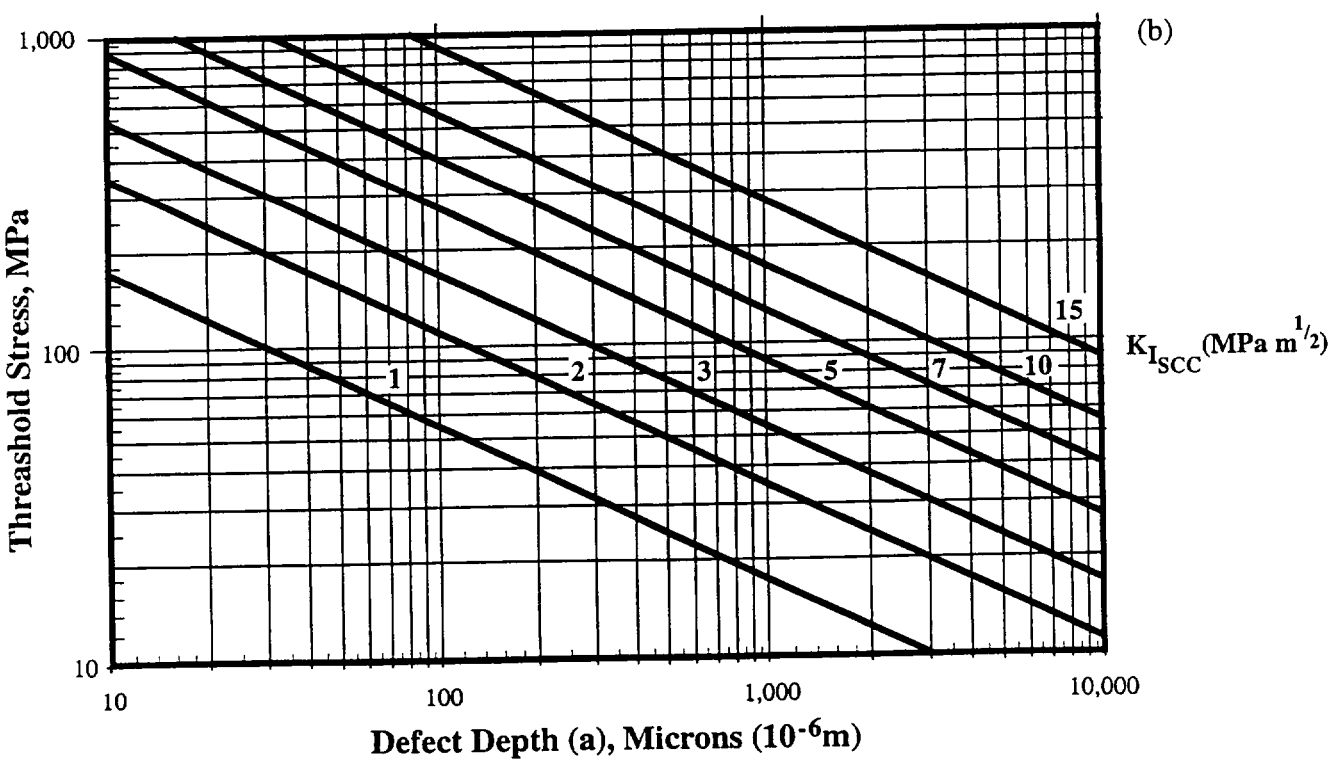
$$x = A\,[H^+]^n\,[x]^p\,\sigma^m\,e^{\frac{E-E_o}{b}}\,e^{\frac{Q}{RT}}\,t^q$$

6. Alloy Composition

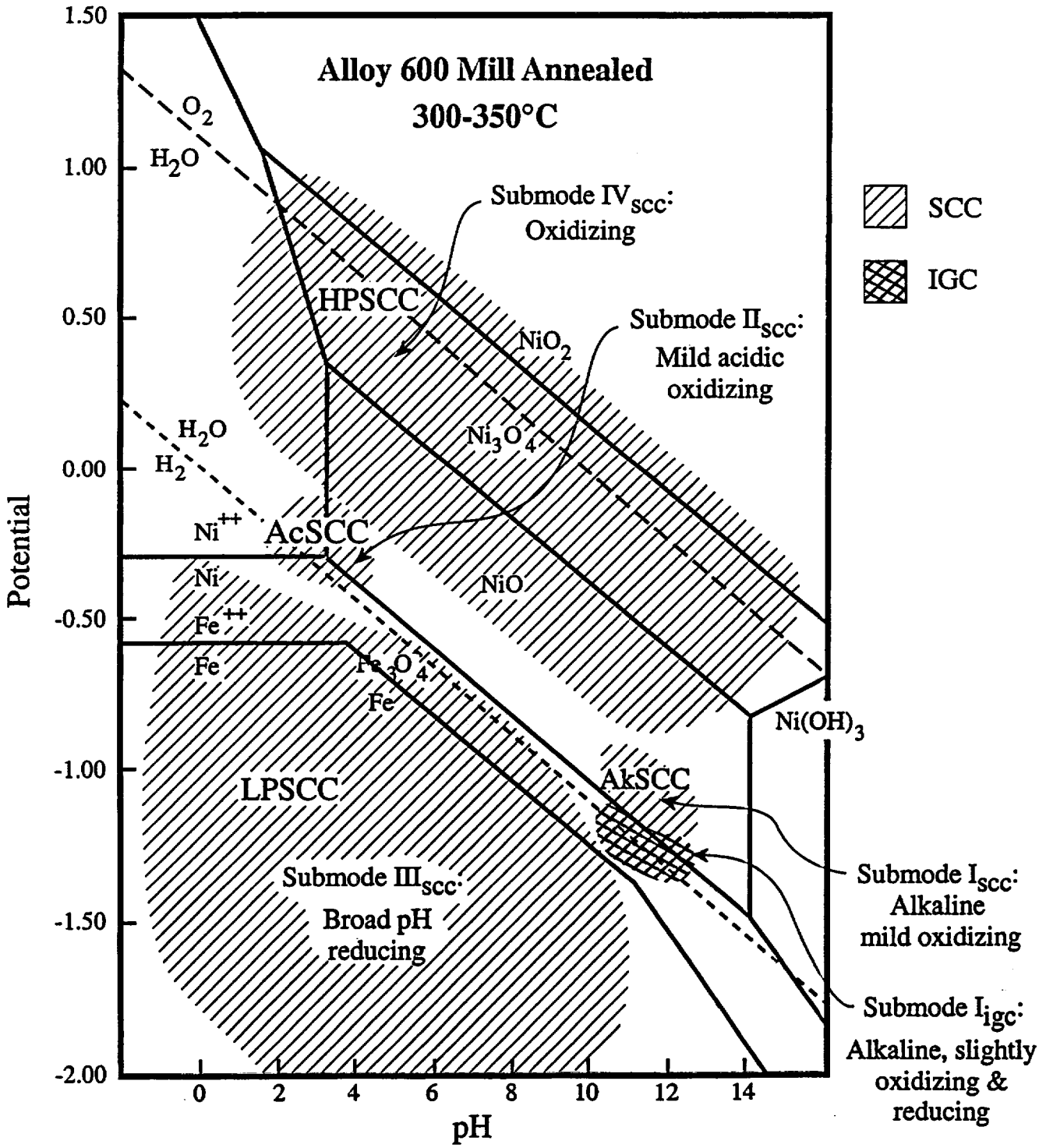
7. Alloy Structure

4. Stress

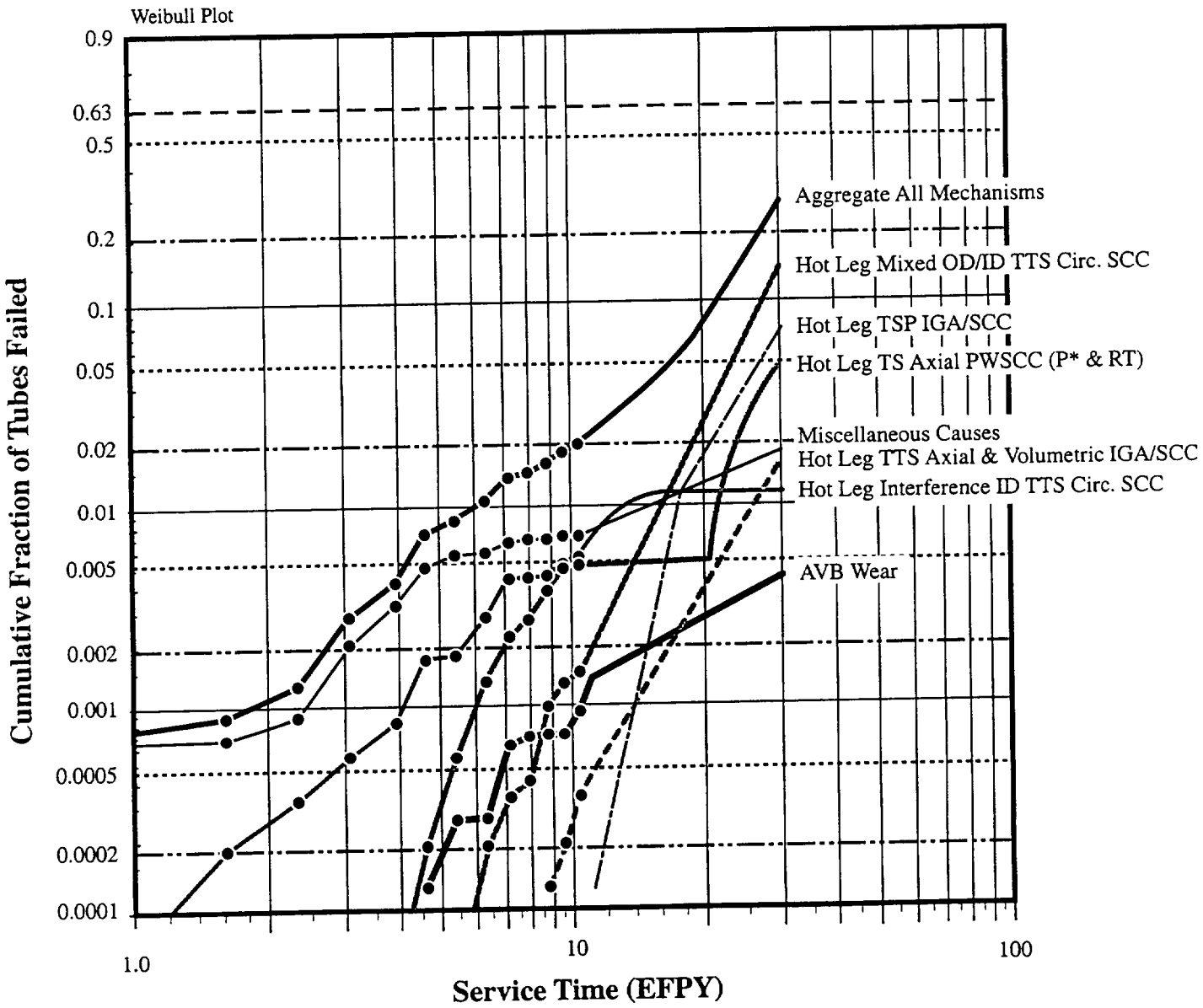


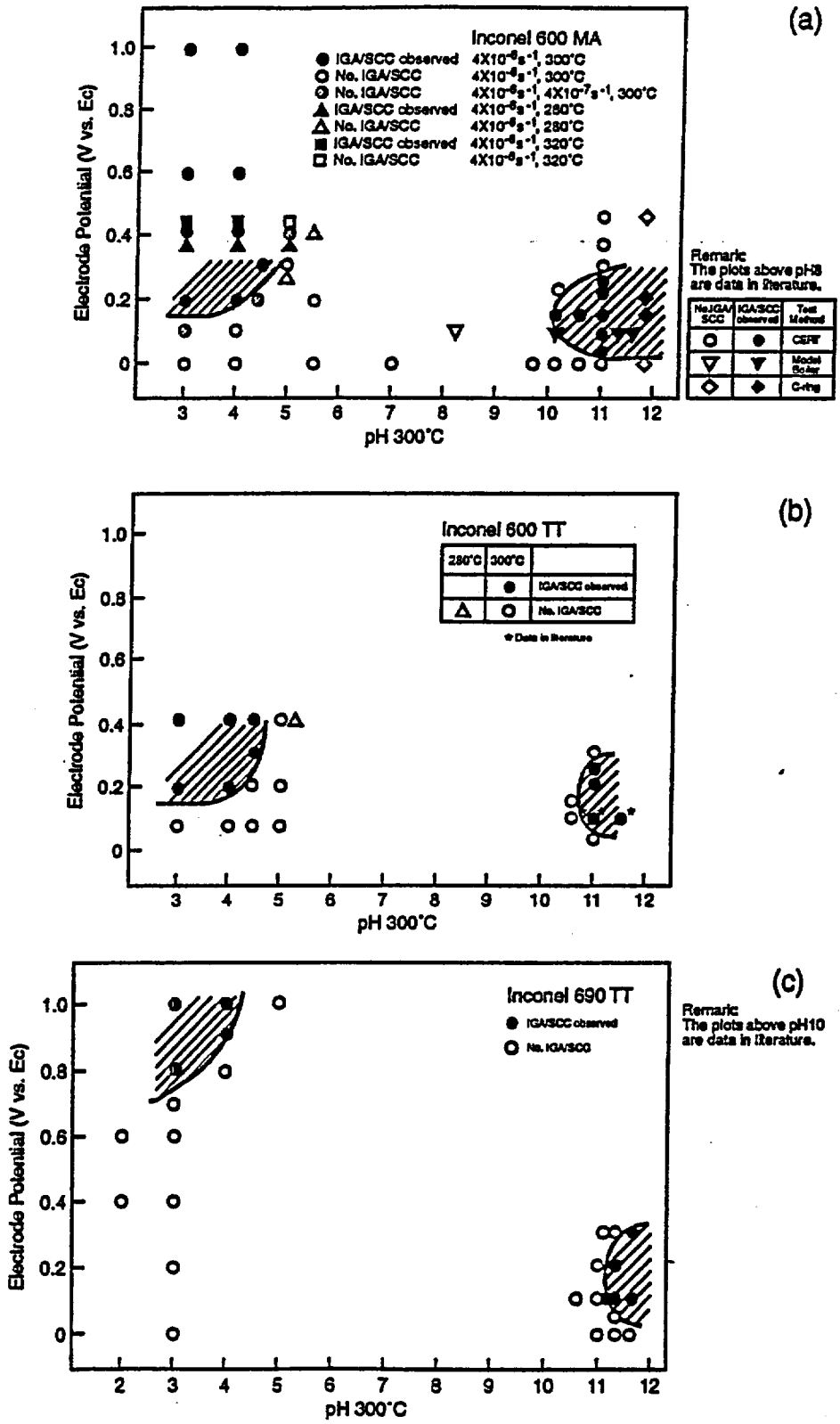

Distinguishing between initiation and propagation. (a) Schematic view of log stress versus log of defect depth for the cases of initiation stress as determined from smooth surface and SCC growth as determined from a pre-cracked specimen. (After Staehle[2]) (b) Log-log plots of parametric values of threshold stress (horizontal lines) and $K_{iscc}$ (-1/2 slope).




Occurrence of major modes, $MD_j$, and submodes, $SD_j$, of SCC and IGC for mill annealed Alloy 600 in the range of 300-350°C plotted with respect to aqueous equilibria for nickel and iron. Submodes included are alkaline SCC, acidic SCC, low potential SCC, high potential SCC. (Diagram originally from Staehle and Gorman [20] and modified in Staehle [13].)

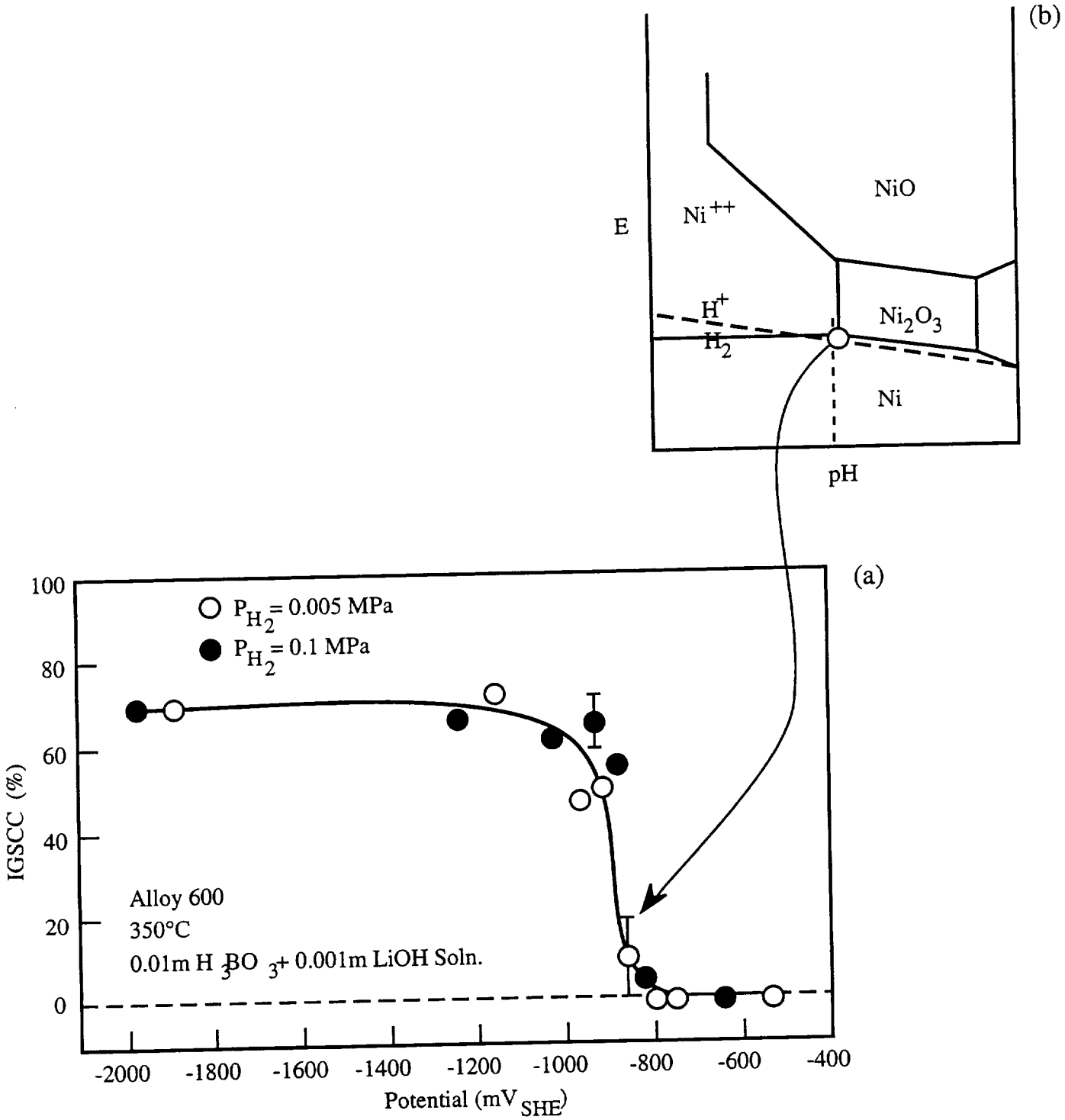



Cumulative fraction of tubes failed versus service time in EFPY (Equivalent Full Power Years) for seven mode-location cases from the set of steam generators in the Ringhals 4 pressurized water nuclear plant. "TTS" refers to "Top of Tube Sheet." "TS" refers to "Tubesheet." "Circ. SCC" refers to "Circumferential SCC." "P*" refers to a special location where SCC may not be serious. "RT" refers to SCC at the "Roll Transition" location. "AVB" refers to "Anti-Vibration Bars" (At top of steam generator to stabilize the tops of the U-bends.) (Unpublished data provided by L. Bjornkvist of Vattenfall and J. Gorman of Dominion Engineering.)



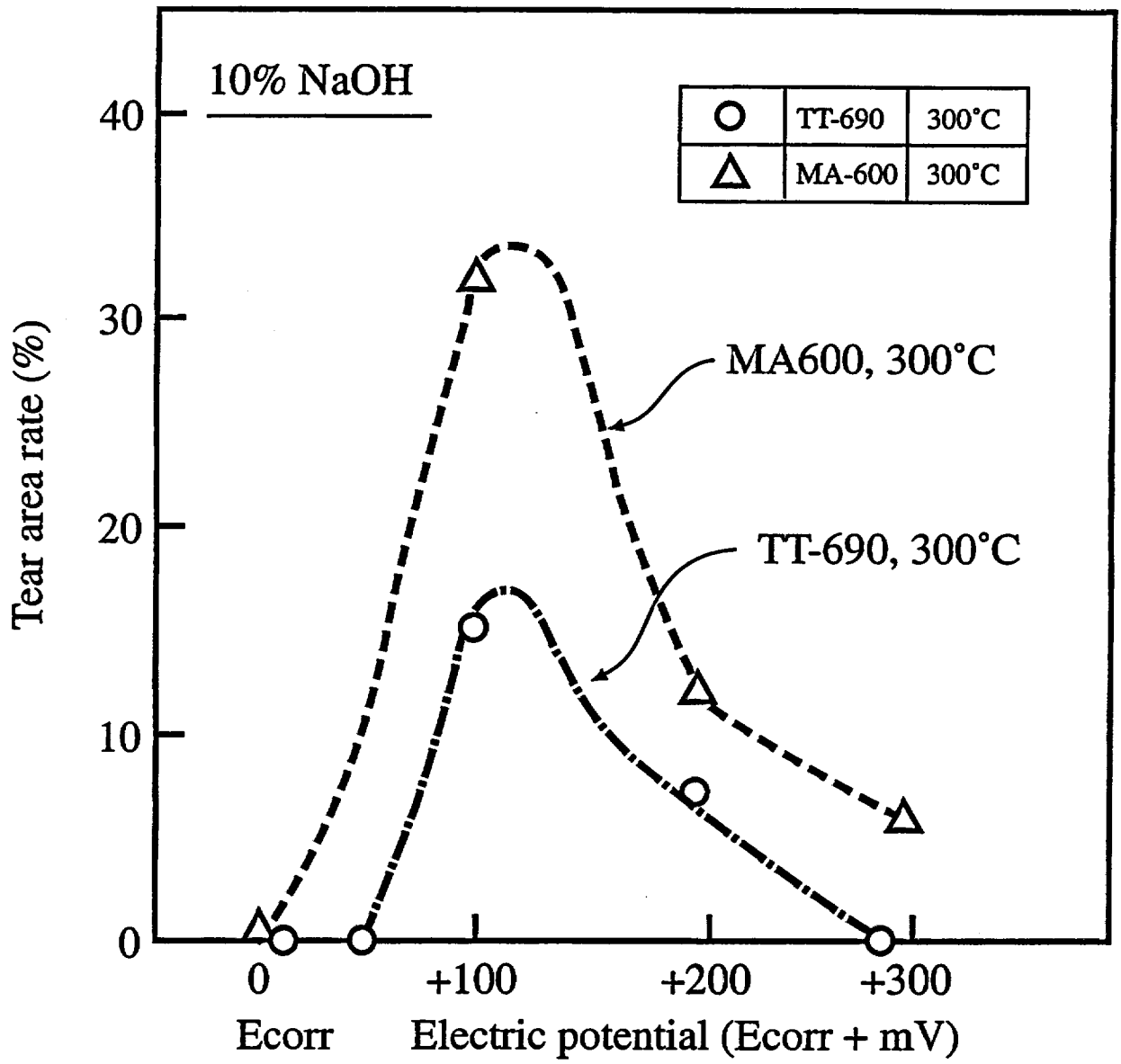

IGA/SCC tests results in the range of 280 to 320°C range as a function of electrode potential and pH taken at 300°C for (a) Alloy 600MA, (b) Alloy 600TT, (c) Alloy 690TT. From Ohsaki et al.[43]

43. I. Ohsaki, K. Onishi, Y. Ohkubo, T. Hattori, and S. Tokunaga, "Study of the Improvement of Steam Generator Tubing and Tube Support Plate Materials," presented at the 2nd International Steam Generator and Heat Exchanger Conference, June 1994, Toronto.

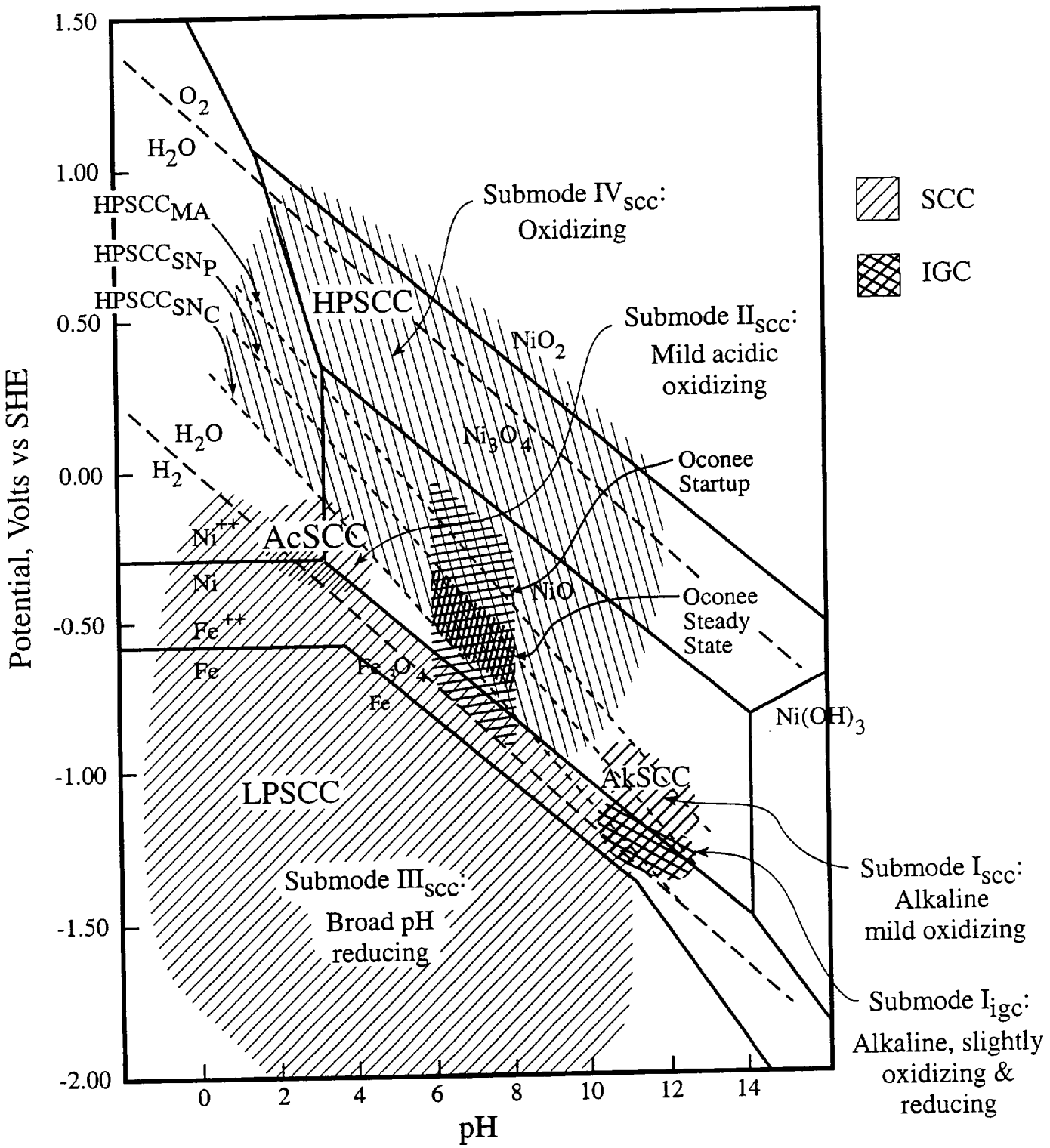



(a) Percent of fracture surface with IGSCC as a function of applied potential for Alloy 600 tested at 350°C using SSRT for two pressures of hydrogen. The open circuit potential is compared with the E-pH diagram for nickel in water in (b). Data from Totsuka and Smialowska.

N. Totsuka and S. Smialowska, Proceedings of the Third International Symposium on Environmental Degradation of Materials in Nuclear Power Systems – Water Reactors, Eds. G.J. Theus, J.R. Weeks, New York, AIME, 1988, p. 691.

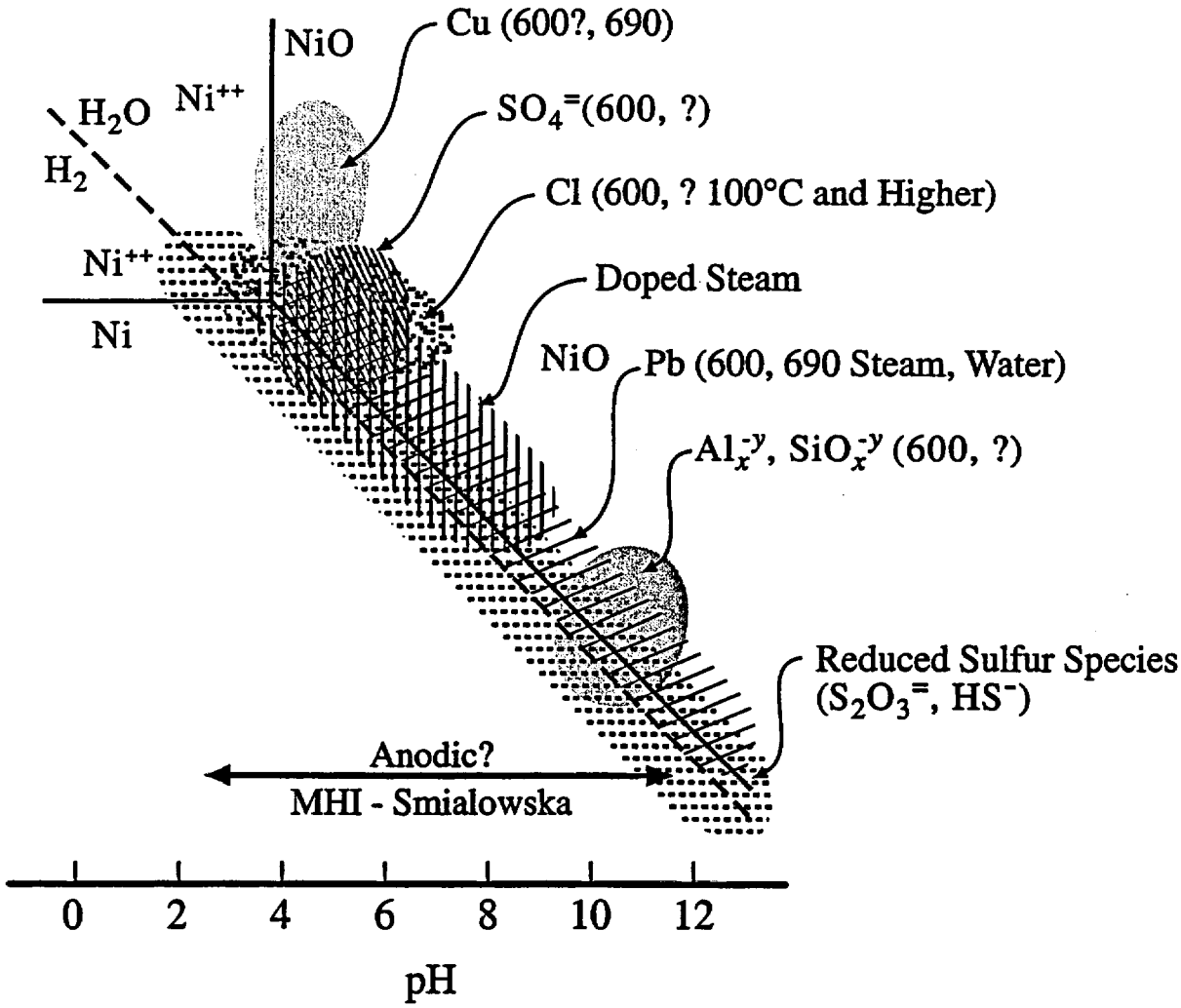

10% NaOH
TT-690 300°C
MA-600 300°C
MA600, 300°C
TT-690, 300°C
Tear area rate (%)
40
30
20
10
0
0
+100
+200
+300
Ecorr
Electric potential (Ecorr + mV)

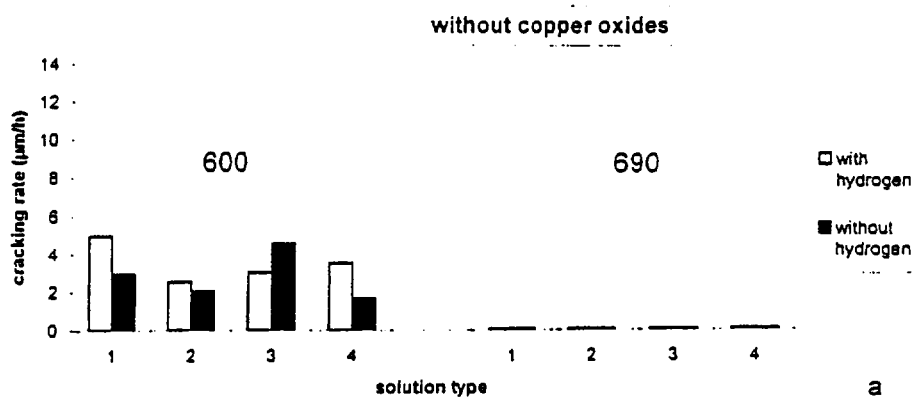
# Alloy 600 Mode Diagram (1999)
# Mill Annealed and Sensitized
# 288°– 350°C
# Compared with Oconee Steady State and Startup

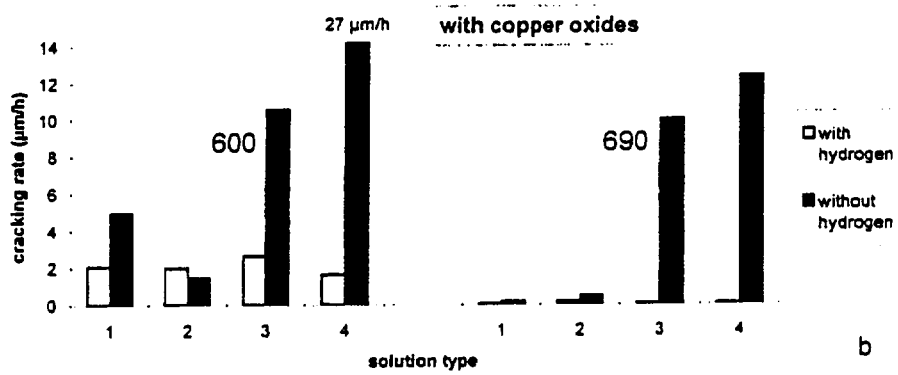


# Alloy 600, 690

## Minor Submodes, Applied to Temperature Range of 288-350°C






Maximum cracking rates obtained with solutions 1 to 4 for alloy 600 (lots 9831and 9649) and for alloy 690 (lot 7430).

Table 1. Composition and pH calculated at 320°C (MULTEQ calculation) of the test solutions

| Solution | Composition | pH |
|---|---|---|
| 1 | 0.082m $Na_2SiO_3$, 0.3m $Fe_3O_4$, 170g/l cationic resins | 2.6 |
| 2 | 0.082m $Na_2SiO_3$, 0.3m $Fe_3O_4$, 170g/l cationic resins, 0.012m Pb | 2.6 |
| 3 | 0.75m $Na_2SO_4$, 0.25m $FeSO_4$ | 4.4 |
| 4 | 0.75m $Na_2SO_4$, 0.25m $FeSO_4$, 0.1m PbO | 4.8 |

E. Pierson, C. Laire, "The Influence of Copper on the SCC of Alloy 600 and Alloy 690 Steam Generator Tubes," in Fontevraud IV- *Contribution of Materials Investigation to the Resolution of Problems Encountered in Pressurized Water Reactors*, Vol. 1 Proceedings, Societe Francaise d'Energie Nucleaire, September 14-18, 1998

# CBDA: Mode Definition--Applied to YM.
## Mode Definition Applied to C-22

1. Analogy to Alloy 600 of major and minor submodes is good place to start

2. All of the Fe-Cr-Ni alloys exhibit about the same general features in their proneness to SCC

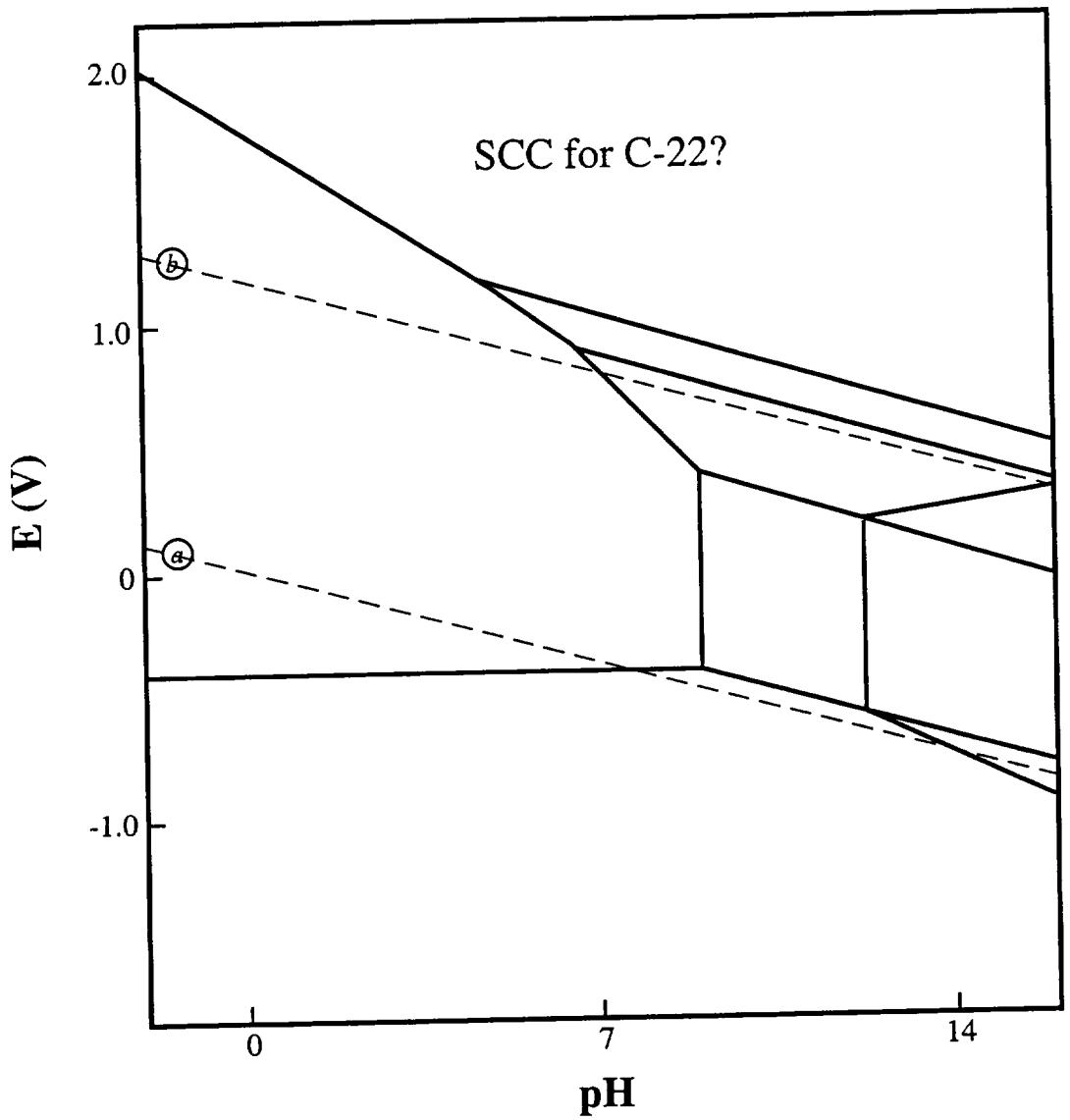
3. Sensitizing heat treatments change regions of proneness to SCC:

   a. Sulfur species

   b. Low temperature proneness

4. So far there is no definition of SCC modes for C-22.

# Mode Diagram for C-22
# (Based on Nickel Background)



# CBDA: Mode Definition--Applied to YM.
## Mode Definition Applied to Ti-Gr7

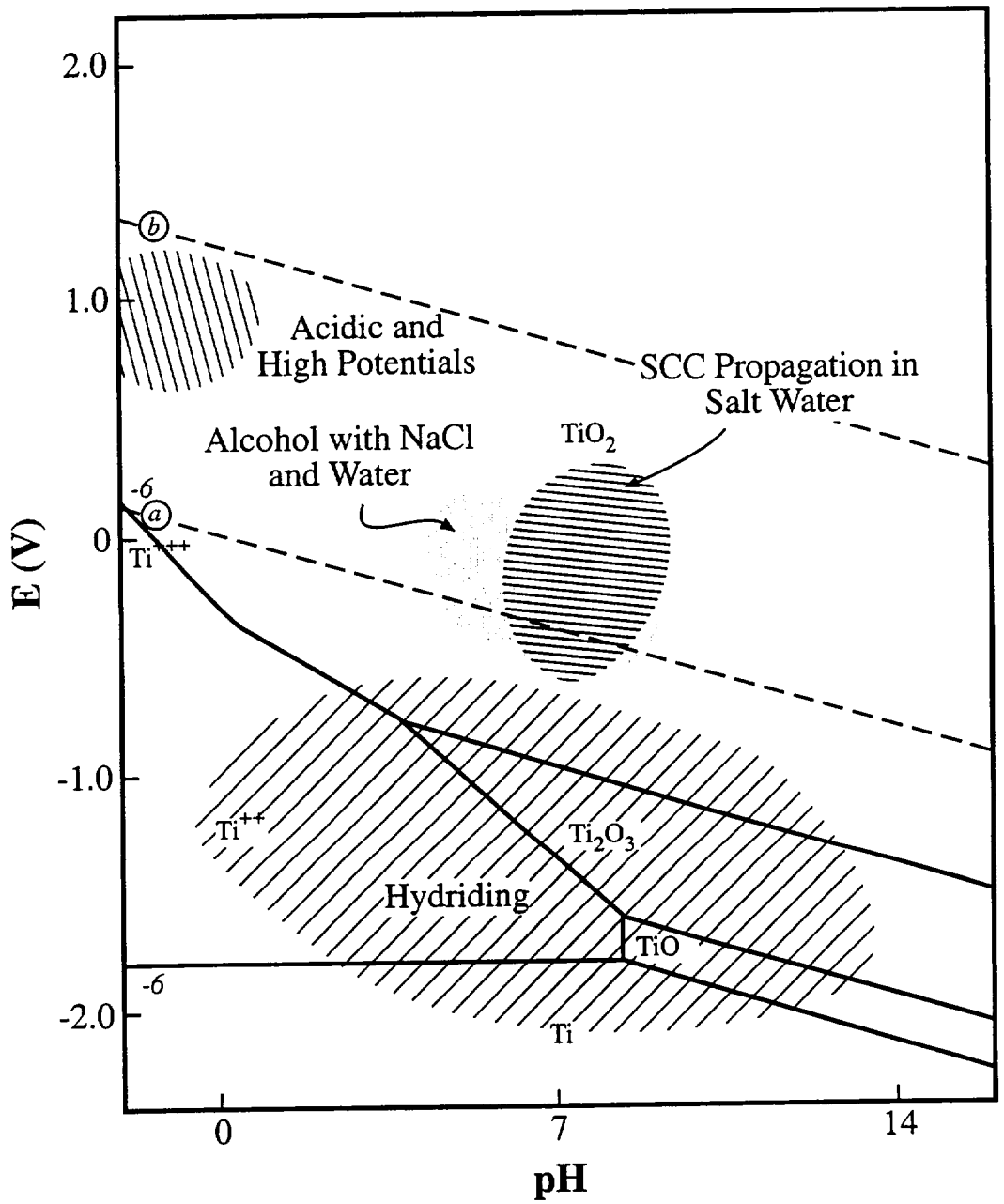
1. Presence of Pd produces a persistently high potential

2. Some features of Ti SCC submodes generally are known

   - Propagation in sea water
   - Acidic oxidizing conditions
   - Alcohol s
   - Iodine

3. Generally, the submodes relevant to YM are not well established.

# General Regions of SCC on Commercial and Alloy Titanium




Note:

- Also SCC in Halide gases

# CBDA: Mode Definition for SCC--Applied to YM. Problems with Dependence on Methods A and B

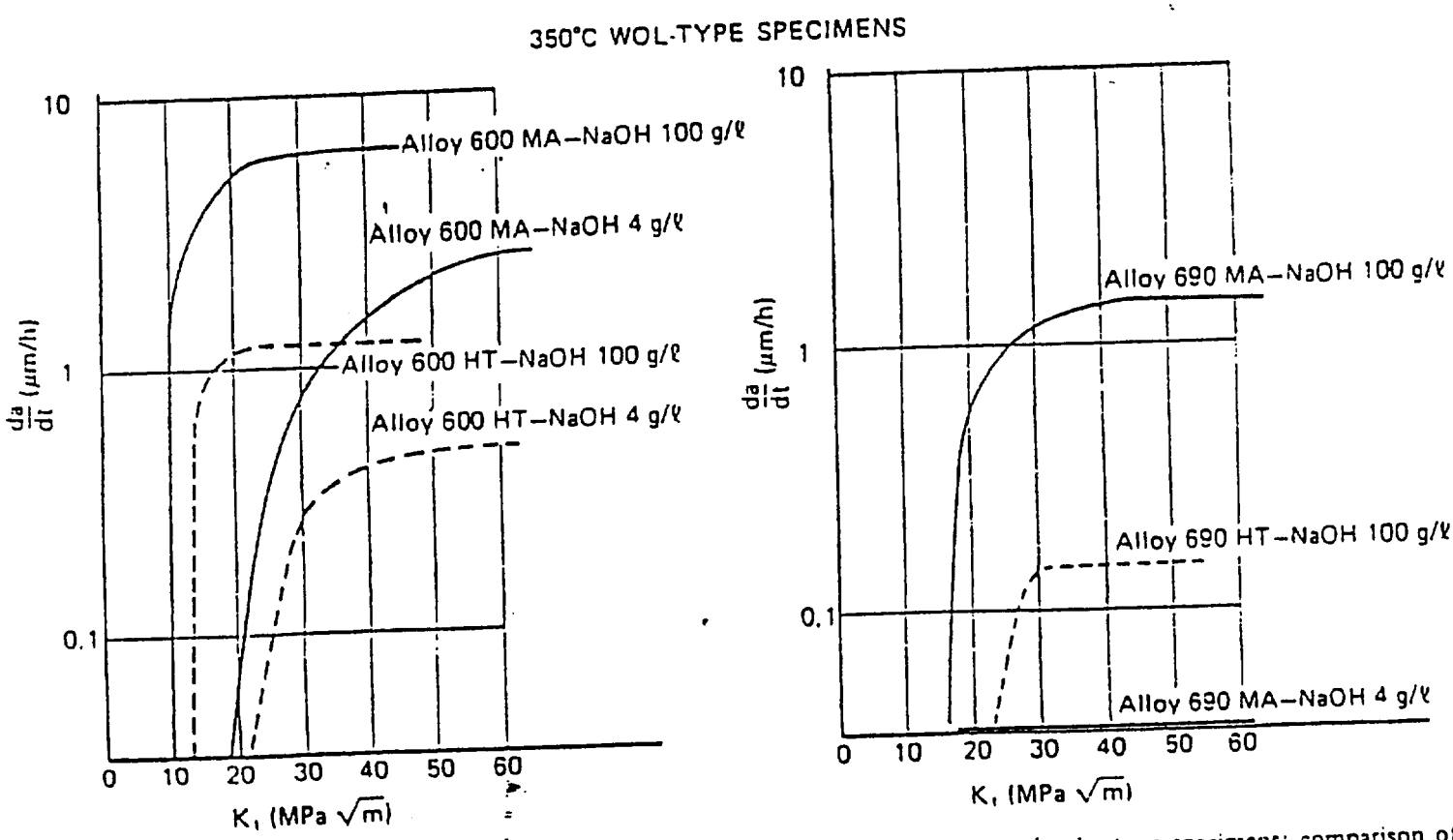
1. The $K_{ISCC}$ determined for C-22 is relevant to only a limited set of conditions and most likely not to the concentrated chemistry expected on a heated surface. e.g. the $K_{ISCC}$ for Alloy 600 in alkaline environments is in the range of 10 Ksi $in^{1/2}$.

2. The relationship

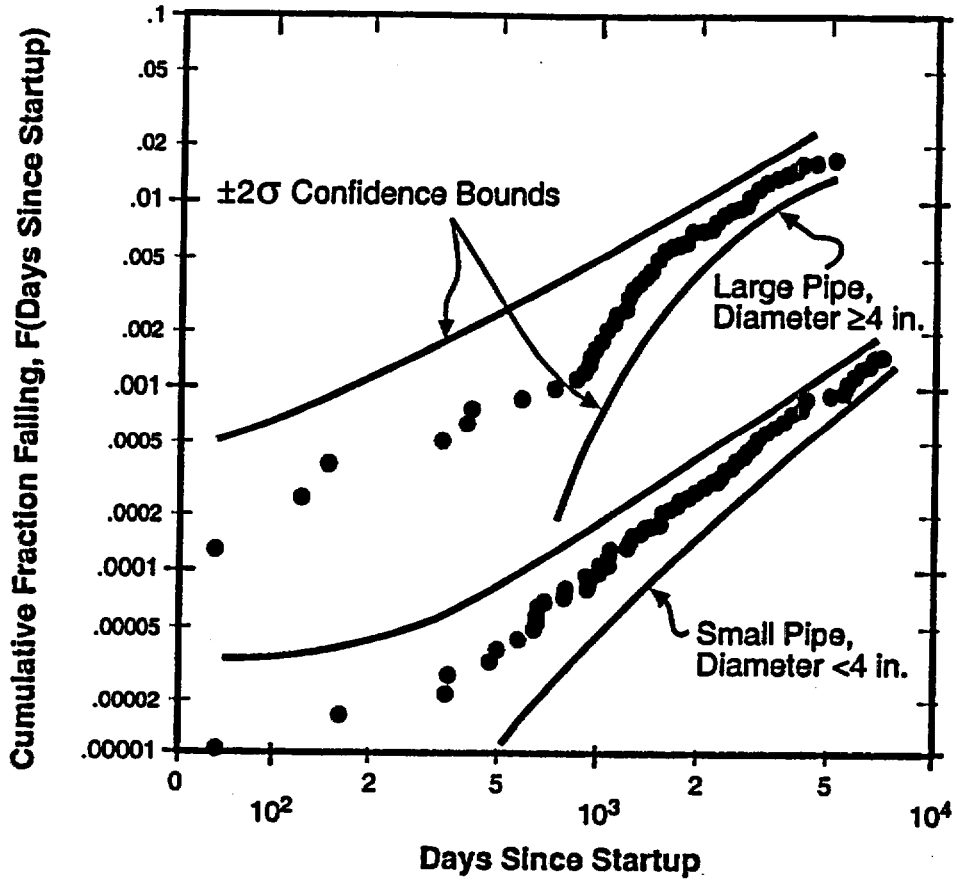
$$V_t = A\left(\dot{\varepsilon}_{ct}\right)^n$$

   does not predict anything. It only correlates data and does not apply nor distinguish readily the many submodes of SCC observed on the secondary side of steam generators.

3. These relationships do not interpret the actual occurrence of SCC in BWRs in the statistical array as occur in the field.




Stress corrosion tests in deaerated sodium hydroxide at 350°C on fracture mechanics-type specimens: comparison of Alloys 600 and 690 behavior. Effect of heat treatment at 700°C for 16 h.



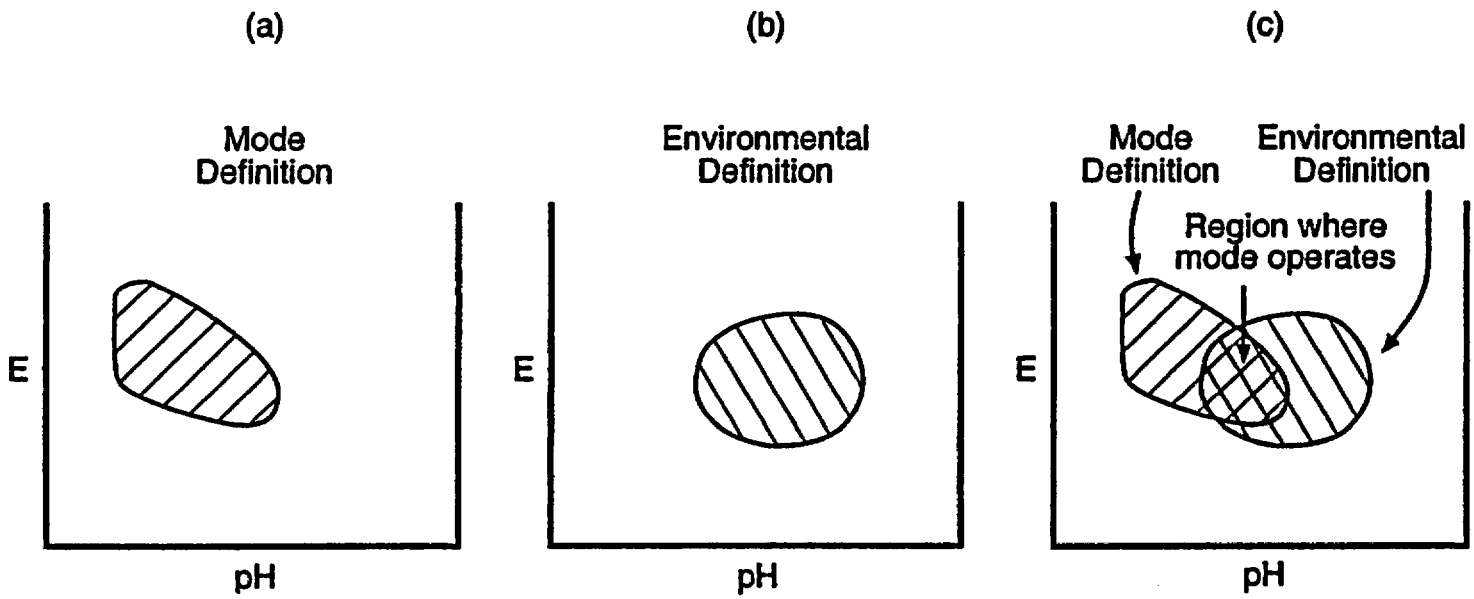

*Cumulative fraction failed versus time for piping of two ranges of diameters exposed in boiling water nuclear reactors where the environments are pure water. The larger diameter pipes include only IGSCC, and the smaller pipes include all failure modes although they are mainly IGSCC. The Weibull characteristics, θ, and slopes, b, are 144 years and 1.2 and 1675 years and 1.4, respectively, for the large and small pipes. (Adapted from Eason and Shusto [27].)*

# CBDA: Superposition--Applied to YM.

1. Superposition involves comparing environmental definition with mode definition for a specifically defined material

2. Require thorough definitions of SCC (and other corrosion) submodes.

3. Require thorough definition of environments




*(a) Mode definition, (b) environmental definition, and (c) overlap shown schematically in the coordinates of potential and pH. (From Staehle [21].)*

# CBDA: Accelerated Corrosion Testing—Applied to YM

1. Accelerated testing must be responsive to the following for container and drip shield:

    a. real conditions of hot surfaces including deposits

    b. complicated chemistry of the YM

    c. diversity of metallurgy

2. Isothermal testing is not adequate for heated surface condition; adequate if it considers environments on heated surfaces.

3. Analogy of model boiler (in the commercial reactor world) necessary to study integrated corroding systems.

4. Prototype of "unit cell" in YM required to model full environmental conditions of YM as they affect one cell.

5. Real manufactured containers required for realistic testing.

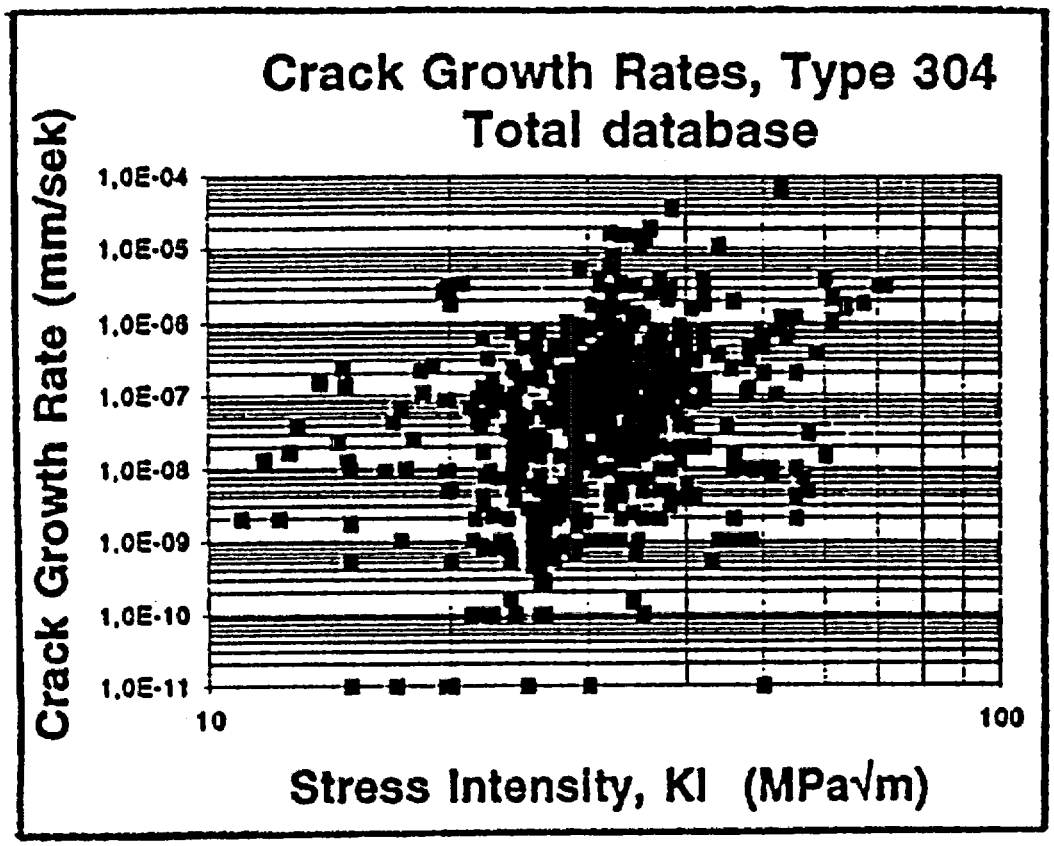
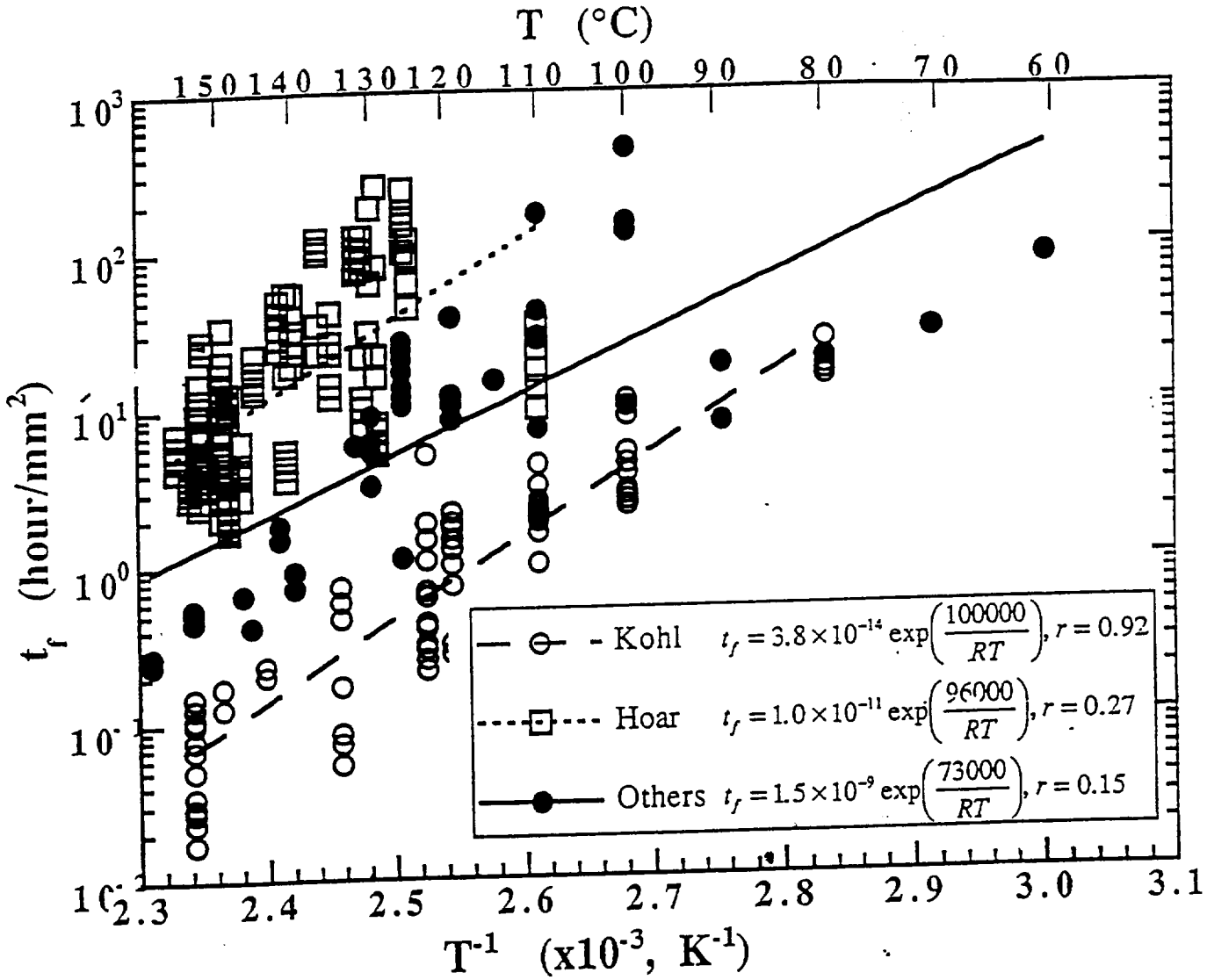



**Fig 1 All available CGR data in the database for Type 304 in various BWR environments**

Note –

- Data not censored
- Multiple test methods, some of questionable validity

C. Jansson and U. Morin, "Assessment of Crack Growth Rates in Austenitic Stainless Steels in Operating BWRS." *Proceedings: Eighth International Symposium on Environmental Degradation of Materials in Nuclear Power Systems – Water Reactors,* Eds. A.R. McIlree and S.M. Bruemmer, American Nuclear Society, La Grange Park, Illinois, 1997.




Times-to-failure versus temperature for the 23 sets of data measured for stainless steels in boiling 35-42% $MgCl_2$ solutions at open circuit potentials. Data from Table 2.

X.C. Jiang and R.W. Staehle, "Effects of Stress and Temperature on Stress Corrosion Cracking of Austenitic Stainless Steels in Concentrated Magnesium Chloride Solutions,"*Corrosion Journal*, Vol. 53, No. 6, June, 1997, pp. 448-466.

# Tests to Explore Specific Aspects of the Corrosion Resistance of C-22

Professor Aaron Barkatt
Dr. April Pulvirenti
Catholic University of America

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Performed for the State of Nevada
and Geosciences Management Inc.

October 18, 2000
ACNW meeting
Rockville, Maryland

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# Preliminary Tests in Aggressive Environments

- Purpose of tests was to determine in a preliminary fashion whether species such as lead, mercury, arsenic or sulfides could aggravate corrosion of C-22 (e.g., SCC, pitting or crevice corrosion).
- Tests explored acid and caustic environments with and without lead, mercury, arsenic and sulfides.
- Tests of U-bends, mostly at 250 °C.
- Tests of static disks at 163°C

# Species Concentration in Simulated 1000x J-13 Concentrate

| Species | Concentration (ppm) |
|---|---|
| $Ca^{2+}$ | 30 |
| $Cl^{-}$ | 6123 |
| $F^{-}$ | 1550 |
| C | 1546 |
| Si | 8404 |
| $K^{+}$ | 4792 |
| $NO^{3-}$ | 6729 |
| $Na^{+}$ | 44082 |
| $SO_4^{2-}$ | 15711 |
| $Li^{+}$ | 36 |
| B | 17 |

# U-Bend Tests - Matrix and Results

| Sample ID | Temperature (°C) | $pH_{RT}$ | $pH_T$ | Weld? | Minerals?# (10g/Vessel) | Tuff? (10g/Vessel) | Accelerant • | Potential | Duration (days) | Results |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 250 | 2.6* | 5.6 | no | yes | no | none | --- | 32 | tarnished |
| 2 | 250 | 2.6* | 5.6 | no | no | no | none | --- | 32 | slight pitting |
| 3 | 250 | 12.5 | 9.6 | no | yes | no | none | --- | 32 | tarnished |
| 4 | 250 | 12.5 | 9.6 | no | no | no | none | --- | 32 | tarnished |
| 5 | RT | 2.6* | 2.6 | no | yes | no | $H_2$ | --- | 61 | none |
| 11 | 200 | 12.5 | 9.8 | no | yes | yes | none | --- | 35 | none |
| **12** | **250** | **0.53†** | **1.6** | **no** | **no** | **no** | **Pb** | **---** | **15** | **through specimen crack** |
| 14 | 250 | 11.92 | 9.6 | no | no | no | S | --- | 21 | tarnished |
| 15 | 250 | 1.32† | 4.53 | no | no | no | Hg | --- | 8 | very severe pitting |
| W-1 | 250 | 2.6* | 5.6 | yes | yes | no | none | --- | 32 | tarnished |
| W-2 | 250 | 2.6* | 5.6 | yes | no | no | none | --- | 32 | slight pitting |
| W-3 | 250 | 12.5 | 9.6 | yes | yes | no | none | --- | 32 | tarnished |
| W-4 | 250 | 12.5 | 9.6 | yes | no | no | none | --- | 32 | tarnished |
| W-5 | RT | 2.6* | 2.6 | yes | yes | no | $H_2$ | --- | 61 | none |
| W-13 | 200 | 12.5 | 9.8 | yes | yes | yes | none | +200mV | 35 | none |
| W-14 | 250 | 12.11 | 9.6 | yes | no | no | Pb | --- | 29 | tarnished |
| W-15 | 250 | 0.59† | 1.6 | yes | no | no | S | --- | 29 | severe pitting |

* with sulfuric acid; † with hydrochloric acid;

• Hydrogen Gas Saturated and Over-Laid; Lead Acetate at 5000 ppm Pb; Sodium Sulfite at 3200 ppm S; Mercury Acetate at 6300 ppm Hg;

# mineral mixture consists of 70% pyrite ($FeS_2$), 20% galena (PbS) 5% cinnabar (HgS) and 5% realgar ($As_2S_2$)

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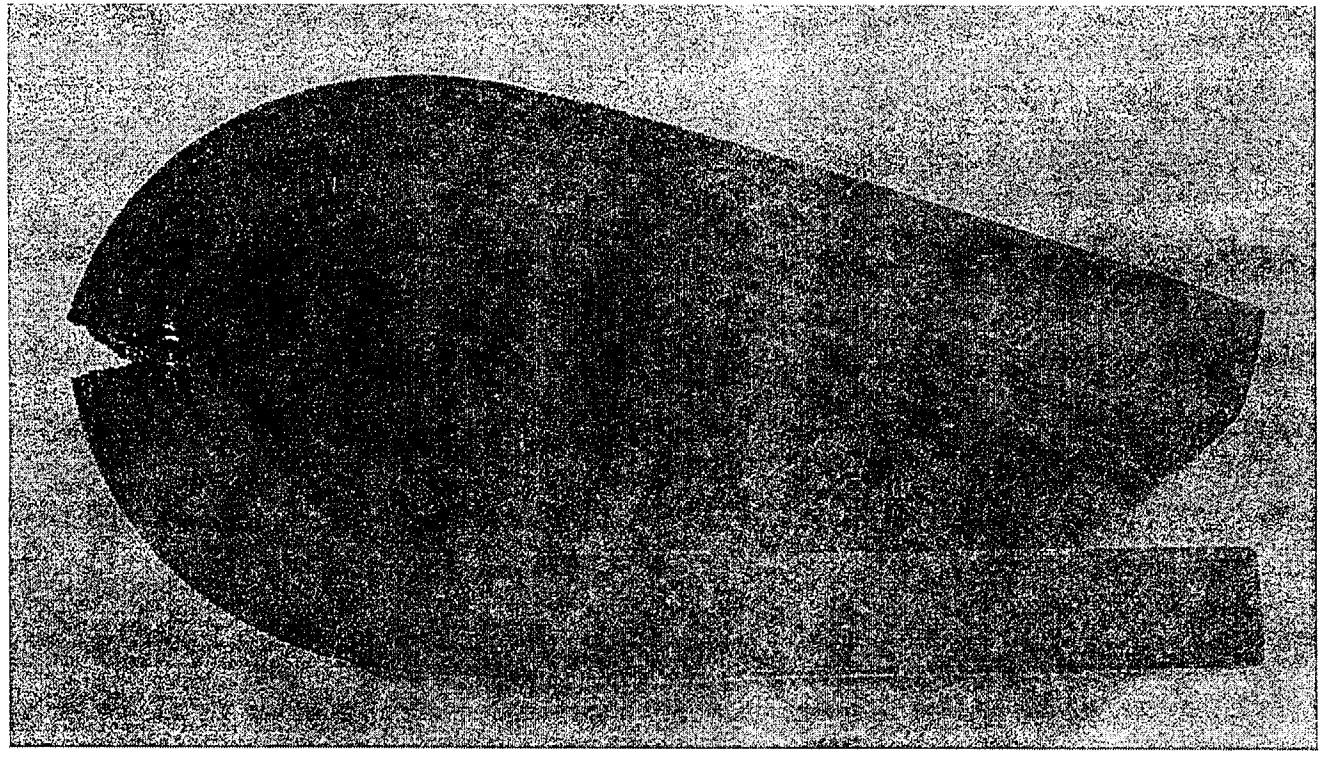
# U-Bend Tests - Matrix and Results (Cont.)

| Sample ID | Temperature (°C) | $pH_{RT}$ | $pH_T$ | Accelerant | Duration (days) | Concentration in Post Test Solution (mg/L or ppm) | | | | | % Weight Lost | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cr | Ni | Fe | Mo | Pb | | |
| 1 | 250 | 2.6 | 5.6 | none | 32 | 3 | 70 | 120.5 | NM | 3.1 | 0.14 | tarnished |
| 2 | 250 | 2.6 | 5.6 | none | 32 | 21 | 39 | 3.2 | NM | 0.6 | 0.10 | slight pitting |
| 3 | 250 | 12.5 | 9.6 | none | 32 | 1 | 1.2 | 0.35 | NM | 0 | 0.00 | tarnished |
| 4 | 250 | 12.5 | 9.6 | none | 32 | 43 | 1.4 | 0.45 | NM | 0.65 | 0.00 | tarnished |
| 5 | RT | 2.6 | 2.6 | $H_2$ | 61 | 3.4 | 19 | 82 | 0.7 | 5.85 | 0.00 | none |
| 11 | 200 | 12.5 | 9.8 | none | 35 | 0.8 | 0.7 | 1.1 | 3.1 | 7.3 | 0.00 | none |
| **12** | **250** | **0.53** | **1.6** | **Pb** | **15** | **16** | **3217** | **857** | **31** | **NM** | **0.88** | **through specimen crack** |
| 14 | 250 | 11.92 | 9.6 | S | 15* | 2 | 0.8 | 6.3 | 21 | NM | 0.00 | tarnished |
| 15 | 250 | 1.32 | 4.53 | Hg | 8 | 5.1 | 413 | 65 | 151 | 12.1 | 0.54 | very severe pitting |
| W-1 | 250 | 2.6 | 5.6 | none | 32 | 3 | 70 | 120.5 | NM | 3.1 | 0.12 | tarnished |
| W-2 | 250 | 2.6 | 5.6 | none | 32 | 21 | 39 | 3.2 | NM | 0.6 | 0.13 | slight pitting |
| W-3 | 250 | 12.5 | 9.6 | none | 32 | 1 | 1.2 | 0.35 | NM | 0 | 0.00 | tarnished |
| W-4 | 250 | 12.5 | 9.6 | none | 32 | 43 | 1.4 | 0.45 | NM | 0.65 | 0.00 | tarnished |
| W-5 | RT | 2.6 | 2.6 | $H_2$ | 61 | 3.4 | 19 | 82 | 0.7 | 5.85 | 0.00 | none |
| W-13 | 200 | 12.5 | 9.8 | none | 35 | 0.8 | 0.7 | 1.1 | 3.1 | 7.3 | 0.00 | none |
| W-14 | 250 | 12.11 | 9.6 | Pb | 29 | 117 | 0.3 | 1.8 | 91 | 1311 | 0.00 | tarnished |
| W-15 | 250 | 0.59 | 1.6 | S | 29 | 15 | 2574 | 507 | 0.1 | 4.4 | 0.42 | severe pitting |

* mid-test sample, not post-test solution

# Sample 12 (Lead-Acid)



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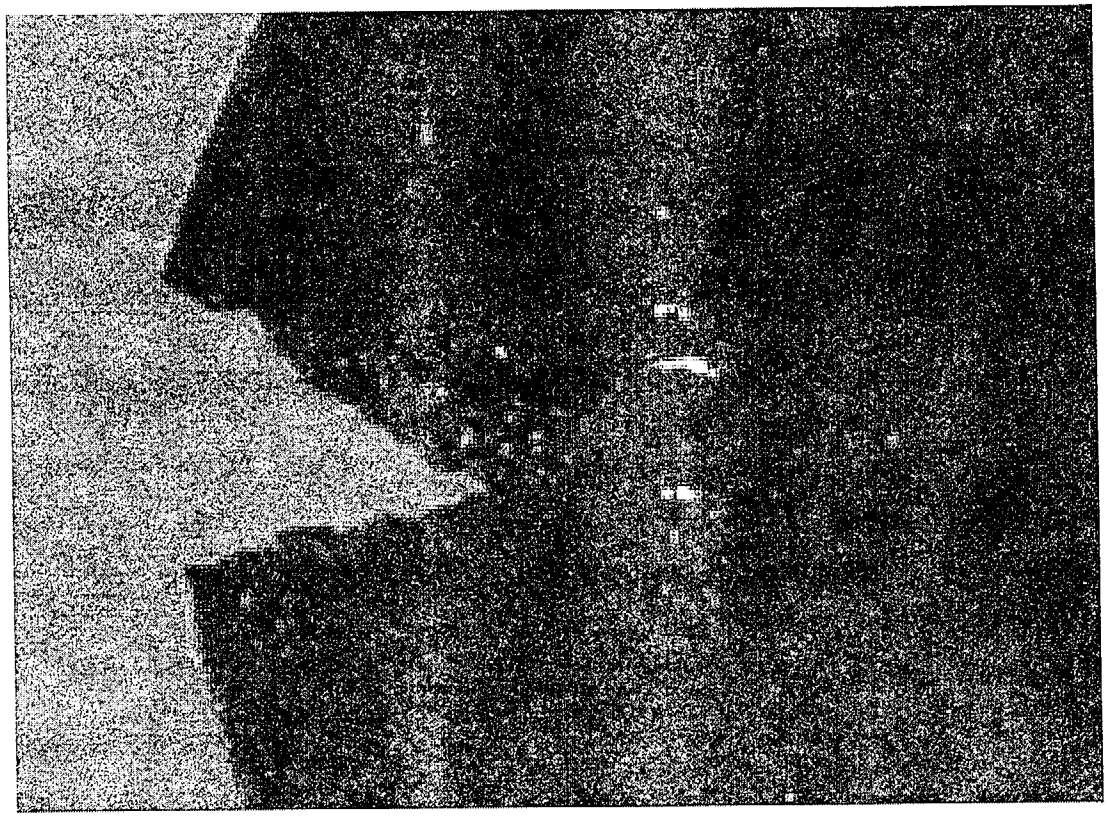
# Sample 12 (Lead-Acid)



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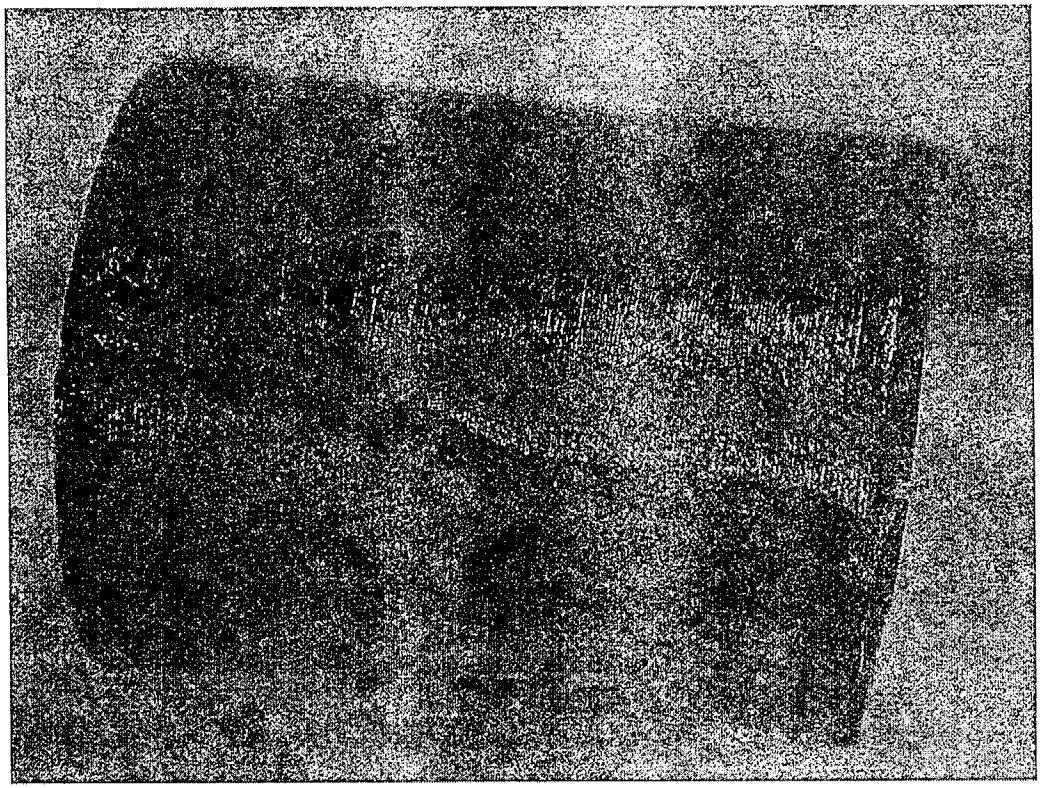

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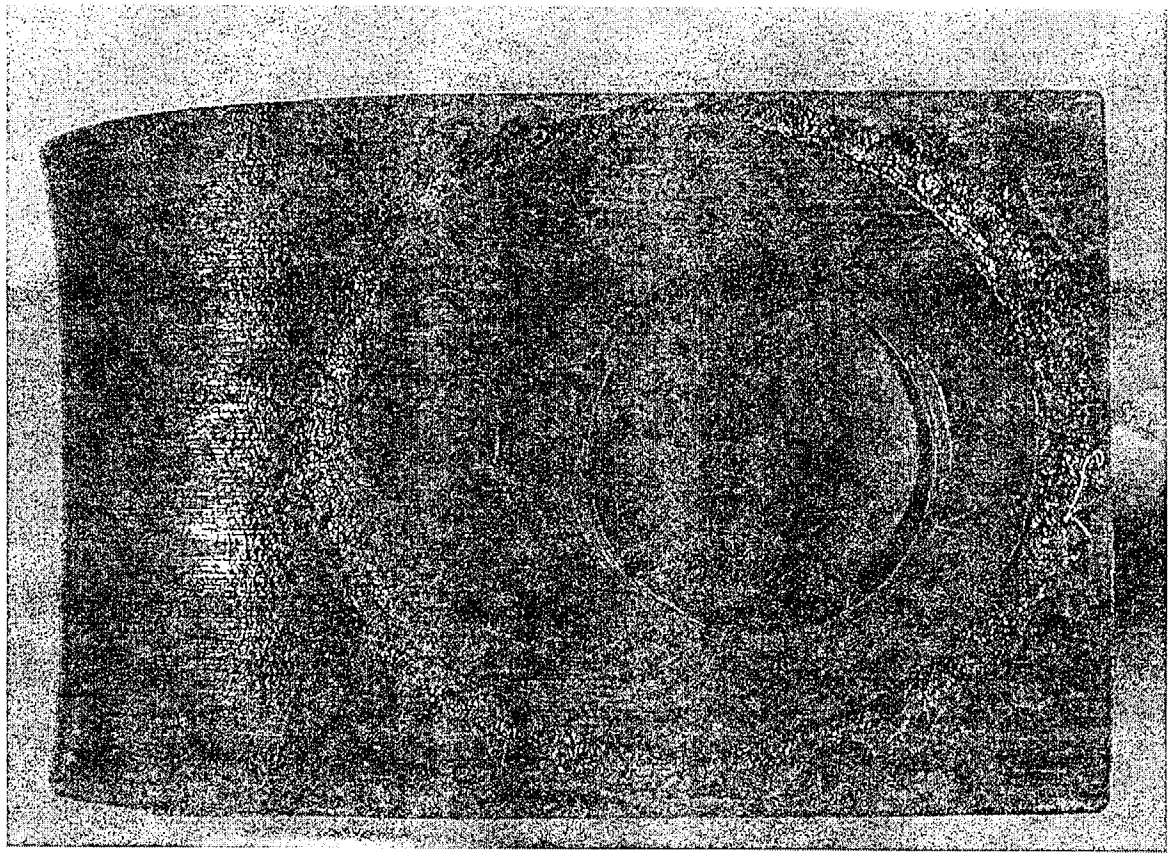

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# Sample 12 (Lead-Acid)

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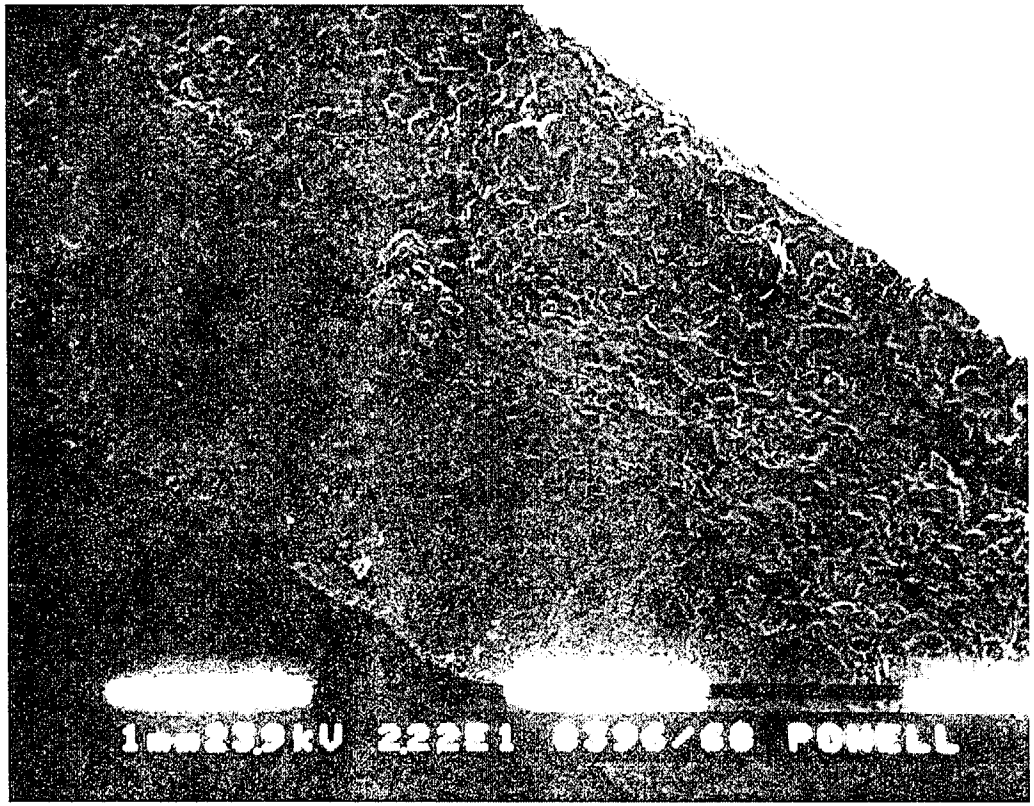


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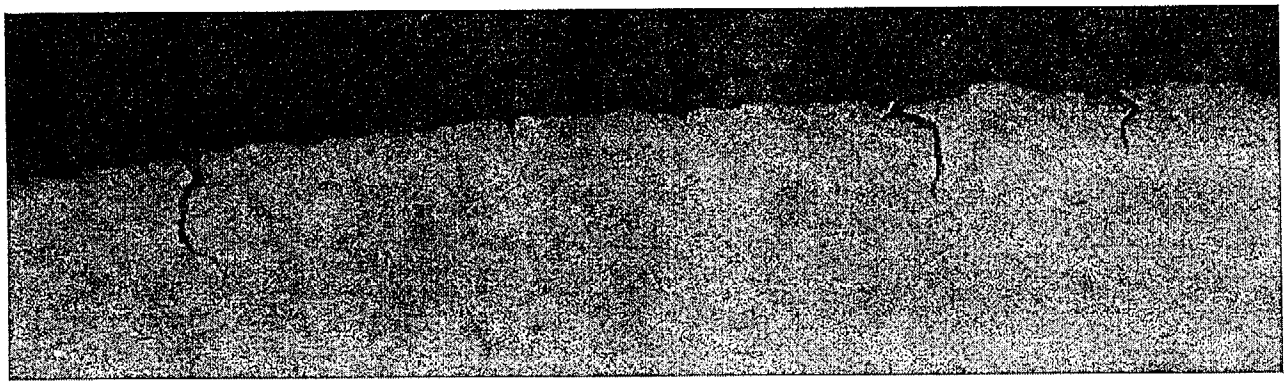
# Sample 12 (Lead-Acid)



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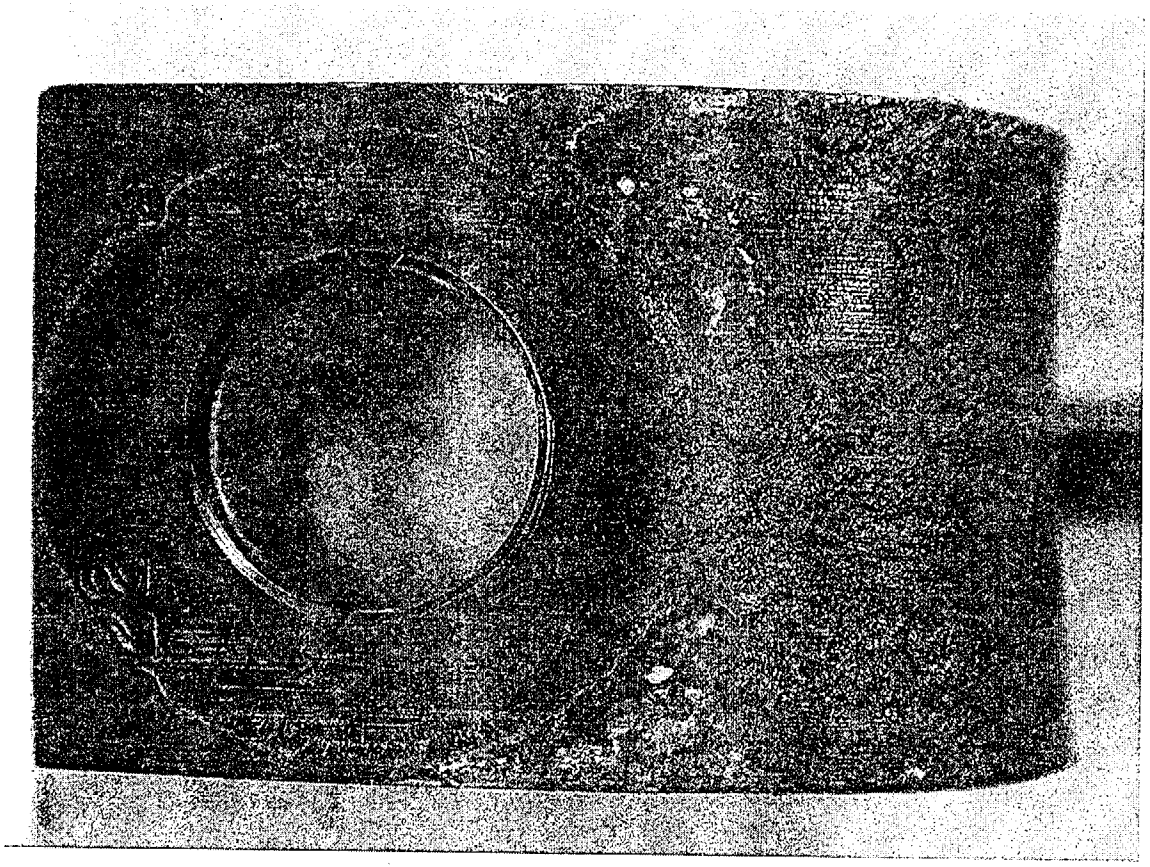
# Sample 15 (Mercury-Acid)



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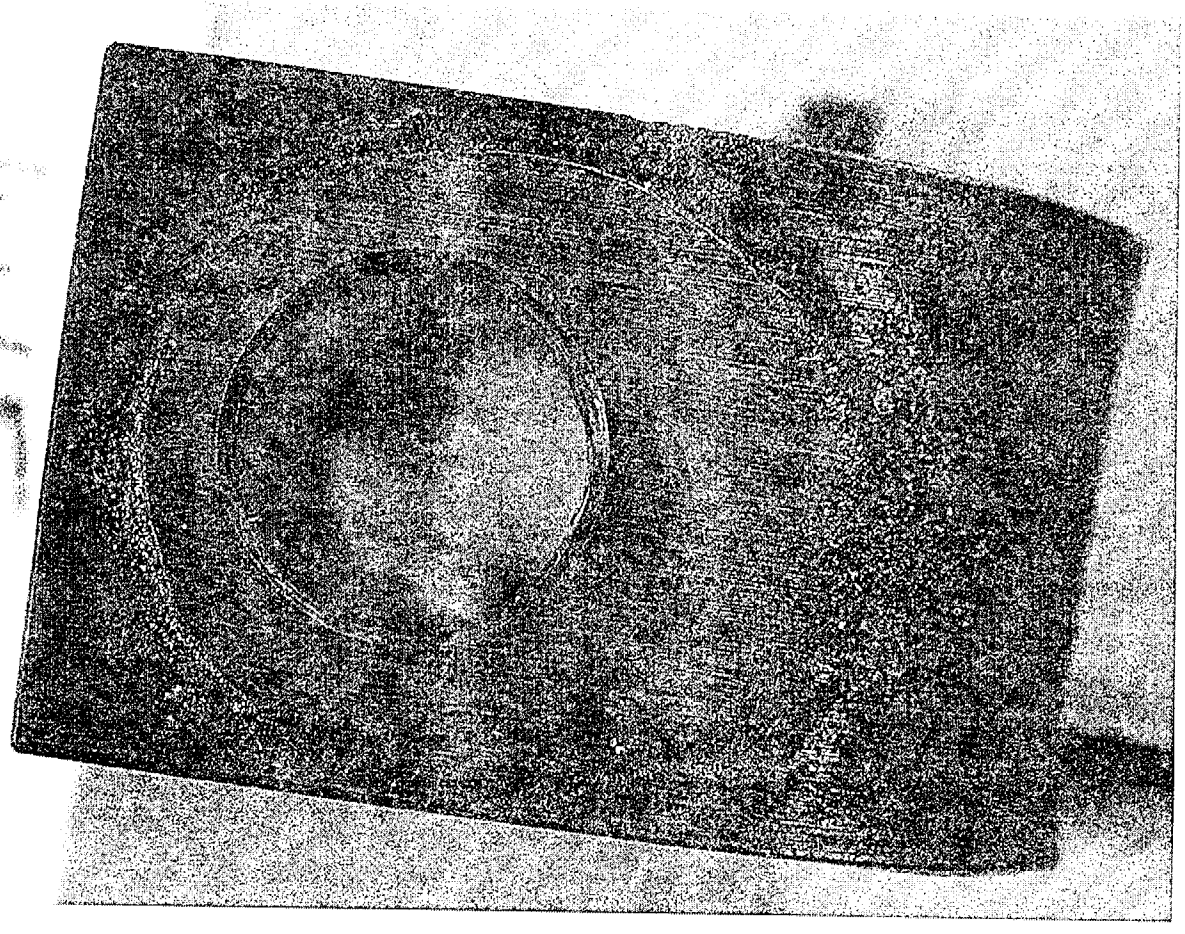
# Sample W-15 (Sulfur-Acid)



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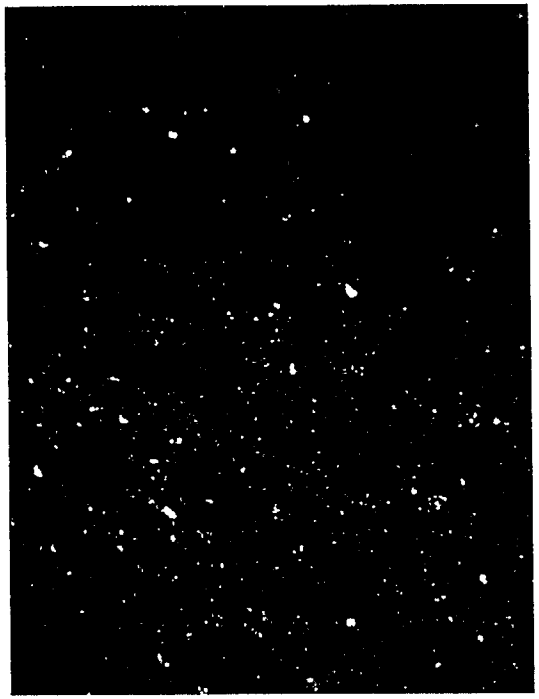
# Concentrations of Main Alloying Elements After Testing

Tests of C-22 Unstressed Disks, 20 mL of solvent, 163°C, 15 days

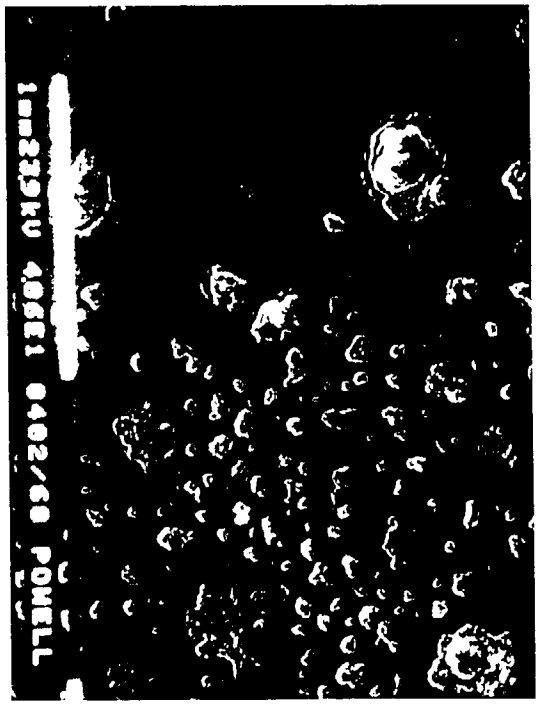
| Additives to 1000x J-13 Water | $pH_{RT}$ | Concentrations (mg/L or ppm) | | | |
|---|---|---|---|---|---|
| | | Cr | Ni | Fe | Mo |
| 2.25% $H_2O_2$ | 12.89 | 3.8 | 0.7 | 1.5 | 3.3 |
| 3.86% $Pb(OAc)_2$ | 13.15 | 4.3 | 0.5 | 0.2 | 4.1 |
| 4.34% $CuCl_2$ | 13.21 | 2.7 | 0.4 | 0.4 | 2.1 |
| 4.50% $Na_2CO_3 \cdot 1.5H_2O_2$ + 1.93% $Na_2SiO_3$ | 13.25 | 4.4 | 0.8 | 2.5 | 3.3 |
| 3.50% $As_2O_3$ | 12.90 | 1.8 | 0.7 | 1.3 | 1.4 |
| 4.50% $FeCl_3$ | 13.17 | 1.2 | 0.3 | 0.4 | 2.3 |
| none | 13.20 | 2.8 | 1.0 | 2.1 | 2.3 |
| 4.0% $Hg(OAc)_2$ | 13.15 | 75.9 | 0.7 | 4.2 | 60.9 |
| 3.86% $Pb(OAc)_2$ + $H_2SO_4$ | 2.52 | 250.4 | 1868.8 | 7.0 | 22.0 |
| 4.0% $Hg(OAc)_2$ + $H_2SO_4$* | 2.65 | 421.5 | 1727.5 | 48.8 | 266.3 |

* Test duration only 7 days

# Sample C20 (Lead-Acid)



Stereomicroscope




SEM

# Main Findings - Tests of U-Bends

30-day tests were conducted on stressed U-bend samples in modified 1000x concentrated J-13 water at 250°C

- Acidified solution ($pH_{RT}$ 0.5) without additives:
  - The corrosion is mild and involves shallow general corrosion and pitting, possibly with some deposition.
- Acidified solution ($pH_{RT}$ 0.5) with mercury:
  - Strong general corrosion, pitting, and deposition of corrosion products are observed.
  - No accumulation of mercury is observed on corroded surface.

# Main Findings - Tests of U-Bends (Cont.)

- Acidified solution ($pH_{RT}$ 0.5) with lead:
  - Cracking occurs first in a transgranular mode.
  - When this cracking relieves the stress (at about the halfway point), crack growth continues in an intergranular mode.
  - Numerous secondary cracks, mostly intergranular, are observed.
  - Corrosion product deposition is observed, mostly in the transgranular (TG) region. The deposit-covered TG region is enriched in silicon and depleted with respect to nickel and tungsten.
  - Pitting may precede the transgranular cracking.
  - A large amount of lead concentrates at the crack surface.
- The corrosion mechanism in the presence of lead appears to be different than the mechanism in the presence of mercury.

# Main Findings - Tests of Unstressed Disks

In 15-day tests on unstressed disks in J-13 water concentrated X1000 at 163°C, corrosive attack was identified in specimens exposed to moderately acidic environment ($pH_{RT}$ 2.5) in the presence of lead.

- The surfaces of the specimens were strongly pitted.
- Extensive deposition of corrosion products was observed.
- A very large amount of lead concentrated on the pitted surface.
- Ongoing tests indicate that mercury aggravates pitting.

# Main Findings - Tests of Unstressed Disks: Chemical Analysis of Dissolved Species

- In moderately acidic media ($pH_{RT}$ 2.5) both lead and mercury caused extensive dissolution of C-22 ingredients, in particular nickel.
- In basic concentrated J-13 ($pH_{RT}$ 13) mercury, but not lead, caused moderately significant dissolution of chromium and molybdenum.
- In general, surface characterization and wet analysis agree with respect to lead and mercury exhibiting large specific effects of enhancing C-22 corrosion.

# Conclusions from Preliminary Tests

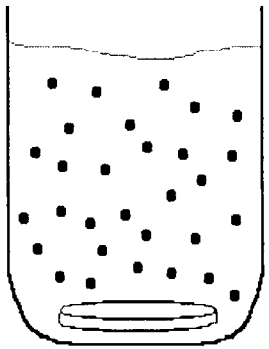
- The preliminary tests indicate that, in some environments, small amounts of aggressive species that could be present in the repository water, such as lead and mercury, can strongly aggravate pitting, crevice corrosion and SCC of C-22.
- It is concluded that the qualification program for alloy C-22 may need to evaluate the possible presence and effects of aggressive species such as lead, mercury, arsenic, and sulfides.

# Concentration versus Inventory

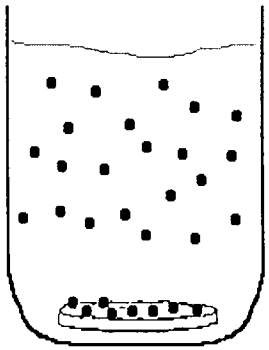
- Aggressive species concentrations may be less important than their inventories (total mass in the environment)
- If C-22 adsorbs aggressive species, surface concentrations will be high, even if environmental concentrations are low
- High surface concentrations could be deleterious
- Geological measurements indicate that aggressive species inventories are high, even though concentrations may be low

# Concentration Hypothesis

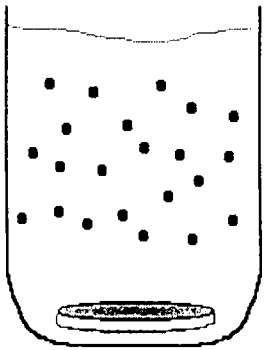
## High concentrations of aggressive species are required for accelerated corrosion



Pb concentrated in solution



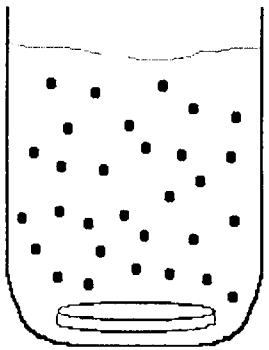
Little or no lead sorbed to the surface



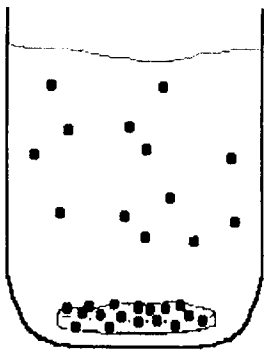
Most Pb remains in solution and does not contribute to corrosion

# Adsorption Hypothesis

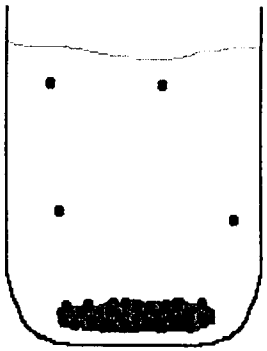
## High inventories of aggressive species are required for accelerated corrosion



Pb concentrated in solution



All Pb is eventually scavenged by the C-22



All Pb contributes to corrosion — very little remains in solution

# Lead Adsorption Testing

- Unstressed C-22 Disks
- J-13 x1000, minus lead precipitating species
- 160°C
- 14 day incubation
- Several levels of lead (<0.01 to 275 ppm in 15 ml)
- Measured lead
  - original solution
  - decanted solution

# Results of Lead Adsorption Tests

| Initial Pb | | Pb in Decanted Solution | | Percent Sorbed on C-22* | Appearance |
|---|---|---|---|---|---|
| Concentration | Inventory | Concentration | Inventory | | |
| ppm | μg | ppm | μg | | |
| <0.01 | < 0.01 | <0.01 | < 0.01 | — | Almost unchanged |
| 35 | 0.518 | 4.7 | 0.07 | 87 | Light tarnish |
| 125 | 1.88 | 0.9 | 0.014 | 99 | Light tarnish |
| 275 | 4.12 | 14.4 | 0.216 | 95 | Tarnish |

* Calculated based on fraction of initial inventory absent from the decanted solution

# Lessons from Nuclear Power Plant Experience

Numerous materials selected on basis of good general corrosion resistance have turned out to be susceptible to SCC. Examples include:

- Austenitic stainless steels (SS) for BWR structural materials
- Inconel 600 for PWR steam generator (SG) tubes
- X750 in AH heat treatment for bolting and similar hardware
- A286 for reactor internals bolting
- 17-4 PH SS for high temperature valve parts and bolting
- Martensitic SS for bolting and other hardware
- Zircaloy fuel rod cladding

These case histories highlight that, despite apparently careful selection and qualification, significant corrosion in service can occur.

# Example 1: BWR Stainless Steel Cracking

- Extensive cracking has occurred at welds in austenitic SS in BWR piping and internals. Lengthy and expensive inspections and repairs have been required.
- Austenitic SS was chosen based on its good general corrosion resistance. Selection failed to adequately consider:
  - Effects of sensitization at welds
  - Effects of oxidizing potentials caused by radiolytically produced oxidants
  - Effects of residual stresses and local cold work due to grinding

# Example 2: Inconel 600 SG Tube Cracking

- Extensive cracking has occurred of Inconel 600 SG tubes and has required extensive plant changes, water chemistry upgrades, inspections and SG replacements.
- Selection of Inconel was based on its good general corrosion resistance and resistance to chlorides, but failed to consider:
  - Large variation in susceptibility to SCC as a function of processing history and compositional variations (1000x!)
  - Effects of low potentials, cold work and residual stresses on SCC from primary side
  - Effects of oxidizing potentials, concentration of impurities (leading to high and low pH), and trace aggressive species (such as lead) on intergranular attack (IGA) and SCC from secondary side.
  - Effects of minor elements in the metal, such as boron, on susceptibility to SCC.

# Example 3: Failures of High Strength Materials

- Many failures have occurred of high strength materials such as X750, A286, 17-4 PH, and martensitic SS. These have resulted in extensive inspections and replacements.
- Materials were selected based on their good general corrosion resistance. Selection failed to consider:
  - Susceptibility to SCC in long time exposure to reactor environments of material heat treated based on aerospace applications.
  - Effects of local residual stresses and cold work on susceptibility to SCC.
  - Effects of time at temperature on material properties (embrittlement) and susceptibility to SCC.
  - Needs for detailed quality control to assure that desired material conditions (proper heat treatment) are achieved.

# Example 4: SCC of Zircaloy Cladding

- Many failures occurred due to SCC of zircaloy fuel rod cladding associated with "pellet clad interaction."
- Zircaloy was selected for fuel rod cladding because of its good general corrosion resistance and low neutron cross section. Selection failed to consider:
  - Effects of fission products such as iodine and cesium on possible SCC.
  - Effects of high strains and stresses caused by clad creep down onto pellets and subsequent pellet expansion.

# Summary of Lessons Learned from Nuclear Power Plant Experience

- Reasons for unexpected failures include:
  - Full range of realistic service environments not considered (potential, pH, aggressive species)
  - Realistic range of material conditions and compositions not evaluated
  - Realistic range of total stresses (including residual stresses) and applied strains not adequately considered
  - Long term susceptibility in realistic environments not adequately tested (need for accelerated testing)
  - Aggravating effects of fabrication details, surface damage, and local residual stresses not adequately considered
  - Long term material aging effects not adequately addressed

# Summary of Lessons Learned from Nuclear Power Plant Experience (Cont.)

- Main lesson - all of the above factors need to be addressed.
- Several of these factors may have not been suitably addressed to date for C-22.

# Testing Status of Alloy C-22

While significant numbers of tests have been and are being performed of Alloy C-22, some aspects may require more attention:

- Tests thus far reported do not appear to have addressed possible effects of trace aggressive impurities such as lead, mercury, arsenic and sulfides on SCC and other modes of corrosion.
- Tests thus far do not appear to have addressed full range of water chemistries and concentrations that could occur, especially in heated crevices and under deposits.
- Tests thus far do not appear to have addressed full range of base material composition variations (including trace deleterious impurities) and conditions (e.g., welding, cold work and sensitization).

# Objectives of the Experimental Program

- Identify the mechanisms of possible corrosion phenomena
  - Pitting
  - Crevice corrosion
  - Under deposit corrosion
  - IGA/SCC
- Determine the effects of crevices and deposits on the near field chemistry (pH, aggressive species concentrations and potentials) and the resultant effects of those chemistry changes on corrosion phenomena

# Objectives of the Experimental Program (continued)

- Develop a scientifically based method for predicting the long term performance of Alloy C-22 using temperature accelerated experiments
- Evaluate the ability of Alloy C-22 to scavenge and concentrate aggressive species (lead, mercury, *etc.*)
- Determine the correct measure of aggressive species activity: inventory or concentration

# NRC Rulemaking Activities for Entombment of Power Reactors

Stephanie P. Bush-Goddard, Ph.D.
NMSS/IMNS
122nd ACNW Meeting
October 17-19, 2000

## Goals/Objectives

- Regulatory History
- What is Entombment?/NRC Entombment Papers and Activities
- Scope of Rulemaking Action and Options for Entombment
- Current Status of Rulemaking Effort
- Guidance from ACNW



## Regulatory History

- Final Decommissioning Rule (10 CFR 50.82)
- Radiological criteria for license termination (10 CFR Part 20 Subpart E)



## What is Entombment?

- Decommissioning alternative
  - Radioactive contaminants are encased in structurally long-lived material
  - Structure maintained
  - Surveillance continued until radioactivity decays to levels permitting termination of license with *unrestricted release*

## NRC Entombment Papers/Activities

- SECY-99-187, July 1999
  - Information Paper on the Viability of Entombment
- Public Workshop, December 1999
- SECY-00-0129, June 2000
  - Workshop Findings and Staff Recommendations
- SRM to SECY-00-0129, July 2000
  - Proceed with Rulemaking



## PNNL Report
### Entombment Experience in the U.S.

- Three Small DOE reactors
  - Hallam Nuclear Power Facility
  - Piqua Nuclear Power Facility
  - Boiling Nuclear Superheater Power Station (BONUS)
- Hanford Site
  - Former Plutonium Production Reactors
  - Partial dismantlement/subsequent entombment
  - Characteristics similar to commercial power reactors



## Isolation Assessment

Referenced PWR Facility (3500 MW(t))

- Radioactivity
- Transport through containment
- Long term integrity
- Dispersal through the environment



## Isolation Assessment Conclusions

- No current isolation assessment data
- Performance assessment similar to LLW disposal sites
- Difference between entombment and LLW
  - Source term
  - Site characteristics

## Postulated Entombment Scenarios

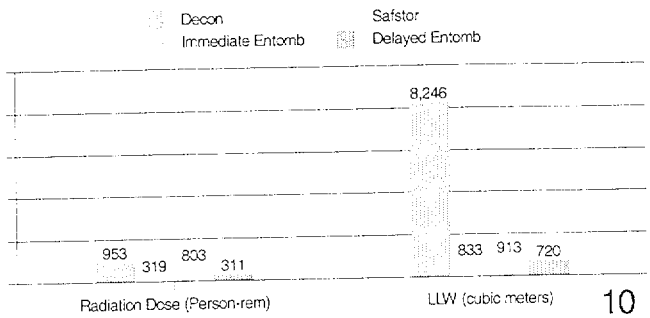
Spent Fuel and GTCC has been removed

- Immediate Entombment
  - Dismantlement occurs immediately
  - Sealed and monitored for 130 years
- Deferred Entombment
  - Placed into safe storage (100-120 years)
  - Then sealed and monitored for another 10 years



## Decommissioning Scenarios

Radiation Dose and Radioactive Waste Volumes






## NRC Entombment Papers/Activities

- SECY-99-187, July 1999
  - Information Paper on the Viability of Entombment, PNNL Report
- Public Workshop, December 1999
- SECY-00-0129, June 2000
  - Workshop Findings and Staff Recommendations
- SRM to SECY-00-0129, July 2000
  - Proceed with Rulemaking



## Workshop Findings

- No attendees challenged the capability to construct a technically viable entombment
- States (seven represented) viewed entombment favorably but had concerns
- LLW Policy Act was not working
- Prefer excluding Greater Than Class C waste
- Need for Study Specific to NRC-licensed Reactors

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## SRM on SECY-00-0129

- Commission has not objected to the development of a rulemaking plan
- Coordinate the rulemaking with ongoing effort to update the generic environmental impact statement
- Address the issue of Greater than Class C waste
- Ensure the ACNW is appropriately consulted

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## Scope of Rulemaking Action

- Current requirements for entombment
  - Decommissioning 10 CFR 50.82
  - License Termination Rule 10 CFR 20 Subpart E
- Rulemaking Plan
  - Provides Regulatory Issues
  - Provides clear options for entombment rulemaking
  - Specifies preferred option
- Advanced Notice of Proposed Rulemaking
  - Provides regulatory process for stakeholders to be involved

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## Options for Entombment Rulemaking

- Maintain Status Quo (case basis)
- Terminate the License
  - Amend 10 CFR 50.82 and 10 CFR 20 Subpart E maintaining the dose criteria
- Retain the License
  - Amend regulations to permit entombment under an NRC license, specify the time when the license could be terminated
- Other

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## Projected Schedule for Rulemaking

- Rulemaking Plan and Advanced Notice of Proposed Rulemaking
  - Currently in NRC Office Concurrence Cycle
  - To Agreement States
  - Analyze/Resolve Comments
  - Back for Office Concurrence
- To Commission, February 2001



## Guidance from ACNW

- What dose reduction credit can be given for engineered barriers in an entombed structure?
- What should be the regulatory framework?
  - Amend 10 CFR 50.82?
  - Put Entombment under another existing regulation?
  - Create a new license for onsite disposal of radioactive waste, maybe under a new part?
  - Other suggestions?