ORIGINAL

OFFICIAL TRANSCRIPT
PROCEEDINGS BEFORE

NUCLEAR REGULATORY COMMISSION

THE ATOMIC SAFETY AND LICENSING BOARD

DKT/CASE NO. 50-454 OL & 50-455 OL

TITLE COMMONWEALTH EDISON COMPANY
(Byron Nuclear Power Station, Units 1 & 2)

PLACE Rockford, Illinois

DATE 3/3/83

PAGES 697-934

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION
BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

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In the Matter of:	: Docket Nos.:
COMMONWEALTH EDISON COMPANY (Byron Nuclear Power Station Unit 1)	: 50-454 OL
COMMONWEALTH EDISON COMPANY (Byron Nuclear Power Station Unit 2)	: 50-455 OL

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United States District Courthouse
211 South Court Street
Rockford, Illinois

March 3, 1983

The hearing in the above-entitled matter convened, pursuant to notice, at 9:00 A. M.

BEFORE:

IVAN W. SMITH,
Administrative Judge

DIXON A. CALLIHAN,
Administrative Judge

RICHARD F. COLE,
Administrative Judge

APPEARANCES:

On behalf of Licensee, Commonwealth Edison Company:

Alan Bielawski, Esq.
Joseph Gallo, Esq.
Victor Copeland, Esq.

Isham, Lincoln & Beale
Three First National Plaza

Chicago, Illinois 60602

On behalf of Nuclear Regulatory Commission Staff:

Steven Goldberg, Esq.
Richard Rawson Esq.

On behalf of the Intervenors:

Bryan Savage, Esq.
Diane Chavez
Paul Holmbeck
Betty Johnson

C O N T E N T S

JUDGE SMITH: Good morning, ladies and gentlemen.

Is there any preliminary business?

(No response.)

Ms. Johnson.

MS. JOHNSON: Your Honor, I hope this is the proper place to present this, because our counsel is not here this morning.

When I got home late last night I discovered that I had a call from Dale Bridenback, our witness on steam generators, Contention 22, which is scheduled to begin, you know, as we know there might be a little flexibility, on the 14th.

He could barely speak. He is going in the hospital Monday for a throat operation and the doctor says he cannot use his voice at all for two weeks after the operation.

I do not know, you know, whether it's possible to do anything. I did not talk with him much because he could hardly speak. He sort of spoke in a hoarse whisper. He will try to discuss this with Mr. Thomas, our attorney. He could not reach him.

The only proposal I can think of -- and whether or not -- I know it involves moving witnesses and all kinds of things. We just have the one and then one on hydrology. I wondered whether it might be possible to move either or both Class 9 -- the contention on Class 9 and the contention on hydrology a week earlier. I don't know if this would be possible but it's something that we have to talk about.

JUDGE SMITH: Certainly. First, we appreciate you raising the matter as soon as you have. That's quite responsible on your part.

Generally, we leave the scheduling of the issues to the parties and, of course, you have a strong voice in when the issues are scheduled.

Have you brought the matter up with the other parties yet?

MS. JOHNSON: No, I have not.

JUDGE SMITH: That is your first step.

MS. JOHNSON: I understand that we would have to discuss it.

JUDGE SMITH: Then if you really do need the Board, which I would doubt, then you can come back to us.

However, we would appreciate knowing as soon as possible what the --

MS. JOHNSON: I understand. That's why I brought it up.

JUDGE SMITH: -- what the solution is.

Thank you.

MS. JOHNSON: Thank you.

JUDGE SMITH: I want to announce the procedure which we will use for direct testimony.

There will be -- the reporter, as I understand, will continue to have five copies but there will be a single official copy which I wish to post during the qualification of the witness, so that testimony which is not accepted, written testimony which is not accepted or testimony which is stricken will be physically stricken by me on that document, so that when you receive it, you will know that that's it.

Now, as it turned out, Mr. Woodard's testimony is in the testimony intact and that leads to confusion. So after this I will do the striking or the witness will.

Now, Mr. Sonntag, let's go off the record on that.

(Discussion off the record.)

JUDGE SMITH: Is there anything further preliminarily?

(No response.)

JUDGE SMITH: Dr. Woodard.

(Resuming stand.)

MR. BIELAWSKI: Good morning, Dr. Woodard.

THE WITNESS: Good morning.

CROSS EXAMINATION

(Continuing.)

BY MR. BIELAWSKI:

Q You are aware that you are still under oath?

A No, but I know now.

Q We have had the benefit of the evening reflecting on what your testimony was yesterday.

In all candor there is still some confusion in my mind as to what your position exactly is on some of the issues. I am going to try to get some clarification to help everybody's understanding of what your concerns are and how you would like to have those concerns resolved.

Now, is it fair to say that you have changed your position, modified your position, since the time I deposed you on January 13th, I believe, of this year.

A You mean my basic position? The contention --

Q Well, yes, let's start with your basic position.

A No. My basic position hasn't changed for several years, actually.

Q That basic position is what now?

A Well, there are several aspects to it.

One, we don't know whether the Plum River Fault is capable or non-capable.

Two, we don't know what causes earthquakes specifically in Northern Illinois except that we know they are produced by release of strain in basement rocks.

And not knowing the parameters which are generated by earthquake activity in rocks of Northern Illinois, it's unsafe to use calculations for various kinds of major structures without having any data.

Those are my major points.

Q Fine.

A Those are in different words, of course, than they were in the contention, but those are my major points and have been, actually, for eight years, I guess now.

Q At least for my purposes that clarification was very helpful. Thank you for that.

Now, how long have you been working with the League with respect to geology and seismic questions you have with respect to Byron?

A I can't answer that directly, because I don't remember; but I can tell you when I -- when the initial contact was made and that may have some meaning to you.

It was made at the time of discovery and excavation of the faults on the Byron site.

Q That was in --

A Mid '70's.

Q '76?

A Somewhere in there, yes.

Q Could it have been as early as 1974?

A I couldn't answer that.

Q Do you know when Illinois Geological Survey Circular 491

was made available to the public?
A '76, I believe.
Q Do you remember when you received that circular, sir?
A No, I have no idea.
Q Would it have been within the past year?
A Oh, no.
Q Long before that?
A Well, certainly some time before that. I don't know when.
Q In the '70's?
A It came into our library probably in the '70's; certainly, it came in some time maybe '76 or '77 whenever the problem got classified, catalogued.
Q When it comes into the library, you generally read the items?
A No, I would like to say that that were true but it depends on when I get through certain piles of material.
Q I am trying to get a general understanding of when you first read Circular 491.
A I can't answer that. I really don't know when I first read it.
Q How about a range? Was it a -- within the past year?
A Well, I saw the circular prior to this year, I mean the past year.
Q When did you read the circular?
A Well, I suppose I read it whenever I first saw it, I

probably read through it, at least quickly.

I can't answer those questions. I just don't know.

JUDGE SMITH: I don't have your cross examination plan easily at hand but I don't recall this line of questioning being suggested nor do I understand the purpose of it.

MR. BIELAWSKI: Well, I will explain the purpose of it and I think you are right, it's not in the cross examination plan. My plans have changed rather dramatically since yesterday.

The questioning is really directed at trying to determine when Dr. Woodard first become aware of the problems insofar as he is concerned with the Illinois Geological Survey's methodology of dating the Plum River Fault; and that's an important aspect of his concerns, because the state, Commonwealth Edison Company and the Staff have all relied to some extent on that survey. I think it's important to go into this.

JUDGE SMITH: Since his awareness is not likely to affect the laws of nature, however, I hope you don't go too far along this line.

MR. BIELAWSKI: No. The questioning should not last that long.

BY MR. BIELAWSKI:

Q Now, yesterday you stated that the first time you became aware of concerns that you have with respect to the Survey's methodology in dating a fault was after the deposition that you gave in January of this year; is that right?

A No, I don't think that's really correct. I don't recall the exact reference you are making to yesterday; but I have contended and -- I have contended in the predessors of Contention 106 for I don't know how many years, on several, that we didn't know whether the Plum River Fault was capable or not capable.

Q Yes. Now I am talking about the actual problem that you had with the terms of the methodology, the boring methodology --

A I see, yes.

Q -- that ISG used to date the fault?

A Right.

Q That, I believe -- I could refer to the transcript -- but I believe yesterday you said you became aware of that after the deposition because you would have undoubtedly made me aware of that concern at the deposition.

A I think I actually told you that after we broke up here yesterday afternoon. That's correct.

In fact, my detailed re-reading of that document confirmed something that I think was there at the time of the deposition -- well, it was, because it was in the contention.

Q I believe you said that you suspected that there was a problem but you didn't know exactly what the problem was?

A Right, yes.

Q Have you ever met Mr. Kolata, one of the authors of Circular 491?

A Yes, I have.

Q Have you ever expressed your concerns to Mr. Kolata regarding your suspicions on the Survey's conclusions regarding the Plum River Fault zone?

A I don't think I have seen Dennis since the publication of that article, actually.

Q Before 1976?

A It was before 1976 when he was working as a Ph.D. student at the University of Illinois.

Q When you say you haven't seen him, you haven't had any contact at all with Mr. Kolata?

A None at all.

Q Now, as a geologist, when you come across a report which will be, as you know, relied upon in making important decisions regarding safety, regarding the environment, not only nuclear power plants but a number of other types of decisions, and if something in the report is, in your judgment, in error, do you believe it's appropriate to contact the authors of the report and raise your concerns with them?

A Well, it certainly is appropriate. Whether that gets done or not depends on how -- how one handles this material with respect to a whole raft of other things that you are doing simultaneously.

This was a -- this was not -- this whole project has never been a high priority project from my point of view other than the fact that I am very interested in the --

Q Aren't you concerned about the public health and safety indications?

A I certainly am.

Q Nonetheless, it's not been a high-priority item for you?

A Well, this -- I guess I would have to ask if you look at the length of time that I have spent on this issue and compare that with the length of time I have spent on all the other things that I have been doing in this world since 1976 or whatever the date was we started with, this would take a very small piece of my time.

Q I find it surprising, perhaps you can explain to me, if you don't find it surprising, that you had the circular before and you read the circular before having taken the deposition, and if you had a very significant concern about the dating of the fault, how come you didn't raise that concern before then?

I would think as a professional geologist you would have read the circular and you would have raised your concerns as soon as possible.

A Well, I don't know that I can answer the question other than to say more or less what I have said before, and that is that I don't know that my -- I don't know that my objections to the circular really jelled prior to the last few weeks. That's essentially what we said to begin with here.

Q Are your objections to the circular such that you would conclude that the geologist who did the work for the Illinois Geological Survey and the staff of Sargent & Lundy geologists who reviewed that work were irresponsible in reaching the conclusion that they reached?

A Absolutely not. I mean, you see, it's an interpretation of that data that we are talking about; and I interpret the data differently than you interpret the data or they interpret the data. I think my interpretation is justified.

Q So really what you are telling me is that they used their professional judgment wisely and so do you and you just come up with different conclusions?

A That's right, that's right.

Q Now, my recollection of what you told me at the deposition with respect to the significance of the dating of surface faults in Illinois was that, really, in your mind wasn't

all that significant; that the significant thing in predicting earthquakes in Northern Illinois is looking for faults in the basement; is that correct?
A That's correct.
Q Therefore, even if we demonstrated to your satisfaction that the Plum River Fault was 100,000 years old, 200,000 years old, your concerns would still be there; is that correct?
A Well, as I said to begin with, I have more than one concern. One of them is with the Plum River Fault, and that's a concern I think that could be reasonably easily answered. I believe I said this yesterday as well.
I also said that one of my second concerns was the cause of earthquakes in the basement rocks of Northern Illinois and that's a much more difficult concern to speak to.
Q Okay. So irrespective of the resolutions to your satisfaction of the Plum River Fault issue, you would still have the concern regarding the faults in the basement and the potential for earthquakes resulting from those faults?
A I certainly would.
Q Now, have you, based on our conversations of yesterday, I am sure you were made aware that you would be questioned to some extent with respect to the report you showed us

entitled Rock Mechanics Research Development Report.

Is that right, you realized you would be questioned on that report today?

A May I make one statement with respect to that? May I, please?

JUDGE SMITH: Yes, please, witness.

A (Continuing.) That document was introduced into testimony yesterday to illustrate -- in a sense to refute two points that you have been putting forward. One of them is that strain data in the basement is not important, and the second one is that we don't know how to measure it anyhow.

Both of those are erroneous.

MR. BIELAWSKI: Okay. We will go onto that in a second.

A (Continuing.) That's the only reason that piece of data was put forward.

MR. BIELAWSKI: We will go into that immediately.

BY MR. BIELAWSKI:

Q As a result -- did you read Chapter 4 of that report last night?

A No, I did not.

Q Did you look at the document at all last night?

A No, I did not.

Q Have you read Chapter 4 in detail?

A Not since a week-and-a-half or two weeks ago when I originally read it.
Q And you read it in detail; is that right?
A I looked at it yesterday afternoon briefly when we were talking about it but that's all.
Q You feel that you are familiar with --
A I am reasonably familiar with what's in that, yes; but that's the only section I have read. I haven't read any other section of the book.
Q Do any of the other sections deal with -- well, I guess you wouldn't know that. Strike that question.

MR. BIELAWSKI: I would like to mark this Chapter 4 of the report for identification.

(The document was thereupon marked Applicant's Exhibit No. 1 as of March 3, 1983.)

JUDGE SMITH: You propose to offer this into evidence?

MR. BIELAWSKI: Not necessarily.

JUDGE SMITH: It is a possibility, however?

MR. BIELAWSKI: Yes, it is.

JUDGE SMITH: You do want it marked, however?

MR. BIELAWSKI: Yes, I do.

JUDGE SMITH: This will be then Applicant's Exhibit 1.

BY MR. BIELAWSKI:

Q Dr. Woodard, I just handed you what has been marked as Applicant's Exhibit No. 1.

Can you identify this document?

A It looks like Chapter 4 of the publication concerning rock mechanics.

Q Do you have --

JUDGE SMITH: Give the complete title of the publication.

BY MR. BIELAWSKI:

Q Do you have your copy of the entire publication, sir?

A The complete title of the publication is Rock Mechanics Research Requirements from Resource Recovery Construction and Earthquake Hazard Reduction.

JUDGE SMITH: And give the date and the publisher.

THE WITNESS: The publisher is the National Academy Press and the date is 1981.

JUDGE SMITH: Is there an author?

THE WITNESS: No, your Honor, there isn't. There is a whole group of individuals involved in this.

JUDGE SMITH: Okay. In the future when we want to take -- as you correctly have done, a relevant part of a larger document, let's also add the cover sheets and the necessary information to identify it.

BY MR. BIELAWSKI:
Q Dr. Woodard, can you compare the document I gave you marked Applicant's Exhibit No. 1 with Chapter 4 in your publication and tell me if they are the same, if this is an accurate copy of Chapter 4?
A I believe the last page is missing.
Q Let's try to do it this way, Dr. Woodard.
Does this accurately reflect Pages 42 through Pages 64 of the report that you have?
A I believe you mean Page 65. I have a Page 65; but there is a Page 66. I don't think, though, that that's important with respect to this.
Q I don't think so, either.
The last three or four pages are simply references; is that correct?
A That's correct, although I didn't want to indicate by my response that those references are not important.
Q Certainly. I don't think they are important for my examination of you.
A Right.
Q I refer you to Page 59 of that report, sir.
A Yes.
Q There is a paragraph starting in the middle of the page entitled "Extend Measurements" -- "Measurements Technology to High Temperatures and Pressures and to Hostile

Environment."

Have you read that paragraph before, sir?

A I have.

Q What in your mind does that paragraph mean?

A That paragraph is talking about collecting data in the environments in which we are talking about here.

That is in basement rocks.

Q Does reading -- can you read -- have you read this paragraph recently, sir?

A I read it a week or two ago.

Q Would you like to read you again before I question you in detail about it.

A Pause. I believe I know what it says.

Q Does this paragraph have any bearing on your conclusions regarding the feasibility of performing strain gauge tests on basement rock in Northern Illinois?

A Well, it obviously has some bearing; but I don't know what that means, because I don't know how truthful -- I don't know how up-to-date this paragraph is.

Q When was this report published?

A 1981.

Q Do you believe this report to be an unreliable report?

A No, I don't believe it to be unreliable. It demonstrates what I tried to use it to demonstrate, that, in fact, devices are available to measure strain in rocks.

Q Does it demonstrate that these devices are available to measure strain in rocks at 3,500 feet below the earth's surface?
A This publication?
Q Yes.
A It does not -- no, let me backup from that. That's not true, either. It depends on what technique you use. The techniques that we were talking about using strain gauges the other day, it will not demonstrate that, that's correct.
Q Do you have any independent information which would cause you -- well, independent information which causes you to believe that strain gauge tests can actually be performed given today's technology on rocks 3,500 feet below the earth's surface?
A I believe I answered that question yesterday when I said that I didn't know how deep a strain gauge could presently be emplaced in a bore hole.
Actually, though, it raises another question, and that is that there are techniques available that can certainly look at those rocks down there. This, the techniques that we are looking at here, are some of those; but they are not the -- the techniques possible are not limited to these.
Q Sir, there is a chart which is also located in Chapter 4 --

A Page 49, I believe.

Q Table 4-4.2, which, you are correct, is located at Page 49. On the left-hand side of that chart there are a number of techniques for measuring stress in rocks identified; is that correct?

A That's correct.

Q What other techniques do you know of which can be used to measure stress on rocks at 3,500 feet given today's present technology?

A One of them is the technique of undercoring.

Q Once again, can you please describe for me what undercoring is?

A Well, just in a general way. I have never performed it although it's been performed.

Q Give it to me to the extent that you know what undercore is.

A Yes, you core a large diameter core from the rock, you remove the core from the hole and then you core small holes in it and measure the strain released caused by the removal of the small hole, the removal of the small material. It's called undercoring. In other words, you core the original core.

Q Is that a -- strike that.

To your knowledge, have you ever heard of anyone performing stress measurements through undercoring in

rocks found 3,500 feet below the earth's surface?
A I can't answer that. I could tell you someone who has done the work but I don't know whether it was at 3,500 feet below the surface. I think it was more than that.
Q The question still stands. To your knowledge, do you know of anybody having done that, sir?
A And you want specifically an answer with respect to 3,500 feet?
Q I want a yes or no or at least a depth of 3,500 feet or below.
A No, no.
Q Thank you. Do you disagree with the statements presented on Page 59 with respect to the paragraph I referred you to earlier, particularly the third sentence in that paragraph?
A The one that talks about the 40 -- the 50 meter relationship?
Q That's right.
A Well, I don't know whether that's true or not. I said that yesterday.
Q So you don't agree or disagree, you just don't have any information?
A That's correct. I still don't know how deep one can set one of these strain gauges that they are talking about in a bore hole.

Q Do you have any reason, any independent reason, to believe that this statement might not be accurate?
A Oh, yes.
Q And what is that?
A It's the statement itself. They are pointing out in this report that these are the places where we need to do immediate research work to get the technical answers to get this kind of data.
Q Sir, I refer you to Page 58, in the middle of that page there is a word standing alone. What does that word say?
A Intermediate.
Q Do you know what that refers to?
A It refers to the hierarchy. It refers to their hierarchy of placing these things in order to get them done.
Q When you say immediate research work, what do you mean by immediate research work?
A What do I mean?
Q Yes.
A Or what do they mean?
Q What do you mean?
A I would think it would be something you would be working on right now.
Q And when would you want to achieve a result from your research?
A I can't answer that.

Q It's an unfair question. I apologize.

JUDGE SMITH: I didn't hear your last question.

MR. BIELAWSKI: I apologized for the question. I don't think it was very clear.

BY MR. BIELAWSKI:

Q You refer you now to Page 43 of that report, sir.

A Yes.

Q Can you read the sentence in the middle of the page starting with "furthermore at large distances" and continue on through that paragraph before I ask you any questions about it.

Actually --

A May I go back and read the paragraph before because it applies, I mean somehow?

Q Certainly. In fact, I think you should read that whole section.

MR. BIELAWSKI: I would like the record to reflect that Dr. Woodard is currently reading a section entitled, "Introduction," starting on Page 42 and running onto Page 43.

A I have read it.

BY MR. BIELAWSKI:

Q Can you read for me out loud the sentence starting with "furthermore," going to the end of that paragraph?

A "Furthermore, in large distances from a working surface or in highly fractured rocks the measurements themselves are not easily made. The challenge is to extend the ability to make accurate stress determinations." Note it says stress, not strain. Stress determinations -- I have lost my place.

"The challenge" -- to back up.

"The challenge is to extend the ability to make accurate stress determinations to more complex field settings and at reasonable cost. Present technology is not adequate to match the needs of engineering designs requiring knowledge of stresses in deep or remote locations, in ductal or in elastic rocks or in hot or corrosive environments. Neither do generally accepted procedures exist for integrating measurements of in situ stress made over small volumes of rock at widely separated locations into a tectonic framework for fault motion prediction."

Q What does that you just read mean to you?

A It means it's a difficult task.

Q Does it mean it's, as of the date of this report, an achievable task, given the state of the art?

A Quite possibly. You don't solve any problem until you try it.

Q Who are the authors of this report, sir?

A You mean the total?

Q The entire report.
A Do you want me to read the one hundred or so names?
Q No. I would like to know; and what I am asking, I am asking you for the committee or the counsel or the organization which sponsored this report.
A This was sponsored by the U. S. National Committee for Rock Mechanics.
Q Of the --
A Of Assembly of Mathematical and Physical Sciences National Research Council.
Q Do you recognize that name as a professional geologist?
A Surely I recognize them.
Q Is this committee a well-recognized committee in your field?
A Well, I don't know all the people on the committee but I certainly know several of them.

JUDGE SMITH: I think the direction of the question is not only do you know them, do you know them by reputation, too?

THE WITNESS: Yes, your Honor.

BY MR. BIELAWSKI:
Q What is their reputation in your field?
A Oh, I think all of these individuals are top-notch people.

JUDGE SMITH: Would you be more specific now? You say some of them you know. You mean you know them personally?

THE WITNESS: Personally.

JUDGE SMITH: Others you know by reputation?

THE WITNESS: That's correct.

JUDGE SMITH: All of them you know by reputation?

THE WITNESS: Oh, no, no, I wouldn't say that. There are some of them I have never heard of.

JUDGE SMITH: All right.

BY MR. BIELAWSKI:

Q Would you say that based upon your reading of Chapter 4 that it's fair to characterize the authors of this report as stating that performing measurements of stress on rocks located at depths greater than 3,500 feet was not achievable as of the date of this report?

A No, I don't think they say that. They say it's very difficult. I don't think they know what's achievable in this report.

Q They don't present -- you don't think they present their views as to whether something is achievable?

I will refer you back to Page 59, sir. Can you read the third full sentence in that report?

A Starting with --

Q In the middle paragraph.

A Starting with "first?"

Q That's right.
A "First, only hydrofracture measurements are capable of being made at present beyond about 50 meters from a free surface from which drilling can be done."
Q What does that sentence mean to you?
A For the methods at least that they are discussing in this report, it means that something in the order of 50 meters would --
Q Do you have any reason to believe that they, the authors of this report, are not talking about -- strike that.

JUDGE SMITH: You struck it but had you completed your previous answer?

THE WITNESS: Could you tell me what my previous answer was, your Honor?

JUDGE SMITH: Mr. Reporter.

(The record was thereupon read by the Reporter.)

A I see what you mean. It means that something in the order of 50 meters from the drilling site would be required in order to set these particular strain gauges that they are talking about, assuming that you don't use a different method.

MR. BIELAWSKI: Let's refer you back to Table 4.2.

JUDGE SMITH: Before he leaves that particular answer, hydrofracture measurement is not one made with strain gain, is it?

THE WITNESS: No, it isn't, your Honor. It actually is a direct measurement of stress. One would then have to determine strain from that relationship.

JUDGE SMITH: Mr. Bielawski, do you mind if I attempt to understand --

MR. BIELAWSKI: Yes.

JUDGE SMITH: -- my understanding of the sentence compared with his?

MR. BIELAWSKI: Certainly.

JUDGE SMITH: I don't want to interfere with your cross examination.

MR. BIELAWSKI: Go right ahead.

BOARD EXAMINATION

BY JUDGE SMITH:

Q As I read it as a layman --

A This is Page 59, again, your Honor?

Q Yes. The sentence that you just referred to.

It says, "only hydrofracture measurements are capable of being made beyond about 50 meters."

A That's correct. You see, they are talking about stress.

Q But isn't that an exclusionary statement? I mean anything other than hydrofracture measurements cannot be -- I mean isn't that the inference that normally one would draw from the sentence and that's the point I want to ask you to make.

If that is not the appropriate inference, would you explain what a reasonably alternative inference would be?

A I am not sure how to respond to your question.

Let me try this way.

Q Well, maybe my question doesn't make any sense, too. If that's the case, be free to tell me.

A The hydrofracture method that they are talking about here is a direct method for measuring stress in the rocks.

Q Yes.

A In the other methods that they are talking about using strain gauges is for measuring stress as well. They convert the strain measurements to stress determinations. So there are some methods where your determining strain in rocks which are not discussed in this report. This report is not a report talking about strain in rocks. It's a report talking about stress in rocks and it happens to be very closely interrelated in some ways, but there are ways which it isn't. There are some things that are not discussed in this report that --

Q Okay. Then I am talking about now, as far as the report is concerned, what information we can reliably gather from the report.

A From my reading of that sentence, you can get the information, that if you want to measure stress in rocks in what they call hostile environments, then the hydrofrac method is the method you should use.

Q But if you are talking about strain, it may be another consideration?

A If you are talking about strain, it may be another consideration.

MR. BIELAWSKI: Judge, could I ask a few questions -- just one question to clarify something that just came up?

CROSS EXAMINATION

(Continuing.)

BY MR. BIELAWSKI:

Q Dr. Woodard, do you remember yesterday when the issue of this document came up?

A Yes.

Q Do you remember what you stated in terms of the importance of this document?

Let me read this to you. This is from yesterday's transcript. Judge Smith asked you to remind the parties what you found out in that document. Your answer was, "Well, the main thing I found out in the document was the question I couldn't answer in the deposition. I was asked in the deposition what kinds of strain gauges could be placed down holes, that is, in drill holes; and I mentioned some possibilities of strain gauges but I didn't know because I had never done it what the status with respect -- what the status was with respect to that."

Didn't you in fact offer that document as the basis for your conclusion that strain gauges could be placed on rocks to measure strain?

A Sure.

Q At depths greater than 3,500 feet?

A No. I said yesterday, in fact, that I didn't know what depths they could be placed down hole.

Q And doesn't this document which you offered yesterday for -- doesn't this document say that the only method of measuring stress presently, the only method of measuring stress below 50 meters is by hydrofracture, hydrofracturing?

A For measuring stress, yes, that's correct, it does say that.

JUDGE SMITH: Now we have come to a point which I just don't know what is the best way to proceed. He is not represented by counsel.

You don't have to agree with the premise of every question put to you. I don't recall that you offered that document yesterday. I recall that that document was produced on cross examination.

MR. BIELAWSKI: If I said offered, I didn't mean that he offered it. I asked -- I think it was a question with respect to what the basis for his conclusion is that we can put strain gauges at the depths that we are talking about; and I believe, as I remember yesterday's proceedings, he offered that document as a basis for that conclusion.

JUDGE SMITH: Yes. It was not an affirmative effort on his part. You developed the information on cross examination.

MR. BIELAWSKI: That's right. I didn't mean to represent that he had offered it.

BY MR. BIELAWSKI:

Q Let's turn to Table 4.2 on Page 49 of the exhibit.

There is the third column of that table says, "measured quantity," does it not?

A That's correct.

Q What is the measured quantity for the door stopper, comma, CSIR?

A Strain.

Q What is the measured quantity for the triaxial strain cell CSIR, Grand, South Africa?

A Strain.

Q What about for the biaxial photoelastic gauge?

A Strain.

Q The sixth column entitled, "number and type of readout

equipment per hole"; is that right?
A That's correct.
Q What does it say with respect to bore hole deformation gauge under that column?
A Three strain indicators.
Q And with respect to the door stopper?
A One strain indicator.
Q With respect to the triaxial strain cell?
A One strain indicator.
Q With respect to those devices or techniques, what is the maximum depth from working surface given with respect to the bore hole deformation gauge?
A 50 plus meters.
Q How about for the door stopper?
A Ten plus meters.
Q How about for the trixial strain cell?
A 50 meters.
Q What, in your opinion, does the plus represent?
A I don't know. It means greater than, and that's what they were saying.
Q Now, if you look to the hydraulic fracturing column, which is the first technique identified on that list --
A Right.
Q -- what is the maximum depth from working surface given there?

A 5,000 plus.
Q Let me ask you the question this way.
When you see 50 plus on this column, do you think that means 50 to 3,500 or 50 to 1,000 meters?
A I don't know what it means. I can tell you what I think it mines.
Q Tell me what you think it means.
A I think it means they think the equipment can be placed down holes greater than 50 meters but it hasn't been trade.
Q How much greater than 50 meters?
A I don't know.
Q Now, we were talking about and focusing on 3,500 feet.
Is it not a fact that foci of earthquakes in Northern Illinois are assumed to be as deep as three to nine miles?
A I think that's probably on the right order. I don't remember the exact number but that's --
Q But it certainly is deeper than 3,500 feet?
A That's correct.
Q Would you propose that strain measurements should be performed on rocks at that depth?
A At 3,500 feet?
Q No. At around the foci, focus, of earthquakes which have been experienced.

A That would be the best place to have them.
Q It's about three miles?
A Yes, something on that order. It's a little too deep for getting them there but that would be the best place to have the measurements if you really wanted good measurements.

MR. BIELAWSKI: I have no further questions.

JUDGE SMITH: Go ahead, Mr. Goldberg.

CROSS EXAMINATION

(Continuing.)

BY MR. GOLDBERG:

Q Yes. Dr. Woodard, is it correct the present formulation of Contention 106 states that Edison should be required to perform strain gauge tests on faults cutting basement rock located in Illinois; is that correct?
A That's correct.
Q Is that your position in this case?
A I guess it is, right.
Q Do you recall being asked during your January deposition what form of strain gauge test was available to conduct strain measurements at that depth?
A Yes.
Q And you indicated, I believe, some kind of quartz measurement?
A That's right.

Q And you indicated yesterday that you now regard that as unfeasible; is that correct?
A That's correct.
Q Do you recall my asking you yesterday what forms of strain gauge tests were available to perform strain measurements at those depths?
A Would you repeat that?
Q Yes. I asked you now given your retraction or reconsideration of the feasibility of some quartz measurement, what form of strain gauge test were now available to perform strain measurements at basement rock, at those depths.
A Do you want me to answer that question now or --
Q Yes.
A Well, I can't answer it. That's what I said yesterday.
I don't know how far down hole these measurements can be made.
Q Yesterday you identified certain forms of tests that you felt could be utilized to perform strain measurements --
A That's correct.
Q -- at some unstated depth?
A That's correct.
Q What was the origin for the test that you identified yesterday? Was it this report?
A This was the -- this was, as I said earlier, was to

demonstrate that these instruments are available.

Q Now, given the examination that you have just conducted, what instruments now are available on the basis of this report to perform stress measurements at the department that we are talking about here, at the depth which you recommend?

A Stress measurements now?

Q Stress measurements and not strain measurements.

A Not --

Q Stress measurements and not strain measurements as you indicated yesterday; is that correct?

A No, I don't think that is correct.

Q I asked you yesterday what strain tests were available to measure strain at the depth at which you recommended in Contention 106; is that correct?

A I don't think that is correct.

Q What is correct?

A I don't know. You have --

MR. GOLDBERG: Could he be supplied with a copy of his testimony yesterday?

JUDGE SMITH: Only if you supply it. Yo should have an extra copy.

I assume you want us to follow it?

MR. GOLDBERG: Yes, Judge. Start with Page 617.

MS. JOHNSON: Excuse me. Could we have one to look at?

JUDGE SMITH: No, Ma'am, no, unless somebody -- I mean if somebody will loan you one.

MS. JOHNSON: That's all I meant, not to keep it.

JUDGE SMITH: My answer, I just don't have any to loan you.

MR. GOLDBERG: Why don't you take a chance to familiarize yourself with the line of questions that begins on Page 616 with my examination, which followed your colloquy with the Board on strain gauge measurements.

BY MR. GOLDBERG:

Q Have you had a chance to acquaint yourself with that?

A I am reading.

Q Okay. Let me know when you are done reading.

A I think I have read it through, at least Page 618.

Q Okay. On the bottom of Page 616 I asked you what strain test you utilized in the laboratory; is that correct?

A That's correct.

Q You gave me an answer; is that correct?

A Yes.

Q I asked you on Page 617 whether these kinds of strain gauge tests are usable in the field; is that correct?

A That's correct.

Q And your answer is on Line 18, Page 617 -- well, there are

some strain gauges that are usable in the field?
A That's correct.
Q You indicate trixial cells?
A Yes.
Q And a fulcrum strain gauge?
A Right. That's the wrong word but that's what I said.
Q And I asked you on Page 618, question Line 9, "In your opinion are any of these tests that you have described usable for the purpose which you indicate their use in this proceeding. Your answer, "Well, I know that there are some that are usable. I could give you the publication which says that."
A Yes.
Q What publication were you referring to?
A I was referring to this publication.
(Indicating.)
Q Later on during cross examination by Mr. Bielawski on Page 627, which I would like you to refer to presently.
A Where am I reading?
Q The question on Line 4, Page 627, by Mr. Bielawski. Take a minute to familiarize yourself with that question and your answer.
A I see what it says.
Q Mr. Bielawski's question on Line 4, Page 627, is, "Let's get back to the mechanics of performing strain gauge

testing on cross cutting basement rock."

"How would you propose specifically to install the strain gauge in the rock?"

A That's correct.

Q And your answer?

A "I don't think I could answer that."

Q Question on Line 11 --

JUDGE SMITH: Wait a minute. Let's have the full answer.

BY MR. GOLDBERG:

Q Would you like to read the answer you gave?

A "I don't think I could answer that. I could dream up some ways but I don't think I could really answer that."

Q The follow-up question on Line 11, "Do you know whether it's ever been?"

Your answer, please?

A "It's certainly been done to certain depths but to what depths I don't know."

Q And completing the answer?

A "I could give you the reference if you like. I think it's published by the U. S. Government, as a matter of fact."

Q Then I think that the transcript reflects that the reference is indeed the same rock mechanics report that we have been discussing this afternoon which was first mentioned yesterday?

A That's correct.

Q The same document to which you alluded in answer to my question with whether or not strain gauge tests have ever been performed at the depths at which you recommend in Contention 106; is that correct?

A There is no discussion in this statement yesterday of depth.

Q Correct. Depth was unknown at the time and now we have had a chance to obtain a copy of the document from which you have been questioned this morning; is that correct?

A Depth was unknown at the time? No, we knew 3,500 feet at the time. We talked about it.

Q 3,500 feet was the depth at which you recommended and you believe that it was achievable to perform strain gauge measurements; is that correct?

A That's not what I was talking about here.

Q What were you talking about there?

A I was talking about this publication and the fact that you could use strain gauges in rocks to measure strain.

Your contention is that you can't measure strain.

Q I am asking --

JUDGE SMITH: Now, I don't think he understands your earlier question when he suddenly shot off on 3,500 feet. Be sensitive to that and be careful, Dr. Woodard. Take a little bit more time and make sure you understand the question.

BY MR. GOLDBERG:

Q Dr. Woodard, it's very simple. I am not trying to ask you any trick questions. I am trying to establish now what is the basis for the recommendation in the contention that strain gain tests be performed on faults cutting basement rock.

Now, if I understand properly the questions that I just reviewed with you yesterday, you were asked what strain gauge tests are available to do that; is that correct?

A That line of questioning that was going on that we just went through here was not talking specifically about testing basement rocks at 3,500 feet depth or any other depth.

In fact, it was talking about the fact that we could do it.

Q Okay. And the basis for your opinion that it can be done was your reading of this particular document; is that correct?

A No.

Q What is your independent basis for belief that it could be done at those depths?

A Because I think it has been done.

Q Okay. Where has it been done?

A In Colorado.

Q What method?

A The undercore method.

Q By whom --

JUDGE SMITH: Wait a minute. Is this the first time you have referred to this? The Colorado and undercore method?

THE WITNESS: It is.

MR. GOLDBERG: I think maybe we can still, even though it's the first time, perhaps get a little closer to understanding the witness' testimony.

BY MR. GOLDBERG:

Q I would like you to refer you to Page 51 of rock mechanics research requirements, the document, the Natural Resource Counsel document that you have before you.

JUDGE SMITH: Which has been identified as Applicant's Exhibit No. 1.

MR. GOLDBERG: Yes, I am sorry, Judge, it has been identified as Applicant Exhibit 1.

BY MR. GOLDBERG:

Q I would like you to look at the statement there entitled, "bore hole deformation gauge," and ask you to familiarize yourself with the definition of that gauge and ask you then whether that -- well, let me have you read it first and then I will ask you the question.

JUDGE COLE: What page, Mr. Goldberg?

MR. GOLDBERG: That is Page 51, Dick.

THE WITNESS: Shall I read the next page, too?

MR. GOLDBERG: If you like. Why don't you read the entire definition of that bore hole deformation gauge.

THE WITNESS: I have read it.

BY MR. GOLDBERG:

Q Isn't it true that that particular methodology is also referred to as overcoring?

A That's correct.

Q Now, you tell me what is this concept of undercoring that you are talking about? Is that distinguishable from overcoring?

A Well, I am not sure now that you ask that question and make me read this again.

Q It might well be the same process?

A It might well be the same process.

Q And assuming it's the same process, it's among those processes described in this report for which -- which is incapable of being performed at depths 50 meters from free surface; is that right?

A 50 plus meters.

Q 50 plus meters?

A That's correct.

Q Do you know any other methodoligies then of your own experience or elsewhere that would substantiate your position now that it may be possible to perform strain gauge tests at the kind of depths that you are recommending?

A I do not.

MR. GOLDBERG: I have no further questions.

JUDGE COLE: Dr. Woodard, I was going to ask you a question about the undercoring technique and now I am not sure whether we are talking about undercoring or overcoring.

THE WITNESS: I am not, either.

BOARD EXAMINATION

BY JUDGE COLE:

Q If I understood your description of the undercoring, I don't believe it appears to be what they described on Page 51 and Page 52, though.

A I don't, either, but I am not sure. I am not sure about that, so I would back away from undercoring. Undercoring has been done and has been done by the U. S. Geological Survey and it has been done in Colorado; but I don't know -- I don't know whether it's this process or not.

Q All right, sir. Well, I guess I have a more fundamental question which I hope you will be able to answer.

Looking at the undercoring process as you described it earlier -- and correct me if I am wrong, sir -- I

believe you stated that they take out a larger section of rock and then I assume that's taken out of the hole.
A That's correct. Well, as I understand it it is, yes.
Q All right, sir. And then they determine the strain and subsequently the stress in the rock by then drilling holes into the rock upon which strain gauges have been placed to then determine the stress relieved by the boring; is that essentially the process?
A That's how I understand it, yes.
Q Well, I guess my question is. With respect to the validity of the results that one might attain by that.
My problem is you have taken a section of rock out of the environment that placed the stress upon the rock and how does this -- that's in effect relieving the external stress that might cause the strain or did cause the strain in that rock and what sort of considerations are made in that technique to take into account that the cause of the stress in the rock has been relieved and then you are going to conduct a test on it?
A Well, I am not sure that I can adequately answer that question.
All I can say would be, I think, that there are differing kinds of strain and that it may -- it certainly is true that if you take that out of the core -- as a matter of fact, if you just drill a hole in the earth, the

stress-strain relationships at the bottom of that hole are changed from what they were prior to the drilling.

So all of those -- all of those things are serious variables in these processes of measurement.

Q All right, sir.

So if anything I would assume that whatever values are received from -- of strain and stress would be under estimates of what would actually be in situ?

A Well, I don't know. That depends on whether you are adding a correction of some sort to them.

Q I assume that the if the correction is not made, that's why I say, the values you get from the tests without corrections --

A That's correct.

Q -- would be below --

A They would be low, that's correct.

Q All right, sir.

Looking at this document, sir, it indicates that the -- with respect to the bore hole deformation gauge on 51 and 52 in the latter part of that section which appears on Page 52, it says the deformation gauge which might be the technique that is used in -- which is, apparently, the technique that is used in the overcoring and might also be the same procedure used for undercoring, that has been used successfully only down to 46 meters?

A That's correct.
Q That means to me, sir, that it might be getting close to its .
Does that mean the same thing to you?
A It does. Well, it does in terms of how -- yes, I agree, in the case of that particular one, yes.
Q So would you say that that would not be -- based upon what is presented here -- would not be a practical technique to use at 3,500 feet?
A I think that is probably a fair statement.
I think that also comes out in a table on page -- Table 4.2 as well.
Q I have lost my Table 4.2.
A I am wrong in my assumption, anyhow. It doesn't come out. It says the same -- essentially the same thing. It says 50 plus in the Table 4.2.
Q All right, sir.
But it has not been tested even at 50?
A Well, that's a discrepancy in the information in this report.
JUDGE COLE: All right, sir. Thank you.
I am sorry. I am finished. Thank you.
JUDGE SMITH: Do you have additional cross?
MR. BIELAWSKI: No, I don't.
I would like to move the admission of Chapter 4 of

this report into evidence subject to additional questioning from the Board if the Board wants to.

JUDGE SMITH: Are there any objections?

(No response.)

JUDGE SMITH: I think it should be.

JUDGE COLE: Yes.

JUDGE SMITH: Applicant's Exhibit 1 is received.

(The document referred to, Applicant's Exhibit No. 1, received in evidence, follows:)

ROCK-MECHANICS RESEARCH REQUIREMENTS for Resource Recovery, Construction, and Earthquake-Hazard Reduction

Panel on Rock-Mechanics Research Requirements
U.S. National Committee for Rock Mechanics
Assembly of Mathematical and Physical Sciences
National Research Council

Applicant's Ex. No. 1

NATIONAL ACADEMY PRESS
Washington, D.C. 1981

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The project was supported by the National Science Foundation, the U.S. Department of Energy, and the U.S. Geological Survey.

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Irvine, California

†James R. Aggson
U.S. Bureau of Mines
Denver, Colorado

James T. Engelder
Lamont-Doherty Geological Observatory at Columbia University
Palisades, New York

---

*Current address: Department of Geological Sciences, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.
†Current address: J.F.T. Agapito and Associates, Grand Junction, Colorado.

Kate H. Hadley
Offshore District
Exxon Company, U.S.A.
Harahan, Louisiana

Mark D. Zoback
Office of Earthquake Studies
U.S. Geological Survey
Menlo Park, California

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Branch of Engineering Geology
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Denver, Colorado

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Berkeley, California

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Golden, Colorado

Terence K. Young, *Consultant*
Department of Geophysics
Colorado School of Mines
Golden, Colorado

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Houston, Texas

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University of California, Berkeley
Berkeley, California

Carl R. Peterson
Department of Mechanical Engineering
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Cambridge, Massachusetts

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Rio Blanco Oil Shale Company
Denver, Colorado

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Twin Cities, Minnesota

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University of Texas
Austin, Texas

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Consultant
Champaign, Illinois

Ellis L. Krinitzsky
Engineering Geology and Rock Mechanics Division
Waterways Experiment Station
Army Corps of Engineers
Vicksburg, Mississippi

*Howard R. Pratt
Terra Tek, Inc.
Salt Lake City, Utah

Z.T. Bieniawski, *Consultant*
Department of Mineral Engineering
Pennsylvania State University
University Park, Pennsylvania

Charles E. Glass, *Consultant*
College of Mines and Geological Engineering
University of Arizona
Tucson, Arizona

*Current address: Science Applications, Inc., La Jolla, California.

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U.S. Geological Survey
Reston, Virginia

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U.S. Geological Survey
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Center for Tectonophysics
Texas A&M University
College Station, Texas

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SUBPANEL ON NUMERICAL MODELING

Mihran S. Agbabian, *Chairman*
Agbabian Associates
El Segundo, California

Maciej P. Bieniek
Department of Civil Engineering and Engineering Mechanics
Columbia University
New York, New York

Francois E. Heuze
Lawrence Livermore National Laboratory
Livermore, California

Darrell E. Munson
Shock Wave Phenomena Division
Sandia Laboratories
Albuquerque, New Mexico

*David K. Parrish
Center for Tectonophysics
Texas A&M University
College Station, Texas

†Christopher St. John, *Consultant*
Department of Civil and Mineral Engineering
University of Minnesota
Minneapolis, Minnesota

STAFF

Robert L. Bangert, *Executive Secretary*
Susan V. Heisler, *Assistant Executive Secretary*
Barbara S. Adams, *Administrative Assistant*
Jean L. Hensley, *Secretary*

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*Current address: RE/SPEC Inc., Rapid City, South Dakota.
†Current address: J.F.T. Agapito and Associates, Grand Junction, Colorado.

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Determination of *in Situ* Stress

INTRODUCTION

In situ stress in rocks arises both from actively applied forces and from stored residual-strain energy. The *in situ* state of stress is measured for two principal reasons: to predict rock response to changed loading conditions caused by construction or excavation and to further understand tectonic processes, including earthquakes (Table 4.1). Included in construction and excavation are both traditional activities and new engineering procedures such as *in situ* extraction of geothermal power, *in situ* coal gasification, and storage of high-level radioactive waste—procedures that make use of the *in situ* stress field to guide the formation of fractures or their sealing as part of the design.

Unfortunately, the stress field cannot be measured directly. Instead, it is determined indirectly from the measurement of rock response to a perturbation of the stress field. That response is usually a strain or deformation measured over a small volume of rock or fluid pressure measured over a somewhat larger, but still small, volume. If the properties of the rock are well known, the stress state can be obtained from inversion of the measured quantity. When the rock properties are reasonably continuous, elastic, homogeneous, and reversible, the inversion is straightforward and successful measurements of stresses are not difficult. However, if the rock behavior cannot be characterized easily, the inversion can be correspondingly inaccurate. If the rock behavior is variable in space, then, depending on the study's needs, stress measurements may have to be treated individually or it may be acceptable to average them to obtain the stress state in what is presumed to be a representative

TABLE 4.1 The State of Stress in Crustal Rocks: Fields of Application

Design of Excavations (e.g., mines, tunnels, power plants, storage facilities)
Short- and long-term stability
Safety
Cost reduction
Subsurface Hydrodynamics (e.g., conventional oil-field work, tight gas-sand exploitation, shale and coal gasification, geothermal-energy extraction, nuclear-waste disposal)
Orientation of hydraulic fractures
Dominant permeability directions
Subsidence
Containment
Induced Displacements (e.g., nuclear tests, explosive impacts, excavations)
Containment
Vulnerability of structures
Earthquakes (seismic and aseismic regions)
Occurrence
Mechanics
Prediction
Induced or triggered seismicity
Global Dynamics
Tectonic processes
Flow processes
Plate tectonics

volume of rock. However, the methodology for averaging is not well developed. Furthermore, at large distances from a working surface or in highly fractured rocks, the measurements themselves are not easily made. The challenge is to extend the ability to make accurate stress determinations to more complex field settings and at reasonable cost. Present technology is not adequate to match the needs of engineering designs requiring knowledge of stresses in deep or remote locations, in ductile or inelastic rocks, or in hot or corrosive environments. Neither do generally accepted procedures exist for integrating measurements of *in situ* stress, made over small volumes of rock at widely separated locations, into a tectonic-stress framework for fault-motion prediction.

BACKGROUND

The state of stress is typically specified at a point by principal stresses, a unique set of three orthogonal normal stresses and their orientations, for which all shear stresses vanish. Six independent quantities are thus required to define the stress state at any point, and any or all of these values can vary from point to point. Therefore, defining the stress field through a finite volume of rock can be a difficult problem. Interpreting the stress field in a volume from a few stress measurements involves some simplifying assumptions. The most critical assumptions are discussed in this chapter, and some of them are central to future research efforts.

A further step in the interpretation is the "cause" of the stress. Calculated *in situ* stresses represent the sum of various components elucidated below, and it is often necessary to remove unwanted components from the desired cause. Although the terminology for describing measured and inferred components of rock stress is unsettled, the concept of multiple sources is important. The following annotated working definitions are presented to highlight some of the difficulties involved in this interpretive step:

Gravitational stress—the portion of the total stress field produced by the weight of the overlying rock or soil material. The vertical component of the gravitational stress is simply ρgh, where ρ is the average density of the overlying material. The horizontal components resulting from lateral confinement are a fraction of the vertical and are dependent on Poisson's ratio for the rock.

Tectonic stress—the portion of the total stress field resulting from tectonic movements in the earth's lithosphere. Because the earth's surface is a free surface, tectonic stresses are sometimes assumed to be essentially horizontal and not to contribute to the vertical-stress component. This is strictly true only at the earth's surface, although, in general, vertical stress does correlate closely with the expected contribution of the gravitational stress (McGarr and Gay, 1978; Brown and Hoek, 1978).

Thermal stress—the portion of the total stress due to the elastic expansion or contraction of a confined rock mass from heating or cooling. Thermal stress can arise from diurnal or seasonal temperature changes, from deep-seated natural sources such as magmatic intrusions, or from human activities such as nuclear-waste disposal. A thermal stress is actually a *change* of stress relative to the ambient stress of the rock at a reference temperature.

Hydrodynamic stress—the portion of the total stress field caused by fluid movements within the rock mass. This stress is often negligible, and even more often neglected, in *in situ* stress interpretation.

Residual stress—"stress remaining in a solid under zero external stress after some process that causes the dimensions of the various parts of the solid to be incompatible under zero stress, e.g., (i) deformation under the action of external stress when some parts of the body suffer permanent strain, (ii) heating or cooling of a body in which the thermal expansion coefficient is not uniform throughout the body" (International Society for Rock Mechanics, 1975).

Residual stress is generally understood to be stress stored in the rock even after confinement is removed. Residual-stress magnitudes may be as large as 100 MPa, and the stresses may persist in rocks for periods as long as 3 billion years (Gay, 1975). They tend to be relatively more important to the measured stress field at shallower sites (Gay, 1972; Haimson and Voight, 1977). Engineering problems involving residual stress were recognized long ago, and examples cited commonly included time-dependent relaxation (Muller, 1964; Coates, 1964). Purely elastic residual stresses also exist and can be observed as episodes of instantaneous strain release, as strain-gauged rocks are overcored concentrically with progressively smaller core bits (Swolfs *et al.*, 1974; Nichols, (1975). It is clear that in an engineering sense residual stress may or may not be equivalent to the measured values from *in situ* tests. Furthermore, the *in situ* measurements indicate extremely complex behavior on a small scale, and attempting to scale local behavior to predictable effects on larger excavations or openings presents almost insurmountable problems. ⟨Finally, the tectonic interpretation of residual stresses appears to be straightforward only in a minority of rocks (Friedman, 1972).⟩

Paleostress—a stress condition that existed prior to the present time at the point of measurement. A paleostress state commonly is inferred from permanent strain features. It may also bear a general relation to the present residual-stress state, but residual-stress measurements are not likely to be a direct measure of the true magnitude or orientation of that paleostress.

The stress field calculated at a point is assumed to be a reasonable approximation of the total field at that point in space and time; this assumption is borne out by both laboratory and field measurements under controlled stress conditions. Separation of the total field into its component parts is a simple step to accomplish mathematically, but in practice it is often impossible because few of the components can be measured independently or apart from the others. The terms defined above are interpretations of the origin of portions of the measured field, and this interpretive division is an important part of the successful analysis of the *in situ* stress field.

The art of stress measurement and its associated technology evolved primarily through the efforts of mining engineers attempting to improve design, stability, and safety criteria for surface and underground man-made structures (Hast, 1958). The development of the required tools and methods was dictated by the task at hand—the determination of the absolute field stresses in the near vicinity of the excavation.

As mines were extended to greater depth in highly stressed areas, such as the Coeur d'Alene mining district in the United States and the South African gold fields, simple analyses based on lithostatic-stress conditions at depth were inadequate to explain the behavior of tunnels and mine workings and incorrectly estimated their stability. Existing designs had to be revised. By determining the stress state independently, the overly simplified assumption of a gravitational-stress state could be eliminated and the mathematical model of the opening could be improved.

The only viable technique for determining the absolute stress at great distances from the surface grew out of the oil- and gas-field practice of forcefully inducing fractures into target subsurface formations to enhance recovery of the economic commodity. Demand for greater knowledge of the state of stress at crustal depths has increased dramatically in recent years as deeper excavations and engineering processes have been contemplated and as the geophysical community has become aware of the utility of the knowledge in resolving such questions as the mechanics of crustal faulting and the driving mechanisms of plate tectonics.

Modern engineering needs are placing even greater emphasis on ambient stress levels. An example of the present scale of the problem is the successful stimulation of a deep geothermal field (Aamodt, 1977). In the Hot Dry Rock Experiment of the Los Alamos Scientific Laboratory (Blair et *al.*, 1976), fracture orientation is important in the location and spacing of additional wells for completing the subsurface path of fluids. The orientation of the fracture in turn is controlled by rock anisotropy and the ambient stress field. Another example is the prediction of stresses in a high-level radioactive-waste disposal site. The problem is complicated by stress fields changing with time as the result of heating of the host rock by the decaying waste. Yet, the site should effectively isolate the waste during both the initial heating phase and the subsequent cooling of the rock. The effect of the stress change should be predicted by accurate mathematical models to assure that the stress changes will not breach the security of the site. Finally, underground fuel-storage vaults are subjected to pressure changes that flex the walls of the vault. The degree of "working" of the walls from pressure changes is sensitive to the ambient stress state in the surrounding rocks. If the stress state is known, the optimum orientation and shape of the vault can be determined to minimize the hazard of vault failure.

On a scale useful for elucidating tectonic processes, the stress field is as yet only poorly known, mostly from earthquake fault-plane solutions. However, several recent papers attempt to synthesize regional- or global stress patterns from earthquake data together with the *in situ* stress measurements (Sbar and Sykes, 1973; McGarr and Gay, 1978; Zoback and Zoback, 1980). The measurement of *in situ* stress levels and stress changes is recognized as important both for understanding the mechanism of earthquake generation (Zoback and Roller, 1979) and for predicting impending earthquakes (Sbar *et al.*, 1979; Swolfs and Brechtel, 1977; Clark, 1981).

The technology of *in situ* measurements has been a common theme in international conferences and symposia among both engineers and geophysicists. An early, but quite comprehensive, summary of thinking for both groups is in the proceedings of the International Conference on State of Stress in the Earth's Crust, held in 1963 in Santa Monica, California (Judd, 1964). The summary reviews both the types of instruments being developed (esp. Merrill *et al.*, 1964; Jaeger and Cook, 1964) and the importance of ground stresses to surface and subsurface stability problems (esp. Muller, 1964; Bergman, 1964; Coates, 1964). Later summaries of instrumentation by Leeman (1964), Obert (1966), Fairhurst (1968), Jaeger and Cook (1969), and Hall and Hoskins (1972) chronicle the considerable improvements in measuring techniques, particularly strain-relief techniques, resulting from wider recognition of the significance of the ambient stress field. A few key comparisons among different types of instruments were conducted (e.g., de la Cruz and Raleigh, 1972; Gay, 1975; Gysel, 1975), but considerable differences of opinion were voiced by numerous workers. It became clear that experience with the use of specific techniques is an important factor in the quality of the results obtained (Grob *et al.*, 1975).

During the same period, the methods of interpreting hydraulic-fracturing data developed beyond the original theoretical work of Hubbert and Willis (1957) and Kehle (1964). Laboratory results (Haimson and Fairhurst, 1970; Zoback *et al.*, 1977) are consistent with theory, and field data (Haimson, 1973; Haimson *et al.*, 1974) appear to be consistent with other measurements.

Proceedings of the Fifth International Symposium on Recent Crustal Movements (Pavoni and Green, 1975), held in Zurich in 1974, emphasized regional patterns of stress distribution (esp. Greiner, 1975; Gay, 1975). However, most information still was obtained from seismic and geodetic data rather than from *in situ* stress measurements.

The International Symposium on Investigation of Stress in Rock, held in Sydney in 1976, considered advances in applications of stress measurements to practical engineering problems, particularly in underground openings (Bridges, 1976; Schaller *et al*., 1976; Myrvang, 1976; Ishijima, 1976). To a lesser degree, instrumental problems were also reviewed (Enever and Khorshid, 1976; Worotnicki and Walton, 1976; Haimson, 1976).

Proceedings of the International Symposium on Field Measurements in Rock Mechanics (Kovari, 1977), held in Zurich, updated the instrument technology (esp. Blackwood, 1977; Bonnechère and Cornet, 1977; Pahl, 1977; Filcek and Cyrul, 1977; Haimson, 1977; Pariseau and Eitani, 1977; Sellers, 1977). Also documented were numerous applications to engineering problems, particularly in underground openings, slopes, and foundations.

The importance of *in situ* stress measurements to understanding tectonic processes recently has become clear as a result of several review articles. McGarr and Gay (1978) summarize measurements from different parts of the world and discuss the state of stress as a function of depth. Brown and Hoek (1978) also analyze the relationship between vertical stress levels and depth. Zoback and Zoback (1980) review *in situ* stress determinations in the United States and distinguish "provinces" in which the horizontal stress field appears to be relatively continuous.

The International Society for Rock Mechanics is in the process of preparing a number of "Suggested Methods" publications for measuring *in situ* stress in rocks, an indication of the growing view that no additional fundamental improvements in measurement instrumentation are needed to justify their effective use in the field. The efforts to develop new instruments and techniques appear to be on the decline. This is a sign of increasing maturity in the field, as the major effort shifts to more-widespread use of existing methods to solve the fundamental rock-mechanics problems ahead.

STATUS OF MEASUREMENT TECHNOLOGY

Values of the ambient stress state are determined from measurements in two fundamentally different modes, active and passive (Hult *et al*., 1966). In the active mode, the stress component is determined by eliminating stress-induced deformations with a counterbalancing force (e.g., fluid under pressure). In the passive mode, the stress components are inferred from measured displacements (strains) and are calculated using known elastic moduli.

The measure of the instantaneous shut-in pressure (ISIP) during a hydraulic-fracturing test is, in a limited sense, an example of the active technique. Fluid pressure is applied until the compressive-stress concentration at the hole is counterbalanced, then exceeded. In principle, no knowledge of rock properties is needed when using an active technique. The passive technique requires that a portion of the host rock containing the instrument be removed from its surroundings by, for example, overcoring. The extent to which rock properties are needed with the passive technique depends on the rigidity of the instrument relative to that of the host rock. Stiff, passive instruments are relatively insensitive to elastic moduli because they essentially prohibit the deformation of the rock. Their rigidity exceeds the rock rigidity by a factor of 3 to 5. Soft instruments permit the strain in the rock to be complete; hence, the stresses are directly proportional to the rock's elastic modulus.

Passive techniques are used far more frequently than active ones. They perform best in rocks, whose initial response upon relief is elastic. Principal stress orientations are determined by obtaining measurements in three or more noncoplanar but known directions. With some passive techniques, this may require the drilling of additional nonparallel holes; however, with more-sophisticated equipment, all the information can be obtained in a single hole. The hydraulic-fracturing technique reliably will give only the magnitude of the minimum principal stress. Separate equipment is required to produce an impression or picture of the induced fracture in the wall of the open hole, which is used to obtain information about principal stress orientations. Fracture tests in cased holes require remote-sensing equipment to detect the extension direction.

The measurement of relative stress changes can be accomplished using both active and passive techniques. Passive techniques that use adhesives for coupling in the hole are less likely to yield stable data over long periods than those that use spring-loaded or wedged devices, owing to time-dependent creep of the bonding material. Because measurements of relative stress change are of long-term duration in all cases, time-dependent deformation of the instruments and the rock must be considered.

Instrumentation

The main features, performance ratings, and fields of application of commonly used instruments or procedures are summarized in Table 4.2. With few exceptions, it does not include instruments or techniques that have a limited data base or are being developed. Instruments that are now being modified or redesigned for operation at, for example, elevated temperatures are identified by principal agency or laboratory. The following discussion of field performance of each instrument includes performance in rocks that are elastic, ductile, fractured, wet, and disking. The latter adjective refers to rock that disks or chips in a pilot drill core, usually indicative of high differential stress—i.e., in excess of one half the unconfined strength of the host rock.

HYDRAULIC FRACTURING

The hydraulic-fracturing technique consists of pressurizing a portion of a borehole until a tensile fracture is induced in the wellbore. As shown

TABLE 4.2 Techniques for Absolute and Relative Stress Measurements

Techniques	Type	Measured Quantity	No. of Individual Measurements at a Point in Single Hole	No. of Holes for Complete Stress Determination	No. and Type of Readout Equipment Per Hole	Coupling in Hole	Maximum Depth from Working Surface (m)	Additional Rock-Property Determinations Required	Auxiliary Equipment Required	Elevated Temperatures	High Fluid Pressures	Fields of Current Applications
Hydraulic fracturing	Active	Pressure	1 to induced fracture	1, assuming $\sigma_v = \sigma_{min}$	1 downhole pressure gauge	Packers	5000+	None for $S_{H\,min}$; density, tensile strength or K_{IC}, poro-elastic parameter	Impression packer, televiewer	*a* Redesign of packers proposed	Good	Oil and gas, Geothermal, Nuclear testing, Excavation, Research, Containment, Earthquake
Flat jack	Active	Pressure	1 to slender slot	3 slender slots (biaxial only)	1 pressure-gauge transducer	Cemented	Surface to 300	None	Displacement gauge	*a* P/T effect unknown	N.A.	Mining, Research, Earthquake
					1 manometer				None			
					1 differential pressure transducer	Wedged						
Borehole deformation gauge, USBM	Passive, soft	Displacement of cantilevers	3 in plane to hole axis	3	3 strain indicators	Spring-loaded	50+	Elastic modulus; Poisson's ratio	Biaxial cell	*a* Redesigned by Rogers White, Grand Junction, Colorado	N.A.	Mining, Underground, Waste disposal, Storage, Nuclear testing, Research, Earthquake
Doorstopper, CSIR (South Africa)	Passive, soft	Strain	3 or 4 in plane to hole axis	3	1 strain indicator	Glued	10+	Elastic modulus, Poisson's ratio; stress concentration factors	Biaxial cell	*a*	N.A.	Mining
Triaxial strain cell, CSIR (South Africa)	Passive, soft	Strain	9 or 12	1	1 strain indicator	Glued	50	Elastic modulus; Poisson's ratio	Hoek-Franklin triaxial cell	*a*	N.A.	Mining, Underground, Waste disposal, Research, Earthquake, Rock burst
Biaxial photoelastic gauge	Passive, soft	Strain	Principal strain directly, plane perpendicular to hole axis	3	1 optical viewer	Glued	10+	Elastic modulus, stress concentration factors	Biaxial cell	*a*	N.A.	Mining

a No results likely.

Undercoring -
technique.

by Hubbert and Willis (1957), the fracture should form (in an impermeable rock with pore pressure, P_o, and $S_{H\ min} \leq S_v$) when the borehole pressure reaches the breakdown pressure, P_b, given by

$$P_b = T + 3S_{H\ min} - S_{H\ max} - P_o, \tag{1}$$

where $S_{H\ max}$ and $S_{H\ min}$ are the greatest and least principal horizontal stresses (compression is positive), P_o is pore pressure, and T is the tensile strength of the rock. The fracture should form at the azimuth of $S_{H\ max}$. After the fracture has been extended, the pumping is stopped, the well is sealed off, and the shut-in pressure is measured. This pressure is assumed equal to the least principal compressive stress because the fracture should propagate in a plane perpendicular to the direction of this stress. Assuming that one of the principal stresses is due only to the vertical pressure of the overburden, S_v, the fracture both initiates and propagates in a vertical plane, and $S_{H\ min}$ is taken to be equal to the shut-in pressure. Estimates of the least principal stress that are based on the use of shut-in pressure are consistently reliable and often show regional conformity (Bredehoeft *et al.*, 1976). P_o can be either measured or estimated, T can be determined from laboratory tests on recovered core, and Eq. (1) theoretically can be used to yield $S_{H\ max}$.

Because recovery of core for determination of tensile strength can be expensive, and T is a fairly unreliable parameter, an alternative to Eq. (1) for computing $S_{H\ max}$ has been used by several investigators. By repeatedly pressurizing the well after fracture formation, the pressure at which the fracture opens abruptly (with zero strength) can be determined. $S_{H\ max}$ can then be determined with $T = 0$ substituted into Eq. (1). Zoback and Roller (1979) show that very repeatable results can be obtained with this method.

An alternative and physically more-rigorous theory for use in impermeable, fractured, or jointed rock comes from fracture mechanics (Abou-Sayed *et al.*, 1978):

$$P_b = \frac{0.75K_{IC}}{\pi\sqrt{L}} - 0.5S_{H\ max} - 0.5P_o,$$

where K_{IC} is a critical-stress-intensity factor, L is the natural fracture or joint length, and the other terms are as defined above. In this theory also, $S_{H\ min}$ is taken to be equal to the shut-in pressure. Although the fracture-mechanics approach is more exact in fractured and jointed rock, and although most rock is flawed to some extent, the difficulty of estimating K_{IC} and L has precluded its widespread application.

Both linear-elastic and fracture-mechanics formulations can be adapted for use in permeable rock, but, here again, additional information about the rock-mass properties is required. This information, a poroelastic parameter, is not usually available.

FLAT JACKS

Flat jacks are simple devices that, in principle, can be used to measure stress and the static value of Young's modulus near free rock surfaces. These devices, made by welding together two metal sheets and incorporating a tube for oil or water to enter between them under pressure, are usually inserted or cemented in long, narrow slots cut into rock surfaces using the drill-and-broach method. The slotting relieves the normal stress parallel to the working surface and causes a measurable amount of closure across the slot and extension in the host rock adjacent to the slot. Subsequent pumping of the flat jack expands the slot until a pressure is reached at which the initial closure is canceled. This pressure is equal approximately to the original stress that existed across the slot before it was cut. This technique is one of the examples of the active method of stress measurement (Jaeger and Cook, 1969).

The technique has been adapted for measurements in boreholes by Potts (1959), May (1960), and Panek (1961), among others. These adaptations measure changes in stress induced by excavations and other man-made disturbances. The flat-jack-slot technique also has been modified to monitor remotely the stress changes associated with earthquakes and rock bursts (Swolfs and Brechtel, 1977).

The major limitations of this active or direct method of stress measurement are the necessity to remain near a free working surface, time-dependent effects associated with the slot cutting, and the fact that each device measures only one stress component. The borehole (passive) devices suffer from a largely unknown relationship between the measured change in pressure and stress change, usually assumed to be equal. The effects of changes in temperature and thermal stress on stress-change data are difficult to assess, but, in principle, compensating mechanisms to minimize their influence can be devised at some cost.

BOREHOLE DEFORMATION GAUGE

The U.S. Bureau of Mines (USBM) borehole deformation gauge has been used successfully in rocks with a wide range of physical properties. The gauge construction and details of the overcoring process have been well documented (Hooker and Bickel, 1974). The overcoring process consists of drilling a pilot borehole, positioning the deformation gauge in the pilot borehole, and drilling a concentric borehole over the gauge. The gauge measures three diametral deformations (in the same plane) during overcoring (Hooker *et al.*, 1974).

The thick-walled cylinders that are obtained after overcoring can be tested in a biaxial pressure cell (Becker, 1968) to determine the elastic constants and their anisotropy in the rock. The core can also be tested in a triaxial pressure cell at stress levels comparable with *in situ* levels (Obert, 1964). The unloading secant elastic properties obtained from the triaxial test are used in the subsequent calculations because these properties compensate for nonlinearities in the stress-strain curve of the rock (Aggson, 1977). The deformation measurements and the anisotropic elastic properties are then combined to calculate the stress distribution in the plane normal to the borehole (Merrill and Peterson, 1961; Hooker and Johnson, 1969). If borehole deformation measurements are obtained in three nonparallel boreholes, the complete three-dimensional state of stress can be calculated (Panek, 1966).

The USBM borehole deformation gauge has been evaluated under both field (de la Cruz and Raleigh, 1972; Ageton, 1967; Merrill *et al.*, 1964; Van Heerden and Grant, 1967) and laboratory (Merrill and Peterson, 1961; Austin, 1970) conditions. The laboratory tests consisted of overcoring the deformation gauge in large, concrete samples under known load. Calculated stresses were within 15 percent of the applied load. The concrete used in these experiments contained 1.5-in. (3.8-cm) coarse aggregate. Thus, errors of 15 percent were not unreasonable because the elastic properties were highly variable. Similar experiments in fine-grained granite produced errors of less than 5 percent.

The deformation gauge has been used successfully in boreholes up to 150 ft (46 m) deep. The use of this gauge and overcoring method is limited to rock in which a minimum of 8 in. (20 cm) of continuous core can be recovered (Hooker *et al.*, 1974). The USBM deformation gauge has been used successfully in holes drilled vertically up, vertically down, and at numerous other inclinations. The presence of water in the hole has no effect on the measurement.

DOORSTOPPER

The Council for Scientific and Industrial Research, South Africa (CSIR) doorstopper may be used successfully in both hard and soft rocks that respond in an elastic manner on relaxation. In special cases, the doorstopper also gives data on the time-dependent relaxation of rocks. The quality of these data is highly dependent on the properties of the adhesive used to bond the doorstopper to the rock.

Most doorstoppers are designed to fit into an *NX* (7.6-cm) or smaller borehole. The sample to which the doorstopper is bonded is then less than 7 cm in diameter. This relatively small sample size permits use of the doorstopper in a more intensely fractured rock than is possible with other passive techniques. However, the interpretation of stress data within highly fractured rock is still a subject of considerable debate.

The doorstopper may be bonded to rock in holes filled with water, provided the proper epoxy is used. The main limitation in a hole filled with water is that debris from drilling is difficult to clear, and in many cases the doorstopper is bonded to surfaces that cannot be checked for cleanliness. Even in dry holes drilled downward, the depth to which holes can be cleaned is limited to less than 10 m. Doorstoppers have been used most successfully in holes drilled upward; in this case, debris is easily cleaned from holes 10 m or more in depth.

In rocks that disk or are ductile, doorstoppers are difficult if not impossible to use. The CSIR doorstopper or other similar instruments are described by Leeman (1969), Greiner and Illies (1977), Gay (1977), and Sbar *et al.* (1979).

TRIAXIAL STRAIN CELL

The original CSIR triaxial strain cell (Leeman and Hayes, 1966; Leeman, 1969) was designed to obtain six independent strain measurements by overcoring in a single borehole. The device contained three 3-gauge strain rosettes that were bonded to the wall of the pilot borehole at known orientations and positions $\theta = \pi/2$; $\theta = 7\pi/4$). After overcoring with an oversized bit, the complete stress tensor was calculated from the six independent strain changes, using the known elastic constants of the rock.

Further developments and modifications of the triaxial strain cell are reported by Grob *et al.* (1975) and Van Heerden (1976). The former uses pneumatic pistons to set and bond three 3-gauge rosettes to the borehole wall; the latter employs three 4-gauge strain rosettes to improve the precision of the measurement. A recent report by Herget *et al.* (1977) contains a complete description of a 12-gauge device (Van Heerden, 1976) that is commercially available.

PHOTOELASTIC SENSORS

There are two basic types of photoelastic sensors, plastic and glass. The plastic strain gauge (Hawkes and Moxon, 1965; Preston, 1966) is used in much the same way as the doorstopper (Leeman, 1969) and the direct strain-gauge technique (Swolfs *et al.*, 1974). These devices are bonded to flattened surfaces or ends of pilot boreholes and subsequently overcored. The plastic strain gauges have the advantage that poor bonding conditions are immediately detectable, which is not the case with electrical strain gauges. The applications of photoelastic coatings in rock-strain measurements are described by Pincus (1966). A more-recent development is the cast-in-place epoxy method of Riley *et al.* (1977) in shallow boreholes.

The photoelastic stressmeter (glass plug) is a rigid-inclusion borehole device that makes use of the birefringent properties of prestressed glass (Roberts *et al.*, 1964, 1965; Roberts and Hawkes, 1979). The use, applications, and limitations of the device in measuring relative stress are described by Hall and Hoskins (1972) and Roberts (1977). The major advantages of the glass plug are its low cost and efficienty in the field.

Data Reduction

For economic and other pragmatic reasons, data-reduction methods for each instrument are designed to be straightforward and simple to use. Time-consuming and tedious routines are rarely used, except in research applications. Plane-stress or plane-strain conditions are generally assumed, as is collinearity of one of the principal stresses with the wellbore or borehole or normal to the slot in which the stress measurement is made. All passive techniques, but especially the soft types, require some knowledge of the elastic moduli of the host rock. This information is usually obtained by pressure cycling the overcore and instrument in a radial, biaxial cell or by subjecting rock samples to known applied loads in testing machines. Some data-reduction techniques incorporate effects due to anisotropy or nonlinearity in rock behavior.

For many traditional engineering and mining applications, the data-reduction methods are considered adequate. Unfortunately, the magnitude of the error introduced by the various assumptions and idealizations is difficult to assess *a priori*. For example, Benson *et al*. (1970) report a factor-of-2 difference in the moduli computed from plane-stress, thick-walled cylinder measurements (a biaxial technique) and those derived from uniaxial tests of the same material. Even the best-designed laboratory tests can only approximate the *in situ* loading conditions on the rock; thus, if major differences exist between the elastic constants determined by various means, the absolute values of the calculated *in situ* stresses must be regarded as estimates only.

Rock heterogeneity is another source of uncertainty. *In situ* stresses are determined by measuring some property of the rock mass over a small area, a few square centimeters to a few hundred square meters. It is not clear how these should be averaged in heterogeneous rocks to create a representative value for the bulk volume. With many methods, measurements made at separate points in the rock mass must be combined to calculate the principal stresses. Thus, each of these principal stresses is itself an "average" of the stress state in the rock, even before combination with other principal stress values.

Jointing and fracturing are the most widely discussed sources of rock heterogeneity, but rock-property variations due to depositional or intrusive contacts are equally common in the field. Rock heterogeneity can easily account for a 20 percent difference in stress magnitudes measured at adjacent sites (Hobbs and Clarke, 1966).

System Geometry

Boundary conditions assumed in data reduction include circular holes, rigid planar boundaries, and uniform far-field stresses. These conditions may not hold for the rock under study. The assumption of the infinite or semi-infinite extent of the rock medium reduces the accuracy of the interpretation in the vicinity of a free surface, either natural (topographic) or man-made (slope or subterranean excavation face). Much discussion has been devoted to the difficulty of interpreting surface measurements owing to the presence of near-surface bedding, shallow fracturing, and weathered zones. However, in the subsurface, relief by fracturing or flow in the area of high stress concentrations around the working face and the damage zone created by blasting can cause just as much difficulty in interpreting the virgin stress state from measurements in mines or other excavations. In general, stresses in these zones are lower than those predicted by elastic analyses.

Geophysical and Geological Observations as Stress Indicators

Attempts to measure stresses by relieving strains or producing hydraulic fractures can be augmented by careful geophysical and geological observations. Several methods have been used, including earthquake fault-plane solutions, fracture mapping in surface and subsurface rocks, and observations of geologic structures and microstructures.

Earthquake fault-plane solutions—the determination of quadrants of compressional and "tensional" first motions of P waves—can be related closely to the orientations of maximum and minimum principal stress directions at the earthquake focus, and thus can be used to estimate stress conditions at depth (Scheidegger, 1964; Sbar and Sykes, 1973). The magnitude of the stress difference is a function of the model of the earthquake source, but strong seismic constraints (Brune, 1970; 1971) and other geophysical evidence (Lachenbruch and Sass, 1980) seem to indicate that shear-stress drops during earthquakes are probably limited to 10 MPa or less. The ambient shear-stress levels cannot be determined directly. The passive seismic methods of determining deep crustal stress levels are dependent on a natural earthquake source and are not discussed further in this chapter.

Careful mapping and analysis of fracture patterns is a useful method of determining a considerable amount of stress-related information. In many cases, the ambiguous age of the fractures does not permit the separation of present stress conditions from paleostresses. But Price (1974) describes the process of fracture formation in otherwise undeformed sediments and argues that careful analysis and sound deduction are likely to yield at least the present stress orientations (see Raleigh *et al.*, 1972). At the other extreme, the presence of active fault systems can be used to deduce principal stress directions (Anderson, 1951) that match other measurement methods in some locations (Zoback and Zoback, 1980). Commonly, the most difficult geological question is the age of the structure. It is not always possible to distinguish among structures formed in the past in a paleostress regime, those being formed from the relief of residual stress (e.g., by erosional unloading), and those being formed by an applied stress due to continuing tectonic activity.

Microstructures can also be used to great advantage in determining the stress history of the rock (Carter and Raleigh, 1969). The microstructures in minerals tend to be a permanent record of all deformation since the mineral crystallized or recrystallized; hence, the analysis may not be able to distinguish active stress from paleostress. Some minerals, particularly quartz, can record residual stress as an elastic lattice distortion detectable by x-ray methods (Friedman, 1972), so the presence of residual stress can be established.

None of the more indirect methods of inferring stresses can give as complete a description of the stress state of the rock as the strain-relief or hydraulic-fracturing methods. Even so, they should not be overlooked for their ability to provide independent corroboration of the measured stress state of the rock.

STATE OF NEED AND RECOMMENDATIONS FOR RESEARCH

Current and continuing needs in the measurement of stress *in situ* include the following:

- *Improve characterization of* in situ *rock-mass properties.*
- *Improve data-reduction and instrument-calibration procedures, including time stability for stress-change measurements.*
- *Improve spatial and temporal averaging techniques for in situ stress measurements, including methodologies for integrating point-stress measurements into a unified picture of stress on a larger scale and understanding of space-time coherence of stress variations.*
- *Make more widespread the use of in situ stress measurements and the availability of results.*
- *Improve pore-pressure measurement techniques.*
- *Develop reliable methods for obtaining information about the state of stress in remote volumes of rock and in hostile environments.*
- *Develop alternatives to in situ stress measurement for special applications.*

Although not a specific research need, reduced cost or improved cost-effectiveness would increase usage in engineering, geological, and geophysical applications.

Research activities addressing these needs are discussed in the paragraphs that follow; recommendations are considered in three categories, based on the projected length of time and ultimate cost to achieve research goals. The categories are immediate (lower cost, 0-5 years), intermediate (higher overall cost, 5-10 years), and long-range (technological breakthrough required, probably greater than 10 years). This categorization does not reflect the relative magnitude of particular needs. One, improved characterization of rock-mass properties, is fundamental to the achievement of all the rest; but, in general, advances in one area of need are linked to advances in several others. Thus, it is not suggested or even possible that one research activity should be pursued to the exclusion of others.

Immediate

- *Improve data reduction and instrument calibration.*

The existing instruments have been calibrated relatively thoroughly, and data-reduction techniques appear to be reasonably accurate, though not very elaborate. Nevertheless, some problems remain; for example, the access holes required by all current techniques produce their own stress concentrations. These become complicated at the end of the hole where doorstopper gauges are attached. Newly developed strain-measuring instruments need further calibration, especially as the instruments are adapted to high temperatures. Ground-surface thermal-stress effects are observable as deep as 3 m but are seldom removed by data-reduction techniques.

The data-reduction and calibration area will probably require a continued research effort as the techniques are adapted to new thermal and depth regimes.

* *Improve understanding of coherence between measurements in space and time.*

A lack of consistency in results with different types of instruments at the same site, with the same instrument at nearby sites, or with the same instrument at the same site but at different times, is a source of legitimate concern. Instrumental problems must be separated from actual, local variations of stress level in the rock itself. For detailed engineering design purposes, the establishment of a variable-stress level in the rock can be used advantageously when supports or excavation geometry are considered. For tectonic analysis purposes, integration of the stress field into an "average" field generally is desirable, and it is important to be able to explain or eliminate the anomalous data in favor of the most representative data. Therefore, it is valuable to understand the causes of the variations and, if possible, to use the information to improve the characterization of the stress field.

The accuracy of the current measurement technology is too poor to detect the magnitude of absolute stress changes that can be expected from tectonic forces during short periods of time (e.g., years). Relative stress changes can be detected by existing instruments, but they must be installed, maintained, and monitored to provide time-dependent changes. Improved absolute stress measurement coherence could permit detection of true changes in stress from a sequence of absolute measurements. However, because the same point cannot be measured a second time, the coherence between immediately adjacent holes must also be established to validate the results.

* *Refine methods of monitoring stress changes with time.*

Instruments capable of monitoring small changes in stress with time are being developed. Current instruments are either wedged or grouted into place and are useful only for measuring changes, not absolute stress values. These techniques probably do not yet employ the ultimate in instrument design. The stress changes being observed are consistent with tectonic conditions, but the details of the changes are suspect because nearby measurements do not track consistently and instrument drift is poorly known. Few independent measuring techniques are available to verify the stress-change measurements, and more research and applications are needed to establish the techniques as valid.

* *Improve cost effectiveness.*

The present costs of making a successful *in situ* measurement are high—on the order of hundreds to thousands of 1980 dollars per measurement. Numerous successful measurements are needed to verify local stress levels, and, as a result, each useful set of measurements is a substantial project.

There are at least three ways of improving cost effectiveness: reduce the cost of making each measurement, reduce the number of unsuccessful measurements, or reduce the number of successful measurements necessary to establish a local stress state with confidence. The number of unsuccessful measurements in a field program can run as high as 80 percent of the total attempted. Therefore, considerable time and cost savings could be obtained by developing methods to pretest the site for feasibility of measurement. Other high-cost items include drilling, the need for highly skilled field technicians, and installation and measurement electronics—all areas in which equipment development might reduce overall costs.

- *Make more widespread the use and availability of* in situ *stress data.*

An underlying problem with *in situ* stress measurements to date has been the relative paucity of publicly available data. A large number of measurements is required, particularly for regional interpretations, but each measurement is expensive and time-consuming, and the data base is expanding only slowly. To some extent, this problem will be solved with time, but the tools exist now to make relatively good measurements. Therefore, a very valid research objective is simply to obtain enough field data at the present state of the art to permit more detailed analysis of the problems we do face.

Intermediate

- *Improve characterization of* in situ *mechanical properties of the rock mass.*

Stress fields obtained from *in situ* measurements using soft, underground devices depend on accurate values of elastic moduli, particularly in the low-stress range in which stress relief is occurring during the measurements. The presence of fractures, anisotropy, local heterogeneity, or anelastic or irreversible stress-relief behavior would have a substantial effect on the stress value finally obtained. This concern is reflected in attempts to obtain rock-mass behavior characteristics *in situ* rather than by restressing cores in the laboratory at a later time. However, *in situ* properties are difficult to measure, and improvements in the techniques for making the measurements, particularly at locations far from a free surface, would be of major benefit in increasing the quality of stress values obtained nearby.

- *Improve methods of integrating point-stress measurements.*

Stress measurements being made today suffer from the shortcomings of most point measurements. The data are extremely location-sensitive and may bear little relation to the actual integrated value of stress over some meaningful volume. Although long-baseline strain nets covering several kilometers are now common at the ground surface in tectonically active areas, stress measurements commonly are made on baselines a few millimeters long. At that scale, many rocks are highly heterogeneous in terms of both mineralogical composition and fracture spacing. New methods of making more-integrated measurements could reduce both the scatter of the data and the number of independent measurements necessary to obtain a satisfactory "average" stress value.

- *Improve measurement of pore pressure at depth.*

In areas where pore pressures are important, the tectonic (or active) stress being sought is, in fact, the total stress value minus the pore pressure, i.e., the effective stress. Pore-pressure measurements are extremely difficult to make at depth, especially in fine-grained rocks where permeability is low and the pores might not be interconnected. Pore-pressure measurements in fine-grained rocks are particularly sensitive to normal sampling, and the mere drilling of the access hole will have considerable effect on pore pressures in the wall rocks adjacent to the hole. How large this effect is and how seriously if affects future stress measurements are not known. However, it is clear that the presence of high pore pressure can drastically change the predicted fracture stress of the rock based on the total ambient stress measurement alone. Furthermore, high pore pressures have an unknown effect on most of the types of measuring devices now being used. Research could be directed profitably both to the pore-pressure measurements themselves and to improved methods of discounting their roles in the total stress measurement.

- *Extend measurement technology to high temperatures and pressures and to hostile environments.*

Existing measuring techniques are being adapted to make important measurements of stress levels at greater depths from the ground surface and in thermally active environments. Three major problems confront this work. First, only hydrofracture measurements are capable of being made at present beyond about 50 m from a free surface from which drilling can be done. Second, the harsh environments require a generation of new, highly stable, measuring instruments. Third, stress values are both temperature and pressure sensitive; thus, the differentiation of tectonic stress from thermal or gravitational stresses, especially in geologically heterogeneous terrain, will require more-complicated data analysis. This work is likely to be verified only after numerous measurements with different techniques can achieve similar results.

- *Refine or develop alternatives to* in situ *stress measurements.*

Many rock-mechanics applications for which *in situ* stress measurements currently are being used might benefit more from other methods of predicting rock-mass behavior. *In situ* stress measurements are less effective for detecting imminent rock failure than are several monitoring methods that make use of the change in rock behavior near the failure point. A good example is the monitoring of acoustic emissions prior to major failures in overstressed rock. Patterns of acoustic emissions appear to be capable of indicating both the location and the time of failure. Likewise, characteristic strain-rate or convergence-rate changes in openings can signal the onset of unstable rock behavior.

Because progressive-strain and acoustic-emission measurements are easier to make than absolute stress measurements, research into the applicability of these stress-related effects is desirable. If a specific type of rock behavior can be characterized adequately by a more indirect or empirical approach, then the difficult inversion from a measured strain value to stress and reinversion from stress to rock response could be eliminated and the behavior predicted more directly.

Long-Range

- *Develop reliable geophysical methods for obtaining information about the state of stress in remote volumes of rock.*

The Subpanel recognizes a specific need for developing methods of making measurements of stress values in remote volumes of rock, i.e., either not easily accessible from the ground surface by drilling or purposely intended to remain intact for specific future uses. Measurements of stress under these conditions are likely to depend on the secondary stress effects on a more easily measurable property (e.g., seismic velocity or attenuation, heat flux, magnetic or gravitational field) than on direct stress relief. Such secondary measurements are likely to be greatly affected by other rock properties at the site. It is believed that if alternate remote measuring techniques can be developed at all, a major geophysical-research effort will be required and a ten-year time scale for the research and development phase is not unrealistic. While the goal is probably achievable, a specific research program is needed to remove this particular limitation in our abilities to make stress measurements in rocks.

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Do you have any -- who is representing --

MS. JOHNSON: (Indicating.)

JUDGE SMITH: You are?

MS. JOHNSON: Yes.

JUDGE SMITH: Do you have redirect?

MS. JOHNSON: Yes, I have some, which I have been changing as it went long.

REDIRECT EXAMINATION

BY MS. JOHNSON:

Q Dr. Woodard, has the technology been developing in this field since this report was made in 1981?

A I am sure it has. I am not familiar with how far that development has come along.

Q You mentioned that you knew someone who had done some of this. I suppose that was reference to the Colorado.

Did you know a person?

A That's correct. I just -- I think -- that's correct.

Q Dr. Woodard, did you rely solely on this document for your testimony on the possibility of using strain gauge tests in the basement rocks in the Plum River Fault?

A No.

Q Then on a little different subject, Dr. Woodard, yesterday in your testimony, is it correct that you and the Applicant witnesses testified that the Plum River Fault was discovered in 1976 after the Byron plant received its

construction license in 1975, as far as you know?
A Would you repeat that?
Q I am sorry. I am probably not stating this very well. I will just state that as a fact and then just ask a question. I am sorry. I don't know how to do this properly.
Dr. Woodard, my memory is that both you and the Applicant witness yesterday testified that the Plum River Fault was discovered in 1976 after the Byron plant received its construction license in 1975.
Is that correct as far as you know?
A I am not sure I know the date when the license was issued.
The fault was reported on by -- in Illinois Circular 491 in 1976.
Q Dr. Woodard, are you aware that the Applicant states in the Byron Final Safety Analysis Report that the Plum River Fault ends 5.3 miles from the Byron site boundary?
A I either read or heard that value or both.
Q In your opinion, Dr. Woodard, is it possible to say that the Plum River Fault ends exactly 5.3 miles from the Byron site boundaries?
A No, I don't think you can say that.
Q Would you give us the basis, the reasons for that opinion?
A Well, the fault is not exposed on the eastern end. It's buried by glacial deposits and we really don't know where

the end of the fault is. It might be plus or minus several miles on it.

MS. JOHNSON: That is all. Thank you.

JUDGE SMITH: Dr. Woodard, is there anything you feel you should add to your testimony to make a complete record or to correct any mistaken impressions that may have been gathered from your testimony?

THE WITNESS: I think not, your Honor.

JUDGE SMITH: You feel that you have had a complete opportunity to express yourself?

THE WITNESS: I think I have.

JUDGE SMITH: All right. We appreciate very much your coming over and we recognize that it has taken an investment in time and effort. Thank you very much.

THE WITNESS: Thank you for having me.

MR. BIELAWSKI: Thank you, Doctor.

JUDGE SMITH: Just one more question.

JUDGE COLE: I am sorry. I forgot to ask this when I was speaking to you before.

BOARD EXAMINATION

BY JUDGE COLE:

Q You mentioned the Colorado undercore method --

A Yes.

Q -- or the undercore method that we used in Colorado and I got the impression that that was an application that was at considerable depth.

A That's my impression because it was related to depth faulting at depth; and I said Colorado, but it's really in Montana. I will change the state. And it was done by a fellow by the name of Raleigh with the U. S. Geological Survey when he was exploring reasons for faulting in an oil field in Montana.

Q To what depth?

A I can't answer that. I don't know.

JUDGE COLE: All right, sir. Thank you.

JUDGE SMITH: Anything further?

(No response.)

JUDGE SMITH: Thank you, Dr. Woodard.

(Witness excused.)

MR. GALLO: Is there another witness?

JUDGE SMITH: Are you ready for your witness?

MR. GOLDBERG: Judge, can we take a five-minute recess before the witnesses take the stand?

JUDGE SMITH: Sure.

(Recess.)

JUDGE SMITH: May I administer the oath, please? Would each of you stand?

(Witnesses sworn.)

INA ALTERMAN

ROBERT ROTHMAN

called as witnesses by counsel for the Nuclear Regulatory Commission, having first been duly sworn by the Chairman, were examined and testified as follows:

DIRECT EXAMINATION

BY MR. GOLDBERG:

Q Dr. Alterman, you have before you a document entitled, "Testimony of Ina Alterman on Lead Contention 106"?

A (WITNESS ALTERMAN) Yes, I do.

Q Did you prepare the document?

A (WITNESS ALTERMAN) Yes, I did.

Q Do you have any changes you wish to make in the document?

A (WITNESS ALTERMAN) No.

Q You prepared the accompanying statement of your professional qualifications?

A (WITNESS ALTERMAN) Yes, I did.

Q Do you have any changes you wish to make to that statement?

A (WITNESS ALTERMAN) No.

Q Are the contents of the testimony and the accompanying professional qualifications statement true and correct to the best of your knowledge?

A (WITNESS ALTERMAN) Yes, they are.

Q Do you adopt it as a statement of your direct testimony in this proceeding?

A (WITNESS ALTERMAN) Yes.

MR. GOLDBERG: At this time, Judge, I would move that the described testimony and qualification statement be received into evidence and bound into the transcript as though read.

JUDGE SMITH: Are there any objections?

MR. BIELAWSKI: None, your Honor.

JUDGE SMITH: The testimony is received.

(The document referred to, the prepared testimony and professional qualifications statement of Dr. Alterman, received in evidence, follows:)

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
COMMONWEALTH EDISON COMPANY	)	Docket Nos. 50-454
	)	50-455
(Byron Station, Units 1 and 2)	)	

TESTIMONY OF INA ALTERMAN ON LEAGUE CONTENTION 106

ALTERMAN SUMMARY

This testimony addresses the geological aspects of League contention 106. It incorporates relevant sections of the SER. It makes the following points:

1. The Plum River and Sandwich Faults lie approximately five and six miles from the site, respectively. The Illinois Geological Survey has conducted detailed investigations of these faults. The evidence demonstrates that these are Paleozoic faults with later movement probably not after the Cretaceous Period (65 million years before present). As no seismicity is associated with either fault, and no evidence for surface displacement more recent than 125,000 years (the youngest age of the Illinoisan till) has been observed, these faults are considered noncapable within the meaning of 10 CFR Part 100, Appendix A.

2. The Applicant has performed excavation mapping and a fault-specific geotechnical investigation demonstrating that minor subsurface faults present at the site are covered by a flat-lying and undisturbed overburden of Pleistocene glacial drift, loess, and alluvium interpreted to be no younger than 125,000 years. There is no evidence of surface displacement or capable faults within the meaning of 10 CFR Part 100, Appendix A, at or within five miles of the site.

3. Strain gauges are designed to measure the strain rate along faults. At present strain gauges have not been devised to measure the vanishingly small strain rates that may exist along the Plum River and Sandwich Faults. The fact that there has not been movement in these zones in at least the last 125,000 years, coupled with the lack of earthquake occurrences, indicates that strain is minimal and, therefore, neither earthquakes nor movement is likely enough to occur on these zones such that it must be considered for Byron design purposes.

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
COMMONWEALTH EDISON COMPANY	)	Docket Nos. 50-454
	)	50-455
(Byron Station, Units 1 & 2	)	

TESTIMONY OF INA B. ALTERMAN REGARDING
LEAGUE CONTENTION 106

Q1. Please state your name and affiliation.

A1. My name is Ina B. Alterman. I am a staff Geologist in the Geosciences Branch in the Office of Nuclear Reactor Regulation U. S. Nuclear Regulatory Commission. A copy of my professional qualifications is attached.

Q2. What is the purpose of your testimony?

A2. The purpose of this affidavit is to address the staff position with regard to geologic aspects of League Contention 106.

Q3. Do you adopt Sections 2.5.1 and 2.5.3 of the February 1982 Byron Safety Evaluation Report (SER) on the geology of the Byron site as part of your testimony?

A3. Yes. As the geology reviewer of the FSAR for the Byron site, I wrote Section 2.5.1 and 2.5.3 of the SER (copies attached) and adopt them as part of my testimony concerning Contention 106.

Q4. What is the staff position about the age and capability of the Sandwich Fault.

A4. At the construction permit stage of review, the Sandwich Fault, the northern end of which comes within seven miles of the site, was determined to have formed in association with the nearby and subparallel LaSalle Anticlinal Belt which is dated as post-Pennsylvanian (290 million years before the present (mybp) to pre-Mesozoic (240 mybp).[1] The minor faults within the site region were determined to be pre-Sangamonian (125,000 ybp) based on unfaulted Pleistocene till overlying the faults, and probably pre-Cretaceous (63 mybp) based on regional geologic history. Since the construction permit stage, the Illinois Geological Survey has performed a detailed study of the Sandwich Fault Zone to determine its extent, amount of offset, age, and nature of faulting. See Circular 505 (1978).[2]

Detailed investigation by the Illinois Survey of the Sandwich Fault Zone confirmed that no glacial material nor subjacent residual soil was offset anywhere along the entire length of the fault wherever the young material was observed. Reexamination of glacial tills have strongly supported an Illinoian age (500,000-125,000 ybp) for the tills at the Byron site and in the Byron area.[3] This would require the undisturbed residual soil beneath the till to be of the Yarmouth interglacial period (600,000 ybp). See also the discussion of this matter in 2.5.1 of the SER.

Q5. What is the Staff position on the capability of minor faults found during mapping of excavations for Category I structures?

A5. According to an August 1975 report by the applicant,[4] subsequent responses to staff questions concerning information in this report[5], staff testimony at the construction permit hearing on the minor site faults in August, 1975,[6], and a letter report by members of the Illinois Geological Survey staff,[7] it was determined that the faults in the excavations were parallel and subparallel with the Sandwich fault and had about 1 to 6 inches of offset. These faults were overlain by an interglacial residual soil and glacial till that were not offset. Since the minimum age of the residual soil must be 70,000 ybp (the last interglacial period) the faults were determined to be non-capable according to the criteria established in Appendix A to 10 CFR Part 100.

Q6. When was the Plum River Fault discovered and what is the Staff position on its capability?

A6. The Plum River Fault Zone, which comes within 5.3 miles of the site, was originally thought to be an anticlinal structure. A detailed study done by the Illinois Survey provided evidence that it was a fault zone with several hundred feet of offset. The staff position on the non-capability of the Plum River Fault Zone (discussed in section 2.5.1 of the SER) was based on information and analysis in the Illinois Survey report on the Plum River Fault Zone including the age of the overlying residual soil and glacial till, the lack of fault escarpment and regional tectonic history. See Circular 491 (1976).[8]

Q7. In its response to Staff interrogatories in this case, the League suggests that there is a connection between the Plum River Fault Zone and the minor excavation faults at the site. Is there any evidence to connect these?

A7. No. The evidence as reported in the Applicant's Fault Specific Geotechnical Investigation Report,[4], and observed by geologists of the NRC, U. S. Geological Survey and Illinois State Geological Survey, does not indicate any relationship between the Plum River Fault Zone which strikes east-west and the minor faults, which strike N70W (North 70° West). The minor faults at the site, however, are parallel with the Sandwich Fault Zone and are considered to have been formed in response to the same stresses that produced the Sandwich Fault. The minor faults and the Sandwich Fault Zone have been shown to be non-capable. Furthermore, detailed investigation by the Illinois Survey led to the conclusion that the Plum River and Sandwich Fault Zones are not continuous although they probably formed during the same tectonic events.

Q8. In its further response to Staff interrogatories in this case, the League claims that not enough work has been done to find decisive evidence as to whether or not the Plum River Fault is capable. The League attributes this position to a Dr. Henry Woodard. What was the nature of the investigation of this fault zone?

A8. The investigation reported by the Illinois Survey (Circular 491)[8] included detailed field mapping, well records, drill cores and sample studies, and seismic refraction work. Computer-constructed base maps were developed from the subsurface information.

Q9. What was the nature of the post-Construction Permit Illinois Survey review of the Sandwich Fault?

A9. The Illinois Survey Sandwich Fault Zone study (Circular 505)[2] included all the elements cited in response to Question 8 above, plus downhole geophysical logging and earth resistivity profiles. All of the latest techniques available were applied to the separate studies of the area.

Q10. In its further response to Staff interrogatories in this case, the League suggests that strain gauge tests ought to be applied to the Plum River Fault Zone to determine any possible future movements of the fault. Can a strain gauge test help in this determination?

A10. No. Strain is the response of a body, in this case a body or volume of crustal rock, to deforming stresses. All areas of the crust are subject to stresses, but these are the equilibrium stresses that do not deform. When the stresses in one set of directions (N-S, E-W, vertical, etc.) greatly exceed the stresses in all other directions, they are referred to as the deviatoric or deforming stresses. The volume of rock responds by being compressed, or shortened, if the deviatoric stresses are compressive; extended or elongated, if the stresses are tensional; or twisted if the compressive stresses are in the form of a shear couple, acting in the same plane but not along the same line. Rupture will occur when the rock has reached the limit of its ability to compress, stretch or twist, and the stresses are sufficient to overcome the cohesion and frictional resistance of the rock.

Measurement of strain, therefore, is the amount of shortening, elongation or rotation that a volume of rock is experiencing. The quantity of measurement used is a percentage or ratio of the change in the length of lines within the rock body (dL) over the original undeformed length (L).

The strain rate is the percent change in a given period of time. Strain gauges are designed to measure the strain rate along faults. Although there are several sophisticated instruments, the basic idea of the strain gauge is bolting a wire of known length across a zone that is suspected of being strained measurably, and measuring the change in the length or the straightness of the wire over a given period of time. For the San Andreas Fault in Calfiornia, where the movement along the fault is, conservatively, about two centimeters per year, instruments are capable of measuring the small increments of strain.

Along the Plum River and Sandwich Faults, undisturbed residual soils at least 125,000 years old lie across the fault. This indicates that no measurable strain has occurred over this period. During that time, the San Andreas Fault has moved 2,500 meters. At present, strain gauges have not been devised to measure the vanishingly small strain rates that may exist along the Plum River and Sandwich Faults. Even if such techniques were available, the fact that there has not been movement on these zones in at least the last 125,000 years and most likely not since Pennsylvania time (290 myBP), coupled with the lack of earthquake occurrences, indicates that strain is minimal and therefore neither earthquakes nor movement is likely enough to occur on these zones such that it must be considered in the design of this facility.

REFERENCES

1. Byron and Braidwood SER for CP-NUREG 75/023 (April 4, 1975).

2. The Sandwich Fault Zone of Northern Illinois by Dennis R. Kolata, T.C. Buschbach, and Janis D. Treworgy, Illinois State Geological Survey Circular 505 (1978).

3. Letter to Dr. Ina B. Alterman from Dr. John P. Kempton, Illinois State Geological Survey, dated Nov. 18, 1981.

4. Fault Specific Geotechnical Investigation - Byron Station, dated August, 1975, by Sargent & Lundy Engineers and Dames and Moore, Consultants to Commonwealth Edison Company.

5. Answers to NRC Questions Pertaining to the Fault Specific Geotechnical Invstigations Report, by Sargent and Lundy Engineers, and Dames and Moore, dated October 20, 1975.

6. Testimony of NRC Staff regarding Preliminary Evaluation of Faulting in Byron Station Excavation by Dr. Robert E. Jackson, Geologist, USNRC, August, 1975.

7. Observations relating to the age of the minor faults in the Galena Dolomite at the Byron Nuclear Generating Station of the

Commonwealth Edison Company, by H. B. Wilman, Geologist and Dennis R. Kolata, Ass't. Geologist with the Illinois Survey; Letter Report of Illinois Geological Survey, included as Appendix 2 to "Fault Specific Geotechnical Investigation-Byron Station".

8. Plum River Fault Zone of Northwestern Illinois by Dennis R. Kolata and T.C. Buschbach, Illinois State Geological Survey Circular 491 (1976).

2.5 Geology and Seismology

For this SER, the staff has reviewed all available relevant geologic and seismologic information obtained since the issuance of the SER and a supplement to the SER (SSER) for the construction permit in 1975 in accordance with the SRP, except for a deviation from the SRP, in the determination of the SSE as discussed and justified in Section 2.5.2.4.

In the CP-SER the staff concluded that

(1) Geologic and seismologic investigations and information provided by the applicant and required by Appendix A to 10 CFR 100 provide an adequate basis for determining that no capable faults exist at the plant site or within 5 mi.

(2) Earthquakes that have occurred in the region cannot be related directly to any faults in the area.

(3) Ground motion values of 0.20 g and 0.09 g anchoring Regulatory Guide 1.60 response spectra at the foundation level of rock-supported structures for the SSE and the OBE, respectively, are adequately conservative.

After careful review of the new information as provided and evaluated by the applicant, the staff concludes that there is no basis for altering its conclusions stated in the CP-SER concerning the safety of the Byron site.

The staff has evaluated the FSAR and subsequent documents and information, including excavation mapping, a trenching and drilling program in a solution basin, and new determinations by the Illinois Geological Survey on postulated faults and the age of the glacial till in the site vicinity. The staff has concluded that the applicant has (1) performed site and regional geologic and geophysical investigations, (2) reviewed all available pertinent literature, and (3) provided the staff with all information necessary to evaluate, assess, and support the applicant's conclusions concerning the safety of the Byron site from the geologic and seismologic standpoint, except as noted in subsequent sections. In addition, the staff finds the applicant has satisfied the requirements of and is in compliance with applicable portions of the following:

(1) Appendix A to 10 CFR 50

(2) Appendix A to 10 CFR 100

(3) SRP Sections 2.5.1, 2.5.2, and 2.5.3

(4) Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants," Revision 2

(5) Those portions of Regulatory Guide 1.132, "Site Investigations for Foundations of Nuclear Power Plants," applicable to the development of geologic and seismologic information relevant to the stratigraphy, lithology, geologic history, and structural geology of the site

(6) Regulatory Guide 4.7, "General Site Suitability Criteria for Nuclear Power Stations"

(7) Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants"

In the following sections, the staff reviews briefly the geologic and seismologic information and bases for its conclusions.

2.5.1 Geology

2.5.1.1 Summary of Regional and Site Geology

The site is located in the Till Plains Section of the Central Lowland Physiographic Province which is characterized by undulating low relief topography of Pleistocene loess, glacial drift, and residuum (1+ million-15,000 years old) overlying horizontal or gently dipping strata of Paleozoic age (600-250 million years before the present (mybp)). The site is underlain by a thin veneer of loess and glacial drift, ranging in thickness from 4 to 37 ft, which overlies Ordovician age (500-430 mybp) bedrock of primarily dolostone. Thickness of the Paleozoic section beneath the site is estimated to be 2000-3000 ft. Beneath this lies the primarily granitic Precambrian (800+ mybp) basement.

At the site, the glacial deposits consist of Illinoisan-stage drift (400,000 to 125,000 ybp), and less. In the PSAR, the applicant stated that the glacial drift was of Illinoisan and Wisconsinan stages of the Pleistocene. Recent studies and reevaluation of the till by the Illinois State Geological Survey have led to the determination that all of the till at and near the site is of

Illinoisan age. The numerical age determinations of the site glacial deposits are based on correlation with glacial deposits in Nebraska and western Iowa, where a volcanic ash interbed in the Kansan drift, the Pearlette ash, has been isotopically dated at 500,000 to 1 million ybp (John Kempton, geologist, Illinois Geological Survey, personal communication). While there are no datable materials in the younger drift formations, calculation of rates of (1) development of interglacial weathered soils, (2) ice-cap formation, (3) advances of the ice, (4) melting, and (5) drift deposits, correlated with sea level curves, allows credible estimates of ages of the Illinoisan and Wisconsinan glacial drift.

The uppermost rock unit below the glacial and soil overburden is the middle Ordovician Galena Group that consists of dolostone strata of the Dunleith and Guttenberg formations. Because of the carbonate content of these rocks, solutioning has occurred along joints, at joint intersections, and along bedding planes. In the site vicinity and at the site, solutioning at joint intersections has resulted in a few solution basins, oval depressions at the surface about 50 ft in diameter. One such basin has been found to be larger, almost 150 ft in diameter. These have been termed sinkholes in the FSAR. However, at a recent meeting, the applicant and his consultants demonstrated by drilling and trenching one solution basin that the horizontal bedding continues undisturbed at the rim and on the floor of the depression, thereby excluding a collapse origin for the basin. They are preparing a report of this investigation to be submitted later. The results of the staff review of the findings will be presented in a supplement to this SER. Drilling and excavations for Category I structures have not uncovered larger voids or caves capable of causing collapse in the Galena Group in the site region. Additionally, Dennis Kolata of the Illinois Geological Survey (personal communication) has confirmed that large scale or extensive solutioning is not characteristic of the dolomitic carbonate rocks of Northern Illinois.

Based on the information presented as the result of the applicant's site investigation and by the Illinois Geological Survey, the applicant concludes that it is unlikely that large voids or caves capable of causing ground collapse are present in the subsurface of the site and site vicinity. The staff concurs with this assessment.

Structurally, the site is located on the northern flank of the Illinois Basin, near the crest of the Wisconsin Arch, in a region characterized by broad upwarped domes, arches and anticlines, and downwarped basins. These are all considered to be Paleozoic in age, based on stratigraphic evidence. The upwarps are commonly associated with faults or fault zones that parallel them and are related in age.

Major faults closest to the site are the east-west trending Plum River Fault, the eastern end of which comes to 5.3 mi northwest of the site, and the Sandwich Fault, 6 mi southwest of the site. Detailed investigations by the Illinois Geological Survey (Ill. Geological Survey Circulars 491 and 505) conclude that these faults predate the Pleistocene epoch because the Illinoisan till that overlies these faults is undisturbed in the vicinity of the faults. Some disturbances of glacial till and blocks of bedrock close to the Plum River Fault have been interpreted as "ice-shove" structures attributed to glacial movement during the Pleistocene period, and not of tectonic origin (Ill. Geol. Survey Circular 395). Knowledge of the regional tectonics supports the conclusion that there are Paleozoic faults with later movement probably not after the Cretaceous period (65 mybp). As no seismicity is associated with either fault, and no evidence for surface displacement more recent than 125,000 years (the youngest age of the Illinoisan till) has been observed, these faults are considered noncapable within the meaning of Appendix A to 10 CFR 100.

Structural anomalies in the subsurface in the site region (listed in the CP-SER as postulated faults), such as the Janesville Fault in southern Wisconsin and the Oglesby and Tuscola Faults in northern Illinois, have since been reinterpreted by the Wisconsin and Illinois Geological Surveys as irregular erosion surfaces or minor flexures in subsurface bedrock. They are, therefore, not considered significant in the safety evaluation of the Byron station.

Minor faults discovered during the excavation for Category I structures were subject to extensive investigation by the applicant. In a report entitled "Fault Specific Geotechnical Investigation" submitted as Attachment 2.5C of the FSAR, the applicant and his consultants concluded that undisturbed residual soil above the faults was formed about 200,000 years ago, and provided supporting evidence by letter reports from experts of the Illinois Geological Survey. They, therefore, concluded that the faults at the site are noncapable within the meaning of Appendix A to 10 CFR 100. The staff concurs with this conclusion.

2.5.3 Surface Faulting

The applicant has shown through borehole data, geophysical studies, remote sensing techniques, and, since the CP-SER review, excavation mapping and a fault-specific geotechnical investigation that subsurface faults present at the site are covered by a flat-lying and undisturbed overburden of Pleistocene glacial drift, loess, and alluvium interpreted to be no younger than 125,000 years.

Therefore, the applicant has concluded, and the staff concurs, that there is no evidence of surface displacement or capable faults, within the meaning of Appendix A to 10 CFR Part 100, at or within 5 mi of the site.

INA B. ALTERMAN, PH.D.
GEOSCIENCES BRANCH
DIVISION OF ENGINEERING
U. S. NUCLEAR REGULATORY COMMISSION

My name is Ina B. Alterman and I am presently employed as a Geologist in the Geosciences Branch, Division of Engineering, Office of Nuclear Reactor Regulation, Washington, D.C. 20555.

PROFESSIONAL QUALIFICATIONS

I have a B.S. in Geology (1963) which was awarded Magna Cum Laude from City College of New York, where I was also a member of Phi Beta Kappa. My Ph.D. in Structural Geology was awarded in 1972 by Columbia University where I held a Faculty Fellowship.

My professional experience began with University teaching and field and laboratory research. I taught Introductory Geology, Historical Geology, and Optical Mineralogy in various colleges (City, Hunter, Barnard and Columbia) as a part-time lecturer while in Graduate School. As a full time Assistant Professor at Lehman College, starting in 1971, I also taught Structural Geology, Tectonics, and Igneous and Metamorphic Petrology until coming to NRC in October, 1979.

My major research activities were grant-funded field mapping, structural analyses of multiple deformation, mechanisms of ductile deformation, and ancient plate tectonics. Some of this mapping, in Pennsylvania, is now included on the latest official geologic map of Pennsylvania, published by the Pennsylvania Geological Survey. For two summers in 1976 and 1977, I did a study of linear structures and brittle fracturing of the earth's crust for the National Aeronautics and Space Administration using Landsat and other remote sensing techniques.

I am often sent papers on various aspects of structural geology to edit and/or review for journals and proceedings volumes (for example, Journal of Geology, Basement Tectonics Vol.). My own publications include articles in the Earth Science Encyclopedia, Petrology Volume (still in press), articles on stratigraphy, mechanisms of slaty cleavage formation, Paleozoic plate tectonics in the Appalachian Piedmont and late brittle faulting in the Appalachians.

At NRC I have been involved in the review of recent geologic features near Rancho Seco, and at the Washington Nuclear Plant No. 2 on the Columbia River Basalt Plateau in Central Washington State. I recently supervised the compilation of information concerning the geologic and tectonic setting for every nuclear facility in California, including university and industrial research reactors and power plants.

I am a member of the following professional and scientific organizations:

- Geological Society of America
- American Geophysical Union
- American Association for the Advancement of Science
- New York Academy of Science
- Potomac Geophysical Society
- Washington Geological Society
- Sigma XI
- Phi Beta Kappa

BY MR. GOLDBERG:

Q Dr. Rothman, you have before you a document entitled "Testimony of Robert Rothman on League Contention 106"?

A (WITNESS ROTHMAN) Yes.

Q Did you prepare that document?

A (WITNESS ROTHMAN) Yes.

Q Do you have any changes you wish to make to the document?

A (WITNESS ROTHMAN) Yes, I have a few minor changes.

Q Would you please describe those now?

JUDGE SMITH: Are there changes on the copy that the reporter has?

MR. GOLDBERG: Yes, they have been made in the reporter copy.

A (WITNESS ROTHMAN) On the first page after the title page, which is the summary, at the top of the page it says, "Rothman Testimony."

In Paragraph No. 1, following the words "Safe Shutdown Earthquake," there is parentheses, says "SES", which should be "SSE."

JUDGE CALLIHAN: What page, please?

(WITNESS ROTHMAN): This is the first page after the title page of the testimony, Paragraph No. 1.

JUDGE CALLIHAN: Headed "Rothman Testimony"?

(WITNESS ROTHMAN): Yes.

JUDGE CALLIHAN: Come again on the change.

(WITNESS ROTHMAN): The paragraph numbered one, it reads, "At the construction permit stage of review, the staff found a Safe Shutdown Earthquake," parentheses, and inside the parentheses it should read "SSE."

JUDGE SMITH: Let's go off the record.

(There followed a discussion outside the record.)

JUDGE SMITH: Back on the record.

BY MR. GOLDBERG:

Q Dr. Rothman, with the corrections to your prepared testimony and accompanying statement of professional qualifications, are the documents true and correct to the best of your knowledge?

A (WITNESS ROTHMAN) Yes, they are.

Q You adopt it as a statement of your direct testimony, statement of qualifications, in this proceeding?

A (WITNESS ROTHMAN) Yes, I do.

Q Dr. Alterman, beginning with you, would you please give a brief summary of your prefiled testimony?

A (WITNESS ALTERMAN) My prefiled testimony addresses the geological aspects of Contention 106, and I will summarize related to the Revised Contention 106.

First, I address the Plum River Fault Zone.

I adopt and accept the Illinois Geological Survey's interpretation of the age of that fault as being Paleozoic in age based on the evidence presented and on the fact that there has been no seismicity associated with that fault, and accept the fact that the glacial deposits overlying the fault have not been disturbed and, therefore, the minimum age of the fault would be the age of the glacial deposits, interpreted to be anywhere between 125,000 to 200,000 years old.

The second part of the summary deals with the strain gauge aspect of the contention.

Field strain gauges are devised to measure strain along faults at or near the surface of the earth, and at present, to my knowledge, strain gauges have not been devised that can measure the very small strains that may exist along the Plum River Fault Zone; and since there is no movement recognized along that fault zone, I accept the fact that strain gauges will not be of any use in, perhaps, predicting earthquakes along it.

Q Dr. Rothman, can you now give a summary of your direct testimony?

A (WITNESS ROTHMAN) Yes. My testimony addresses the seismological issues in this contention.

It briefly reviews the staff review of the Byron site from a seismological viewpoint, pointing out that, at the construction permit stage, the staff accepted a safe shutdown earthquake, with a peak acceleration of 0.2 at the till bedrock interface, to be adequately conservative, and this was based on a postulation of the possibility of an occurrence of a Modified Mercalli Intensity 8 earthquake near the site.

At the operating license stage of the review, which was a review of the final safety analysis report, the -- a comparison of the Byron Safe Shutdown Earthquake response spectrum, which is a Regulatory Guide 1.60 spectrum with a high frequency anchor of 0.09 G with a site specific response spectra obtained from the analysis of strong ground motion records with magnitude, geology and distance parameters similar to those at Byron confirmed the conservatism of the Byron SSE.

It then goes on to point out, too, that the Applicant justified the operating basis earthquake of 0.09 G, which is less than half the Safe Shutdown Earthquake, by computing a return period of 2150 years as a recurrence interval for the maximum Modified Mercalli Intensity 6 earthquake.

Staff's consultant, Lawrence Livermore Laboratories, calculate a return period in the range of 200 to 1,000 years for a peak acceleration of 0.09 G.

The difference in these estimates is most probably caused by the different techniques used and the assumptions made in performing the study.

Another expert researcher has obtained a return period on the order of a thousand years for accelerations of about the SS -- excuse me -- about the OBE, and all three studies return -- predict return periods for the OBE much longer than the expected operating life of the Byron plant; and the 0.09 G OBE is an adequate estimate of the earthquake likely to occur during the operating life of the plant.

I then go on to point out, from a seismological point of view, the Plum River Fault is not capable, since a review of the seismicity studies indicates no evidence for any seismicity directly associated with the Plum River Fault.

Then I address the Arkansas earthquake of July 5, 1982, and point out that it has no significance as far as damage to nuclear power plants is concerned, since it was a high frequency, short duration event, and caused no damage to buildings where the recording was made only 200 meters from the epicenter.

JUDGE SMITH: Thank you.

These summaries are, I think, probably valuable to the audience. They should be directed toward the layman and they should be quite brief.

BOARD EXAMINATION

BY JUDGE SMITH:

Q I wonder if you could give us a very brief layman's explanation of the regulatory philosophy of the Safe Shutdown Earthquake and the Operating Basis Earthquake, just very brief.

A (WITNESS ROTHMAN) Yes, certainly.

The Safe Shutdown Earthquake is that ground motion which is defined by a spectrum, which is an amplitude of ground motion as a function of frequency, at which the plant has to be capable of closing down.

If this level is reached, the plant has to be capable of reaching a safe shutdown, going into a safe shutdown situation, without any release.

The Operating Basis Earthquake --

Q You call that the OBE?

A (WITNESS ROTHMAN) That's right, that's the OBE.

The Operating Basis Earthquake is defined by a response spectrum, also; and it's that ground motion at which the plant has to be shut down and investigations performed to determine if there has -- if any damage has occurred.

Q It's allowed to operate up to that point, however?

A (WITNESS ROTHMAN) Yes, that's right. The plant can operate up until that level; and if that level is exceeded, they have to perform an investigation to see that there has been no degradation of the facilities.

MR. GOLDBERG: Judge, at this time I would like to formally offer Dr. Rothman's prefiled testimony and statement of qualifications into the record and bound into the transcript as though read.

JUDGE SMITH: Dr. Cole was conferring.

Would you repeat that?

MR. GOLDBERG: Yes. I would like to formally offer Dr. Rothman's testimony and statement of qualifications into the record and be bound into the transcript as if read.

JUDGE SMITH: The testimony is received without objections.

(The document referred to, the prepared testimony and statement of qualifications of Dr. Rothman, received in evidence, follows:)

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
COMMONWEALTH EDISON COMPANY	)	Docket Nos. 50-454
	)	50-455
(Byron Station, Units 1 and 2)	)	

TESTIMONY OF ROBERT ROTHMAN ON LEAGUE CONTENTION 106

ORIGINAL

ROTHMAN TESTIMONY

This testimony addresses the seismological aspects of League contention 106. It incorporates the relevant section of the SER. It makes the following points:

1. At the construction permit stage of review, the Staff found a Safe Shutdown Earthquake (SSE) of 0.2g to be adequately conservative for the Byron site based on the postulated occurrence of a ~~magnitude 5.8~~ Modified Mercali intensity VIII earthquake near the site.

2. At the operating license stage of review, a comparison of the Byron SSE response spectrum with site-specific response spectra obtained from the analysis of strong ground motion records with magnitude, geology and distance parameters similar to those at Byron confirmed the conservatism of the Byron SSE.

3. To justify an Operating Basis Earthquake (OBE) of 0.09g, which is less than half the SSE, the Applicant computed a 2150 year recurrence interval for a maximum MM intensity VI earthquake. The Staff consultant, Lawrence Livermore National Laboratory, calculated a return period in the range of 200-1000 years. The difference in return periods between the Applicant and Lawrence Livermore estimates is most probably caused by different methods and assumptions used. Another expert researcher has obtained a return period on the order of 1000 years. All three studies predict return periods for the OBE much longer than the expected operating life of the Byron plant.

4. The OBE of 0.09g is an adequate estimate of the maximum earthquake motion likely to be experienced at the site during the operating life of the plant.

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
COMMONWEALTH EDISON COMPANY	)	Docket Nos. 50-454
	)	50-455
(Byron Station, Units 1 & 2)	)	

TESTIMONY OF ROBERT L. ROTHMAN REGARDING

LEAGUE CONTENTION 106

Q1. Please state your name and affiliation.

A1. My name is Robert L. Rothman. I am a Seismologist in the Geosciences Branch, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission. A copy of my professional qualifications is attached.

Q2. What is the purpose of your testimony?

A2. The purpose of this testimony is to address the seismological aspects of League Contention 106.

Q3. Do you adopt the seismology section (2.5.2) of the February 1982 Byron Safety Evaluation Report (SER) as part of your testimony?

A3. Yes. I prepared that section of the SER (copy attached) and adopt it as part of my testimony.

Q4. Contention 106 alleges, in part, that the Plum River fault is capable. From a seismological point of view, is the Plum River fault capable as that term is used in 10 C.F.R., Part 100, Appendix A.

A4. No. In addition to the geological definition of capable faults in Appendix A III(g)(1), section III(g)(2) defines a capable fault as one which exhibits "macro-seismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault". A review of seismicity studies of the Byron Station region[1] indicates no evidence for any seismicity directly associated with the Plum River fault.

Q5. Did the Staff perform a particularized seismology study of the earthquake hazard for the Byron Station during its safety review?

A5. Yes. As discussed in Section 2.5.2 of the SER, the Staff reviewed the SSE design input used for the Byron Station with respect to the particular seismological conditions of the site. This included the assumption of the occurrence of a maximum Modified Mercalli (MM) intensity VIII, magnitude (m_b) 5.8 earthquake near the site. The comparison of site-specific response spectra obtained from the analysis of strong ground motion records with magnitude, geology and distance parameters similar to those at Byron to the Byron SSE response spectrum was made.

[1]Byron Station Final Safety Analysis Report, Figure 2.5-32 and Table 2.5-9, and Earthquake Source Zones In The Central United States Determined From Historical Seismicity by Otto W. Nuttli and Kenneth G. Brill, Jr., NUREG/CR-1577.

The site-specific spectra used in these comparisons were generated from real accelerograms of earthquakes with body wave magnitudes of 5.8 ± 0.5 (5.3 to 6.3) recorded at rock sites, at distances of approximately 25 kilometers (15.5 miles) or less.

Based on its review the Staff concluded that the SSE with a high-frequency acceleration of 0.20g anchoring a Regulatory Guide 1.60 spectrum at the foundation level of the structures founded on rock is adequately conservative.

Q6. Does the maximum MM intensity VI earthquake which occurred in 1972 30 miles from Byron have any association with the Plum River fault or the Sandwich fault?

A6. No. A comparison of the epicenter of the September 15, 1972, maximum MM intensity VI, magnitude (m_b) 4.4 earthquake, Latitude 41.6°, Longitude 89.4°[2] with the locations of the Plum River and Sandwich faults as indicated on Plate 1 (Structural Features in Illinois) of Illinois State Geological Survey Circular 519, indicates no association of this earthquake with either fault.

[2] Nuttli and Brill, Jr. NUREG/CR-1577.

In any event, the occurrence of this earthquake is of no significance to the safety of the Byron Station since it is smaller and at a greater distance from the plant site than the earthquake assumed for the establishment of the SSE.

Q7. Is the 0.09g maximum ground acceleration for the Byron Operating Basis Earthquake (OBE) consistent with 10 CFR Part 100, Appendix A?

A7. Yes. At one point, Appendix A defines the OBE as being that earthquake which, considering the regional and local geology and seismology and specific characteristics of local subsurface material, could reasonably be expected to affect the plant site during the operating life of the plant (III(d)). This implies a probabilistic assessment over the 40 year operating life of a plant. Elsewhere in Appendix A, the maximum acceleration corresponding to the OBE is required to be at least half that of the SSE V(a)(2).

Based on earthquake data for most of the U.S. an acceleration level of one-half that of the SSE does not correspond to an event reasonably expected during a 40 year period but rather to an earthquake having a much larger return period. This is evident for the Byron site from both the Applicant's estimate of a recurrence interval of ?150 years for a maximum MM intensity VI earthquake and Lawrence Livermore National Laboratory's (LLNL) calculation of a return period in the range of 200 to 1000 years for a Regulatory Guide 1.60 spectrum with a high frequency anchor of 0.09g. See SER, Appendix E.

To meet the better definition of the OBE as specified in Appendix A paragraph III(d), the Staff has accepted OBE acceleration values of less than half those of the SSE for some sites. This is done when supporting data such as probabilistic analyses of earthquake hazard justifies it. In the Byron context, from a seismological point of view, the difference between a Regulatory Guide 1.60 spectrum anchored at 0.09g and one anchored at 0.10 is less than the scatter of the data.

Q8. Is the apparent difference between the Applicant and LLNL estimates of return periods significant?

A8. No. The apparent difference in return periods between the studies performed by the Applicant and LLNL are most probably caused by the different methods and assumptions used. Recently, Dr. Robert B. Herrmann of Saint Louis University has performed some, as yet unpublished, probabilistic estimates of earthquake hazard in the central United States. He obtained a return period on the order of 1000 years for peak accelerations of about the OBE level in the site area. More importantly, all three of these studies predict return periods for the OBE much longer than the expected operating life of the plant. Thus, there is no reason to doubt the adequacy of the Byron Station OBE value.

Q9. Dr. Henry H. Woodward in his deposition of January 13, 1983 referred to a recent earthquake in Arkansas with a reported horizontal acceleration of 0.59g. Do you know of such an earthquake and if so can you describe it?

A9. Yes. On July 5, 1982 at 04:13:49.81 GMT (4 July 1982, at about 11:14 p.m. CDT) there was a magnitude 3.8 earthquake with an epicentral location of 35° 11.1' North latitude, 92° 13.72' West longitude, near the town of Enola, Arkansas. This earthquake was one of over 20,000 small earthquakes which have occurred in the area since about January 12, 1982.

An SMA-1 strong motion seismograph was located about 200 meters from the epicenter and recorded a peak acceleration of 0.59g on its east-west component. Another strong motion seismograph, a DR-100 which was co-sited with the SMA-1 recorded a peak horizontal acceleration of 0.19g. The discrepancy in accelerations between the co-sited SMA-1 and the DR-100 instruments is currently unexplained. The Tennessee Earthquake Information Center (TEIC), the agency which is monitoring the earthquake has stated that: "A distinct possibility is that the high SMA-1 acceleration is an installation effect and does not represent a true free-field acceleration."[3] The entire earthquake recording had a duration of about 3 seconds and the high acceleration had a frequency of about 14 hertz.

[3]TEIC Special Report #8, The Central Arkansas Earthquake Swarm Part 1: 12 January - 12 July 1982 By Arch Johnston and Ann Metzger, October, 1982.

Q10. Can significance be attached to this earthquake as far as damage to nuclear power plants is concerned?

A10. No. If indeed this acceleration is not due to installation effects, then it would represent a very close (near field) high frequency, short duration record of an earthquake with little energy. There was no damage reported to the shed in which the SMA-1 instrument is located or to any other building from this earthquake. Since there was no damage to these buildings which were not designed to withstand earthquake motion there is no reason to believe that earthquake motion of this type could cause damage to a nuclear power plant which is designed using a broad band response spectrum which encompasses the wider frequency range and higher energies of larger earthquakes.

2.5.2 Seismology

2.5.2.1 Introduction

In its review the staff has followed the tectonic province approach to determine the vibratory ground motion corresponding to the SSE (Appendix A of 10 CFR 100). Two important considerations in this approach are the earthquakes that can be considered to be related to known tectonic structures and the random individual events which occur in the same tectonic province as the site but which cannot be related to tectonic structures. Where the occurrence of historic earthquakes can be correlated with tectonic structure, the ground motion at the site is determined assuming that the largest earthquake related to the tectonic structure is situated at the point on the structure closest to the site. Where the occurrence of the earthquake cannot be reasonably related to a tectonic structure, ground motion at the site is usually determined assuming that the largest historic earthquake in the tectonic province can occur near the site.

At the conclusion of the CP review, the staff considered an SSE of 0.20 g at the bedrock-till interface to be an adequately conservative value for the Byron site. This was based on the assumed occurrence of a maximum modified mercalli (MM) intensity VIII earthquake at the Byron site. Byron station is located in the central stable region (CSR) tectonic province. Although, the largest historical earthquake, in terms of intensity, which is not associated with tectonic structure is the 1937 Anna, Ohio, event (MM VII-VIII), the staff's position was that the historical frequency of earthquakes in the site region, including three MM VII events within 200 mi, is too high to consider an SSE of less than MM VIII conservative. The staff also concluded that the maximum ground acceleration of 0.09 g for the OBE was conservative and acceptable on the basis of the applicant's computed recurrence interval of 2150 years for an earthquake of maximum MM intensity VI (CP-SER).

It is the staff's current position that the accelerations of 0.20 g and 0.09 g anchoring Regulatory Guide 1.60 spectra at the foundation level are adequately conservative for the SSE and OBE, respectively, for plant structures supported on bedrock. Lawrence Livermore National Laboratory (LLNL) has acted as consultant to the staff in this review and has concluded that an SSE of 0.20 g is adequate and an OBE of 0.09 g is a conservative representation of the maximum earthquake motion likely to be experienced at the foundation level of the Byron site during the operating life of the plant. The LLNL letter report is attached as Appendix E to this SER.

2.5.2.2 Tectonic Province

The Byron site lies within the CSR tectonic province described by Eardley (1962). The CSR is a region of relative consistency of surface geologic structural features characterized by a series of arches, basins, and domes formed during the Paleozoic era. King (1969) describes the area as "platform deposits on Precambrian foldbelts." The province is a rather extensive region which is, in general, characterized by a relatively low level of seismicity. However, a few areas within the province have experienced significant earthquakes and/or activity above this moderate level. Barstow et al. (NUREG/CR-1577) developed an earthquake frequency map of the Central and Eastern United States. Their work shows that the Byron site region has experienced between 4 and 8 earthquakes per 11,680 km^2 in the period 1800 to 1977.

The staff has recognized that the surface geology of the CSR may not explain the fact that different areas of this large region exhibit different levels of seismicity. Earthquakes typically occur at depths (below ground surface) of 5 to 20 km in the Central United States; therefore, the relevant explanation of the geologic mechanism causing earthquakes is to be found in the geologic structural features at these depths rather than those at the surface. In the absence of any definite knowledge as to the causative geologic structure, levels of seismicity are an important means of assessing earthquake potential.

2.5.2.3 Maximum Earthquake

As discussed in Section 2.5.2.1, to determine the vibratory ground motion under the tectonic province approach, the largest historical earthquakes in the site's tectonic province are considered. The largest historical earthquake, in terms of intensity, in the CSR tectonic province was the 1929 Attica, New York, event (maximum MM intensity VIII). This earthquake is associated with the Clarendon-Lindon structure (CP-SER Nine Mile Point Nuclear Station Unit 2, June 1973; CP-SER Erie Nuclear Plant Units 2 and 3, July 1978). The largest historical earthquake, in terms of intensity, in the CSR tectonic province that has not been associated with tectonic structure is the 1937 Anna, Ohio, event (maximum MM intensity VII-VIII). As stated in the CP-SER (NUREG-7023), historically 3 earthquakes of maximum MM intensity VII, 6 of maximum MM intensity VI, 11 of maximum MM intensity V, and many smaller events have occurred within approximately 200 mi of the Byron site. The earthquake of May 26, 1909 which had an epicenter at 42.5 N, 89.0 W (Coffman and von Hake, 1973) probably produced the highest historical intensity (MM VI) at the site. Generally, in the CSR tectonic province the controlling earthquake for nuclear power plant seismic design is an Anna, Ohio, type event (MM VII-VIII). However, based on the seismicity level that was perceived to be relatively higher than other parts of the CSR tectonic province, the staff concluded, at the CP stage, that the likelihood that the site could experience intensity VII is too high for a controlling earthquake of MM intensity less than VIII to be considered conservative. Accordingly, the staff based the SSE for the Byron site on the postulated occurrence of a maximum MM intensity VIII near the site. The applicant, while accepting this position maintains in Section 2.5.2.4 of the FSAR that the maximum earthquake which could be expected near the site should be intensity VII. The staff has not been made aware of any compelling information during the operating license review which would cause us to change its position as to the possible occurrence of an MM intensity VIII event near the site.

2.5.2.4 Safe Shutdown Earthquake

In the CP-SER the staff accepted an SSE of 0.20 g to be an adequately conservative value for the Byron site based on the postulated occurrence of a maximum MM intensity VIII earthquake near the site. While the seismological and geological evaluation of this controlling earthquake has not been altered since the CP review, the staff has in the interim adopted an SRP and Regulatory Guides which have the effect of changing the acceleration for a MM intensity VIII earthquake. Specifically, following the present SRP an MM VIII earthquake is characterized by a peak acceleration of 0.25 g which is used as the high-frequency anchor of a Regulatory Guide 1.60 spectrum. This higher reference acceleration is determined using the trend of the means relating peak acceleration to intensity shown by Trifunac and Brady (1975). The SRP and Regulatory Guides represent one approach which the staff considers acceptable to establish conformance with NRC regulations. Another acceptable approach to establish the adequacy of the seismic design of nuclear power plants is the use of site-specific spectra (see Sequoyah SER, Watts Bar SER, and Fermi 2 SER). In order to compute site-specific response spectra, it is necessary to characterize the earthquake size, the epicentral distance (distance between the surface location of the earthquake and the site), and the site conditions (soil or rock) being modelled. There are relatively few recordings of strong ground motion at intensity VIII and none (at least in the western United States) recorded at rock sites. This and the more dependable classification of strong motion records by magnitude has led the staff to use magnitude estimates in site-specific studies.

Nuttli and Hermann (1978) developed a relation between maximum MM intensity and magnitude for the Central United States. Using this relation results in an estimated magnitude of 5.75 for an MM intensity VIII. Nuttli and Brill (NUREG/CR-1577) estimates the magnitude of the May 26, 1909 northern Illinois earthquake (MM VII) as 5.1. Estimates of the magnitude of the 1937 Anna, Ohio, earthquake (MM VII-VIII) range from 5.0 to 5.3 (Nuttli and Hermann, 1978; Nuttli and Brill, (NUREG/CR-1577). Therefore, using the site-specific spectrum developed from magnitude 5.8 earthquakes provides a conservative estimate of the vibratory ground motion expected at the site.

The staff has available for its use two site-specific spectra that are suitable for use in establishing the adequacy of the Byron seismic design for structures founded on rock. One of these was generated by the Tennessee Valley Authority for the justification of the seismic design of the Sequoyah, Watts Bar, and Bellefonte nuclear power plants (Tennessee Valley Authority, 1979) and the other was generated by LLNL for use in the NRC-sponsored seismic hazard analysis program (NUREG/CR-1581, Vol.4).

Each of these spectra was generated from real accelerograms of earthquakes in the body wave magnitude range 5.8 $\pm$ 0.5 (5.3 to 6.3), recorded at rock sites, at epicentral distances of less than about 25 km. Using a magnitude range helps account for uncertainty in the characterization of the earthquake and also helps ensure an adequate amount of data. The distance range chosen, less than about 25 km, is the distance range to which maximum intensities are felt in the Central United Stages (Gupta and Nuttli, 1976). In addition, at these close distances, the differences in seismic wave attenuation between earthquakes east and west of the Rocky Mountains have not yet affected the ground motion (Nuttli, 1981). It is the staff's position that the 84th percentile spectrum represents an appropriately conservative representation of the site-specific earthquake (see Sequoyah SER, 1979 (NUREG-0011); Watts Bar SER, 1982 (NUREG-0847); Fermi Unit 2 SER, 1981 (NUREG-0793); and San Onofre Units 2 and 3 SER, 1981 (NUREG-0712)). While neither of the two site-specific spectra was established directly for the Byron site, they generally conform to the Byron site-specific spectrum criteria of earthquake magnitude and site geology. The staff has compared the Byron site SSE (Regulatory Guide 1.60 spectrum anchored at zero period by a peak acceleration of 0.20 g) to both of these site-specific spectra and found it to be more conservative than both these site-specific spectra because it exceeds them at all frequencies.

The New Madrid earthquakes of 1811-1812 are the largest historical earthquakes in the United States east of the Rocky Mountains. Nuttli (1981) indicated that the New Madrid 1811-1812 type earthquake would have a body wave magnitude of 7.2. The staff's position has been that the closest approach to the Byron site of a possible recurrence of a New Madrid type earthquake is Vincennes, Indiana. This is over 400 km from the site. The staff has calculated the effect of a magnitude 7.2 earthquake at a distance of approximately 400 km and used the results in conjunction with the mean plus one standard deviation amplification factors from NUREG/CR-0098 to estimate a response spectrum. The Byron SSE response spectrum is greater than the estimated spectrum at all frequencies.

Staff consultants at LLNL used another approach to investigate the adequacy of the seismic design of Byron. They performed a seismic hazard analysis of the Byron site using the data and models given in NUREG/CR-1582, Vols. 2 and 3 and Bernreuter (NUREG/CR-1581). They concluded that the SSE (0.20 g high frequency anchor for Regulatory Guide 1.60 spectrum) for the Byron site is sufficiently conservative. While the staff considers the probabilistic information relevant, it has not used probabilistic procedures to directly determine design ground motion levels for the SSE in operating license reviews. They have been used in a comparative manner such as the comparison of different levels of ground motion at the same site (Sequoyah SER) or equivalent hazard at different sites (Midland Hearing Testimony and Clinton SER). The staff considers the probabilistic approach in the nature of a confirmation of its deterministic approach. Therefore, based on its review and the report of its consultant (Appendix E), it is the staff's position that the SSE with a high-frequency acceleration of 0.20 g anchoring a Regulatory Guide 1.60 spectrum at the foundation level of the structures founded on rock is adequately conservative.

2.5.2.5 Operating Basis Earthquake (OBE)

To justify an OBE of 0.09 g, which is less than half the SSE, the applicant computed the recurrence interval for an earthquake of maximum MM intensity VI in the site region. The result obtained is 2150 years. Using the trend of the means relating peak acceleration to an intensity as shown by Trifunac and Brady (1975) results in a peak acceleration of less than 0.07 g for MM VI. Therefore, the return period for a peak acceleration of 0.09 g should be greater than 2150 years. Consultants at LLNL calculated a return period in the range of 200 to 1000 years for a Regulatory Guide 1.60 spectrum with a high frequency anchor of 0.09 g. This apparent conflict in return periods between the recurrence studies performed by the applicant and LLNL are most probably caused by the different methods and assumptions used. However, in light of the Appendix A to 10 CFR 100 definition of the OBE, these differences in estimated return period do not effect the staff's conclusion that the OBE of 0.09 g is acceptable. This definition states that the OBE is "that earthquake which... could reasonably be expected to affect the plant site during the operating life of the plant." The staff concludes that the OBE of 0.09 g is an adequate estimate of the maximum earthquake motion likely to be experienced at the site during the operating life of the plant.

MR. GOLDBERG: Judge, I now have a few preliminary questions which, hopefully, will clarify some of the issues, but which there has been prior testimony, some of which may be in the nature of rebuttal, which I don't think it improper to combine with the direct testimony for sake of efficiency.

JUDGE SMITH: You may proceed.

BY MR. GOLDBERG:

Q Dr. Alterman, you are a structural geologist; is that correct?

A (WITNESS ALTERMAN) Yes.

Q Just for my benefit, can you please define structural geology?

A (WITNESS ALTERMAN) Structural geology is the study of the mechanisms and geometry of rock deformation. It incorporates, to some extent, the causes of this deformation, but that then goes over into the area of tectonics.

Q What is geochemistry?

A (WITNESS ALTERMAN) Geochemistry would be the study of the chemical aspect of the rocks and -- the rocks of the earth, both the compositions and the interactions and interrelationships of geochemical processes in the formation of rocks and other chemical aspects of the earth.

Q Dr. Alterman, I understand that you accept the Illinois Survey position on the date of the Plum River Fault; is that correct?

A (WITNESS ALTERMAN) Yes, it is.

Q In their Circular 491 on the Plum River Fault, do they draw the conclusion that the till overlying the fault is not offset?

A (WITNESS ALTERMAN) Yes, they do.

Q Can you explain the basis for that conclusion?

A (WITNESS ALTERMAN) Well, first of all, they do conclude that there is no evidence that the till has been deformed in any of the places where they have observed or studied the fault.

It is true they do not give any specific details of locations where they have observed this.

However, I believe that it is implicit in their report -- in fact, it's implicit in the fact that this fault was not found -- not considered to be a fault for many years.

Although they knew of offsets in the rocks, there was no surface offset, so they thought of it as an anticlinal structure.

The fact that the surface material did not give them any clues to the presence of a fault indicates that the surface material had not been disturbed.

Also, in their description of their doing some seismic refraction work to identify the fault and to determine various factors about it, including the offsets of the beds and the location of the fault and the orientation of the fault structure -- that is, whether it was vertical or dipping at some angle -- in doing this seismic refraction work, in order to identify the position of the fault, they did some drilling in two locations, assuming that these locations were on either side of this fault. The drilling was done through the glacial deposits to the top of bedrock, what we call top of rock, in order to determine the elevation of the bedrock.

They went through the bedrock to determine the nature of the rock at either of these two -- at both of these two locations.

It was based on those corings -- those core borings -- that they determined the presence of the fault was between these two locations, since the rock at the same elevations were of entirely different ages, and that to juxtapose rocks of entirely different ages, Ordovician, 450 million years, and Silurian, 400 million years of age -- to juxtapose, you would have to assume a fault.

They did the seismic refraction work then across there and confirmed that the fault did exist between these two locations.

The fact that they had to do this kind of indirect determination to find the fault indicates that the surface materials were not disturbed.

I subsequently spoke to members of the Illinois Survey, including Dennis Kolata, and have received letters from them re-affirming this position that they have never found disturbed till anywhere overlying any of the faults in Northern Illinois.

It is on those bases that I determined that the glacial deposits have not been disturbed, and, therefore, the age of the glacial deposits gives us the minimum age for the fault.

Q Are there any other lines of evidence --

MR. GALLO: Judge Smith, can we approach the bench?

JUDGE SMITH: Yes.

Off the record?

MR. GALLO: Yes.

(There followed a discussion outside the record.)

JUDGE SMITH: On the record.

Mr. Gallo, may I summarize the bench conference?

MR. GALLO: Please do, your Honor.

JUDGE SMITH: Mr. Gallo brought to the Board's attention that there has been what has been conceded to be rebuttal testimony by Dr. Alterman.

He pointed out that Mrs. Johnson isn't represented by counsel, the League of Women Voters, and that it is not fair for rebuttal testimony of this amount, this substance, to be presented without notice; and I told him I think that was a commendable effort on his part to be sensitive of that.

Of course, when we indicated at the outset that we may -- with some rebuttal testimony, we don't know, until we hear it, how large it is.

Mr. Goldberg believes it's perfectly permissible and he wants to save hearing time.

We haven't heard from Mrs. Johnson yet.

At that point the Board decided that the discussion should be on the record.

Now we will hear from Mrs. Johnson.

What is your feelings on it, Mrs. Johnson? Do you feel that you have been put at a disadvantage by the additional testimony of Dr. Alterman?

MS. JOHNSON: Somewhat, yes.

JUDGE SMITH: What would be your plan for -- what would you request? What do you think would be helpful?

MS. JOHNSON: We would like to proceed with our cross examination as outlined to you.

Of course, we do not want to prolong the proceedings, but we would feel that was better for us to get our cross examination in and then have this kind of rebuttal.

JUDGE SMITH: As I understand, the problem has really arisen because Dr. Woodard, at the time of his deposition, really wasn't up to speed for his testimony, nor was he required to be; and much of his testimony -- much of his testimony on cross examination, which was 100 percent appropriate and necessary, was in the nature of surprise to all of the parties, so there is a legitimate need for rebuttal. There is no question about that in my mind.

It is not a yes or no issue as far as I can see. I mean, a little bit of rebuttal is appropriate.

If it is so much that the other party is unfairly caught by surprise, well, then the judgment has to be made.

The fact that you are not represented by counsel is a procedural consideration that I think we will have to be sensitive to, but it should not be a substantive consideration.

It was very optimistic that seismicity could be covered in one day, anyway.

My estimate was two days when I received that.

With all of those observations, are there any further comments?

(No response.)

JUDGE SMITH: What would you prefer? Would you prefer to have the rebuttal put off to some other day? Would you be better prepared, do you think?

MS. JOHNSON: Are you asking me that?

JUDGE SMITH: Yes, ma'am.

Sooner or later the rebuttal testimony will have to be --

MS. JOHNSON: I see no reason we could not -- yesterday we proceeded with cross examination of Commonwealth Edison's witnesses without a rebuttal.

It seems to me we can do the same thing now with the Nuclear Regulatory Commission witnesses.

JUDGE SMITH: That is true, that is true, as far as now is concerned.

But the Staff has indicated the need for rebuttal testimony some time, so that testimony will have to be received some time.

MS. JOHNSON: Yes. Couldn't it be after we are finished?

JUDGE SMITH: Today after you are finished?

MS. JOHNSON: Yes. That's what I said.

JUDGE SMITH: Well, I don't see how that helps you any, because you are going to be busy on cross examination, and you can cross examination on the rebuttal all at once; but if you think that helps you, we will work it that way.

I don't really think that Mrs. Johnson is really capable of taking the advantage that you have made available to her.

MR. GALLO: Well, Judge Smith, if she was represented by counsel, I believe her counsel would say that he would like to see the rebuttal in one of two forms: Either written, so that he has the opportunity to review it first some time, in accordance with the requirements of 2.743 on evidence, or that it be elicited orally and that he be given the chance for the evening to read the transcript so that he could prepare.

JUDGE SMITH: I think maybe you have touched upon the fair solution: That we proceed with the rebuttal testimony, that a copy of the transcript of it be made available to the Intervenors, and if they request an opportunity to address rebuttal later after consultation with Dr. Woodard and counsel, we will entertain that motion.

Does that seem fair to everybody?

MR. GOLDBERG: May I be heard on this, Judge?

JUDGE SMITH: Yes.

MR. GOLDBERG: First of all, 2.743 does not exclude oral rebuttal testimony. It talks about oral or documentary evidence.

JUDGE SMITH: That's correct. It's a matter of degree.

MR. GOLDBERG: I agree it's a matter of degree; but one of the goals in the practice of having the Staff testify last is that it has technical responsibility separate and apart from the adjudication; and while it is a litigant, it also has a certain posture in the overall administrative process, and that is to observe and to listen to the testimony that has preceded it and maybe be influenced in its positions and opinions.

Now, we have expert testimony here which we are prepared to offer.

JUDGE SMITH: Now, Mr. Goldberg, you don't have to argue the need for rebuttal; it's only the timing of it.

MR. GOLDBERG: Okay. All I am saying is that this was not the League that raised this issue, and I don't think that their lack of representation really should, you know, entitle them to a departure from the customary practice, I think, of combining, where feasible, direct and/or rebuttal testimony.

It has been done in other NRC cases, and I think it should be up to the party, really, to have the benefit now of hearing the full evidence and then formulate their questions on that basis.

JUDGE SMITH: Okay. Well, just let the Board consult.

The Board's ruling is that Mr. Goldberg will proceed with his rebuttal testimony.

We will allow Mrs. Johnson to combine her cross examination.

We will give her a recess, if she needs it, to have cross examination on rebuttal testimony.

MS. JOHNSON: May we have this writing?

JUDGE SMITH: I beg your pardon?

MS. JOHNSON: Will he provide this?

JUDGE SMITH: If you have questions, when I get done, then I will answer them.

MS. JOHNSON: Excuse me.

JUDGE SMITH: After the transcript is prepared, we will proceed -- well, before that the Board itself will ask questions to try to assure that there is a complete record on the rebuttal testimony, if necessary.

After the witness has concluded the testimony, we will give -- make available to the Intervenors a copy of the rebuttal testimony. They will be given an opportunity to consult with counsel and with their technical advisor, Dr. Woodard. Then they can move for an opportunity for whatever relief might be required.

The most serious of any relief would be to recall the rebuttal witness; and in that respect you better concentrate your rebuttal as much as possible into one witness.

However, we are not saying we will give you that opportunity. We will see what is necessary.

Perhaps an interrogatory, perhaps a stipulation or perhaps something less than that. Perhaps nothing.

We can't decide until we know exactly what deficiency there has been in your opportunity to address the rebuttal testimony.

Okay?

MR. GOLDBERG: Judge, before proceeding, can I confer with the witnesses?

I am sure they want to minimize any risk of being recalled, from any other professional obligations, at a later date, and maybe I won't pursue the line of questioning at all.

JUDGE SMITH: I would recommend it. That is a potential. Until we know just basically how --

MR. GOLDBERG: I appreciate this. I would like to confer with them.

Let's go out in the hall.

JUDGE SMITH: We will take a five-minute recess while Mr. Goldberg is conferring with his witnesses.

(Recess.)

JUDGE SMITH: Mr. Goldberg.

MR. GOLDBERG: Yes. At this point I would like to proceed as follows: In the first instance, I don't regard the questions that I have posed to Dr. Alterman thus far as having been in the nature of rebuttal. It was commenting on reports referred to by other witnesses -- namely, the Geological Survey -- not disputing evidence adduced by other parties from other witnesses, merely explaining the basis for the Staff analysis documented in the testimony and the attached safety evaluation report and more in the nature of explanatory information for the benefit of the record, much as the Board directed questions to Dr. Rothman about the nature of the SSE and OBE review performed by Staff.

I would like to proceed with a few questions in that line.

I will withhold any rebuttal evidence, which is clearly rebuttal evidence, until the conclusion of the cross examination, then determine at that time its necessity.

My only objective was not surprise or to be unfair to any other party, but merely to develop a full record and to try, through Staff experts, to clarify some terminology and procedural mechanisms that might have been misused by past testimony.

BY MR. GOLDBERG:

Q Dr. Alterman, in that vein, can you tell me -- we have had a lot of discussion on the record about stress and strain.

I wonder if you could tell me the difference between the two.

A (WITNESS ALTERMAN) There is always a lot of confusion about stress and strain, even amongst professionals in the field for a long time.

Stress is related to force. It's almost a mathematical concept of the measurement of force per unit area in a body -- or acting upon a body -- sorry -- acting upon a body.

Strain, in a very general sense, is the response of the body -- usually in this case we are talking about rock or it could be a steel beam or something. Strain is the response of that body to the application of these forces or, as we call them, stresses.

In strain we deal with the changes of shape of the body, which -- we call that distortion, or the change of volume, which we call dilatation.

Mostly what we are concerned about, when we are dealing with the application of stresses, is the deformation or distortion of a body; and what we want to measure are changes in the shape of the body.

We can't do that directly when you have a body of rock that's many thousands of feet thick and many thousands of miles in the other two dimensions, but what we can do is measure small units of this body and the changes in imaginary lengths of lines within a certain volume.

So that in the theoretical aspects of working with strain, we imagine a small sphere within this part of the body that we wish to stress to determine the changes of shape of this sphere within the body; and if we establish a hypothetical radius or diameter of this sphere, we can then measure theoretically the changes of that sphere in terms of the lengths of the lines when it becomes an ellipsoid as we change the shape of it.

You can sort of imagine a ball made of sponge and deform it in some way, compress it in one direction or pull it out in another direction, and measure the changes in the dimensions of that.

We then have changes -- we then describe that as measuring the strain in this body. That's essentially what we are talking about when we talk about strain in bodies.

BOARD EXAMINATION

BY JUDGE SMITH:

Q As strain -- the strained body reacts or responds to the stress, does not the strained body, as Dr. Woodard suggests, develop potential energy which returns then stress upon the stresser?

A (WITNESS ALTERMAN) Wait. I am not quite sure I understand your question.

Yes, the body responds to stress and it does accumulate the strain; what we call stored strain energy.

Q What does it do with that energy?

Does not it produce a stress itself back upon the stresser?

A (WITNESS ALTERMAN) Yes, yes, on a very minute scale when we talk about a stress at a point; and the strain that we evaluate is minute, vanishingly small points in the rock.

We are imagining it to be certain shapes and sizes.

Yes, we have equal and opposite reactions, so to speak.

Q Until it reaches equilibrium?

A (WITNESS ALTERMAN) Well, the equilibrium comes from the external forces.

For example, in elementary physics you learn about what is called the hydrostatic stresses.

If you sink a body into water, at some critical depth, the forces acting on that body from all directions are equal. It has to be at some critical depth; and then no matter what directions you are talking about, the forces acting on that body are equal. That we refer to as the hydrostatic stresses.

That will not distort a body. It will change the volume, which is dilatation. It will compress it, and it will remain a circle or a sphere and be compressed inward, this way.

(Indicating.)

All right. Release the stresses and it will then return to its normal shape and size. That's -- that would be stresses equal in all directions.

I don't know if I am answering your question properly.

We do -- when we -- in order to get distortion or deformation of rock bodies, a stress is superimposed upon this hydrostatic stress, let's say at some depth within the crust, and it is that superimposed stress that takes the body out of equilibrium.

Those are called the deviatoric stresses. Sometimes more familiarly we refer to them in general as differential stresses; and it is those differential stresses which, under a general set of conditions, can cause the rock to fracture, break or deform in some other way, depending upon the conditions.

That, essentially, is what we are talking about when we discuss strain. That's just very the barest outlines of a very complex subject.

BY MR. GOLDBERG:

Q Briefly, what is measured when you measure both stress or strain?

A (WITNESS ALTERMAN) Which are you talking about now, stresses or strains?

Q First stress.

What is measured when you measure stress?

A (WITNESS ALTERMAN) Well, in the field -- are you talking about in the field or in the laboratory?

Q In the field.

A (WITNESS ALTERMAN) In the field, generally speaking, we measure the orientations of stresses.

We find that in almost all places of the crust there are stresses, not only the vertical stresses which result from gravity and the burial of materials on other materials, but also lateral stresses, those that act parallel -- nearly parallel to the surface of the earth; and in various places they differ.

We don't know all the reasons why, but they do differ; and in some places the major -- what we call the maximum compressive stress is oriented in certain geographic directions such as northeast-southwest or northwest-southeast, and you have what is called the minimum compressive stress, that with which the least pressure is exerted, and that's usually perpendicular to 90 degrees geographically or geometrically from the maximum compressive stresses.

Those help us to understand something about the state of stress in the crust when we deal with fractures, earthquakes, because in mentioning before the study of the geometry of rock deformation, there are ways -- and part of the principals of structural geology involve being able to predict the orientation of fractures depending upon the orientation of stresses in the crust.

We cannot go directly from strain to stress, at least not for the most part. We do not yet know enough to be able to do that.

The strains are so complex and are dependent upon so many factors.

Stress alone, the normal oriented crustal stresses, are not directly determinable from strains as we know them today.

Q Dr. Alterman, briefly what is measured now in measuring strain?

A (WITNESS ALTERMAN) Well, are you talking again in laboratory experimental work or in the field?

Q Let's talk about in the field.

A (WITNESS ALTERMAN) In the field you are still talking about changes in the shape of a body, or most of the strain measurements that I am familiar with are those we use across faults, active surface faults today, as in California, referred to commonly as creep meters.

What they are measuring there is the strain in the body across a fault; and it's -- the basic idea is to stretch a wire across that fault and bolt it to some part of the ground surface and then, through some electronic devices, to measure the change in the lengths of the wire, which determines the change in the shape of the rock surface and thereby determine the amount of strain in that way, so that, again, they are talking about change in the shape of the surface material there.

Q Is this phemonenon known as differential strain?

A (WITNESS ALTERMAN) That is not a term that is used in structural geology.

Differential stress, yes, which produces the deformation.

BOARD EXAMINATION

BY JUDGE COLE:

Q Dr. Alterman, are you talking about strain or are you talking about displacement there?

A (WITNESS ALTERMAN) It's still -- they are not dissimilar, let me put it that way, because strain itself, when you are talking about the change of a shape of a body, whether you are dealing with a very minute part of it or whether you are dealing with a larger body, you are actually dealing with the -- either the minute or larger motion of particles within that body that are actually being displaced, so that in order to take a sphere and to change it into an ellipsoid by compressing it in various ways, you are actually moving material within that body to change from a sphere to an ellipsoid.

Q That gets a little closer to a definition that I am familiar with of strain.

But you talked about stretching a rubber band across a fault and then making measurements there; and that's really displacement, isn't it?

A (WITNESS ALTERMAN) Yes, to -- yes, it is displacement. You are measuring the displacement or motion along there; but from the theoretical point of view, from the technical point of view, it is strain that you are measuring; and there is a relationship between the measurement of the displacement of the surface rock and the change in the shape of this wire, because the measurement of strain is not in terms -- in theory, the measurement of strain is not in terms of inches or centimeters and so on. It is referred to as percent. It is a non-dimensional concept; and what you do -- the mathematics it is not necessary to get into here, but it is the change in the length of a line, let us say, if we are using a line, divided by the original length of that line.

So if you have shortened it by 10 centimeters, and the line was originally 100 centimeters, then you now have 90 -- I am sorry -- 10 centimeters over 100 centimeters -- the percent strain was 10 percent, something like that. That is the way we measure.

So they would be using this wire to determine the change in the length of the wire and direct -- and then make some sort of calculations to direct that into the change of displacement or the displacement on fault.

Q I guess I can visualize that it could be a little bit closer to an actual strain measurement if the band were shortening and the pieces were coming closer together without any vertical or horizontal displacement; but if it's something other than that, I just couldn't see how it could be a strain measurement.

A (WITNESS ALTERMAN) We don't have it -- as I understand it, we do not have instruments that do that.

So far the ones that have been developed for surface faults are the ones in California, mostly strikes your surface, motions parallel to the surface, and that's essentially what has been measured in terms of faulting.

There are other ways of measuring strain in rocks for other reasons, but that is not a way in which I understand or have known in the past strain to be measured. That is in vertical displacement.

Q Dr. Rothman, it looked like you were going to say something.

A (WITNESS ROTHMAN) Yes. There are other techniques that have been used in California for measuring surface strain, and among them are just the plain surveying techniques in which they do triangulations from a base station a significant distance away from the region under study and they reoccupy the survey points periodically and look at the relative displacement between these points and then calculate strain and strain rate from these kinds of studies.

Q Okay. Are you talking about relatively rapidly moving-faults?

A (WITNESS ROTHMAN) Yes, we are talking about a plate boundary area in California where we have significant amounts of displacement that are measurable.

Q Do we have any situations like that near Byron?

A (WITNESS ROTHMAN) No; not to my knowledge, no. There is no indication at all of surface displacement at all at Byron.

BY MR. GOLDBERG:

Q My final question for Dr. Alterman:

How do the strain measurements translate into predicting fault movement?

A (WITNESS ALTERMAN) As I mentioned before, as far as I know, we have not yet developed a technique for translating strain measurements to predicting faults.

There are so many factors involved in strain and in straining a particular rock, the conditions at the place where the fault occurs, and it's different for different rocks in different environments.

It has to do with depth, with what we call confining pressures. That is the pressure at great depths within which increases at depth, temperature, the strain rate, the rate at which the stresses are applied and at which the material is deformed, the rate at which that happens.

Rapid rates will produce certain types of mechanical behavior and slow rates will produce a different type of behavior.

There are so many factors that have to be known before one can go from strain to stresses that I believe -- and I think that this document that Dr. Woodard introduced yesterday confirms -- that we have not yet reached that stage of knowledge that we can do that.

Q Dr. Rothman, I have only one question for you.

I wonder if you can describe how the earthquake parameters, magnitude, ground motion, peak acceleration, are utilized in power plant design or nuclear power plant design.

A (WITNESS ROTHMAN) Yes. The basic concept that we have is to determine what the controlling earthquake is for a nuclear power plant; and this can be characterized either by its magnitude or its intensity.

Once we have established the controlling earthquake under the tectonic province approach, which was the approach that is used in the central stable region, which is the -- this area of the United States, we assume that the controlling earthquake can occur in the vicinity of the nuclear power plant.

We then establish what the ground motion due to that earthquake would occur in the site vicinity, and we represent this by a response spectrum, which is a characterization of the ground motion as a function of frequency.

This motion is then used for the analysis -- for design and analysis -- of the plant.

MR. GOLDBERG: I have no further preliminary questions, and I tender the witnesses for cross examination.

JUDGE SMITH: Mrs. Johnson, are you aware that there is a special provision in the regulations of the Commission whereby cross examination can be conducted by a scientific expert?

MS. JOHNSON: Yes, I am.

JUDGE SMITH: In other words, I am suggesting that if you prefer to have Dr. Woodard conduct cross examination, that is permissible under our procedures.

MS. JOHNSON: Yes, I am aware of that, and I asked Dr. Woodard, unless he has changed his mind, do you feel that you would like to do it?

MR. WOODARD: I would prefer that Mrs. Johnson do it.

MS. JOHNSON: He will help me with it --

JUDGE SMITH: Okay. We won't --

MS. JOHNSON: -- if that's possible.

JUDGE SMITH: We won't stick to an either/or situation, although that would be preferable that one or the other take the primary responsibility; but if you come to a point that you think is so technical you would like to take over and it doesn't cause any prejudice, let's consider that.

MS. JOHNSON: Thank you very much.

JUDGE SMITH: Sure.

CROSS EXAMINATION ON BEHALF OF INTERVENOR
ROCKFORD LEAGUE OF WOMEN VOTERS

BY MS. JOHNSON:

Q Dr. Alterman, you state that Illinoian age till overlies the Plum River Fault and it is not displaced by the fault; is that correct?

A (WITNESS ALTERMAN) Yes.

Q Have you ever seen an exposure of this fault and the overlying till which demonstrated this relationship?

A (WITNESS ALTERMAN) No.

Q Do you know specifically any geologist who has observed this -- directly observed -- this relationship?

A (WITNESS ALTERMAN) Yes.

Q Could you explain who that is?

A (WITNESS ALTERMAN) Yes. Dennis Kolata of the Illinois Survey. He has directly stated that he has seen this.

Q Where?

A (WITNESS ALTERMAN) In his studies of the Plum River Fault Zone and of the Sandwich Fault Zone.

Q We are talking about the Plum River.

Can you explain explicitly where?

A (WITNESS ALTERMAN) He did not tell me explicitly where, but he has stated --

Q This is hearsay; this is not in the --

MR. GOLDBERG: Judge, I don't think the questioner should be arguing with the witness.

MS. JOHNSON: I am sorry.

JUDGE SMITH: Well, she certainly --

MR. GOLDBERG: The question was asked whether she knew a particular piece of information, and she indicated the source for her knowledge of a particular piece of information.

JUDGE SMITH: Well, she is going in a direction where she certainly is permitted to go. It's just that she got there rather abruptly.

MR. GOLDBERG: Then she objected that the answer contained hearsay, and I am --

JUDGE SMITH: She is just trying to establish that.

MS. JOHNSON: Whether it was from the -- I should have asked that.

BY MS. JOHNSON:

Q Is this information from your talking with the geologist or from Circular 491?

A (WITNESS ALTERMAN) Essentially it's from discussions with Dennis Kolata and from letters from the Survey.

JUDGE SMITH: Mr. Savage, without any particular commitment on your part or notice of appearance or anything else, if you feel like helping Mrs. Johnson, don't stand back.

MR. SAVAGE: I will, your Honor.

I think that just if I interrupt the questioning, when people are talking to her, she is going to lose track.

JUDGE SMITH: All right.

BY MS. JOHNSON:

Q Specifically, Dr. Alterman, what is the basis for your statement that the Plum River Fault is not capable?

A (WITNESS ALTERMAN) There are several lines of evidence, I believe.

First, accepting the Illinois Survey's contention or conclusion that the Illinoian glacial till is not disturbed over the fault zone.

Secondly, that there is no seismicity associated with the fault zone.

Thirdly, that there is no scarpment -- this is more indirect evidence. There is no scarpment across the fault zone, indicating a long period of erosion with no deformation, no further movement.

Those are at least three of the reasons.

Q Would there have to be a scarp associated with the fault if it were a capable fault?

A (WITNESS ALTERMAN) No.

Q Then the lack of a scarp does not prove or disprove capability?

A (WITNESS ALTERMAN) No; that's true.

Q You state that your evaluation of the capability of the Plum River Fault is made on the basis of data presented in the Illinois Geological Survey Circular 491; is that correct?

A (WITNESS ALTERMAN) That's correct.

Q Are you familiar with Figure 7 of that publication?

A (WITNESS ALTERMAN) I don't have it in front of me, but --

Q We have these to hand out.

A (WITNESS ALTERMAN) I have a copy.

MR. GOLDBERG: I would like a copy.

MR. SAVAGE: Do the Judges want a copy?

MS. JOHNSON: Yes, they do.

JUDGE SMITH: Please.

MS. JOHNSON: I will give you a minute to look at that.

A (WITNESS ALTERMAN) (Continuing.) I am prepared to respond to any questions.

BY MS. JOHNSON:

Q Are you familiar with Figure 7 of that publication, which shows a geologic cross-section of the Plum River Fault Zone?

A (WITNESS ALTERMAN) Yes.

Q That Figure 7 shows topographic relief of approximately 10 to 12 feet on the bedrock surface adjacent to the fault; correct?

MR. GOLDBERG: Judge, I object to the form of the question.

I think she should ask the witness what the figure depicts rather than make a statement of what the figure --

MS. JOHNSON: I said, "Is that correct."

MR. GOLDBERG: -- of what the figure depicts when it may be interpretive of the figure.

MS. JOHNSON: Do you want me to restate that? I said, "Is that correct."

JUDGE SMITH: Your concern is that the question may not accurately reflect what the figure states?

MR. GOLDBERG: It may be interpretive of the figure rather than a statement of what the figure consists of.

JUDGE SMITH: Yes. You want to be sensitive to that concern.

BY MS. JOHNSON:

Q What is your interpretation?

A (WITNESS ALTERMAN) It shows an irregular surface, a surface of irregular topography, irregular bedrock topography.

Q In your opinion, could that represent a fault scarp?

A (WITNESS ALTERMAN) I am sorry. Would you repeat that question?

Q In your opinion, could that --

A (WITNESS ALTERMAN) I am sorry. I mean, can you rephrase it, because I know what you are saying but I don't understand it?

Q In your opinion, could that topographical relief represent a fault scarp?
A (WITNESS ALTERMAN) Not in the form in which it is depicted here.
Q Why not?
A (WITNESS ALTERMAN) Because as it is depicted here, there is no offset of the surface across the fault itself, as interpreted here. I don't see that as a fault scarp.
Q Might that be the case?
A (WITNESS ALTERMAN) Can you rephrase that in some way?
Q Do you know what main techniques were used by the Illinois Geological Survey?
A (WITNESS ALTERMAN) Yes. To determine this cross-section, they did seismic refraction work. The seismic refraction work determines or describes the surface -- the subsurface structure by reflections of various types of sound waves, and based on the results of their survey, the seismic refraction survey, this is the interpretation that comes from it.
As I see it, they have depicted it that there is no offset of the surface along the fault.
Q Have you ever run across any seismic refraction -- run. I am sorry.
Have you ever run any seismic refraction profiles?
A (WITNESS ALTERMAN) No; not myself, no.

Q Do you know what accuracy can be expected from these?
A (WITNESS ALTERMAN) Yes, more or less I don't know what you mean. A level of accuracy, percent error? I am not sure.
Q Plus or minus.
A (WITNESS ALTERMAN) Plus or minus what? I am sorry.
Q Plus or minus in feet.
A (WITNESS ALTERMAN) Oh, I am afraid I wouldn't know that.
Do you know?
A (WITNESS ROTHMAN) Would you mind if I --
MR. GOLDBERG: Judge, Dr. Rothman is indicating that he would like to comment on --
MS. JOHNSON: Is this a panel?
MR. GOLDBERG: -- the question.
This is a panel.
A (WITNESS ALTERMAN) Dr. Rothman, as a seismologist, may have more experience with that kind of thing than I do.
MS. JOHNSON: This would be fine.
A (WITNESS ROTHMAN) For a number of years I was employed by New York State Department of Public Works, and my primary function was conducting seismic refraction surveys in glaciated areas of New York State, so I am quite familiar with the technique.
It's very difficult.
I have not read this paper, but I can give you some

estimates based on the work that I am familiar with.

First of all, in glaciated areas you have a very good differentiation between the overburden, which is the glacial till, and the rock below. There is a very nice velocity contrast, so you get very good refractions.

There is very little weathered rock below the glacial till, so you get a very sharp contrast between the two materials and it's very easy to define the rock surface.

The accuracy of the survey depends on the distance between the stations at which you have seismometers.

What happens with a refraction survey normally is you put out a group of portable seismometers.

I believe that's what they are showing here in Figure 6 on this page. They show a Point A and Point B, which are the two drill holes represented below in the diagram, and then they have the locations, I believe, indicated by the numbers 1, 2, 3, 4, et cetera, to show the location of the seismographs, the portable seismographs that were put out, but an energy source is then used to transmit energy down to the rock surface where it's refracted. Energy propogates through the till and through the rock, and by recording the arrival times of these sound waves, it's possible to do a calculation and calculate the depth of the rock at each location.

Depending on how close these stations are, you can get -- and the depth of the rock -- you can get accuracies on the order of plus or minus one foot.

I base these numbers on the fact that I have done refraction surveys where drill holes were later drilled and the depth of the rock was reaffirmed by the drill holes themselves.

BY MS. JOHNSON:

Q Is -- well, Dr. Alterman, I guess I should go back to you, but if you can't answer it -- is this accuracy enough to tell if the fault is capable or not?

A (WITNESS ALTERMAN) Accepting what Dr. Rothman has said about the ability to see the ground surface quite clearly or the distinction between the till and the ground surface, I would say yes, it is enough to determine that the till is not offset; and assuming the age of the till -- based on various studies, the age of the Illinoian till to be at the minimum 125,000 years, that meets our definition for non-capability.

Q If this rock surface that you mentioned has relieved, will this reflect on accuracy?

A (WITNESS ALTERMAN) I would rather give that to Dr. Rothman.

A (WITNESS ROTHMAN) I don't know what you mean by reflect on accuracy.

You mean if there is surface relief?

No. If you will look at the cross-section there, you will see that the stations are spread out, and what happens is you get an arrival at each station.

I have not read the paper, so I don't know the technique that was used; but normally the technique that is used is called reverse profiling, in which you put a source at one end of the line and make a recording and then you put a source at the other end of the line and make a recording and you plot the first arrivals from each of these recordings on a piece of graph paper.

You are able to determine the differences in relief, because a station over a high point -- say, a little mound as depicted in this rock -- would have an early arrival in both directions, so you could tell where the relief was and approximately what the differences in relief are.

MR. GOLDBERG: Judge, I am not sure if this is an important line of questioning to the League.

MS. JOHNSON: I don't understand the --

MR. GOLDBERG: If it would be, if it is, perhaps Dr. Rothman can be given an opportunity to familiarize himself with Circular 491, which is in Dr. Alterman's possession.

If it's not an important line of questioning and the answers of the witnesses are, you know, satisfactory, we can proceed and see how it goes; but we do have the document.

MS. JOHNSON: My understanding is that Dr. Alterman is familiar with that circular and we feel she should be able to answer these questions.

JUDGE SMITH: You mean you are testing her mastery of that circular without the circular?

MS. JOHNSON: No. We have a reason for doing this, but we just want to -- she can look it up if she wants to.

MR. GOLDBERG: Well, the questions were in the particular discipline with which Dr. Rothman is more readily acquainted.

JUDGE SMITH: He is making an offer to you. You can accept it or reject it.

MS. JOHNSON: Do you have something?

Is it appropriate for Dr. Woodard to --

MR. WOODARD: Your Honor, this line of questioning deals with whether the Plum River Fault has been demonstrated to be capable or not capable.

I tried in my testimony to demonstrate that the Plum River Fault, on the basis of available data, the published data in Circular 491, is -- it's unknown whether it's capable or incapable.

We went through most of this kind of testimony with a different witness yesterday; and I think from my point of view, at least, we demonstrated that you couldn't tell.

I don't know, of course, how the Board takes that testimony yesterday.

It might not be necessary to go through all of this again.

JUDGE SMITH: Well, we certainly cannot tell you whether we are convinced one way or the other at this juncture of the case.

MR. WOODARD: I understand that.

JUDGE SMITH: So you assume that you would have to make your case.

MS. JOHNSON: We are willing to let Dr. Rothman get familiar with the document, if that's the case.

We understood that Dr. Alterman was familiar with it from her testimony that she filed, but if Dr. Rothman would like to read it, how much time will he need to do this?

MR. BIELAWSKI: This might be a suitable time to break for lunch and come back afterwards.

JUDGE SMITH: Yes, that's a good observation. Let's break. We will take a break until 1:15.

(Whereupon, at 11:55 P. M., the hearing in the above-entitled matter was recessed, to reconvene at 1:15 P. M. the same day.)

JUDGE SMITH: You may proceed.

MR. WOODARD: Your Honor, we have discussed this over the lunch hour and I am going to try and ask a few questions directly, if that is permissible.

JUDGE SMITH: Sure.

CROSS EXAMINATION

BY MR. WOODARD:

Q I would like to address the first question to Dr. Rothman.

I believe you earlier testified that, by using seismic refraction techniques, there would be an inaccuracy of approximately plus or minus one foot in the determination of bedrock depth to bedrock surface; is that correct?

A (WITNESS ROTHMAN) I said I had seen studies in glacial areas with that type of accuracy.

I don't know exactly what it would be here unless I went and --

Q Is this degree of accuracy sufficient to determine if the Plum River Fault is or is not capable?

A (WITNESS ROTHMAN) I couldn't -- I couldn't answer that.

Q Isn't it true that displacement of only a few inches, if they had occurred during the last 35,000 years, would demonstrate a capable fault?

A (WITNESS ROTHMAN) Displacement within the 35,000 years would be -- would demonstrate a capable fault.

However, I believe that displacement of a few inches in the glacial till would be observable, also, and your report indicates there is no displacement visible in the glacial till.

Q Is it possible to record displacement of a few inches or, for that matter, even a few feet, by seismic refraction techniques in glacial till?

A (WITNESS ROTHMAN) No. You would record the displacement in the rocks' surface, in the surface of the bedrock, not in the till itself.

Q Thank you.

Isn't it true, then, that you just said that seismic refraction techniques might have inaccurate -- inaccuracies at least of plus or minus one foot?

A (WITNESS ROTHMAN) In the measurement of depth to bedrock, yes, I said that.

Q Then doesn't this show that this technique does not produce data of sufficient accuracy to prove capability of the fault?

A (WITNESS ROTHMAN) Well, I have not reviewed the data. I have just reviewed the method that was described here. I haven't seen the data, so I don't know what kind of accuracies they have been able to obtain.

JUDGE SMITH: Could you back up just a moment and explain what seemed to me to be failure to communicate.

You were talking about a seismic displacement and you are talking about then suddenly the inaccuracies or accuracies of measuring the overburden, or was it the till?

MR. WOODARD: The till.

JUDGE SMITH: The depth of bedrock seemed to be interplaced. I don't know.

Could you review just what has happened just the last few questions and answers. Would you do that, just what you understand the last few questions and answers to have established?

A (WITNESS ROTHMAN) Would you like me to review it?

JUDGE SMITH: We started talking about a few inches in seismic displacement as compared to a foot and a margin of error in measuring down to bedrock.

It seems to me the answer became interchangeable there and doesn't make sense.

A (WITNESS ROTHMAN) The way I understood it, I was asked what the accuracy was in determining the depth to bedrock using this technique, and I stated that I had seen accuracies on the order of one foot, using technique similar to this, in regions with these same kind of physical conditions of glacial till overlying a glacially scoured surface, where you have a nice velocity contrast between the till and the rock.

I was then asked what kind of displacement I would expect to see in the till, and I said I don't think you could measure the displacement in the till using the refraction techniques. You might be able to measure displacement in the rocks ' surface.

JUDGE SMITH: What was your syllogism? That's what I am missing.

MR. WOODARD: The significance of this, your Honor, is, I believe, we have demonstrated that the technique will neither discern a capable fault by using the top of the bedrock as an indicator or by using horizens in the glacial till as an indicator.

MR. GOLDBERG: Judge, Dr. Woodard now is in his role as examiner.

This is not testimony, I take it?

Sometimes he crosses the line.

JUDGE SMITH: I understand it to be explaining the testimony that he has elicited.

MR. GOLDBERG: He is not offering testimony that otherwise wasn't adduced through this witness.

JUDGE SMITH: I understood you to create a syllogism to the effect that -- well, I can't recreate the syllogism. That's exactly what my question is.

Just give me a moment to confer with the Board.

Dr. Cole has explained the testimony. I am sorry to have interrupted. I understand it now.

MR. WOODARD: May we proceed?

JUDGE SMITH: Yes, please.

MR. WOODARD: I would like to shift to Dr. Alterman now, if I may, for a moment.

JUDGE SMITH: I am sorry. I didn't hear you.

MR. WOODARD: I would like to shift to Dr. Alterman now for a moment.

BY MR. WOODARD:

Q Dr. Alterman, you say you are familiar with the techniques used by the Illinois Geological Survey in order to publish the data presented in Circular 491; is that correct?

A (WITNESS ALTERMAN) I said I was familiar with the information in 491.

Q Do these -- do they say anything in Publication 491 as to what their chief data gathering techniques were?

A (WITNESS ALTERMAN) Yes, they describe a variety of techniques.

Q Could you mention some of those, please?

A (WITNESS ALTERMAN) Yes. They mentioned drill cores, seismic refraction, a geologic mapping and subsurface mapping techniques.

Q Do they mention heavy reliance on water wells?

A (WITNESS ALTERMAN) Well, to establish their subsurface data, they have gotten information, I suppose, from wells as well as other drilling techniques.

Q Do you know how water wells are typically drilled in Northern Illinois?

A (WITNESS ALTERMAN) No.

Q Are you familiar with a cable tool drilling rig?

A (WITNESS ALTERMAN) No.

Q Could you briefly explain what a cable tool drilling rig is?

A (WITNESS ALTERMAN) If I am not familiar with it, sir --

Q I guess you can't.

What accuracy for determination of depth plus or minus feet, to a given stratographic who rides even, would you expect to get from this technique?

A (WITNESS ALTERMAN) I don't know the technique, sir.

Q Your written testimony, Answer 10 specifically, on your written testimony, on strain in rocks compares the Plum River Fault with the San Andreas Fault in California; is that correct?

A (WITNESS ALTERMAN) No, it does not compare it. It simply gives examples of strain rates that are present in the crust that can be measured.

Q Then it wasn't your intention to draw any sort of comparison between the San Andreas system and the Plum River Fault system?

A (WITNESS ALTERMAN) Not really, except in terms of strain rates, one is possible to measure and one is not possible to measure.

Q I see. You used the terminology, if I can find the -- you used the terminology in your written testimony -- and I believe it's still in Answer 10, but I am not certain of that. I have lost my reference to it.

You used the terminology "vanishingly small"; is that correct?

A (WITNESS ALTERMAN) Yes.

Q Could you be more specific or could you be more quantitative, if you like, when you talk about vanishingly small strain rate cannot be measured?

A (WITNESS ALTERMAN) Well, it's a mathematical term that is used in calculus dealing with very minute dimensions or rates of whatever the numbers are, which in this case, if you say it has zero movement in 125,000 years, we cannot predict over what length of time we must wait before we find any evidence of movement or strain here at all, and it may take 10 or 15 generations of watching that strain gauge to find some evidence of movement.

So in place of guessing a number, vanishingly small simply implies that the rates are so small that there is no conceivable way to enter this.

Q Well, I think I understand what you mean by the term vanishingly.

It's the application of vanishingly small to the phrase, "cannot be measured."

A (WITNESS ALTERMAN) At the present state of the art, I believe that's true.

Q Let me give you an example to possibly clarify it for me.

Let's assume that I have a core, a drill core, sitting on this tabletop. Let's say it's a foot long and two inches in diameter. It's sitting here. It's like a stack of these cups or something.

If I were to take and attach a strain gauge to that core, with the right instrumentation, of course, and if I were to put my forefinger on that core and generally push down on it, would -- the strain gauge affixed to the side of that granite core, would I, in fact, measure the strain?

A (WITNESS ALTERMAN) It's possible, yes. It's a type of strain we call creep; but it is a very, very low strain rate, and it may take you sitting there for many tens of months or years before it finally records any movement; but it will be. There is undoubtedly strain going on.

Q Do you know that such small strains can readily be measured in rock cores? They are vanishingly small, as I take it from your testimony but, in fact, we measure them all the time in the laboratory?

A Yes, in the laboratory.

We were not talking about the laboratory, sir. We were talking about techniques for measuring strain in the field.

Q Thank you.

I would like to come back to Mr. Rothman, if I may, your Honor.

Dr. Rothman, in your Answer 10 in your written testimony, you draw an analogy regarding potential earthquake damage between the Byron plant and a shed near Conway, Arkansas; is that correct?

A (WITNESS ROTHMAN) In my Answer 10 I said that the shed in which the instrument which recorded .59 G peak horizontal acceleration was located did not have any damage nor did other buildings located near the strong-motion instrument.

Q Then you do not mean to draw any comparison between that shed and the Byron plant?

A (WITNESS ROTHMAN) The only comparison I would make is if you have an outbuilding to a house or the house itself, and these supposedly are not designed to withstand laboratory ground motion at the level that Byron is, and they did not exhibit any damage due to this earthquake, we would not expect the Byron plant to exhibit any damage from this type of an earthquake.

Q Then are you saying that the vibratory characteristics of

the Byron plant are the same as that shed of yours in Arkansas?
A (WITNESS ROTHMAN) I say that the design of the Byron plant is much better than the shed, yes.
Q Would you say that the analogy you use with respect to just the use of the Byron shed, as an example, is a good use?
A (WITNESS ROTHMAN) Byron shed?
Q I am sorry. The Conway shed, the Arkansas shed.
A (WITNESS ROTHMAN) No. The point I was trying to make in my testimony was the fact that although this earthquake was reported to have a very high peak acceleration, there was very low energy associated with this event and it has caused no damage to any buildings around there, and these buildings are not even seismically designed, or I should say, aseismically designed.
Q Well, it's certainly true -- I know and you know -- that this is a low energy event.
If the ground acceleration for that low energy event -- I believe it was 3.8 on the Richter scale.
If that ground motion was or approached 0.59 G, what do you think the ground motion would have been if that -- if the magnitude had been 5.8 G -- 5.8 on the Richter scale?
A (WITNESS ROTHMAN) The ground motion from --

Q The acceleration.
A (WITNESS ROTHMAN) -- the acceleration?
Q Uh-huh.
A (WITNESS ROTHMAN) Well, based on my knowledge of the response spectrum of suites of earthquakes with an average magnitude of 5.8, we have found that the peak acceleration, as depicted on these spectra, was less than .2 G.
Q How many readings do you have to base that upon?
A (WITNESS ROTHMAN) How many spectra we used in the --
Q That's correct.
A (WITNESS ROTHMAN) In the TVA study I believe approximately 22 spectra were used, and I am not sure how many we used in the Lawrence Livermore study, but on that order, on that number order we used; and these events arranged in magnitude from 5.3 to 5.8. They were all recorded at distances of less than about 25 kilometers and some of them as close as 2 kilometers from the epicenter of the earthquake.
Q You stated that the basis for your opinions on the -- strike that. Let me start out again. I use his terminology. He is smart.

You state that the instrument in use to record an acceleration of 0.59 G at Conway, Arkansas, on 5 July, 1982, specifically an SMA-1, may have had, quote, installation effects, unquote, which influenced this high reading; is that correct?

A (WITNESS ROTHMAN) I didn't use the word Conway, Arkansas. I never used that term.

Otherwise, yes, the SMA-1, yes, recorded that amount, the high readings due to installation effects.

Q You stated the basis of your opinions is an article by Arch Johnson, dated October, 1982; is that correct?

A (WITNESS ROTHMAN) Yes. Also, I have had telephone conversations with Arch Johnson subsequent to that regarding that article.

Q Did you know that the same Arch Johnson published a paper in [ERTS on December 14, 1982?

A (WITNESS ROTHMAN) That paper, in essence, is an extract, a shortened version of the larger report. It contains all the information in the larger -- the larger report contains that information.

Q In that article Mr. Johnson recognized -- yes, Mr. Johnson recognizes the 0.59 G reading as possibly indicating the need for site correction.

He further goes on stating -- and I would like to make a quote, and this is a quote from that article.

"Nevertheless, the relatively low predominant frequency, 15 hertz, and the fact that strong accelerations exceeded one second duration for so small a quake, should make this record one of considerable interest given the paucity of strong motion data in the central or Eastern United States."

Your testimony seems to not bear that out; is that true?

A (WITNESS ROTHMAN) No, I don't disagree with that; but we recorded other earthquakes with high peak accelerations in the near field from small earthquakes.

For example, peak acceleration of 0.25 G was recorded from an earthquake of magnitude 2.7 in South Carolina and a peak acceleration of .7 G was recorded from a Magnitude 4-3/4's from an earthquake in California and small mine tremors due to rock burst have had recordings of 12 G's in the near field from these events; but these are small events that are recorded in the near field and they don't really have any energy.

Q Then you don't think that it's very -- there is very much chance for an even larger event to generate even larger ground accelerations?

A (WITNESS ROTHMAN) Oh, there is always a possibility for that, but we believe we encompass this in the way we characterize the earthquake for the determination of the SSE.

We use an enveloping assumption, which takes into account all the uncertainties inherent in the limited knowledge about the seismology of the Eastern United States.

When I say "Eastern United States," I mean that area east of the Rocky Mountains. We, therefore, use the techniques prescribed in Appendix A.

We envelope the largest earthquake. In fact, for this case we have used an earthquake larger than the largest historical earthquake ever reported in the central stable region which was not associated with a particular structure, and we have characterized this earthquake by site specific spectra; and we have shown that the spectrum use for the design of the nuclear power plant is equal to or greater than that site specific spectra at all frequencies, so we have taken into account the uncertainties.

MS. JOHNSON: I just have a couple of other questions.

CROSS EXAMINATION

BY MS. JOHNSON:

Q Dr. Alterman, I understand that you were the author of the sections in the Byron Final Safety Analysis Report on seismology?

A (WITNESS ALTERMAN) Yes.

Q How did the --

A (WITNESS ALTERMAN) Excuse me. Just the geology section

of the SAR.
Q The geology section, yes.
A (WITNESS ALTERMAN) Of the safety evaluation report, is that what we are talking about?
Q Maybe Dr. Rothman will have to answer this. I do not know whether you know the answer to this.
A (WITNESS ALTERMAN) Okay.
Q How did they determine -- the Applicant determine -- that the Plum River Fault ended exactly 5.3 miles from the site?
A (WITNESS ALTERMAN) That was the last known exposure or indications of faulting, as I understand it.
Using the Illinois Survey's determinations, based on their recognition of decrease in offset of the bedrock as they went eastward until they could find no evidence of the fault. As I understand it, it was based on that.
Q How much -- how many borings east of that did they make, do you know --
A (WITNESS ALTERMAN) I don't know.
Q -- or what kind of -- you don't know?
A (WITNESS ALTERMAN) I don't know.
Q You don't have any information on that at all?
A (WITNESS ALTERMAN) I don't know.
Q You don't have any idea?
A (WITNESS ALTERMAN) No.

Q Let me explain -- and I don't know whether -- I am not sure how to get this into the right form of a question.

My concern is that, according to Appendix A, this -- if a fault of 1,000 feet or longer is within five miles of a site, I believe it's indicated that a much more extensive investigation into whether it's a capable fault is required, and so that is my concern with the exact end of that 5.3 miles.

I am making a statement instead of a question. I am not sure how to make that --

JUDGE SMITH: Perhaps the panel can be of assistance.

A (WITNESS ALTERMAN) Yes. If you give me the reference, I think I can help you; but I need the specific wording.

Just tell me where it is. I have got the --

BY MS. JOHNSON:

Q This is according to Appendix A, under 4, Required Investigations, and it's B, Required Investigation for Surface Faulting, No. 4. It's -- it's in the whole -- that whole section, but the exact quote is for faults greater than 1,000 feet --

A (WITNESS ALTERMAN) All right. Appendix A, required investigations, is that what you are talking about?

Q Yes.

A (WITNESS ALTERMAN) I believe it says capable faults, for capable faults. In other words, it has to be determined that the fault is capable before you are required to do the more detailed study.

However, when the construction permit was issued to Commonwealth Edison, the Plum River Fault was not yet identified, so it was not known.

By the time they came around to their application for an operating license, it had already been investigated by the Illinois Survey, and according to their research and lines of evidence, they concluded it was at least 200,000 years old or older.

Testimony from our own -- no. I am sorry. Strike that. That was a different thing.

And on that basis presented that as evidence for the fact that there was not a capable fault within five miles of the site.

In my evaluation of all of the evidence, all of the FSAR, the Illinois Survey's report and all other information that I could gather, I accepted that determination that the Plum River Fault Zone was not capable.

Q Did they not do any more field investigation of that?
A (WITNESS ALTERMAN) No. They were not required to by the regulations.
Q I believe that in evidence that was brought forth --

again, I am getting into a statement instead of a question.

Why did they not, for the faults that were found onsite under excavation, admittedly small -- I believe it was Fault 1034 with a six-inch displacement.

Why did they not follow the end of that fault offsite -- I mean off -- the end of that fault on the western end of that fault? Why didn't they?

A (WITNESS ALTERMAN) That one was clearly recognized as a non-capable fault, because there very clearly was the observation of undeformed pre-Illinoian soils which had to be more -- considerably more than 200,000 years old, because that's the date of the till, and this is pre-till soil, which is estimated to be 400,000 to 500,000 years.

Based on that, they were not required to do further work.

Q But then when they found that later that the Plum River Fault was 5.3 miles and was close to that area and it might have made a difference in the safe shutdown earthquake design and for the plant, why didn't -- they didn't feel that that was enough -- that there was anything new enough for them to investigate further?

A (WITNESS ALTERMAN) That was my responsibility. I made the determinat that they did not have to do any more work after reading all of the information, going out there and seeing whatever evidence there was.

Reading and investigating my own way is the way we do it there.

I determined that they were not required to do any more work. I was convinced that the Plum River Fault Zone is not capable.

Q Without further work?

A Without further work, yes.

Q But we have heard evidence -- isn't it correct that we have heard evidence from Dr. Woodard, and I believe some others agreed that there has actually been no determination of whether or not the Plum River Fault is capable or is not?

A (WITNESS ALTERMAN) That's Dr. Woodard's opinion.

I believe the evidence clearly shows that it is not capable within the meaning of Appendix A.

Q What evidence would you require to show that it had -- that fault had moved within the last 500,000 years several times?

A (WITNESS ALTERMAN) Offset of the till is probably the only evidence that would convince me that it was not --

Q If it was a horizontal slip instead?

A (WITNESS ALTERMAN) Even if it was a horizontal slip, there would still be deformation of the till.

It might not be offset in a vertical manner, but you would see a fault within the till.

Q Since the -- I understand.

Well, I guess -- now, let's see if there is anything else here. I am probably getting into something I shouldn't.

I think that the other things are in the record that I would have asked you.

JUDGE SMITH: Mr. Bielawski, do you have cross examination?

MR. BIELAWSKI: I just have a few questions.

JUDGE SMITH: We did not receive a cross examination plan from you.

MR. BIELAWSKI: Actually, I have only one question of Dr. Alterman.

I wasn't planning on cross examination until evidence came out as a result of Mrs. Johnson's examination.

JUDGE SMITH: Go ahead.

CROSS EXAMINATION

BY MR. BIELAWSKI:

Q Dr. Alterman --

JUDGE SMITH: You didn't take my remark as a restriction on your right to cross examine, did you?

MR. BIELAWSKI: No.

BY MR. BIELAWSKI:

Q Dr. Alterman, arriving at your conclusion that the Plum River Fault is not a capable fault, do you rely exclusively on the fact that there does not appear to be a scarp present on the fault?

A (WITNESS ALTERMAN) No. In any scientific project, research and so on, a conclusion is usually based on a variety of information that all leads to that conclusion, and so there was several lines of evidence that were used to make that determination.

Some of them I outlined this morning in some of my remarks about the way in which the Illinois Survey did its study, indicating that there was no evidence for surface displacement anywhere in their study, that there is no seismicity associated with the fault.

There are also other lines of evidence, including the regional tectonics, which are always included in understanding deformation in an area, and that is that all of the evidence, the closest areas that we have more recent faulting, let's say the Paleozoic, is to the south, and there are Cretaceous beds, which are 65 million years old, which are unfaulted above subsurface faults, and that also led the Illinois Survey to conclude that the faulting in Illinois was not younger than 65 million years, any of it.

MR. BIELAWSKI: I have no further questions.

JUDGE COLE: I guess I want to make sure I understand a few things.

BOARD EXAMINATION

BY JUDGE COLE:

Q Dr. Rothman, you were asked some questions and you discussed the ability to measure the depth to bedrock and in certain questions put to you that was related to the ability to determine capability of a fault.

Do you recall that, sir?

A (WITNESS ROTHMAN) Yes.

Q Could you explain to me how the ability to measure depth to bedrock would be related to the determination of capability of a fault?

A (WITNESS ROTHMAN) Yes. When the survey was conducted, this refraction survey, the data indicated that there was a difference in the rock velocity as the survey progressed, I believe, from the north to the south. In other words, the bedrock was a different formation after the survey passed a certain point, which indicated that there had been some type of change in the lithgraphy. there was a considerable difference in the bedrock velocity, indicating a different formation, and if at that point there had been a change in elevation with the -- of the ground surface corresponding to the point where the velocity changed, you would have assumed that these --

that there was possibly a capable fault there because you would have what would be called a scarp in the bedrock surface at that point if there was a change in depth at the point where you saw a change in velocity.

Now, without looking at the data itself, I can't make the judgment whether that scarp is there. These authors have not indicated that there is.

Q All right, sir.

I do not understand how that is a determination of the capability of a fault in view of the fact that capability as we use that term of art is related to movement over certain time periods.

A (WITNESS ROTHMAN) Well, I think Dr. Alterman could address the dating of the last possible movement and the age of that related to the glaciers.

I am not familiar with the ages, but there is an assumption when the glacier scoured that area it made a level or fairly level surface.

A scarp would not be left standing after the passing, after the glaciation, prior to the deposition of the till by the -- that was corresponding with the glacier, so that you could say that since the glacier occurred there, if there is no scarp, there has not been any vertical movement along that fault since that time, at least, and depending on the ages, you would determine

whether you could say whether the fault was capability or not.
Q Dr. Alterman?
A (WITNESS ALTERMAN) This is a panel. May I make a comment about that?
Q Certainly.
A (WITNESS ALTERMAN) First, the presence of a scarp would not by itself indicate a capable fault. We were using -- I -- I had used the argument that the existence of a scarp indicated there had been no recent vertical movement because it takes such a very long time to erode the bedrock that's been uplifted in a fault of that sort; and that since there is no further uplift since the glacial deposits, that would be an indication -- it's not proof, but it would be an indication that there had been no vertical movement since the glacial deposits had been deposited.

So the escarpment itself does not prove or disprove the presence of the capable fault.
Q Okay. Dr. Alterman, how does one make a determination as to the presence or absence of an escarpment?
A (WITNESS ALTERMAN) In this technique, are you talking about the seismic reflection technique, refraction?
Q No. How does one determine whether there is an escarpment or not?

A If it is exposed and there is a sort of a visible evidence of a sort of cliff-like structure, where one block of rock is raised above another, that's essentially what we are talking about.

Q Now, the Plum River Fault, did you or somebody you know make those observations that there is, in fact, no escarpment viewed from the surface?

A (WITNESS ALTERMAN) Yes. I have been to the Plum River Fault Zone and I have crossed it, and it's clear that there is no escarpment there that is obvious; and the seismic refraction work, which is work determining the fault in the subsurface where you cannot see the fault, the evidence described by Dr. Rothman, indicates that there is no uplift of the bedrock -- of the surface, of the bedrock surface, on one side of the fault as in relation to the other. That's what we are saying. Do you understand what I am saying?

Q Yes. I am not sure. I might have to ask a couple of more questions to make sure I understand.

A (WITNESS ALTERMAN) Okay.

(Whereupon, Illinois State Geological Survey Circular 491 was bound into the record, as follows:)

Q I am looking at the Page 16 of Illinois State Geologic Survey Circular 491 and specifically Figure 7, which was

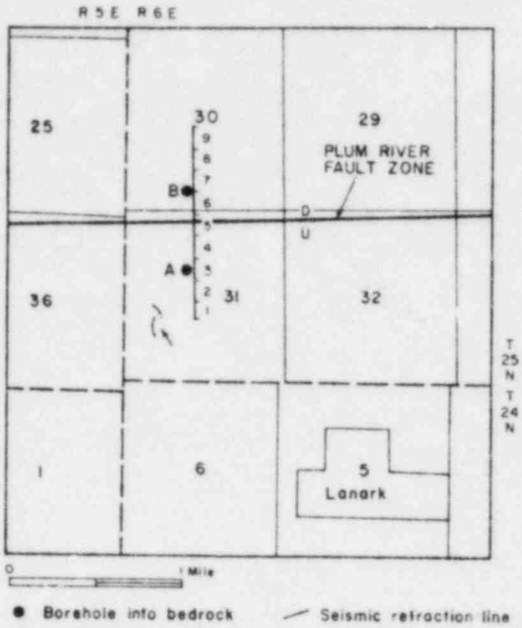

Fig. 6 - Map showing location of seismic refraction transect (profiles 1-9) and boreholes (A and B) northwest of Lanark, Illinois. Arrow shows location of quarries in flat-lying Wise Lake strata (Galena Group) along Straddle Creek. (See geologic cross section in fig. 7.)

An apparent anomaly in the bedrock was encountered along the fifth profile within a distance of 600 feet south of the north line of Sec. 31. In shooting from south to north, there is evidence of a velocity inversion; that is, immediately below the soil layer a velocity of 18,513 feet per second is encountered, but farther out on the time-distance plot a velocity of 9,459 feet per second persists. Conversely, the north to south shooting indicates a velocity of 7,909 feet per second directly below the shot and 19,020 feet per second away from the shot. It appears that dense carbonate rock underlies the soil at the south end of the fifth profile and that rubble or clastic rock with much lower velocity occurs below the soil at the north end. Approximately 1,400 feet south of the north line of Sec. 31 (near center of third profile), a hole was augered 25 feet to bedrock and a core was cut from the Galena Dolomite Group (probably Wise Lake Formation) at an elevation of 836 feet. A second hole, located 600 feet north of the south line of Sec. 30 (south end of seventh profile), was augered

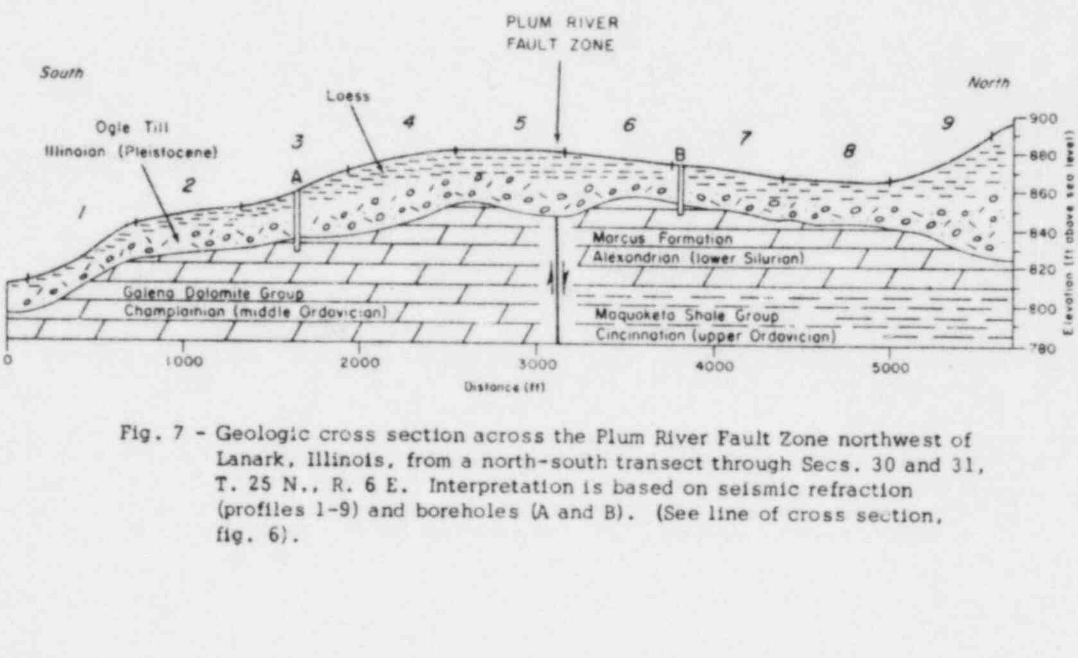

Fig. 7 - Geologic cross section across the Plum River Fault Zone northwest of Lanark, Illinois, from a north-south transect through Secs. 30 and 31, T. 25 N., R. 6 E. Interpretation is based on seismic refraction (profiles 1-9) and boreholes (A and B). (See line of cross section, fig. 6).

shown to you in cross examination.

You answered several questions about that, I believe?

A (WITNESS ALTERMAN) Yes.

Q Now, looking at that cross-section across the fault. I see the ground surface depicted.

That is the top line on that figure?

A (WITNESS ALTERMAN) That's right.

Q And below that we see some Loess material and then some Pleistocene material below that.

Underneath that is what I assume to be the rock surface.

A (WITNESS ALTERMAN) Right, that's right.

Q Now, I want to make sure I understand what this depicts to me.

And if I were going to look to determine whether there is an escarpment, what part of that figure would I look at?

A (WITNESS ALTERMAN) You would look right at the line that indicates the Plum River Fault Zone. You see the line there? Just below where you see Plum River Fault Zone in the center of the diagram -- you see the term Plum River Fault Zone in the center of the diagram?

Q Yes.

A (WITNESS ALTERMAN) There is an arrow leading downward below the Loess till and you will see a line on either side of which are arrows, one going up and one going down.

Q What does that indicate?

A (WITNESS ALTERMAN) That indicates -- that line represents the fault and/or fault zone, the break in the rocks, along which the movement has occurred.

Now, the arrows indicate the way in which the rocks have moved relative -- or the blocks of rock have moved relative to each other.

On the left the arrow moving upward indicates you have older rock that has been uplifted along the fault.

Q I am sorry.

A (WITNESS ALTERMAN) On the left. You see the left side arrow, it's a half arrow. That's a characteristic thing that is done in a long fault. The half arrow points upward.

JUDGE SMITH: Mr. Reporter, would it be possible for you to indicate that Page 16 of the Illinois Geological Survey Circular should be bound into the transcript immediately before Dr. Cole's question? Is that possible?

THE NOTARY: Yes, sir.

JUDGE SMITH: Are there any objections?

MR. GOLDBERG: No objection.

MR. BIELAWSKI: No objections.

JUDGE COLE: Okay.

A (WITNESS ALTERMAN) (Continuing) On the left the half arrow points upward, which indicates the block of rock on the left-hand side of the fault has been displaced upward, vertically upward; and in structural geology we know the reason we are interpreting it this way is these are the older rocks on this side that have been uplifted relative to their original position. Those are the Ordovician rocks.

On the right side of the fault you see an arrow going downward. That indicates that, relative to the left-hand block, that block has moved downward and you have younger rocks, the Silurian rocks, adjacent to these older Ordovician rocks.

That line then is the fault -- depicts the fault and the relative displacement of the blocks on either side of it. Do you understand?

JUDGE COLE: Understood, yes.

A (WITNESS ALTERMAN) (Continuing.) Now, what if those blocks had not been eroded, as has happened over the long period of time since they -- since it was faulted?

Then we would expect the same rock that is on the -- we would expect the same rock that is on the right side of the fault, the same layer, an extension of that, above the layers on the left, because they are just below -- the layers on the left, the Galena formation is Ordovician, and normally stratigraphically lies below the Silurian layers that are found now on the right.

BY JUDGE COLE:

Q The reason why they are depicted at the same level here is that they have been weathered down to the same level?

A (WITNESS ALTERMAN) Right, right. What was originally an escarpment -- in other words, the block on the left-hand side was much higher originally than the block on the right-hand side and would have been a cliff-like structure there exposed on the surface at the time of original faulting prior to erosion.

So that you would have had -- we do have that in many places in the earth today where there have been faults of vertical motion, even recent ones, as well as ancient ones, that have not been totally worn down. We do have escarpment with uplifted blocks still relatively higher than blocks on the other side -- than the downdrop block I should say.

Does that clarify?

Q Now, this erosion is a time dependent process?

A (WITNESS ALTERMAN) Oh, yes, yes, indeed, and very slow.

Q Now, we are talking about the determination of capability?

A (WITNESS ALTERMAN) Right.

Q Now, what other information do we need to know to confirm that that fault is not capable?

We know it has been weathered down to the same level so there is no difference in elevation.

So our ability to measure down to bedrock in the vicinity of the fault within a foot or so, I can see how you would be able to make at least that determination to within a foot or so.

A (WITNESS ALTERMAN) Yes.

Q Now, what other information is confirmatory toward the capability or non-capability of that particular fault?

A (WITNESS ALTERMAN) Okay. The sediments directly above the fault as depicted here indicate that there is no faulting, no crack or no break or offset of the sediments above the fault. Do you see that?

The fault line stops just at the base of the Illinoian till. It stops in the bedrock.

Do you see the line that represents the fault there?

Q Yes.

A (WITNESS ALTERMAN) It stops below the till.

Q If it were to continue into the till, would that -- by what process did you make the determination that it doesn't continue into the till at least for some time -- for some distance?

A (WITNESS ALTERMAN) This is a determination that the Illinois Survey made over a long time of observing various places along the fault zone in which they say that they found no evidence of any displacement in the till of any sort.

There would be a break, there would be a disturbance, there would be faulting in the till.

Q Did they actually observe that or by what manner or mechanism did they determine that there is no displacement in the till?

A (WITNESS ALTERMAN) They claim that they have observed this.

Q By what process did they observe it?

A (WITNESS ALTERMAN) Well, you can observe it if it's exposed on the surface, just as in the excavation where faults were found in -- at the plant site, the excavation itself exposed the fault and you had a surface looking exactly like this drawing here, which you could stand there and see directly in front of you, where you could see this till directly above the fault undisturbed.

Q And you say the Illinois State Geological Survey team actually did that and observed that and documented it?

A (WITNESS ALTERMAN) They claim that that's what they have done.

The report -- the report -- for one thing, the report was not written to prove that there was a non-capable fault there, and it is simply that they did a field study of the fault and made their determinations based on whatever techniques they used -- if it was classical and standard techniques of field work and observations and so on, and made a report which does not always, as many of these reports do not, include the details of every single exposure and site that they visit, but give the broad details, the broad picture, of what they have seen and the evidences for their conclusions. It was based on the information, the nature of the study, the -- I thought a fairly -- a very well planned out and carried out study based on what I read and further discussions with them and other work done in the area showing that none of the faults in the area where these things are directly observable have never shown to have any displacement in any of the soils below the till.

Q Dr. Alterman, you were present in the room when Dr. Woodard was answering questions on this subject.

He made a statement concerning critical observation not having been made.

It seems to me that what you have just said is it's your contention that that critical observation has been made.

Do you recall that section?

A (WITNESS ALTERMAN) Yes, I do; yes, I do.

Q Is it your contention that the critical observation has in fact been made, that the critical observation that he described as being necessary to determine the capability of the fault?

A (WITNESS ALTERMAN) I believe it has, but that is simply by accepting the word of the reseachers, of the Illinois Survey.

Q Is this documented in any written publications?

Is it, for example, in Circular 491, this information directly?

A (WITNESS ALTERMAN) They do not state directly anywhere that they have observed this directly.

They state that -- I forget the exact words, but that the Pleistocene tills have not been observed to be displaced anywhere along the fault zone. That is the statement they make; and I assume from that that they have observed this.

Also, the cross-sections, the seismic refraction work and subsequent studies by them of other fault zones, which also reiterate this point, that nowhere in Northern Illinois are any of the tills displaced by any faults in the area.

Q Okay. Dr. Woodard also commented -- when asked, "Well, how would you make that determination, he said, "You should take a backhoe and make a slice through the area and then observe the soil."

Do you know if they, in fact, did that?
A (WITNESS ALTERMAN) I don't think they did that, no.
Q What did they do then to make the determination that the till had not been displaced?
A (WITNESS ALTERMAN) Well, the seismic refraction work, for one thing. I guess various observations in places where they have seen it and my earlier testimony today which indicated that the till -- it is implicit in their paper that the till is not displaced, because if it had been, they would have been able to find that fault without having to drill to determine its location.
Q Do you recall the conversation concerning drill holes A and B --
A (WITNESS ALTERMAN) Vaguely. I need to be reminded.
Q -- by the Applicant's witnesses?
A (WITNESS ALTERMAN) Yes.
Q Of what use would they be, Dr. Alterman?
A (WITNESS ALTERMAN) What the drill holes determined were two things.
First. the level of top of rock, at what elevation they found top of rock that is below the till, because that was not observable from the surface.
When you are standing on the surface, you are standing on till. You cannot see bedrock at that location.

So the drill cores first determined, going down through the till, at what elevation they would find the bedrock.

Then drilling into the bedrock -- which you can see in the diagram, both drill holes go a little bit into bedrock -- was to identify the nature -- to identify the type of bedrock that was there. That gave them the determination that they had the Ordovician Galena formation on one side and the Silurian formations on the other side.

So it identified two rocks -- two units of rock of different types on either side that were juxtaposed, and therefore they made the determination that the fault had to be between them.

If the till had been disturbed in any way, there would have been evidence on the surface. They would not have needed to do this indirect determination to find a fault between two bodies of rock that were different levels.

Q Well, there was some information in the record concerning an additional use of the bore holes with respect to making an assessment of displacement of the till.

Do you recall that discussion?

A (WITNESS ALTERMAN) Not exactly. I would like to know the point made there.

Q Well, I will try to recall that, although looking at the distance between the holes, I don't h[illegible]e a feel for the value of the information.

JUDGE COLE: I d[illegible] how to stop that.

MR. GOLDBERG: [illegible], either.

JUDGE COL[illegible]alk, right?

MR. GOL[illegible] didn't mean that.

BY JUDGE COLE:

Q Would that be -- would the comparison of the material at different levels found in the bore holes be of any information in determining whether there is any relative displacement of the till across the fault zone? Do you know if they did that and if it would be of any value?

A (WITNESS ALTERMAN) I don't think -- in this case the way it looks here, I don't know that it is of any value. Because of the topographic irregularity of the surface, I am not sure that it is of any value here.

I don't think that was their purpose in drilling here. I think they were just looking for the fault; that there was no evidence on the surface for the fault and that in order to locate it, they had to locate the type of bedrock.

If they had found, for example, Galena at one hole and Galena at the other hole, I don't think they would have been successful in finding the fault, unless they were able to tell which level of the Galena they were; whether they were at -- whether it was the top or the bottom; but the fact that they were able to identify two entirely different rock formations of entirely different ages was convincing evidence that somewhere between them was -- between those two holes -- was the fault.

My point before was that had there been displacement of the till, there would have been some indication on the surface. There would have been a line, a linear of a sort, a linear depression or some indication of disturbance of the till along that line, and they would have had a clue to the presence of the fault without having to go through the drilling technique to find it.

I take from that that it is implicit in what they have written that there was no disturbance of the till to help them find the fault where it was buried.

Q Okay. Thank you. On Page 2 of your testimony, Dr. Alterman, on Line 6, you use the abbreviation MYBP. I am not sure.

Is that -- the last three letters, I think, are years before present.

A (WITNESS ALTERMAN) Yes.

Q Is it thousand or million?

A (WITNESS ALTERMAN) If you look just before that, I say 290 million years before the present and then the

parentheses indicates I am now going to indicate million years before the present, so it's spelled out there first.
Q Okay.
A (WITNESS ALTERMAN) So MYBP refers to millions of years before the present.
Q Okay. I didn't connect those. I thought maybe the present might be MYBP and then I didn't know what the other meant. Okay?
A (WITNESS ALTERMAN) That's a standard procedure.
Q I will try to remember that.

JUDGE SMITH: That is of February 15th.

(Laughter.)

JUDGE COLE: Go ahead.

BY JUDGE COLE:

Q Dr. Alterman, is it customary for persons of your discipline to rely upon Illinois Geologic Surveys and such surveys?
A (WITNESS ALTERMAN) Yes, indeed.
Q Do you believe it's a reliable basis for your opinion?
A (WITNESS ALTERMAN) Yes, we do. The surveys generally have people in there who are experts totally in the geology of that state. All of the money that comes to the survey is spent on that state, in that state, and so they generally become quite conversant and quite knowledgeable with all of the information that is of any geologic

information in that state, primarily for economic reasons, but there are always so many tangential reasons, too, that they are regarded as the experts in the various states.

JUDGE COLE: I think those are all the questions I have for now. Thank you.

JUDGE SMITH: Is there any additional cross based upon Dr. Cole's questions?

JUDGE CALLIHAN: I have a few questions, here.

JUDGE SMITH: I am sorry.

BOARD EXAMINATION

BY JUDGE CALLIHAN:

Q Dr. Alterman, coming back to an insertion in the transcript prior to this discussion, which is identified as Page 16 of Circular 491 of the Illinois State Geological Survey -- and those remarks, of course, are just for the benefit of the reader. Not for us here. We know what we are talking about; and in particular on that page is Figure 7 to which there has been allusion earlier,.

I judge that if the bore hole depths are -- as depicted here are meaningful, one of their purposes, as you yourself said, was to see what was underneath.

Having once determined the first or second, I guess, in each case, strata, one can identify the remainder of the underpinning from more complete information gleaned elsewhere.

Is that your methodology?

A (WITNESS ALTERMAN) Yes; that is correct, yes, sir.

Q If one looks in and assigns some confidence to the scales, those strata look to be like 10 or so feet thick; is that correct?

A (WITNESS ALTERMAN) Probably much, much larger than that, sir.

This is very diagrammatic, those lines that are used. They merely depict a type of rock called dolomite. It's a symbolic combination of a type of rock. It does not purport to indicate the size of the layers.

Q Would you then say that the units on the right of the diagram probably refer more to surface than to substructure?

I am forced to that by your last remark.

If one looks at the right-hand side, the coordinant ranges from 780 to 900 feet above sea level.

A (WITNESS ALTERMAN) Please, sir, could you restate your question? I was not following you.

Q It would read a grapical representation of something. I would say that the Silurian layer lies somewhere between 820 and 830 feet above today's measure of sea level.

A (WITNESS ALTERMAN) Oh, yes, yes.

Q But you have just pulled that out from under me, I

believe, when you said that the structure, the rock structure, is not necessarily describable by that coorinent system. That's what I understood you to say.
A (WITNESS ALTERMAN) Perhaps I misunderstood and I have mislead you a bit.
The elevations there are probably -- I am assuming they are correct and that the bedrock -- the surface of the bedrock below the till is at the levels they state. All right?
Q The surface of the bedrock?
A (WITNESS ALTERMAN) The surface of the bedrock is that line below the material described as the Illinois and Pleistocene till where the little circles are. You see where the circles are going across.
Q In the till, yes.
A (WITNESS ALTERMAN) That's the till, yes. There is a line directly below that, an irregular line.
Q Yes. That's the bedrock.
A (WITNESS ALTERMAN) That line is what we would call the contact between the till and the bedrock below. All right, sir?
Q Yes.
A (WITNESS ALTERMAN) The surface of the bedrock is depicted by that line.
Q Then I return to my earlier remark.

The usefulness or the authenticity of the coordinent depicted as elevation above sea level on the right-hand margin probably is applicable only to the surface and to the top of the bedrock. That's what I interpreted you to say; and I ask you to tell me if I am correct or not -- not to any dimensions of the structure below the present surface of the bedrock?

A (WITNESS ALTERMAN) In general. For example, on the right-hand side where it says the Marcus Formation, Alexandrian, lower Silurian, you see a brick-like pattern with slanted lines. That is the dolomite formation. Directly below that you see a lot of short-dashed lines. Do you see what I am saying?

Q Yes.

A (WITNESS ALTERMAN) And it says Maquoketa Shale Group there, and if you look to the elevation scale it says that the Maquoketa shale is present at 810 feet above sea level, up to about 810 feet above sea level based on that scale there; and above that is the Marcus Formation, which there shows itself to be from 810 to maximum about 850, about 40 feet of rock there.

Q All right.

A (WITNESS ALTERMAN) So in that sense we can use the scale.

I think I misunderstood your question.

Q That was precisely my opening remark.

A (WITNESS ALTERMAN) I am sorry.
Q I thought you pulled the rug out from under me.
A (WITNESS ALTERMAN) I am sorry. I misunderstood what you were saying.
Q We established that and thank you for clarifying it.
One could read this as saying that when the fault did occur, that it was probably a very sizeable event, because as I read this, in light of what you have said, there must be at least 50 foot or so displacement; am I reading this correctly in that?
A (WITNESS ALTERMAN) Yes. In fact, the Illinois Survey, based on other evidence elsewhere, studied this fault across Illinois, has determined that there is at least 400 feet of offset, 400 feet of vertical displacement, though we do not believe that that happened in a single event, no.
Q Can -- say, at the Plum River site, can the demarcation or separation lines between the strata be determined in situ, so to speak, from refraction pattern or does your refraction pattern technique only show gross differences as, for example, between the till and the upper layer, which is unnamed here, but whatever it happens to be?
A (WITNESS ALTERMAN) Well, as far as I understand it -- I think Dr. Rothman can answer that better than I.
Q Well, either of you can.

A (WITNESS ALTERMAN) I will let Dr. Rothman.
A (WITNESS ROTHMAN) It would depend on the velocity contrast between the shale group, the Maquoketa Shale Group and the Marcus Formation. If they had the same seismic velocity or a very close velocity, you could not -- you would not get a critical refraction and, therefore, you would not get energy returning from that interface there, so you could not determine the depth.
If there was a significant velocity contrast, then you would be able to differentiate between those two rock layers.
Q Is my earlier remark perhaps even more correct that the identification of these, which I will term substrata, a layman's terminology, were determined elsewhere and not necessarily here?
A (WITNESS ROTHMAN) I would sav so. In fact, I believe elsewhere in the article reference is made with reference to some quarries north and south of where this line was actually done, where they did actually look at these formations to get an idea of what they were looking at; but I am not sure. I haven't read the whole article.
Q I appreciate strongly that we are all at somewhat of a disadvantage and we have lifted much out of context and talked much about it, perhaps without real right to do so.
Getting back to reality for a moment and speaking of

the interface between the till and the first strata, the bedrock surface, as I think you described it, what sort of accuracy or even what sort of precision, if that's a starting point, can one expect in the determination of such an interface by refractive methods?

A (WITNESS ROTHMAN) Well, as I have said earlier, I have been involved in surveys where accuracies on the order of one foot or so have been attained for velocity contrasts of this type and thicknesses of till of this type.

Q So it's about like a percent?

A (WITNESS ROTHMAN) I have not seen the data and I did not do the interpretation, so I wouldn't want to be held to that; but judging by the type of equipment that they have described that they used, the spacing between their seismographs on the ground, the velocity contrast, the type of reverse continuous profiling which they have done, I would think that they could get that kind of accuracy.

Q I realize we can't discuss what is before us, because we don't know because we haven't read it; but it's the state of the art that I am getting at.

I know you had said earlier one foot; and I wondered if that's an absolute thing or a relative thing? It's like a percent?

A (WITNESS ROTHMAN) It's a percentage. Say if this till had been 100 feet deep, they probably couldn't resolve it to 1 foot. They would probably have a resolution of, maybe, 5 feet or 10; but for these shallow depths that we are looking at here, I think they could probably resolve it to 1 foot.

Q So for ball park, it's maybe like -- well, this looks like about something less than 100 feet, taking the maximum dimension.

A (WITNESS ROTHMAN) Yes.

Q So it's a few percent?

A (WITNESS ROTHMAN) Say at the north end the accuracy might be less than it would be at the south end.

The north end is on the right-hand side of the diagram and the south end is on the left-hand side of the diagram.

Your accuracy might b. slightly greater to the south than it is at the northern end because you are dealing with thinner material to begin with, but the percentage would probably remain about the same.

Q My question is obvious. I remembered your one foot and I wondered if that were absolute or relative and it's absolutely relative.

A (WITNESS ROTHMAN) That's right.

Q Please feel free to address, either of you, what I have to say.

However, in your testimony, Dr. Alterman, on Page 3, you have a term that I would like to inquire of in a very simple way.

In Answer 5, in a line about halfway through that answer that begins with the word "that," on the left margin, you refer to parallel and subparallel faults.

What is a subparallel fault?

A (WITNESS ALTERMAN) Well, it is not exactly parallel but close to it. In other words, if you have a fault that runs north-south, a fault line that runs north-south and you have faults close to it which vary slightly in their orientation, let's say to north 5 east or north 10 west, just 5 degrees or so -- we don't have a hard number that we put to that, but those that are close to that orientation, we assume that they are -- this again is part of the geometry aspect of structural geology that we can safely say that they are related to the main fault. So the subparallel faults or subparallel breaks in the rocks would be those that are close to the alignment of the original or main fault.

Q And those can be any way; up, down, right, left, from the base line and you still use this term subparallel?

A (WITNESS ALTERMAN) Well, there are two dimensions that we measure in measuring ex-planar structures such as faults or bed or layers. We measure -- one is a line. It's sort of an imaginary line, but it gives us an orientation that

that structure takes along the surface of the earth, and we call that the strike of the fault, and that's more or less the line that we are talking about.

There is the other -- after all, it's a three dimensional plane. The other plane, the other orientation or direction we talk about, is the direction that that plane takes or the orientation that plane has within the earth. It might be vertical, it might be at some slight angle, which we call the dip of the plane. So we have two determinations, a geographic direction and an angular orientation into the ground, which we refer to as the dip. So we have the strike and the dip of a fault.

Now, when we say subparallel, we mean essentially that the planes that we are talking about, these smaller, minor faults are subparallel in both strike and dip to the main fault.

Is that clear?

Q Thank you. On Page 4 in your Answer No. 7, you refer to the Sandwich Fault Zone, which hasn't been discussed greatly, and you have spoken there of minor faults -- this is about two-thirds of the way through that paragraph -- minor faults have been shown to be non-capable.

Were those shown to be so in any particular way? What was the method there?

A (WITNESS ALTERMAN) Yes, indeed. Within the excavations the faults -- there were various -- there were very detailed studies done of this, and there is a report by the Applicant called fault investigation of these minor faults in the excavation.

In digging down for the excavation they uncovered several small faults. The main one was one called Fault 1034.

This one was very carefully studied and there was the kind of hard evidence that one hopes to find all the time.

The pre-Illinoian soils that were totally undisturbed wherever this fault was exposed and it was determined that this pre-Illinoian soil which predates the till -- now, the till is the Illinoian Period is dated at from, conservatively, 400,000 years ago until about a 125,000 years ago, and the soil either occurred prior to the glacial till or some time -- I should say -- I am sorry -- prior to the glacial -- the Illinoian glacial advance or some time during it prior to the deposition of the till.

So at a minimum it would be 125,000 years old; and that was based on that it was determined to be non-capable.

Q Coming back to the Circular 491 page and Figure 7?

Is it your belief or knowledge or opinion that the till shown on top of the bedrock there and designated as the Ogle till, is that glacial?

A (WITNESS ALTERMAN) Yes, that is the glacial till we were talking about.

Q Exclusively glacial?

A (WITNESS ALTERMAN) Yes, it is loose, unconsolidated material.

Q There was a remark -- and I guess this is Dr. Rothman's but, again, divide them as you wish.

There was a remark yesterday, as I remember and as I heard -- and, perhaps, as I didn't understand -- of isolated earth conviction in this area.

Can you elaborate a little on that?

A (WITNESS ROTHMAN) Yes.

Q In what sort of province do they lie? They lie in this province apparently?

A (WITNESS ROTHMAN) Maybe I can start off with discussing the province and work down to this area.

I judged yesterday, from some of the comments, there was a misunderstanding about the central stable region and what the extent of it was, so I think I might just say that the central stable region as used by the NRC is a region that encompasses a large part of the Central United States. It's eastern extent is to, I would say, the Appalachian Mountains. There is a part of it that goes into New York State and almost as far as Albany, New York. It extends to the west, I believe, almost to the Rocky Mountains and in the south it extends down to, I guess, Oklahoma, something like that.

Now, there are regions that are -- it's not a circular region or anything like that. It's sort of an odd-shaped region where other tectonic provinces occur also, but it is a very large region, thousands of square miles.

In general, the area is relatively seismically quiet. There are certain parts of the region where there is a little bit more seismicity than in other parts.

Northern Illinois happens to be one of those regions that has slightly higher seismic activity, but we are not talking about the kind of seismic activity that we see in really active regions like along plate boundaries like in California or Nevada or Alaska or some place like this. It's a region of low to moderate seismicities, as I would classify it.

There have been historically a number of earthquakes. Yesterday seven were discussed. There actually have been more earthquakes than this.

The Staff has relied on a seismicity list established by Professor Otto Nuttli and one of his students by the name of Brill. It appears in a NUREG. We use that as our guide for the seismicity of the Central United States.

Professor Nuttli is probably the foremost authority on Central United States earthquakes, and we have used his locations and his magnitude and intensity estimates to look at the seismicity in Northern Illinois.

We found that there had been several earthquakes of Modified Mercalli Intensity 7 in the region.

At the CP stage, the Staff said that had been a conservative, although there had been several 7's, although there was never an 8 in the central stable region not associated with a particular structure; and the controlling earthquake normally in the central stable region is a modified Mercalli 7-8.

Because of the number of 7 earthquakes in Northern Illinois, they would require a maximum intensity 8 earthquake to be considered for the licensing of this site.

So there has been several earthquakes. None of them have occurred near the site as best we can tell from our plotting of the locations of the earthquakes on maps and observing them with relation to the site and none of them have occurred on known faults in the Paleozoic rocks.

The earthquakes are not associated with any faults that we know of in the Paleozoic rocks. If they are associated with faults, they are at much greater depths.

Q Does that make this type of earthquake any less predictable in recurrence?

A (WITNESS ROTHMAN) Less predictable than what?

Q Than one near a known fault. I pick up the word --

A (WITNESS ROTHMAN) No. The problem is what we nave to do then is because we don't know what kind of a structure it's associated with.

We have to rely more on statistics rather than actual knowledge of the tectonics; and so what we do is we look at how they occur, how many have occurred in recent history, get an idea of the activity and make a judgment on that on what we think might be the maximum earthquake in the tectonic province, and then as a conservatism, we assume that the largest earthquake -- or in this case actually a larger earthquake than the maximum that had occurred historically in the tectonic province near the site, so we have an argument because we have some uncertainty on the causes of earthquakes in this part of the world.

Q Thanks. I asked for a repetition, perhaps, of your earlier remark on the matter of spectrum and spectra.

Will you tell me again what a --

A (WITNESS ROTHMAN) What a spectrum is?

Q -- what a spectrum is?

A (WITNESS ROTHMAN) Do you want me to start on basic fundamentals?
Q No. Just what do you plot?
A (WITNESS ROTHMAN) Okay. The response spectrum itself is the response of a single degree of freedom oscillator at a particular frequency to a time history, which is mathematically run through the oscillator. In other words, it's a mathematical calculation. You take a horizontal oscillator and subject it to a time history and you get one point at the resonant frequency of that oscillator, an amplitude -- in other words, the maximum amplitude of the time history at that particular frequency -- and you do this for a series of mathematical representations of a oscillator, so you get a series of points of amplitude versus frequency.

The way this is used is this is done for a number of time histories.

In the case of the site specific spectra that we used for Byron, they were -- on the order of 22 or 23 time histories were used and then the mean value at each frequency and the mean plus one standard deviation value were evaluated and the Staff determined that the appropriate level of conservatism to use for a characterization of the response spectrum for the site would be the mean plus one standard deviation spectral level. This would give us an added conservatism that we had used adequate ground motion.

There is another kind of spectrum, which is called the Regulatory Guide 160 spectrum, and this was developed in the days before we had as many seismograph records as we have now, and it was done by a single technique but slightly different.

What they did was took records from a large suite of earthquakes, I believe on the order of 25 or 26 seismograms were used, strong ground motion, from a variety of sizes of earthquakes recorded on different materials so that we had a range of sizes of earthquakes and different materials so that the full range of variables was represented in this spectrum.

These were then all scaled at the high frequency end, which we call the anchor point of the zero period anchor point or the high frequency anchor point to the same frequency, and the spectral shape was determined -- a mean spectral shape and a mean plus one Sigma spectral shape was determined for these.

Then amplification factors were determined at four or five different frequencies. That was the amount of amplitude greater than the anchor point at each of those frequencies. In other words, if it was anchored hypothetically at 1 G acceleration just for a scaling, all of these different spectrum with different frequency shapes were all forced to have a 1 G high frequency anchor point. Then the amplification of the mean and the one Sigma level at four or five other frequencies, I believe they were -- something like 9 hertz, 4 hertz and 4 seconds, I believe, were the frequencies at which the level above the 1 G was calculated; and these were determined to be spectral amplification factors.

Then what you can do is when you want to design for a particular acceleration, you can then take this spectral shape, anchor at the acceleration you are interested in and then draw your response spectra through the other points that are equivalently amplified above that level and this is how the REG GUIDE spectrum was determined.

This was done before we had a large enough suite of records to handle different magnitude ranges and different foundation conditions.

Q Is there an identifiable relationship between intensity and spectrum?

A Intensity? Is there an identifiable?

Q Yes. I would presume not but it's a complicated --

A (WITNESS ROTHMAN) There is a -- for the regulatory guide spectrum there is a relationship that is used between intensity and anchor point, because the spectral shape remains the same for the regulatory guide spectrum. You just move it up and down depending on the size of the earthquake.

For a site specific spectra you get different spectral shapes possibly for different magnitude earthquakes and different foundation conditions.

The regulatory guide spectrum is usually a more general but not specific to the site spectrum. It encompasses all different foundation conditions, et cetera, and it has a frequency content based on smaller earthquakes and larger earthquakes.

JUDGE CALLIHAN: Thank you very much, both of you. Thank you, Mr. Chairman.

JUDGE SMITH: Is there any cross examination on the Board's questions?

MS. JOHNSON: We have a couple others that we would like to ask about. If these are not the right -- if they don't fit in with what you think is right, tell me.

JUDGE SMITH: I am sure somebody will.

(Laughter.)

CROSS EXAMINATION

BY MS. JOHNSON:

Q Dr. Alterman, you indicated that -- in your response that -- the Illinois -- that you relied heavily on the Illinois State Geological Survey data.

I wonder why, what you think about the fact that the

Illinois State Geological Survey did not find the Plum River Fault when they were doing their geographical investigation for the Byron Nuclear Power Station before it got its construction license?

MR. GOLDBERG: Judge, I have an objection to the form. I think she ought to ask the witness' opinion about the assumption underlying her question.

JUDGE SMITH: Do you agree with the assumption, the premise of the question that they did not find the Plum River Fault at the time of the -- what was it, the -- prior to the time that they did?

MS. JOHNSON: To get the construction license they did a special --

A (WITNESS ALTERMAN) I didn't know that the Geological Survey had been involved in the investigation of the Byron site for the Byron nuclear plant. I was not aware that they were involved in that.

Is that correct? Were they involved in the geologic investigation of the site?

JUDGE SMITH: I think you are a little bit farther down the road than Mrs. Johnson --

A (WITNESS ALTERMAN) Well, then I don't understand the question.

JUDGE SMITH: Her question is: In view of the fact that the Illinois Geologic Survey, Geological Survey, did not find the Plum River Fault at the time of the construction permit application consideration, does that affect your reliance upon their ability?

The only question that is put to you right now is do you agree with the assumption that they did not find the fault? If there is good reason for them not having found the fault, we will find that either --

A (WITNESS ALTERMAN) No, that's true. I agree with that.

JUDGE SMITH: She agrees with the assumption.

A (WITNESS ALTERMAN) Does that change my reliance on them? No, they had recognized the structure there, which surprises me, considering that all of that material was buried. For a good number of years they had known that there was some kind of structure there. And I think it supports the argument that there is no surface displacement in that it has been buried below glacial tills for a long enough period of time so that they were not able to find it.

I don't know exactly the history of how they did determine it was a fault from the time they knew it -- they surmised it was an anticlinal structure; but it certainly doesn't change my opinion.

In geology there is constant re-evaluation and re-interpretation of geologic phenomena throughout the geologic world and we are always revising and renewing and relearning and remapping every place that I know of.

So it does not change my view of the competence of the Illinois Survey, not in the least.

BY MS. JOHNSON:

Q Is it possible to give me background for why I asked that question? Is that out of place at this point?

I did have some --

JUDGE SMITH: Go ahead and give it and we will see if we can help you in casting it into a question form.

MS. JOHNSON: At the time when they excavated the site under their pre-construction licenses they found --

JUDGE SMITH: Pre-construction.

MS. JOHNSON: Yes.

JUDGE SMITH: All right, pre-construction license.

MS. JOHNSON: They excavated for the area to be under the main buildings.

They found that there were these faults onsite, which have been referred to, minor faults. The largest was a six-inch displacement.

At that time the Illinois State Geological Survey was called in and made an extensive study because they found these sites that they had not expected to find them and they did it of the whole area.

I am assuming that -- and I talked to them about that and they told me they were keeping a constant study and had been involved from the beginning. This is the basis on which I felt they were in at the beginning on evaluating the site for Commonwealth Edison. I don't have an honest --

JUDGE SMITH: Now, can you confirm the events that she referred to. Do you agree those events happened?

A (WITNESS ALTERMAN) I do recall now that they did -- they were invited and I don't know by whom -- to come and evaluate the faults at the site or to see and examine the excavations and I do know that they were. I had forgotten that. They were not -- as I know, they invited to come and examine the excavations.

JUDGE CALLIHAN: Excuse me, Doctor. Who is they?

A (WITNESS ALTERMAN) The Illinois Geological Survey were I know invited to come and examine the excavations and the faults that were found in them.

JUDGE SMITH: Now, using Dr. Altmans' statement as the premise of your question, ask a question, not your impressions, but Dr. Altmans' premises, unless there is an objection.

MS. JOHNSON: Yes.

BY MS. JOHNSON:

Q Using that as the basis of my question, your answer, do you still think that they did a thorough investigation of the area and still did not find that the Plum River Fault was there until after the construction license was granted?

A (WITNESS ALTERMAN) Well, the Plum River Fault Zone is an east-west trending structure.

The minor faults in the excavation, as I recall, were north 70 west, which is a more northwesterly, and pretty nearly parallel to the Sandwich fault.

Now, I don't recall now the chronology of events and whether the Sandwich fault was known at that time; but I believe that a report from the Illinois Survey about the excavation faults did mention that these faults were parallel and subparallel to the Sandwich fault.

I think that in that way they were not led to believe that there is another fault in the area. They simply related it to a fault, as I recall now, they already new existed and it felt fit in quite well with the geometry that it was related to the Sandwich fault, not the Plum River Fault.

So the answer to your question is: it does not change my view of their competence at all.

MS. JOHNSON: Thank you. Let's see. I have one other question and I am not sure.

BY MS. JOHNSON:

Q Dr. Alterman, you guessed -- you said in your answer to the question, you said you guessed the Illinois State Geological Survey made observations on the Plum River Fault.

Do you in fact know whether they did this or not? That was your terminology.

A (WITNESS ALTERMAN) I can only go by what they have read in their report and what they told me and what I have in letters from them, that they have observed this and these are their conclusions. I have no other contradictory information.

JUDGE SMITH: It's the use of the word guess, Dr. Alterman.

MS. JOHNSON: Yes, that's what was concerning me.

JUDGE SMITH: Would you stick by that word?

A (WITNESS ALTERMAN) No. That's an informal term, not meant for legal hearings.

BY MS. JOHNSON:

Q Did you read that they made observations?

A (WITNESS ALTERMAN) Yes, I read this in what they have. in their report. I read it as implicit, as I have mentioned several times, implicit in their report.

I have spoken to them about it and they have told me so.

And I have letters from them stating that they have never observed till offset along any faults in Northern Illinois. I have nothing more to go on but that.

MS. JOHNSON: That clarifies it. Just the term guess bothered me.

A (WITNESS ALTERMAN) I am sorry about that.

MS. JOHNSON: I had one other question and I am not sure whether this is the issue, so you can correct me.

JUDGE SMITH: You are three for three so far. you are doing fine.

(Laughter.)

BY MS. JOHNSON:

Q If the Plum River Fault -- and I say if -- was a capable fault, was found to be a capable fault, would it be possible that the Byron Nuclear Power Station would have to be built to a stronger design?

A (WITNESS ALTERMAN) For that I would have to ask Dr. Rothman to answer that.

MS. JOHNSON: All right.

A (WITNESS ROTHMAN) When we have a capable fault, a determination has to be made as to the largest size earthquake that we would expect to have on that fault.

Now, this is a function of the length of the fault, the slip rate, the tectonics of the region, the largest known historical earthquake to have occurred on the fault, the activity rate, historical activity rate on the fault.

The Staff takes all of these factors into consideration and then assigns a maximum earthquake, postulated maximum earthquake to this fault.

The assumption is then made that this earthquake, this maximum earthquake could occur on the fault as its closest approach to the plant.

So depending on what the -- if the fault was determined to be capable and, A, we could assign a maximum earthquake to it, what this earthquake would be, then we would have to look at the ground motion we would expect to see at the plant from an earthquake at that distance on the fault and then we would have to -- then we could determine a determination whether the design of the plant is adequate.

So these are a lot of ifs and hypotheticalizing and I might add that there are really no known capable faults in the Eastern United States. We do have capable faults in California and we have nuclear power plants built at distance on the order of five miles or less from these nuclear power plants -- from these faults and they have operating licenses. That's all I can say.

Q Thank you. Do you consider that according to the regulations if -- again if -- the Plum River Fault were found to be a capable fault, it would make a difference whether it was five miles from the site or 5.3 miles from the site?

A (WITNESS ROTHMAN) You mean in the size of the earthquake that we would assign to it?

Q No. I am talking about the regulations.

A (WITNESS ROTHMAN) I don't know what you mean, what you are referring to in the regulations.

MS. JOHNSON: Well, I referred to it before.

JUDGE SMITH: In any aspect of the regulations which you work with, would the difference between 5 and 5.3 miles make any difference?

A (WITNESS ROTHMAN) As far as I am concerned in determining the seismic design, no, it wouldn't make any difference. We would use the closest approach to the site and determine the ground motion we would expect from that.

MS. JOHNSON: Thank you. Dr. Woodard has some.

CROSS EXAMINATION

BY MR. WOODARD:

Q Dr. Alterman, I don't want to run this fault scarp into the ground; but I do have one or two points I would like to clarify with respect to fault scarps, fault scarps and unconsolidated material and fault scarps in bedrock.

Have you ever seen a fault scarp in surface con, surficial material, unconsolidated surficial material?

A (WITNESS ALTERMAN) Yes, I have.

Q Where was that?
A (WITNESS ALTERMAN) At the site of the Handford site of the nuclear power plant, not in the plant but in that area.
Q What kind of a fault was it?
A (WITNESS ALTERMAN) It was a high angle reverse fault and it was a capable fault.
Q What did the scarp look like?
A (WITNESS ALTERMAN) It was a juxtoposition of some very highly fractured basaltic rock, some very shored up calcified material in the fault zone and below it some fragmented, till-like material at the base of the scarp.
Q So if I understand you correctly, the hanging wall of the reverse fault was not of unconsolidated material?
A (WITNESS ALTERMAN) No. The basic block was of fractured basalt, ye , but there was some unconsolidated material on it.
Q Have you ever seen a fault scarp developed in unconsolidated material?
A (WITNESS ALTERMAN) I am trying to remember. I have probably seen pictures of them but I can't recall offhand.
Q Well --
A (WITNESS ALTERMAN) Excuse me. Would you consider unconsolidated material badly weathered metamorphic rock which is now in the form of sacralight.
Q I might.

A (WITNESS ALTERMAN) Yes, I have seen that.
Q Where?
A (WITNESS ALTERMAN) In the Belair Fault zone in Georgia.
Q What was the age of the [illegible] motion on that fault?
A (WITNESS ALTERMAN) Let me think. I am not sure it was determined. I can't recall. It may have been tertiary.
Q And you are stating there was a fault scarp there. temporary and a fault scarp?
A (WITNESS ALTERMAN) Well, there is an offset and you can see a difference in the elevations of the two types of rock, yes.
Q Was it a fault scarp or was it a fault line scarp?
A (WITNESS ALTERMAN) That's hard to tell.
Q So we don't know that you have ever seen a fault scarp in unconsolidated material?
A (WITNESS ALTERMAN) Well, they do exist. I may not have seen them but they do exist.
Q They do exist. I have seen many of them, indeed.
Well, my point is that I am not sure that -- let me ask this differently.
You say about the Plum River Fault, you say -- and this is, I think, a quote from your testimony -- it is loose, unconsolidated material.
A (WITNESS ALTERMAN) That is what -- I was explaining what glacial till is for the Board.

Q I think that is a good explanation. I think it's loose, unconsolidated material. How long do you think under post-Pleistocene -- yes, Pleistocene and post-Pleistocene conditions and erosion conditions a fault scarp will in fact continue to exist over the Plum River Fault Zone?
A (WITNESS ALTERMAN) Well, I have seen faults -- not fault scarps but faults -- in unconsolidated tertiary and somewhat tertiary material in the Northern California material around the Humbolt Bay plant, in which the faulting was in loose sand and the geologists there do not work with geologic hammers but with the kind of -- I forget the name of the instrument that is often used by painters to scrape off walls. They use that kind of material to scrape down the vertical surface in order to see the fault. The fault remains no matter what you do; in the most unconsolidated material the fault is present and observable and quite remarkable. It doesn't matter whether it's sand, mud or anything. The fault remains and is observable.
Q And did you say what the age of that fault was?
A (WITNESS ALTERMAN) Some of those are -- were somewhere around 37,000 years as determined by the -- by consultants for the Applicant.
Q Do you know what the evidence was for determination of 37,000 years?

A (WITNESS ALTERMAN) Yes, there was radio carbon dating of fragments of trees in the muds that were faulted.

MR. WOODARD: Thank you.

JUDGE SMITH: Mr. Goldberg.

MR. GOLDBERG: Judge, I have a few questions on redirect. I will not have the rebuttal testimony I thought at the outset I would have so we will be able to, I think, proceed.

REDIRECT EXAMINATION

BY MR. GOLDBERG:

Q Dr. Alterman, you were asked several questions about the fault dating techniques used by the Illinois Survey and your position on the non-capability of the Plum River Fault.

First with regard to the fault dating techniques used by the Illinois Survey, is core drilling a reliable means for attaining information about faults?

A (WITNESS ALTERMAN) Yes, it can be under given sets of conditions.

Q Were those conditions present in the drilling performed by the survey?

A (WITNESS ALTERMAN) I am not sure in this case. It did determine the presence of the fault; but I am not sure that it determines the dating of the fault there.

Q For what purpose did the survey use the core drilling?

A (WITNESS ALTERMAN) They used it to identify the fault. Since the fault was covered with unconsolidated material buried below the glacial till, there was no way to identify its presence or whether it was there or not.

So drilling in two places sort of taking an educated guess that the fault might be somewhere between them, drilling on either side of this postulated presence of a fault and determining that the type of bedrock differed on either side indicated to them that the fault was present there.

Q Was the core drilling then a reliable means for accomplishing the purpose for which it was performed as you just described?

A (WITNESS ALTERMAN) Yes, for that purpose it was certainly useful.

Q And is it not true it's only among the measures taken by the Illinois Survey in arriving at their fault dating conclusions regarding the Plum River Fault; is that correct?

A (WITNESS ALTERMAN) Yes, yes.

Q Did their study disclose any evidence of contemporary strike slip movement along the Plum River Fault?

A (WITNESS ALTERMAN) No, as far as I know, there is no evidence for strike slip movement along the Plum River Fault Zone.

Q Do you agree with Dr. Rothman's opinion or position that there are no known capable faults in the Eastern United States?

A Yes, I do.

Q I gather that encompasses the central stable region tectonic province as well; is that correct?

A (WITNESS ALTERMAN) Yes. When we speak of the Eastern United States, we mean everything east of the Rocky Mountains and there has never been, although we have searched and we have had others search for capable faults. Whenever there is an earthquake there are seems teams of geologists and seismologists running out to see if they can find some surface breakage and we have never been successful in finding any anywhere east of the Rocky Mountains. I should confine it to the central stable region and Eastern United States.

Q Again with regard to the Illinois Survey Circular 491 that has been discussed, particularly Figure 7, the cross-section Al figure upon which you were questioned, do the conclusions reached by the Illinois Survey on the date of the Plum River Fault depend entirely on that diagram?

A (WITNESS ALTERMAN) No, no. I believe that the seismic refraction work was simply another technique to be able to identify the fault where it was buried to see how far it continued and to determine how much offset, how much

vertical offset, there was on the fault.
Q Did the survey find any offset of glacial material along the fault?
A (WITNESS ALTERMAN) As far as I know, they have never found any offset of glacial material.
Q Dr. Rothman, with regard to the seismic refraction work done by the survey, are you familiar with the methods and instruments used in that work?
A (WITNESS ROTHMAN) I have read that description of the techniques that they used. Yes, I am familiar.
Q On the basis of -- I am sorry. Are you finished?
A (WITNESS ROTHMAN) I am familiar with the techniques that were used and the equipment that was used, yes.
Q This comes from your experience performing seismic refraction work in the field?
A (WITNESS ROTHMAN) Yes, yes.
Q Were those methods and instruments appropriate, in your opinion?
A (WITNESS ROTHMAN) For this type of a survey, yes.
Q Were the conclusions reached by the survey on the basis of the seismic refraction work performed appropriate, in your opinion?
A (WITNESS ROTHMAN) Based on the seismic velocities that they measured for the overburden and for the rock and for the station spacing and the length of the lines that were

employed in doing this survey and the techniques that we use, it's continuous reverse profiling, the conclusions they reached were appropriate.

Q Dr. Alterman, Dr. Woodard asked you some questions about your prepared testimony regarding the difference in strain rate measurement between California events and -- seismic events in Northern Illinois, do you recall?

A (WITNESS ALTERMAN) Yes.

Q To your knowledge or in your opinion are there tests that have the ability to measure strain on basement rock at the depths proposed in the contention that is before us?

A (WITNESS ALTERMAN) I was under the impression from all of the knowledge that I have of work in structural geology that it was not possible to do that; and I think the document that was presented yesterday confirmed that, that it is not possible to do strain measurements at the depths that are suggested in the contention.

Q The document that we are talking about I think has been admitted as Applicant Exhibit 1. Is it the document repaired by the National Resource Council entitled Rock Mechanics Research Requirements for Resource Recovery, Construction and Earthquake Hazard Reduction?

A (WITNESS ALTERMAN) Yes, that's the one.

Q Are you familiar, by the way, with the authors of this publication?

A (WITNESS ALTERMAN) I had a brief chance to look at the authors of the various committees yesterday. I have not seen it since and I would request from the Intervenors to look at their copy, so that I may see the authors again. I knew I recognized two or three but I do not recall all of the authors.

MR. GOLDBERG: Can I borrow a copy of the document. Dr. Woodard?

MR. WOODARD: Yes.

MR. GOLDBERG: Thank you.

A (WITNESS ALTERMAN) Would you please restate your question?

BY MR. GOLDBERG:

Q Have you had an opportunity to look at the authors?

A (WITNESS ALTERMAN) I am taking a quick look again from -- actually, they are reports from various committees and I am looking at the members of the committees plus the chair so-called steering group which directed this entire study.

Q I guess the only question I really have relative to the report is whether or not you are familiar with the contributors or authors of the report and have some professional opinion about their reputability or standing in the geological community?

JUDGE SMITH: And what will be the use of that answer?

MR. GOLDBERG: The weight that should attach to the exhibit.

JUDGE SMITH: Are you going to be urging more or less weight?

MR. GOLDBERG: I am not sure what weight was urged but I am prepared to let -- if the witness can give an answer to the question, perhaps it will help us assign some proper weight to it.

JUDGE SMITH: You are just trying to establish. whatever weight should be given, you want it to be known?

MR. GOLDBERG: Right. I say that only because Dr. Woodard was asked the same question, I believe, by the Board.

JUDGE SMITH: Yes, that is correct.

A (WITNESS ALTERMAN) Would you please restate your question? I am sorry.

BY MR. GOLDBERG:

Q Have you read the list of authors and/or contributors to the report?

Now, are the names of the authors and/or contributors to the report familiar to you and, if so, are they reputable persons in the fields of geology and/or seismology, and, if so, what is that reputation?

A (WITNESS ALTERMAN) I am familiar with quite a number of the names of the members of these committees. As a specialist in structural geology, I do a lot of reading and have done a lot of studying of various types of work in structural geology and I can attest to the fact that most of the names that I recognize on here are considered giants in the field. The first name that came is John Handon, who is perhaps the Dean of rock mechanics in the United States, and there has recently been published another volume on rock mechanics which is dedicated to him for the advances he made in the field of rock mechanics which is the experimental study of rock deformation, and I believe that this volume very well states the present state of the art, and its purpose was to -- appears to have been a way of planning how to develop and advance the state of the art in rock mechanics, both in the experimental field and in field applications to that.

So I consider it a very important document in scructural geology.

BY MR. GOLDBERG:

Q Okay. A final question. The document was utilized earlier for the portion on stress and strain measurement techniques; is that correct?

A (WITNESS ALTERMAN) The document, yes.

Q The Applicant Exhibit 1, the document before you.

A (WITNESS ALTERMAN) Yes.

Q The document was published, I gather, in 1981; is that correct?

A (WITNESS ALTERMAN) Yes, yes.

Q Given your testimony about the purpose that you understood the study to represent, what would be your opinion about what advances in the particular areas of stress and/or strain measurement that are discussed in this document -- what is your opinion about what advancs have been done in that field since 1981 when this document was published?

A (WITNESS ALTERMAN) Well, while it's true that advances are being made at great rates these days in various scientific disciplines, I don't believe that there has been much of a change in the state of the art since 1981 of the nature of the plans that they had. They are speaking of five and 10 year plans ahead of what they would seek as goals for improving and advancing the state of the art. I don't believe there has been much change of the techniques of what they have -- of what they describe in 1981.

MR. GOLDBERG: I have no further questions, Judge.

JUDGE SMITH: Mr. Bielawski, I wonder if we could impose on you the task of substituting the task, Applicant's Exhibit 1, of a new exhibit, including the cover page and a list of authors. There has been too much testimony on that to leave it out.

Do you have any additional questions?

MR. WOODARD: I have one, your Honor, if I may.

JUDGE SMITH: Based upon Mr. Goldberg's redirect?

MR. WOODARD: I believe it was. It came up twice.

JUDGE SMITH: All right. Just ask it, any question.

CROSS EXAMINATION

BY MR. WOODARD:

Q I am curious about the definition of a capable fault east of the Rocky Mountains and the non-existence of any capable fault east of the Rocky Mountains and I am curious as to how either or both Mr. Alterman and Dr. Rothman or defining capable fault?

MR. GOLDBERG: I have no objections, your Honor.

A (WITNESS ALTERMAN) The capable fault we define as defined in the regulation as Appendix A to part 100 and that is a surface displacement, surface displacement, that is a fault at or near the surface, at or near the surface, that has moved once in the last 35,000 years or multiple times within the last 500,000 years or has been associated with seismicity.

BY MR. WOODARD:

Q As I read the Chapter 1, Appendix A of the rules, Part G, there is no mention in here of surface relationships with respect to a capable fault. Now, I may be reading them incorrectly.

MR. GOLDBERG: Is the witness able to identify the reference Dr. Woodard is making?

A (WITNESS ALTERMAN) I don't have my copy with me. It's all marked up.

A (WITNESS ROTHMAN) Get the page number.

A (WITNESS ALTERMAN) Would you give us the page number?

JUDGE COLE: I have a copy of the regulation. I will read it into the record. Section G.

A (WITNESS ROTHMAN) What page number?

JUDGE COLE: 673.

JUDGE CALLIHAN: What year?

JUDGE COLE: This is January 1, 1982, version. A capable fault is a fault which has exhibited one or more of the following characteristics. One, movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years.

A (WITNESS ALTERMAN) And macroseismicity is also included.

JUDGE COLE: Two, macroseismicity, instrumentality determined within -- with records of sufficient precision to demonstrate a direct relationship with the fault and other sections.

A (WITNESS ALTERMAN) In all cases it refers to a fault at or near the ground surface.

MR. WOODARD: I suggest you ought to change your regulations because I don't read it that way.

A (WITNESS ALTERMAN) I am sorry. That's outside my responsibility.

MS. JOHNSON: That's what it says. Who could clarify that? It says one or more of the following characteristics. It can only have one of them. which might be -- it says movement at or near the ground surface, at least once within the past 35,000 years or movement of a recurring nature within the -- that's or.

A (WITNESS ALTERMAN) No. That one is one. No. 1 is one of the three or one of the four characteristics.

The one thing that is in common with all of them, as we understand it and as we work with it at the NRC, is that it is a ground surface -- it is a fault at or near the ground surface. Now, it may have either one movement in 35,000 years, multiple movements in 500,000 years, seismicity associated with it or a structural relationship with a capable fault.

MS. JOHNSON: It says one or more of those. It doesn't say it has to be --

MR. GOLDBERG: Judge, I have --

MS. JOHNSON: Understand that --

JUDGE SMITH: Wait a minute, wait a minute. We are not going to argue it.

MS. JOHNSON: I am sorry.

JUDGE SMITH: Let's consider it but let's first recognize that notwithstanding what it says, the testimony is the way they work with it is the way she states.

Now, we may have another problem but at least that is her testimony and that is clear.

MS. JOHNSON: Yes. I understand that. I am sorry.

MR. WOODARD: May I ask one more question?

JUDGE COLE: Just give us a moment.

JUDGE SMITH: Now, Dr. Alterman.

A (WITNESS ALTERMAN) Yes, sir.

JUDGE SMITH: Let's divide it into two ways.

One is we understand that you and your colleagues work with it according to the way you testified, that it must be near the ground in each one of the 1, 2 and 3.

Is there a basis for the -- is there a basis for your interpretation in the language which justifies that or what is your opinion as to the meaning of the language?

A (WITNESS ALTERMAN) Let me think.

JUDGE SMITH: I guess we would be referring to Subsection G.

A (WITNESS ALTERMAN) Yes, I realize that and I am -- I can see what the intervenor is driving at. that the second one does not stipulate a ground surface fault.

MR. GOLDBERG: The second one being what. Dr. Alterman?

A (WITNESS ALTERMAN) Two, macroseismicity instrument alley determined with records of sufficient precision.

MS. JOHNSON: 3.

A (WITNESS ALTERMAN) We are saying there are no capable faults in the central stable region or in the Eastern United States based on our definition; and they are saying that. well. there are. There are earthquakes and we assume that these earthquakes are on faults and, therefore. there must be capable faults somewhere in the central stable region; but we confine it. because of what the purposes of the regulations are in licensing nuclear power plants. our concern is surface faulting, surface offsets which could disturb the foundation of a plant.

And so we regard the definition to relate to the building of nuclear power plants and basement faults which are -- we assume are there but are not recognizable. their position is not determinable at the present state of the art. We don't consider that simply because there are earthquakes that therefore proves there are capable faults.

MR. GOLDBERG: Judge, I --

A (WITNESS ALTERMAN) I am sorry.

MR. GOLDBERG: Do you want to finish your answer? Maybe I could clarify it, sub part C, sub part 2 relates to seismicity. Perhaps Dr. Rothman would be a better person to contribute to our understanding of what that provision states, I express the hope.

A (WITNESS ROTHMAN) Yes, I hope I can.

MR. GOLDBERG: Would you please?

A (WITNESS ROTHMAN) Yes. We know we have earthquakes in the Eastern United States. We have not been able to identify accept in a very few cases a fault which may be associated with this earthquake. We have not been able to place earthquakes on a fault instrument alley located with a precision so that we would know that it's definitely associated with that fault.

If we could do this, then in licensing a plant we would be required to keep that earthquake on that fault.

Since we do not have the capability of doing this, we assume that the earthquake can occur near the plant, so this then envelopes the possibility. We know that there must be faults that these earthquakes are occurring on but since we can't identify them, we just make the assumption that any earthquake within the tectonic region could occur near the plant and this is a more conservative position than trying to identify some kind of a fault at some depth and we don't have any ability to do this.

Does this clear up that question?

JUDGE SMITH: Yes. It just occurred to me that the assumption of near the surface is a conservative assumption, yes.

MS. JOHNSON: An earthquake that -- excuse me.

MR. GOLDBERG: Judge, I am not sure we have a misunderstanding or not but let me clarify it.

BY MR. GOLDBERG:

Q Both doctors Alterman and Rothman, do you believe that your review of the geology and seismology relative to the Byron nuclear power plant seismic design has followed the regulatory requirements discussed here?

A (WITNESS ROTHMAN) Yes, and I have so certified in the SER.

A (WITNESS ALTERMAN) Yes, I believe they have.

BY MR. GOLDBERG:

Q And you have both done a number of such reviews for the NRC, have you not?

A (WITNESS ROTHMAN) Yes.

Q How many have you done, Dr. Rothman?

A (WITNESS ROTHMAN) Well, I don't know how many. I have to stop and think. As I said, I am responsible for approximately 15 plants. I have either reviewed them or in the process of reviewing or have taken over the responsibility for these sites. So how many SER's I have completed, complete, I would say five or six that I have completed since I have been aboard. This is a guess without sitting down, five or six reviews that I have been completed since I have been employed by the NRC.

Q Dr. Alterman, the same thing.

A (WITNESS ALTERMAN) Probably closer to eight or 10 for me, including fault studies associated with new and older nuclear power plants.

Q And you both used the definition of capable fault that is contained in the regulation?

A (WITNESS ALTERMAN) Yes, indeed.

A (WITNESS ROTHMAN) Yes.

MS. JOHNSON: I was just going to -- go ahead. You better do something.

MR. WOODARD: I would like to address a question to Dr. Rothman, if I may.

BY MR. WOODARD:

Q You understand the regulations concerning the definition of capable fault. You do not consider the New Madrid fault zone a capable fault zone?

A (WITNESS ROTHMAN) We consider the New Madrid a seismogenic zone which is different from a capable zone. We have not identified a specific zone. We have a seisemogenic source zone and we consider that as a

seisemogenic source one.
Q A capable one?
A (WITNESS ROTHMAN) I don't understand what you mean by capable.
Q Using your definitions.
A (WITNESS ROTHMAN) We don't consider it a fault. The New Madrid is not a fault. It's a seismogenic zone, which have not identifi a sick fault in that zone.
Q I have another question, if I may.
Do you consider the artificially induced sequence of earthquakes near Denver, Colorado, about six or seven years ago, as being a capable fault zone?
A (WITNESS ROTHMAN) I have not -- I have not reviewed that.
I believe you are talking about the Rangly experiment?
Q No, I am not talking about the Rangly experiment.
A (WITNESS ROTHMAN) Well, I don't know what you are talking about.
Oh, the high pressure injection wells?
Q That is correct.
A (WITNHESS ALTERMAN) I wouldn't consider that a capable fault, we would consider that man-made activity and there is provision in the regulations for the consideration of man-made activity and previous.
MS. JOHNSON: Can I ask a question?

BY MS. JOHNSON:

Q Dr. Rothman --

A (WITNESS ROTHMAN) Yes.

Q -- in your review of these plants and licensing review. are you also responsible for the type of thing that came up the other day, which Dr. Singh mentioned, where you okay the calculation of the earthquakes, for instance. for the Byron plant as the return of a modified Mercalli 6 on which they base taking a lower value than is required by the regulations for the operating basis earthquake? Are you -- do you endorse the 2150 years or the 200 to 1.000 years instead of taking the actual evidence, which shows that within the last 200 years or so they have had six or seven modified Mercalli six within a radius around that plant?

A (WITNESS ROTHMAN) I believe that the intent of the regulation. the intent of the regulation was to ensure that the plant would be closed down and inspected if a certain ground motion was exceeded, and it was to be that ground motion which would be expected to occur during the life of the plant. Now, there is a contradiction in Appendix A, in that we have two definitions of the operating basis earthquake.

We have had a number of plants which have been licensed with operating bases less than one-half the SSE;

and, in fact, we have actually had a Board ruling on one plant which was litigated in which the Board determined that a return period in excess of the life of the plant was adequately conservative for determining the OBE.

Q But there have been two modified Mercalli 6 close to the plant. the last one about 30 miles, with an epicenter about 30 miles in the last 37 years. Isn't the life of the plant 40 years?

A (WITNESS ROTHMAN) An earthquake occurring, modified Mercalli occurring, 30 miles from the plant is not the same as experiencing that intensity at the plant site.

Q I understand that.

A (WITNESS ROTHMAN) Well --

Q Doesn't that affect -- shouldn't that affect the recurrence? I know Dr. Cole asked some questions of Dr. Singh. He indicated it would affect the design.

MR. GOLDBERG: Judge, I am not sure we have got a statement or a question.

MS. JOHNSON: I am sorry.

MR. GOLDBERG: But I --

A (WITNESS ROTHMAN) I am familiar with four studies that have been performed on the return period of ground motion in the Byron area and all of them indicate from mathematical calculations and all of them use different assumptions about the number of the -- about the area over which they were determining it, the seismogenic zones and all of these determinations indicated that return periods on the order of .09 G for peak accelerations would be multims of the operating live of the plant.

Now, you may have concerns because you say we have had four earthquakes but those have been taken into account in these calculations and they were done by different people at different times, using several different probablistic techniques and they have all come out with this. Now --

Q Then you think it is more important to use calculations than it is to use actual earthquake data?

JUDGE SMITH: Wait a minute.

MR. BIELAWSKI: I object to that, Judge.

MS. JOHNSON: I am asking him a question. Can he answer it?

MR. BIELAWSKI: Can I raise an objection? We are going well beyond the scope of Mr. Goldberg's redirect examination here. We have heard all of this before. We have other issues to move onto.

JUDGE SMITH: I am very much aware of that. You heard her question. Is that a fair representation of your opinion?

A (WITNESS ROTHMAN) No, I don't believe that because there have been two earthquakes in Northern Illinois or four earthquakes, that that interval dates the calculations that have been done by various people. Several of these parties have no interest whatsoever in the Byron nuclear power plant and were doing this strictly as seismological research.

JUDGE SMITH: So you restrict the premise of her question?

A (WITNESS ROTHMAN) Yes, I do.

MR. WOODARD: May I ask one more question and then I will quit?

JUDGE SMITH: All right.

CROSS EXAMINATION

BY MR. WOODARD:

Q Dr. Alterman. as a geologist, don't you find it difficult not to define the well-known New Madrid fault zone as a capable fault zone?

A (WITNESS ALTERMAN) The term capable fault is not a geologic term. It is a legal term.

We deal with capable faults when we are talking about nuclear power plants.

When I am out in the field doing geologic research just for fun and myself, I do not see capable faults. I may see active faults, I may see ancient faults but I don't see capable faults. The term capable fault is a legal definition that is applied to the licensing of nuclear power plants and it's on that basis that I have to state that the geoscience branch, Nuclear Regulartoy Commission, we are not convinced that is a capable fault from a legal point of view.

JUDGE SMITH: So then it follows, if you don't recognize in science capable fault, then you don't recognize a capable fault zone?

A (WITNESS ALTERMAN) Exactly.

JUDGE SMITH: Does that get to your point?

MR. WOODARD: It's not logical but it gets to the point.

A (WITNESS ROTHMAN) Might I add that I don't believe that we would ever license in my opinion a nuclear power plant in the New Madrid seismogenic zone.

MS. JOHNSON: Why not? It's not capable.

JUDGE SMITH: Does that help you? Did you hear that answer, Dr. Woodard?

MR. WOODARD: Pardon?

JUDGE SMITH: Did you hear Dr. Rothman's answer?

MR. WOODARD: No. I am sorry.

A (WITNESS ROTHMAN) I said whether it's capable or not, I don't think that we would ever license a nuclear power plant in the New Madrid seismogenic zone.

JUDGE SMITH: All right. Anything further?

MR. GOLDBERG: I have two brief questions.

Judge.

JUDGE SMITH: I hope they are carefully selected.

MR. GOLDBERG: They will be; they will be.

(Laughter.)

CROSS EXAMINATION

BY MR. GOLDBERG:

Q Dr. Alterman, by legal definition of capable fault, you mean contained in the Nuclear Regulatory Commission regulations?

A (WITNESS ALTERMAN) Yes, Appendix A.

Q Namely a regulatory requirement that you are equating with a legal requirement for the purposes of the answer you gave?

A (WITNESS ALTERMAN) Yes, that's correct.

Q Dr. Alterman, what happens when an plant experiences an earthquake?

A (WITNESS ALTERMAN) The operator of the plant, the utility, is required to close down the plant and perform an inspection to ensure that all the equipment is in proper operating condition.

Q So if we have an operating basis earthquake at Byron of .09 G as opposed to .10G G, we would be one-half of the SAFE shutdown earthquake value, in a way that is more conservative because they would have to shut down the plant early early and inspect; is that correct?

A (WITNESS ROTHMAN) If the .09 G REG GUIDE spectrum were exceeded they would be required to shut down and based on probabilities you would assume that you would exceed that probably more often than you would .10 G.

JUDGE SMITH: Is it then that the OBE is not a design criterion then, it's an operating criteria?

A (WITNESS ROTHMAN) I believe that is correct. I am not involved in the actual design of the plant, so I don't know if in any of the equipment or structures there is some requirement but as far as I know, it is an operating requirement but I can't guarantee that it's not a design requirement.

JUDGE COLE: I tried to make a determination as to just what features of the plant might be different for an operating basis earthquake of zero point 1 as compared to 0.09.

Do you happen to know what size -- what acceleration would actually have a return period of about 40 years or the life of the plant?

A (WITNESS ROTHMAN) No, I don't. I haven't done that calculation and I don't have anything with me that would indicate that.

BOARD EXAMINATION

BY JUDGE COLE:

Q It would be considerably less than 0.09?
A (WITNESS ROTHMAN) Yes, I believe so, yes.
Q Well, it's an operating criterion then, a very slight acceleration would force the operator to shut the plant down and check everything; is that practical?
A (WITNESS ROTHMAN) Are you saying that .09, that is your characterization? I mean that would be equivalent at least to an Intensity 6 earthquake and we don't experience those everyday, so I don't --
Q You say if it's an operating --
A (WITNESS ROTHMAN) I believe it's mainly in operating.
Q And the regulations indicate that is for the size earthquake that you would expect the plant to get during its lifetime?
A (WITNESS ROTHMAN) I think it says to occur during the life of the plant. I have to read it to you.
Q That's a very small earthquake and if they have to shut the plant down for that size earthquake --
A (WITNESS ROTHMAN) That's the conservatism in the regulations, I believe. That's what the regulations require.
I did not write the regulations. I just --
Q Properly sized, if it would only occur once, they would only have to do it once?
JUDGE SMITH: Thank you, panel. You are

excused.

Let's take our afternoon break of 10 minutes.

(Recess.)

MR. COPELAND: May I have the official testimony of the -- would you give me one of the copies of the testimony, Mr. Reporter?

THE NOTARY: Yes, sir.

MR. COPELAND: I am Victor Copeland, one of the attorneys for the Applicant.

We wish now to proceed on DAARE/SAFE Contention 9 A.

I would like to call Mr. Carlson and Mr. Pleniewicz to the stand.

JUDGE SMITH: Gentlemen, may I administer the oath, please?

(The witnesses were thereupon duly sworn.)

ROBERT W. CARLSON

RICHARD PLENIEWICZ

called as witnesses by counsel for the Applicant, having first been duly sworn by the Chairman, were examined and testified as follows:

DIRECT EXAMINATION

BY MR. COPELAND:

Q Mr. Carlson, could you state your full name, please, and by whom you are employed?

A (WITNESS CARLSON) My name is Robert W. Carlson. I am employed by the Westinghouse Electric Corporation.
Q Mr. Pleniewicz, could you state your full name please and by whom you are employed?
A (WITNESS PLENIEWICZ) My name is Richard Pleniewicz. I am employed by Commonwealth Edison Company.
Q Mr. Carlson, have you prepared testimony in this case?
A (WITNESS CARLSON) Yes, I have.
Q I now show you a copy of what has been identified as testimony of Robert W. Carlson, consisting of 17 pages of questions and answers and four attached figures.
(Indicating.)
Is this your testimony?
A (WITNESS CARLSON) Yes, it is.
Q Are there any corrections that you wish to make to this testimony?
A (WITNESS CARLSON) No.
Q To the best of your knowledge, is it accurate and correct?
A (WITNESS CARLSON) Yes.
Q Mr. Pleniewicz, have you prepared testimony in this proceeding?
A (WITNESS PLENIEWICZ) Yes, I have.
Q I now show you a copy of what has been entitled "Testimony of Richard Pleniewicz."
(Indicating.)

Is this your testimony, consisting of eight pages?
A (WITNESS PLENIEWICZ) Yes, it is.
Q Are there any corrections that you need to make to this testimony?
A (WITNESS PLENIEWICZ) No, there are not.
Q Is it accurate and correct to the best of your knowledge and belief?
A (WITNESS PLENIEWICZ) Yes, it is.

MR. COPELAND: Your Honors, I would move that these two pieces of testimony be admitted into the record as if read.

JUDGE SMITH: Are there any objections?

MS. CHAVEZ: Yes, your Honor.

I would like to -- I request that I be allowed to ask a series of questions to determine whether or not there is any basis for striking portions of Mr. Carlson's testimony.

JUDGE SMITH: Ms. Chavez, you were present when we had a similar discussion about the difference between expertise and striking testimony.

It is your purpose now to achieve -- to strike portions of the testimony or all of it?

MS. CHAVEZ: Portions.

JUDGE SMITH: Portions, okay.

MR. COPELAND: Your Honor, if we may, may we have a ruling on Mr. Pleniewicz' testimony, since there has been no objection voiced to that?

JUDGE SMITH: Do you object to both pieces of testimony?

MS. CHAVEZ: No.

JUDGE SMITH: All right. Mr. Pleniewicz' testimony will be received into evidence.

(The document referred to, the prepared testimony of Richard Pleniewicz, received in evidence, follows:)

Date: 2/15/83

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
COMMONWEALTH EDISON COMPANY	)	Docket Nos. STN 50-454 OL
	)	STN 50-455 OL
(Byron Nuclear Power Station, Units 1 and 2)	)	

SUMMARY OF TESTIMONY OF RICHARD PLENIEWICZ

Richard Pleniewicz is employed by Commonwealth Edison Company as the Assistant Superintendent of Operations at the Byron Station and, as such, he is responsible for procedures associated with plant operation. His testimony explains the actions which are being taken by Commonwealth Edison Company to implement the recommendations made by Westinghouse for minimizing the occurrence of a KRSKO-type waterhammer event which is the subject of DAARE/SAFE Contention 9a.

Mr. Pleniewicz confirms Commonwealth Edison Company's plan for changes in the check valve arrangement in the Feedwater Bypass System and the Auxiliary Feedwater System. He also relates the actions which are being taken to implement the Westinghouse recommendations. Mr. Pleniewicz also describes the preoperational testing which will occur at the Byron Station to test for conditions which can lead to a KRSKO-type event. He concludes that the actions which will be taken will implement all of Westinghouse's recommendations.

Date: 2/15/83

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
COMMONWEALTH EDISON COMPANY	)	Docket Nos. STN 50-454 OL
	)	STN 50-455 OL
(Byron Nuclear Power Station,	)	
Units 1 and 2)	)	

TESTIMONY OF RICHARD PLENIEWICZ

Q1: Please state your name, present occupation, and present position.

A1: My name is Richard Pleniewicz. I am employed by Commonwealth Edison Company as Assistant Superintendent of Operations at the Byron Nuclear Power Station near Byron, Illinois.

Q2: Briefly state your educational and professional qualifications.

A2: I have a Bachelor's Degree in Electrical Engineering from the University of Illinois at Champaign-Urbana. I also received a Senior Reactor Operator's License for Zion Station Units 1 and 2 in July, 1976. My work experience prior to joining Commonwealth Edison includes 6 years in the United States Navy. As the result of my training I became a Qualified Reactor Operator in 1966. I joined Commonwealth Edison in February, 1973 as a Technical Staff Engineer at Zion Station. I was an active member of the pre-operational and startup test group. In that capacity I was involved in core physics testing and plant-wide transient testing. In September, 1974, I became the Electrical Group Leader. After receiving my Senior Reactor Operator's License, I was appointed to the position of Shift Foreman at Zion Station. In May, 1977, I was promoted to Operating Engineer at the Byron Station. In August, 1980, I was promoted to Assistant Superintendent of Operations at the Byron Station.

Q3: Describe your duties and responsibilities as Assistant Superintendent of Operations.

A3: As Assistant Superintendent of Operations, my basic function is to manage the Station's Operating Department. This entails ensuring that the plant is operated in a safe, efficient and professional manner in accordance with State and Federal regulations, permits and licenses. It also includes providing direction to the Shift Engineer for safe and reliable operation by means of instruction, procedures and policies. I am also a member of the On-Site Review Committee which is responsible for reviewing plant operating procedures and test results.

Q4: What is the purpose of your testimony?

A4: The purpose of my testimony is to explain the actions which are being taken by Commonwealth Edison Company to implement the Westinghouse recommendations for minimizing the occurrence of a waterhammer event in the steam generator bypass line at the Byron Plant like the one that occurred at the KRSKO plant.

Q5: As Assistant Superintendent of Operations are you responsible for writing the procedures associated with the operation of the feedwater bypass system?

A5: Yes.

Q6: Please describe Commonwealth Edison Company's plan for removal and installation of check valves from the Feedwater Bypass System and the Auxiliary Bypass System?

A6: Edison plans to remove the check valve which is presently located on the bypass piping adjacent to the auxiliary nozzle on each of the four steam generators. This valve will be removed prior to the start of Hot Functional Testing.

Edison plans to install a check valve on each of the two pump discharge lines of the Auxiliary Feedwater System upstream of the point where the Auxiliary Feedwater System branches out into the individual pipes that supply the steam generators. These valves will be installed also prior to the start of Hot Functional Testing.

Q7: Are you familiar with the recommendations made by Westinghouse Electric Corporation in regard to prevention of a KRSKO-type waterhammer event?

A7: Yes.

Q8: Does Commonwealth Edison Company propose to implement Westinghouse's recommendations?

A8: Yes. Westinghouse's first recommendation states:

> Temperature sensors should be installed on the bypass piping close to the auxiliary nozzle to detect backleakage of hot water or steam.

To implement this recommendation, Edison plans to install temperature sensors on the feedwater bypass piping adjacent to the auxiliary feedwater nozzle on each of the steam generators at the Byron Station. These sensors will detect backleakage of steam or hot water into the bypass piping by sensing any increase in temperature. The temperature sensors will feed information to the plant process computer which will be programmed to alarm when an abnormally high temperature is detected in the bypass piping. This alarm will alert the reactor operator of the potential conditions for the occurrence of a waterhammer.

The temperature sensors will be in place and the plant program computer will be programmed as stated above by the fuel load date. If the sensors are not in place by the time of Hot Functional Testing, we propose to install sensors at the previously indicated locations and monitor them either locally or in the control room via temporary wiring, if necessary.

Westinghouse's second recommendation states:

> If backleakage is detected, the piping should be slowly refilled or the plant brought to a cold shutdown condition, depending on the circumstances. An analytical study performed by the Westinghouse R & D Center shows that the bypass piping can be slowly refilled safely. The recommended flowrate is on the order of 15 gpm.

To implement this recommendation, my department is developing procedures which will instruct the reactor operator, if the temperature monitoring system indicates backleakage, to slowly purge the bypass piping of the steam or hot water by introducing feedwater into the bypass piping through the tempering line at a flow rate as close as possible to the 15 gpm recommended by Westinghouse. The low flow rate would be continued until the temperature sensors indicate a return to normal conditions in the bypass piping. At that point, the reactor operator will be instructed to maintain a continuous flow while determining the cause of the temperature monitoring system alarm. After the cause is identified, we would initiate any necessary repairs, which could entail shutting down the unit.

It should be pointed out that during power operation, there will be a continuous feedwater flow through the auxiliary nozzle. Below approximately 20 percent of full power operation, this flow is through the feedwater bypass system. From 20 to 100 percent of full power operation the feedwater flow enters the steam generator through the lower main nozzle. However, a tempering flow is maintained through the auxiliary nozzle at those power levels. The tempering flow maintains the auxiliary nozzle at feedwater temperatures and thus reduces the induced thermal stresses when the feedwater is transferred from the main to auxiliary nozzles during plant unloading. The continuous flow of water through the auxiliary nozzle from the tempering flow or the feedwater bypass system makes backleakage of steam into the bypass piping during power operation very unlikely. However, if for some reason the continuous flow through the auxiliary nozzle is interrupted, operating procedures will instruct the reactor operator to monitor the temperature monitoring system prior to reestablishing the flow. If a high temperature is indicated, the reactor operator will be instructed to purge the bypass piping at the recommended slow rate and investigate the cause of the high temperature and initiate any needed repairs.

Westinghouse's third recommendation states:

> The steam generator water level should be maintained above the auxiliary nozzle discharge pipe as much as possible so that if backleakage does occur, water and not steam will leak back into the pipe.

Prior to this recommendation, the steam generator water level was established at a level above the auxiliary nozzle discharge pipe. Therefore, it is not necessary to make any changes to accommodate this recommendation. This water level will be maintained during all normal operating conditions. However, during a turbine trip/reactor trip, the steam generator water level could fall below the auxiliary nozzle discharge pipe. These trips are infrequent and not likely to coincide with a loss of flow through the auxiliary nozzle and excessive backleakage through the check valves.

Westinghouse's fourth and final recommendation states:

> The Auxiliary Feedwater System check valves should be maintained to minimize backleakage.

To implement this recommendation, the Maintenance Department at Byron Station has agreed to establish a regular schedule for testing the check valves for backleakage. The check valves will also be checked and repaired, if necessary, if excessive backleakage is detected in the bypass piping by the temperature monitoring system.

Q9: What preoperational testing does Commonwealth Edison Company plan to test for backleakage in the bypass piping?

A9: Prior to Hot Functional Testing, all check valves which are intended to prevent backleakage into the Auxiliary Feedwater System will be individually tested for excessive backleakage. During the Hot Functional Testing, we will test the ability of the tempering flow system to achieve the low flow rate recommended by Westinghouse for refilling of the bypass piping. Also during Hot Functional Testing, we will stop all feedwater flow into the steam generator and then monitor the bypass piping temperature for indication of backleakage.

Q10: Will the foregoing actions that you have described implement all of Westinghouse's recommendations for minimizing the occurrence of a waterhammer in the feedwater bypass piping?

<u>A10</u>: Yes.

EXAMINATION

BY MS. CHAVEZ:

Q Mr. Carlson, would you look at Page 12 of your testimony.

Describe for me the nature of your expertise to evaluate the design function of the auxiliary feedwater system or other steam generator components.

A (WITNESS CARLSON) Are you referring to a specific part of this page?

Q Correct. I am referring in specific to your use of the word "design function."

MR. COPELAND: For the record, this is the second full paragraph on Page 12?

MS. CHAVEZ: Right.

A (WITNESS CARLSON) Would you repeat the question, please?

BY MS. CHAVEZ:

Q Let me be a little more specific for you.

I refer to the information you provided during a deposition held on February 7th in Pittsburgh, Pennsylvania.

Do you recall -- do you remember the details of that deposition?

A (WITNESS CARLSON) I --

MR. COPELAND: Your Honor, may we have a specific question as to which details she is referring to?

MS. CHAVEZ: Yes.

BY MS. CHAVEZ:

Q Mr. Carlson, in particular I am referring --

JUDGE SMITH: I don't have a copy.

MS. CHAVEZ: If you do not have a copy, I will show you my copy. I have only one copy with me; okay?

But I am referring to Page 43 and 44.

MR. COPELAND: May we have a moment, your Honor?

MR. GOLDBERG: Do you need an extra copy?

MR. COPELAND: No. We have got one.

MR. GALLO: We have got one.

JUDGE SMITH: The copy of the testimony provided to me, Ms. Chavez, does not include Pages 43 and 44.

MS. CHAVEZ: Your Honor, Pages 43 and 44 that I cite relate to the deposition of Robert Carlson which was taken in Pittsburgh, Pennsylvania, on February 7th.

Your Honor, I did not provide a copy of that deposition to the Board. I do not have an extra copy, as I indicated.

JUDGE SMITH: Okay.

MS. CHAVEZ: I will make all of my references to that document as clearly as I can.

JUDGE SMITH: All right. We will take it as it comes.

BY MS. CHAVEZ:

Q Mr. Carlson, on Page 43, in response to the question -- in response to the question which reads -- excuse me. I think it's Page 44.

In response to the question which reads, "Does it" -- "it's another approach to" -- "okay. I see.

"So the counterflow is in a sense experimental?"

"A I wouldn't class that as experimental, no.

"Q What would you class it as?

"A It's another approach to providing preheat function in a steam generator.

"Q That" --

MR. COPELAND: Your Honor, excuse me.

Can we have an identification which lines she is reading, the number of the lines?

MS. CHAVEZ: I am reading from Line 5 now on Page 44.

BY MS. CHAVEZ:

"Q Does it provide improved feedwater heat transfer efficiency?

"A I don't know.

"Q So that area is outside your expertise?

"A The design" -- "the thermal hydraulic design of the preheater as it applies to the steam generator, yes."

A (WITNESS CARLSON) There are two types of preheat steam generators built by Westinghouse.

One of them is referred to as the split flow design;

also as the D2 and D3 design.

There is another design referred to as the counterflow design, also referred to as the D4 and D5 design.

The counterflow design is the type of preheat steam generator at the KRSKO Plant and also at the Byron Plant.

The questions that you asked in this regard during the deposition I assumed to be in regards to the detail -- detailed design of the preheat part of these preheat steam generators.

I was not involved in that effort.

The purpose of the preheater regions is to, because of the baffling arrangement -- due to the baffling arrangement, is to provide improved heat transfer; but I am not familiar with the details of how, for example, the baffles were placed; in other words, why they are as far apart or as close together as they are.

Q Mr. Carlson, that was one specific instance which I wish to cite for you during the course of your deposition.

There are other specific instances that I will cite for you, which lead me to question the basis --

MR. COPELAND: I object to the arguments being made here, your Honor.

JUDGE SMITH: Wait until she finishes her statement.

BY MS. CHAVEZ:

Q -- which lead me to question the basis for your use of the term. "design functions," in terms of your ability to evaluate them technically.

A (WITNESS CARLSON) The --

JUDGE SMITH: Wait a minute, wait a minute. That's not a question.

MS. CHAVEZ: That's not a question.

JUDGE SMITH: All right. What do you say now?

MR. COPELAND: Yes, your Honor. I will restate the objection to the argument being made. It's improper at this time.

MS. CHAVEZ: Okay.

JUDGE SMITH: What is your response to that?

MS. CHAVEZ: Well, I will agree. I will stick to questions from this point on.

JUDGE SMITH: All right.

BY MS. CHAVEZ:

Q Mr. Carlson, on the last page of your testimony, Question 18, you respond that, in your opinion, the recommendations recommended by Westinghouse are adopted as implemented and check valves in the auxiliary feedwater system are installed. The likelihood of occurrence of a KRSKO-type waterhammer event is reduced to an acceptable level.

A (WITNESS CARLSON) That is correct.

Q Upon what basis do you base your opinion?

MR. COPELAND: Your Honor. I object to this. This is not voir dire. It's attacking the substance of the witness' testimony.

JUDGE SMITH: I tend to agree, Ms. Chavez, unless you can say something to that.

(No response.)

JUDGE SMITH: Objection sustained.

BY MS. CHAVEZ:

Q Mr. Carlson, let me refer you to Page 35 of your deposition again, Line 21.

When you respond, in answer to the question, "Are you familiar with the feed rate flow at the KRSKO Plant" --

MR. COPELAND: Can we have a line, please?

MR. CHAVEZ: Yes. Line 21.

BY MS. CHAVEZ:

Q "I am sorry. I don't understand the question."

Line 22. "Do you judge yourself expert to interpret the feedwater flow matters at the KRSKO Plant during normal and under accidental operating conditions?

"A I am familiar with the main and bypass feedwater systems and how they will operate at the KRSKO Plant.

"Q Are you familiar with mainly the mechanical designs of those systems or are you familiar with the operational function of those systems?

"A I am familiar with the system aspects of the two systems which includes how they will be operated.

"Q So you are familiar with operational procedures?

"A In a general way."

Later on, Line 19 on that same page, "Do you regard yourself, then, as having the expertise to evaluate the feedwater operational function of the KRSKO Plant lacking that familiarity with the specific operational manner?"

Answer on the next page, "I believe I have the knowledge in terms of how the system will operate to evaluate the bubble collapse waterhammer issue.

"Q So you would restrict yourself to the bubble collapse waterhammer then?

"A Yes." Mr. Carlson, does any of your qualification pertain to the proposed modifications regarding the installation or implementation of check valves in either the KRSKO Plant or the Byron Plant?

A (WITNESS CARLSON) Yes, it does. That pertains to the system aspects of the system which I referred to and you just cited.

MR. COPELAND: Your Honor. I would like to ask for a clarification right now.

Is the only part that is being asked to be stricken the line on Page 12 of Mr. Pleniewicz' testimony -- I mean Mr. Carlson's testimony?

JUDGE SMITH: I was just going to make a similar observation.

You better direct us particularly to the portion of testimony that you wish stricken, because don't depend upon memory too much.

MS. CHAVEZ: Yes.

MR. COPELAND: Judge.

MS. CHAVEZ: I would -- when I make a formal motion to strike portions of the testimony, then I would specify which portions.

JUDGE SMITH: Yes; but my concern is you are going to specify a portion and you are going to cite back 15 minutes ago as to what he said, and so far his testimony doesn't seem to be clearly falling on one side or another of your objections.

MS. CHAVEZ: Okay. Let me cite questions -- I mean the answer to Question 18 on Page 17 of his testimony, which my line of questioning is going to lead me to move to strike, and on Page 12, the paragraph -- the third paragraph down, I have not yet decided whether or not I would move to strike that paragraph.

MR. COPELAND: Can we have a clarification as to what was the target of the three pages read from the deposition. specifically Pages 35 through 37. which you just read? Was that attacking a specific part of Mr.

Carlson's testimony?

MS. CHAVEZ: Okay. On Page 35 of the deposition. Lines 1 through 18, and particularly Lines 16 and 17. are one of the bases by which I would move to strike question A 18.

JUDGE SMITH: May I ask what question you are reading? Did you say Page 35?

MS. CHAVEZ: Yes, Page 35.

JUDGE SMITH: Lines 16 and 17?

MS. CHAVEZ: Yes. The question on Lines 16 and 17 reads, "Are you familiar with a typical service life to be expected from those valves," and that's a reference to the check valves. "A No."

MR. COPELAND: Your Honor. I still have a request out.

A few minutes ago she just read from Pages 35 to 37. and I have no idea which part of Mr. Carlson's testimony she is attacking by use of those three pages of the deposition.

MS. CHAVEZ: From 35 through 37. did you say?

MR. COPELAND: Yes.

MS. CHAVEZ: Okay. For 35 I have identified question A 18 as the portion to which it would be used to strike.

For 36 and 37. those questions pertain to the paragraph that I identified as still being uncertain as to whether or not I would move to strike those portions.

MR. COPELAND: Thank you.

JUDGE SMITH: We will have to take a short off-the-record break.

(There followed a discussion outside the record.)

JUDGE SMITH: You may proceed.

BY MS. CHAVEZ:

Q Mr. Carlson, what is your familiarity with check valves?

A (WITNESS CARLSON) I am familiar with the purpose of check valves. I am familiar with the different types of check valves. I am familiar enough with check valves to -- relative to how they are used in piping systems.

Q Mr. Carlson, when you state your familiarity, do you mean a general familiarity or do you have a specific design familiarity with check valves?

A (WITNESS CARLSON) I don't see that there is that much to the subject.

A check valve is a type of valve used to restrict flow in one direction only.

I am familiar with maintenance procedures, for example; but I don't think that that bears on their application in systems.

Q Mr. Carlson, if you are familiar with check valves, why did you state on Page 35 of your deposition, Line 16 -- I mean Line 18, that you were not familiar with the typical service life to be expected from those valves?

A (WITNESS CARLSON) Well, the point I am trying to make is that I am concerned and involved with the application of check valves in piping systems.

The question that you are referring to and my answer refers more to the operational aspects of check valves, how frequently they should be maintained, leakage rates and things of that nature.

Q Mr. Carlson, is an operational knowledge necessary to reach the conclusion you reached in answer to Question 18?

A (WITNESS CARLSON) Could you explain what you mean by operational knowledge?

Q I am using the definition that you have yourself given.

A (WITNESS CARLSON) Well, the distinction I am trying to make is that I am familiar with the application of check valves, different types of check valves, how they are used in systems, their purpose.

I am not familiar with the more operational considerations such as valve maintenance, leakage rates, things of that nature.

Q Are these considerations which you do not consider necessary to reach a conclusion that you have reached in response to Question 18?

A (WITNESS CARLSON) I think that my understanding and knowledge of check valves is adequate for me to reply as I did to Question 18.

Q Mr. Carlson, on Page 35, Lines 13 through 15, your response to a question reads," I don't have a value for check valve leakage. That depends, for example, on a valve service life, how long it has been in operation, how it's been maintained."

Do you feel that these last three items have no relation whatsoever to the basis of your opinion on question -- response to Question 18?

A (WITNESS CARLSON) On this particular question of valve leakage, for example, we depend on the Commonwealth Edison Company to provide us with information on that subject based on their experience.

Q Mr. Carlson, my question does not concern Commonwealth Edison's information. My question concerns your familiarity with check valve operations and leakage rates and, in fact, your familiarity with valve service life, the length of operational time and the degree of maintenance for each.

A (WITNESS CARLSON) I am familiar with check valve operation, which was the first item that you mentioned.

I do not have detailed knowledge on subjects such as leakage rates.

Q Mr. Carlson, but doesn't an evaluation of the occurrence of a KRSKO-type waterhammer event rely upon such a basis?
A One of the recommendations that we make is that the check valve should be maintained to minimize leakage.
Q Mr. Carlson, on Page 17 of your testimony, the first two lines, you use the term adequate.
Do you not feel that those considerations with regard to valve operation would be necessary in order to determine whether or not precautions would be adequate to prevent an occurrence of a KRSKO-type event?
A (WITNESS CARLSON) I am sorry. Would you repeat?
JUDGE SMITH: Don't talk to the witness, please.
(WITNESS CARLSON) Would you repeat the question?
MS. CHAVEZ: I have forgotten it. I ask the reporter to repeat it back for me.
(The question was thereupon read by the Reporter.)
A (WITNESS CARLSON) I am not sure I still have the thrust of the question.
MS. CHAVEZ: Okay.
A (WITNESS CARLSON) This Question 17 refers to the preceding set of recommendations.
MS. CHAVEZ: That's right.
A (WITNESS CARLSON) And I do believe that they are adequate to prevent the occurrence of a KRSKO-type event.

MS. CHAVEZ: Mr. Carlson --

MR. COPELAND: Mr. Carlson, I think that you should be --

JUDGE SMITH: Excuse me a second. Counsel, there was nothing wrong with what you said to the witness at all. You asked him to be sure that he understands the question. My consideration was it was not open for -- it could not be well heard throughout by everybody.

MR. COPELAND: Thank you, your Honor. To clear the record, my concern was whether or not he had the right place in the testimony.

JUDGE SMITH: It was appropriate concern and an appropriate statement. It just wasn't out for everybody to hear.

BY MS. CHAVEZ:

Q Mr. Carlson, you have expressed yourself as a system, not an operational expert.

On Page 16 of your testimony, response A 16, you enumerate the recommendations which Westinghouse has made to avoid a KRSKO-type waterhammer event.

Mr. Carlson, are not those recommendations related to operational?

MR. COPELAND: Your Honor, may I have a clarification as to where Mr. Carlson made these statements which Ms. Chavez says he made.

MS. CHAVEZ: Mr. Carlson, I believe, made those statements or at least used the term," systems expert, "in terms of defining his expertise with relation to the valve operation; and he identified himself as an expert's system but not an operational expert in terms of comprehending the operation of valves and pre-heaters.

MR. COPELAND: Your Honor, I repeat my request as to where does she see this?

MS. CHAVEZ: This is not in his testimony. This is his response to the cross. Okay?

MR. COPELAND: Thank you.

BY MS. CHAVEZ:

Q Mr. Carlson, do you still recollect my last question?

A (WITNESS CARLSON) No. Could I have it repeated, please.

MS. CHAVEZ: Okay. I think I can repeat it this time.

BY MS. CHAVEZ:

Q Your response in your testimony to Question 16 identifies recommendations which Westinghouse have made to utilities in order to avoid a KRSKO-type waterhammer event.

My question asked you whether or not those recommendations which Westinghouse has made -- do they not pertain to operational features and not just systems?

A (WITNESS CARLSON) I would say that they probably fall in the area of system modifications.

What I would take -- taking the first one, for example, what I would refer to as operational is taking the temperature sensor data and providing it to a computer and alarm, the design work that is involved in that aspect of the application of that particular recommendation.

I think -- I think the statement as made here is certainly appropriate on the basis of the statement that I am proficient in systems matters.

Q Mr. Carlson, your response refers only to one item of those recommendations.

Do you feel the same way with regard to Item 4, in particular?

A (WITNESS CARLSON) Yes, I do. Certainly, that is a reasonable statement to be made on the basis of system considerations.

Q Mr. Carlson, I believe I have addressed to you a series of questions designed to determine your familiarity with the maintenance of check valves within the auxiliary feedwater system according to your response, you do not have that familiarity; is this correct?

A (WITNESS CARLSON) I don't see that that is pertinent to Recommendation No. 4.

Q Do you not feel that it is not pertinent to an evaluation of the effectiveness of that recommendation?

A (WITNESS CARLSON) The recommendation is that the check

valves should be maintained to minimize back leakage. I
think that's a systems consideration.

Q Upon what basis do you then base your opinion that that
particular recommendation, if followed, would be adequate
to prevent the occurrence of KRSKO-type event at Byron
Station?

A (WITNESS CARLSON) Well, that's just one of four
recommendations.

Q But I am addressing that particular recommendation.
Doesn't that get you into the operational aspects?

A (WITNESS CARLSON) No, I don't -- well, I am a little bit
confused here about the distinction you are drawing
between systems, systems work and operational work.
What I am referring to when I use the word
"systems," is to define how a system is supposed to work,
the components of that system, the requirements of the
system, how the system is to be operated.
Operational considerations to me mean more the
actual manual manipulation of the equipment, the manual
operation of the equipment.

Q Mr. Carlson, I entirely understand your distinction
between those two basic aspects.
However, what I am asking you is not whether or not
you are familiar enough with the systems operation. I am
asking you whether or not you are sufficiently familiar

with the operational aspects as you have just defined them such as to make that recommendation in your response to Question 18 in your testimony.

A (WITNESS CARLSON) Yes, I think I am.

Q Mr. Carlson, I don't understand your response in the sense that although you have told us you are a systems analyst and expert, although you may not have used those exact words, you have identified yourself not to be familiar with the operational evaluation.

A (WITNESS CARLSON) Well, in order to do any systems design work I feel that it's clear that I have to have a general knowledge of how the system is going to operate. That's part of systems design work.

What I am -- the point I am trying to make here is that I am not familiar with the details of the hardware specification, for example, in order that the particular component could be purchased.

I am not familiar with the standards and regulations by which a check valve would be purchased for a nuclear plant.

As I have indicated before, I am not familiar with how a valve is maintained, the procedures that might be involved in resurfacing seats of valves; but I don't think that's necessary to -- in order that I make the statements that I make in my testimony.

Q Mr. Carlson, if you do not know how these are to be maintained, check valves, for example, how can you know that they will be maintained and that, therefore, they are adequate?

A (WITNESS CARLSON) Well, I have the general idea of how check valves would be maintained.

I am not familiar with the details of the machinery, equipment that is used to do that.

Q Mr. Carlson, are you familiar with the specific function of the valves emplaced at the KRSKO Plant?

A (WITNESS CARLSON) Yes, I am.

Q Are you familiar with their design aspects?

A (WITNESS CARLSON) Could you define what you mean by design aspects?

Q Can you identify for me the type of valves to be used at this KRSKO Plant?

A (WITNESS CARLSON) Yes, I can.

Q Please state that for me.

A (WITNESS CARLSON) There are -- with regard to a specific system?

Q With regard to the feedwater system at the plant.

A (WITNESS CARLSON) Well, there are three subsystems, there is the main feedwater system, there is the bypass feedwater system, the auxiliary feedwater system.

Q With respect to the bypass and feedwater auxiliary system.

A (WITNESS CARLSON) With respect to the bypass system, which runs from the main feedwater line to the auxiliary nozzle, there are two valves. There is an isolation valve and a check valve.
Q Can you tell me the location of the check valve?
A (WITNESS CARLSON) The check valve in the KRSKO bypass system is upstream of the point where the auxiliary feedwater system connects to the bypass system.
Q Mr. Carlson, what type of valve is that check valve?
A (WITNESS CARLSON) The -- the check valve in the KRSKO bypass feedwater system is a fast-closing check valve.
Q Mr. Carlson, are you familiar with the check valve to be utilized in the Byron plant feedwater system upstream of the bypass system?
A (WITNESS CARLSON) In a general way, yes. It is a slow-closing check valve. It's a damped check valve.
Q Is there any other identification specific to the KRSKO check valves that you can give me in comparison to the Byron check valve?
A (WITNESS CARLSON) The KRSKO check valve that you are referring to is either a tilting disk or a swing-check type check valve.
The valve that you referred to in the bypass system is a damped tilting disk valve.
Q Mr. Carlson, do you know which of those two valves that

you identified might be the possible valve that you first mentioned is the -- is, in fact, a valve at the KRSKO plant?

A (WITNESS CARLSON) They are both fast closing check valves. The --

Q I --

A (WITNESS CARLSON) Westinghouse does not specify the type of fast-closing valve that would be used at that point.

Q Mr. Carlson, I am asking you if you know specifically what the check valve -- what type the check valve is that is located at the KRSKO plant upstream of the bypass line?

A (WITNESS CARLSON) Outside of what I have said, I do not.

Q Do you, Mr. Carlson, feel that this fact is irrelevant on the operational behavior of that valve?

A (WITNESS CARLSON) It's irrelevant with respect to the system requirements, the system aspects of the bypass system.

Q Do you feel that your -- do you feel that a lack of knowledge as to what type of valve lies upstream of the bypass line in the KRSKO feedwater auxiliary feedwater system is irrelevant to a determination as to the operational ability or adequacy of that system?

A (WITNESS CARLSON) Yes.

Q Mr. Carlson, are you aware of any type of difference in behavior in terms of operational between the different types of valves?

MR. COPELAND: Your Honor, I am going to object to this question as being extremely vague.

BY MS. CHAVEZ:

Q Okay. Mr. Carlson, do you or do you not know that different valves will respond in closing times differently from one another?

A (WITNESS CARLSON) I do know that the so-called slow-closing valve is specifically designed to close at a slower rate than the undamped, fast-closing valve such as is present in the KRSKO bypass line upstream of the point where the auxiliary feedwater system connects.

Q Mr. Carlson, can you repeat that answer? I thought I caught a word in there which slipped passed me?

A (WITNESS CARLSON) What I said was that I am aware that there is a difference in closing time between the slow-closing valve that will be present in the Byron plant in the bypass line upstream of the auxiliary feedwater nozzle and the fast-closing, tilting disk or swing check valve located in the KRSKO plant at the comparable location.

Q Mr. Carlson, are you familiar with any behavorial difference between the swing valve or the check valve at the -- the two valves that you just identified? Are you familiar with any behavioral difference between those two valves?

MR. COPELAND: Your Honor, I will again object to the use of the term or word behavioral.

MS. CHAVEZ: In terms of plant operation.

MR. COPELAND: I will restate my objection.

JUDGE SMITH: Do you understand the question, Mr. Carlson?

A (WITNESS CARLSON) Yes, I think so.

JUDGE SMITH: Objection overruled.

A (WITNESS CARLSON) I understand that there are differences in the closing time of a tilting disk check valve as opposed to a swing check valve; but the details of that difference I am not familiar --

JUDGE SMITH: Is it that you want to know why some valves close fast and why some valves close slowly? Is that what you want to know?

MS. CHAVEZ: I wish to establish that there are operational differences between different types of valves which one has to take into consideration before reaching an assessment of the adequacy of Westinghouse's modifications to the plant operation.

MR. COPELAND: Your Honor, I --

JUDGE SMITH: I think we should have sustained the objection. You are going to have to zero in, I guess.

BY MS. CHAVEZ:

Q Let me refer Mr. Carlson to --

MR. COPELAND: Your Honor, I will object. If this is the point of the line of questioning, I am going to object to it entirely. This is going to the substance of the recommendations in Mr. Carlson's testimony and has no relevance to his qualifications to make these recommendations.

JUDGE SMITH: What if he doesn't know the difference on the effects of the two on the relevant operation?

MR. COPELAND: Well, I would ask that she bring that out in cross examination rather than at this time.

JUDGE SMITH: Well, I think it's a judgment call. If if she can do it now, she will do it later.

BY MS. CHAVEZ:

Q Mr. Carlson, are you familiar with the February 10, 1983, affidavit of Kenneth Ainger, A-i-n-g-e-r, Commonwealth Edison Company, which was served on the parties just recently?

A (WITNESS CARLSON) Yes, I am.

MR. COPELAND: Your Honor, if I may approach the witness, I could give him a copy of that affidavit.

JUDGE SMITH: Let's see if she wants that first.

MS. CHAVEZ: Okay.

JUDGE SMITH: Do you want the witness to have it or do you want to test his knowledge?

MS. CHAVEZ: Well, I can read parts of that.

JUDGE SMITH: But is the purpose for you to gather information from the witness or test his knowledge of it without the report.

MS. CHAVEZ: I can test his knowledge of it without him seeing it.

JUDGE SMITH: Is that what you are trying to do?

MS. CHAVEZ: No, it's not.

JUDGE SMITH: Then give him a copy of the report.

BY MS. CHAVEZ:

Q On Page 3 of Mr. Ainger's affidavit, there is a statement that Ms. Bowen stated that the Byron design included an additional check valve in the bypass piping near the auxiliary nozzle of the steam generator which is not included in the design of the KRSKO plant.

Mr. Carlson, is that fact known to you?

A (WITNESS CARLSON) Yes.

Q Okay. Mr. Carlson, do you feel that that is a significant difference between the Byron plant feedwater system design and the KRSKO feedwater system design?

A (WITNESS CARLSON) Well, this is part of the story. It's true that the KRSKO plant does not have the check valve that you are referring to. However, this check valve is going to be removed at the Byron plant and in its place check valves are going to be added in the auxiliary feedwater system.

Q Mr. Carlson, have you had any input into that recommendation that the check valve at the Byron plant be removed?

A (WITNESS CARLSON) The issue of removing that check valve has to do with what is referred to as classical or accoustic waterhammer.

Analyses have been performed at Westinghouse for the Byron Station. The conclusion -- one of the conclusions of which was that that valve -- actually, there were two alternate recommendations made as a result of that analysis that I am referring to, one being that the two check valves in the bypass system at Byron be replaced by slow-closing check valves. They are presently fast-closing check valves. That's No. 1.

The second alternative was to replace just the check valve upstream of the auxiliary feedwater system connection with a slow-closing check valve and remove the second check valve up near the auxiliary nozzle; and it's the second approach which has been adopted.

To compensate for the fact that that check valve up near the nozzle will be removed, additional check valves are going to be added in the Byron auxiliary feedwater system.

MR. COPELAND: Your Honor, I would point to the late hour and ask that this voir dire be ended. I believe Ms. Chavez has had plenty of time to establish whether Mr. Carlson's testimony is supported by his credentials.

MS. CHAVEZ: Your Honor, I have one more question to direct to the witness and that refers back to Page 34 of his deposition where in response to questions on Line 6, the question reads. "Can you tell me why the Byron system will be utilizing slow closing as opposed to the KRSKO type valve?" The answer is, "that is not my area of responsibility. It has to do with addressing faulty conditions, such as a feed line break.

"Is it your understanding that the check valves slow closing check valves provide more protection against ruptured conditions or feed line breaks?

"Would you please restate that question. Is it the intent of the Byron check valves to add additional safety protection in the event of accidental transients or -- " answer. "that is not my responsibility, my area of responsibility. I cannot comment on that."

Your Honor, on the basis of the questions that I have asked --

JUDGE SMITH: Wait a minute. Was that a question?

MS. CHAVEZ: No.

JUDGE SMITH: I thought you said you had one more question.

MS. CHAVEZ: I am sorry. I forgot that I was asking a question.

BY MS. CHAVEZ:

Q Mr. Carlson, do you feel based upon your statement that it is not your area of responsibility to address faulty conditions such as feed line breaks and ruptures and so forth, that you can adequately evaluate the importance of the differing types of check valves and their operational behavior adequately enough to make that recommendation that you reached in response to Question 18?

A (WITNESS CARLSON) Yes, I think I can. There are two separate issues here. One is the issue of classical waterhammer. specifically the situation of a feed line break followed by a check valve slam. That's the issue that I mentioned that's being, has been evaluated by Westinghouse.

The results of that work bears on whether slow closing or fast closing valves are used.

The other issue, which is the issue I feel related to the contention. is the KRSKO type bone collapse waterhammer issue. What I am saying here in this -- in response to your questions is that I am not intimately familiar with the analyses that were performed in the classical or acoustic waterhammer area involving check valve slam following a feed line rupture.

Q Mr. Carlson, would you agree that the position of that valve, the initial position of that valve at the KRSKO -- I mean at the Byron plant --

MR. COPELAND: Your Honor, I will restate my objection. This voir dire has gone on too long and this is now a second question.

MS. CHAVEZ: If I can have three more.

JUDGE SMITH: Three more.

BY MS. CHAVEZ:

Q Okay. Would you repeat to me the first part of the question?

(The answer was thereupon read by the Reporter.)

BY MS. CHAVEZ:

Q Would you agree with me that that position of that valve was the result of concern related to bubble collapse waterhammer?

A (WITNESS CARLSON) The primary consideration in regards to the location of that valve was not with respect to bubble collapse waterhammer.

Q Mr. Carlson, do you state then that it had no relationship whatsoever to the concerns about water collapse bubble hammer?

A (WITNESS CARLSON) It does have a relationship to bubble collapse waterhammer but as I pointed out previously, additional check valves are being added to the auxiliary feedwater system of the Byron Station to compensate for taking that valve out.

Q Do you feel that the placement of those valves, the alternative placement of those valves, based upon lack of operational data with regard to those placement -- that placement suffices to enable you to reach the conclusion that the recommendation -- that that -- that the operational aspect of those valves is no -- not important in consideration as the adequacy of that system modification?

A (WITNESS CARLSON) Would you re-read that question, please?

BY MS. CHAVEZ:

Q Mr. Carlson, let me address you the question in another way.

Mr. Carlson, do you not feel that the lack of operational experience with the alternative location of those check valves will not prejudice the assessment that you make or statement that you make in response to Question 18.

MR. COPELAND: Your Honor, I will object to the vagueness of the question.

BY MS. CHAVEZ:

Q Mr. Carlson, do you still feel that there is enough --

JUDGE SMITH: You know, just because he objects, it doesn't mean that you have to re --

MS. CHAVEZ: Yes, redefine.

Mr. Carlson, do you understand my last question?

A (WITNESS CARLSON) Could I have it repeated, please.

MS. CHAVEZ: Let me state it again.

JUDGE SMITH: Would you like to rephrase it, in view of his, counsel's, concern that it is vague.

MS. CHAVEZ: Okay.

BY MS. CHAVEZ:

Q There will be no operational experience -- correct me if I am wrong -- with the placement of the valves as they will be placed in the Byron plant in the alternative location?

A (WITNESS CARLSON) That's not true. There is operational

Q Are you directly familiar with that experience?

A (WITNESS CARLSON) Well, KRSKO is one plant where the valves are similarly located as to the way they will be at Byron.

Q How long has the KRSKO plant had that operational experience?

A (WITNESS CARLSON) I don't know how long it's been operating.

JUDGE SMITH: You are in your fifth out of your three questions.

MS. CHAVEZ: Okay. Your Honor --

JUDGE SMITH: Would it be functional testing of valves before you go critical and will there be low power testing which will test the valves?

A (WITNESS CARLSON) Yes.

JUDGE SMITH: At Byron?

A (WITNESS CARLSON) Yes.

JUDGE SMITH: In addition to that -- okay?

MS. CHAVEZ: Well, your Honor --

JUDGE SMITH: That is it. Now you can argue your motion.

MS. CHAVEZ: Okay. I move to strike his response to Question 18 upon the basis that he has not revealed enough familiarity with the operational aspects of the proposed modifications. He has revealed familiarity with the systems and abstract design but not with the operational consideration, which I feel would be the basis for an accurate assessment of those modifications and I state that he has no experience to make that.

JUDGE SMITH: Counsel.

MR. COPELAND: Yes, your Honor. Mr. Carlson's conclusion and recommendations are not based, as she stated, on a precise knowledge of the operation of the plant. His recommendations state clearly if the recommendations are adopted and implemented that the likelihood of the occurrence of a KRSKO type waterhammer event would be reduced to an acceptable level. Clearly, this does not rely on a precise operational knowledge at the Byron plant. He is relying on the utility to follow these recommendations and implement them to the best of their ability.

JUDGE SMITH: Is that correct? One of the assumptions you make in your Recommendation No. 4 is that the auxiliary feedwater system check valves can in fact be maintained to minimize back leakage; that's an assumption?

A (WITNESS CARLSON) Well, the recommendation says that they should be maintained.

JUDGE SMITH: And the assumption is that they can be?

A (WITNESS CARLSON) That they can be, yes.

JUDGE SMITH: That's where you begin?

A (WITNESS CARLSON) Yes.

JUDGE SMITH: Did you have any comments, Mr. Goldberg?

MR. GOLDBERG: No comments.

JUDGE SMITH: Your motion to strike that portion of the testimony is overruled. However, your voir dire testimony is useful as cross examination on the weight that should be given the recommendation.

MS. CHAVEZ: Okay. I am through with the exploration of his qualifications.

JUDGE SMITH: I think that this might be a good time to break for the evening.

MR. COPELAND: Your Honor, may we have a ruling on whether the testimony is admitted into evidence?

JUDGE SMITH: Oh, yes. The testimony is admitted.

(The document referred to, the prepared testimony of Witness Carlson, received in evidence, follows:)

Date: 2/15/83

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
COMMONWEALTH EDISON COMPANY	)	Docket Nos. STN 50-454 OL STN 50-455 OL
	)	
(Byron Nuclear Power Station, Units 1 and 2)	)	

SUMMARY OF TESTIMONY OF
ROBERT W. CARLSON

Robert W. Carlson is a Principal Engineer with Westinghouse Electric Corporation. He is an expert in the bubble collapse waterhammer phenomenom. His testimony addresses DAARE/SAFE Contention 9a as that contention concerns the possibility of the occurrence of a waterhammer event at Byron Station similar to the one that occurred at the KRSKO plant in Yugoslavia.

Mr. Carlson generally describes the steam generator designs of the KRSKO plant and the Byron Station. He also describes the KRSKO waterhammer event and the conditions which are believed to have caused it. Mr. Carlson explains how the plant operating condition affects the likelihood of conditions which can lead to a KRSKO-type waterhammer event. Mr. Carlson explains the damage which occurred at the KRSKO plant due to the waterhammer event and the corrective action taken there.

Mr. Carlson explains the present and proposed check valve arrangement at the Byron Station. He concludes that the proposed check valve arrangement is consistent with Westinghouse's recommendations.

Mr. Carlson relates the recommendations made by Westinghouse to Commonwealth Edison Company for prevention of a KRSKO-type waterhammer event. Mr. Carlson concludes that if Commonwealth Edison Company follows these recommendations, the likelihood of the occurrence of a KRSKO-type waterhammer event at Byron Station is reduced to an acceptable level.

Date: 2/15/83

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
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(Byron Nuclear Power Station, Units 1 and 2)	)	

TESTIMONY OF ROBERT W. CARLSON

Q1: Please state your name, present position, and present occupation.

A1: My name is Robert W. Carlson. I work for the Westinghouse Electric Corporation as a Principal Engineer in the Balance of Plant Systems Design Group of the Nuclear Technology Division.

Q2: Could you please describe your educational and professional background?

A2: I received a Mechanical Engineering degree from Stevens Institute of Technology in 1953 and a Master of Science degree in Nuclear Engineering from Massachusetts Institute of Technology in 1959. I also attended Case Institute of Technology for two years, from 1965 to 1967, as a full-time graduate student in the field of Thermal Sciences.

I accepted a position in 1953 as a Boiler Division student engineer with the Babcock & Wilcox Company. After the one-year program, I joined the Babcock & Wilcox Company Atomic Power Division. In 1955, I took a leave of absence for military service and MIT Graduate School. I returned to Babcock & Wilcox in 1959 and was later promoted to the position of Senior Engineer with the Atomic Power Division. I joined the Westinghouse PWR Division as a Senior Engineer in 1967. My initial duties were as a reactor core thermal and hydraulic designer. In 1975, I was promoted to my present position of Principal Engineer.

During 1975 and 1976, I participated in a test program conducted by Westinghouse at its Research and Development Center in Pittsburgh to investigate the bubble collapse waterhammer phenomenon. One objective of the test program was to gain a basic understanding of the phenomenon as it occurred in horizontal pipe sections. In 1977, I participated in a test program to investigate bubble collapse waterhammer in preheat steam generator designs including the Byron Station type steam generator. I was responsible for the thermal and hydraulic design of preheater scale model test sections and the test vessel. I was also responsible for the initial evaluation of the test data.

I meet, on behalf of Westinghouse, with utility customers and their architect-engineers to provide assistance in the design and operation of the plant modifications recommended by Westinghouse to minimize the likelihood of of bubble collapse waterhammer. As part of this responsibility, I have reviewed the available information on the waterhammer event which occurred in the feedwater bypass system at the KRSKO plant.

Q3: What is the purpose of your testimony?

A3: The purpose of my testimony is to address DAARE/SAFE Contention 9a as that contention concerns the possibility of the occurrence of a waterhammer event at the Byron Station similar to the one that occurred at the KRSKO plant.

Q4: Please describe the waterhammer phenomenon.

A4: In general, there are two forms of waterhammer, classical and bubble collapse. In both cases, a change in water velocity leads to a change in pressure because of the inertia of the water. The two forms differ with respect to the mechanisms by which the change in velocity is brought about. As an example of classical waterhammer, consider a pipe with water flowing inside. If a valve at the downstream end of the pipe is closed quickly, the water will be brought to rest and, as a consequence, a sudden pressure increase will result at the valve. This change in pressure will travel back and forth in the pipe until it dissipates due to friction. Bubble collapse waterhammer refers to a condition where initially a volume of steam is trapped within an enclosed region, for example, a horizontal section of pipe with water slugs on both sides. If the temperature of the water in the slugs is the same as that of the steam, nothing will happen. However, if the slugs contain cold water which comes into contact with the steam, the steam will be condensed rapidly resulting in a sudden local decrease in pressure. A higher pressure behind the water slugs will cause them to accelerate towards each other. When they collide, an increase in pressure will result. This change in pressure will propagate back and forth in the water the same as in the classical waterhammer case.

The magnitude of the pressure change produced at the valve in the classical waterhammer example depends on the rate at which the valve is closed, the initial water velocity, and the density of the water. In the bubble collapse waterhammer example, the pressure change magnitude depends on the rate at which the steam is condensed and the pressure behind the water slugs.

Q5: What are the potential effects of waterhammer?

A5: Waterhammer, whether classical or bubble collapse, will result in a change in water pressure. The change in pressure has the potential for damaging components of the piping system. The pressure change, if large enough, may result in pipe deformation or, in an extreme case, rupture. It may also result in valve damage, for example, damage to valve packing and gaskets. The change in water pressure inside the system is accompanied by forces transmitted to the pipe supports. As a consequence, pipe hangers may also be damaged.

Q6: Please generally describe the steam generator designs of the KRSKO plant and the Byron Station.

A6: Before discussing steam generator features, the terms primary side and secondary side should be explained. The primary side and secondary side of the steam generator refer to the fluid volumes inside and outside the steam generator tubes, respectively. The steam generator is a component in the primary loop which includes the reactor. The primary side water carries thermal energy from the reactor core to the steam generator. The hot primary water is directed into the inlet half of the inverted U shaped tube bundle. The first half of the bundle where the primary water flows upward is referred to as the hot leg side. The second half where the water flows downward is referred to as the cold leg side because the primary water is somewhat cooler having given up some of its thermal energy.

The secondary side refers to the volume outside the tube bundle and inside the steam generator vessel.

During normal operation, the lower part of the vessel contains water and the upper part steam. The fact that both steam and water are present on the secondary side accounts for bubble collapse waterhammer being a design consideration.

The Byron plant and the KRSKO plant both have steam generators of the preheat type referred to by Westinghouse as the Model D. Within the Model D classification, there are two subtypes: the split flow type (D2 and D3) and the counterflow type (D4 and D5). The Byron No. 1 unit and the KRSKO plant both have Model D4 steam generators while Byron No. 2 unit has Model D5 steam generators. The counterflow type steam generator (Models D4 and D5) is shown in Figure 1. For purposes of this discussion, the difference in design between Models D4 and D5 steam generators is not relevant.

The overall height of the Model D steam generator is approximately 68 feet. The Model D steam generators have two connections for introducing feedwater. The 16 inch diameter main nozzle is located in the lower shell approximately 13 feet from the bottom of the vessel. The 6 inch diameter auxiliary nozzle is located in the upper shell approximately 45 feet from the bottom of the vessel.

The preheater section is a baffled region of the tube bundle inside the steam generator located on the cold leg side close to the tube sheet. The feedwater enters the preheater through the main 16 inch nozzle in the lower shell. The purpose of the preheater is to efficiently transfer heat from the cold leg side primary fluid to the incoming feedwater.

Q7: What is the purpose of the Feedwater Bypass System?

A7: It was recognized that the presence of steam bubbles and cold water in the preheater section could cause a bubble collapse waterhammer. Westinghouse undertook a test program in 1977 to investigate and define the effects of this type of waterhammer in the preheater region. As a consequence of this testing, the Feedwater Bypass System was developed and implemented for the preheat type steam generators. The Feedwater Bypass System is designed to automatically prevent the introduction of cold water into the preheater section. In those circumstances where it is necessary to introduce cold water into the steam generator, the Feedwater Bypass System operates to direct the cold water to the upper auxiliary nozzle. The basics of the Feedwater Bypass System are shown in Figure 2. It consists of a 6 inch diameter line which connects the main feedwater line to the auxiliary nozzle.

Q8: What is the purpose of the Auxiliary Feedwater System?

A8: As indicated on Figure 2, the Auxiliary Feedwater System connects to the bypass line. The Auxiliary Feedwater System provides feedwater to the steam generator through the bypass piping and the auxiliary nozzle in the event of a loss of heat sink accident, such as a feedwater pipe rupture.

Q9: Please describe the waterhammer event that occurred at the KRSKO plant.

A9: A bubble collapse waterhammer occurred in the Feedwater Bypass System of the KRSKO Nuclear Power Plant during Hot Functional Testing of the Auxiliary Feedwater System pumps in July, 1981. Steam apparently pushed back into the bypass line and then into the Auxiliary Feedwater System piping. Subsequently, the Auxiliary Feedwater System pumps were started introducing cold water into the piping. Thus, the two elements needed for a waterhammer event were present, i.e., a volume of steam and cold water. The first indications that an unusual event had occurred were the discoveries in early August, 1981 of damage to the feedwater bypass piping inside the containment and of blistering paint on the Auxiliary Feedwater System piping.

Q10: What conditions are believed to have caused the KRSKO waterhammer event?

A10: For steam to push back into the bypass piping, it was necessary that the check valves which are provided to prevent reverse flow in the Auxiliary Feedwater System were leaking and that the steam generator water level was below the auxiliary nozzle internal extension. The auxiliary nozzle connects inside the steam generator to an upwardly inclined pipe extension, the discharge end of which is below the normal operating water level in the steam generator. If the water is kept at the normal operating level, steam cannot enter the internal extension and thus cannot enter the bypass piping. At KRSKO, the water level must have been below the discharge end of the auxiliary nozzle internal extension since steam did enter the bypass piping.

In addition to the below-normal water level, it was necessary for the check valves associated with each of the motor driven auxiliary feedwater pumps to have leaked. The extent of the backleakage of steam and/or hot water was indicated by the blistered paint on the Auxiliary Feedwater System piping which was discovered as far back as the motor driven pumps.

With steam present in the bypass line the motor driven pumps were started as part of Hot Functional Testing, introducing cold water into the bypass piping. The water rapidly condensed the steam resulting in a waterhammer.

Q11: Assuming a failure of the check valves which are provided to prevent reverse flow and assuming the steam generator water level falls below the auxiliary nozzle internal extension, under what plant operating conditions can steam backleakage into the bypass line occur?

A11: Assuming a failure of the check valves and the low water level, backleakage during power operation is very unlikely since between 0 and 100 percent power a continuous flow is provided through the steam generator auxiliary nozzle which effectively prevents the backflow of steam from the steam generator. Above approximately 20 percent power, when the feedwater flow is supplied through the main nozzle, a tempering flow which is equivalent to one to two percent of the main feedwater flow at 100 percent power is maintained through the auxiliary nozzle. The purpose of the tempering flow is to maintain the auxiliary nozzle at feedwater temperature thus reducing the induced thermal stresses when feedwater is transferred from the main nozzle to the auxiliary nozzle, for example, during plant unloading. However, the tempering flow also effecively prevents steam backleakage and consequently the occurrence of waterhammer.

During the normal operations of heatup, cooldown and hot standby, feedwater is supplied only through the auxiliary nozzle. However, only relatively small amounts of feedwater are required, not enough to always permit a continuous flow so that the opportunity for steam back-leakage does exist if the check valves fail and the steam generator water level falls below the auxiliary nozzle internal extension. However, the plant operator is instructed to feed continuously rather than intermittently as much as possible. This practice reduces the likelihood of steam backleakage and therefore waterhammer.

Q12: What damage resulted at the KRSKO Plant as a result of the waterhammer event?

A12: To aid this discussion, two isometric sketches of the feedwater bypass piping at KRSKO are presented in Figures 3 and 4. Figure 3 shows the bypass piping inside containment from the auxiliary nozzle to the containment vessel penetration. Figure 4 shows the section of bypass piping from the containment penetration to the point where the Auxiliary Feedwater System connects.

Inside the containment building, hanger embedment plates were moved, hanger bolts were loosened and pipe clamps were loosened and moved. The locations of affected hangers are identified in Figure 3 by the numbers in ovals. Also inside containment, some change in the location of bypass piping was observed. Also, a bulge was discovered on the upper surface of the bypass piping near the secondary shield wall. The bulged region was approximately six to eight inches long and increased the pipe diameter by approximately one-quarter inch.

Outside of the containment building, there was negligible pipe movement. The paint on the auxiliary feedwater piping was blistered back to the motor driven auxiliary feedwater system pumps.

Despite the damage, the design functions of the Auxiliary Feedwater System and the Feedwater Bypass Systems were not adversely affected.

Q13: What corrective actions have been taken at the KRSKO plant in terms of redesign, repair, operator instruction or procedures for avoidance of waterhammer in the future?

A13: The principal modification was to install two temperature sensors on the bypass piping inside containment close to the auxiliary nozzle of each steam generator. The temperature sensors are connected to the plant's DATA-SCAN Temperature Monitoring System which allows for printing out the temperature values in the control room on request. The system activates an alarm if the temperature values exceed predetermined set-points. Recommended operating guidelines have been provided to KRSKO for utilizing the temperature data.

With respect to KRSKO plant repair, the section of bypass piping containing the bulge, was replaced. Also the hanger damage was repaired. To reduce the likelihood of backleakage, the Auxiliary Feedwater System check valves, which were determined to have been leaking, were refurbished.

With respect to plant operation, Westinghouse has instructed KRSKO to maintain the steam generator water level above the top of the auxiliary feedwater discharge pipe inside the steam generator as much as possible. With the discharge pipe covered, only hot water and not steam could leak back into the bypass and Auxiliary Feedwater System piping, thus greatly reducing the potential for waterhammer.

In the eventuality that the presence of steam is suspected in the bypass line of one or more loop, based on temperature data and water level status and history, the recommended course of action is to slowly refill one loop at a time with the Auxiliary Feedwater System. An analytical study by the Westinghouse R & D Center shows that the safe refilling flow rate is in the range of 15 to 123 gpm per steam generator. To be conservative, Westinghouse has recommended the value of 15 gpm or as close to this as can be provided.

Q14: Are you familiar with the present and proposed check valve arrangements in the Feedwater Bypass and Auxiliary

Feedwater Systems at the Byron Station?

A14: Yes.

Q15: Please describe those arrangements in light of their impact on the potential for steam backleakage into the Auxiliary Feedwater System.

A15: Consistent with Westinghouse recommendations, there should be at least two check valves in each flow path by which backleakage into the Auxiliary Feedwater System could occur. The current Byron design includes two check valves in each flow path effective in preventing backleakage into the Auxiliary Feedwater System. One is located in the bypass line close to the auxiliary nozzle and the second in the Auxiliary Feedwater System itself. Flow that leaks past these two valves would flow through the Auxiliary Feedwater System pump miniflow lines to the condensate storage tank. The check valves in the Auxiliary Feedwater System further upstream of the miniflow lines are thus ineffective for preventing backleakage.

Based on an analysis performed by Westinghouse which considered the classical waterhammer case of feedwater line break followed by check valve closure, Westinghouse recommended that 1) the two 6 inch undamped check valves in the bypass line (which includes the previously described valve close to the auxiliary nozzle) should be replaced by slow closing check valves, or 2), the valve close to the auxiliary nozzle should be removed and the other check valve in the bypass line should be replaced with a slow closing valve. Retaining the current undamped check valve close to the auxiliary nozzle while replacing the other check valve in the bypass line with a slow closing valve is not acceptable since, depending on the location of the feedwater line break, the undamped valve may still close rapidly, possibly resulting in unacceptably high loads.

Commonwealth Edison Company elected the second option described above. However, on further consideration, it was determined that this arrangement would leave only one check valve in each flow path which would be effective in preventing steam backleakage into the the Auxiliary Feedwater System and out through the pump miniflow lines. As a consequence of this determination, a new 6 inch check valve will be installed in the discharge line of each Auxiliary Feedwater System pump. This valve would be located downstream of the pump miniflow lines and upstream of the header and branch lines which supply each of the four steam generators. This check valve arrangement is consistent with the Westinghouse recommendation since it will provide two check valves in each flow path by which backleakage into the Auxiliary Feedwater System could occur.

Q16: As a consequence of the KRSKO experience, what measures has Westinghouse recommended to Commonwealth Edison Company to avoid a similar bubble collapse waterhammer in the Feedwater Bypass System at the Byron Station?

A16: Westinghouse has made the following recommendations to avoid a KRSKO type waterhammer event:

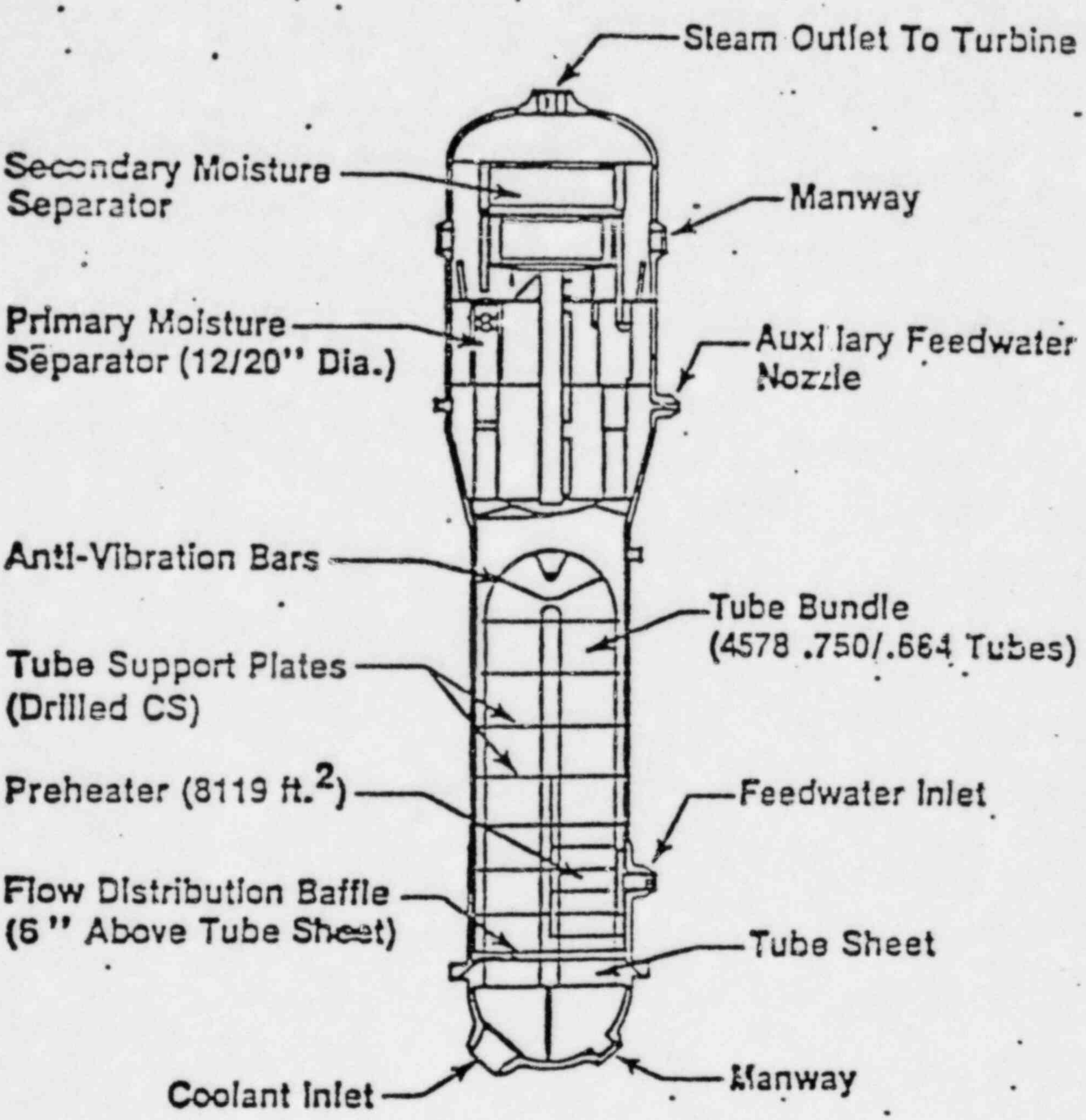
1. Temperature sensors should be installed on the bypass piping close to the auxiliary nozzle to detect backleakage of hot water or steam.
2. If backleakage is detected, the piping should be slowly refilled or the plant brought to a cold shutdown condition, depending on the circumstances. An analytical study performed by the Westinghouse R & D Center shows that the bypass piping can be slowly refilled safely. The recommended flowrate is on the order of 15 gpm.
3. The steam generator water level should be maintained above the auxiliary nozzle discharge pipe as much as possible so that if backleakage does occur, water and not steam will leak back into the pipe.
4. The Auxiliary Feedwater System check valves should be maintained to minimize backleakage.

Q17: Do you have an opinion as to whether these recommendations, if followed, would be adequate to prevent the occurrence of KRSKO type event at Byron Station?

A17: Yes.

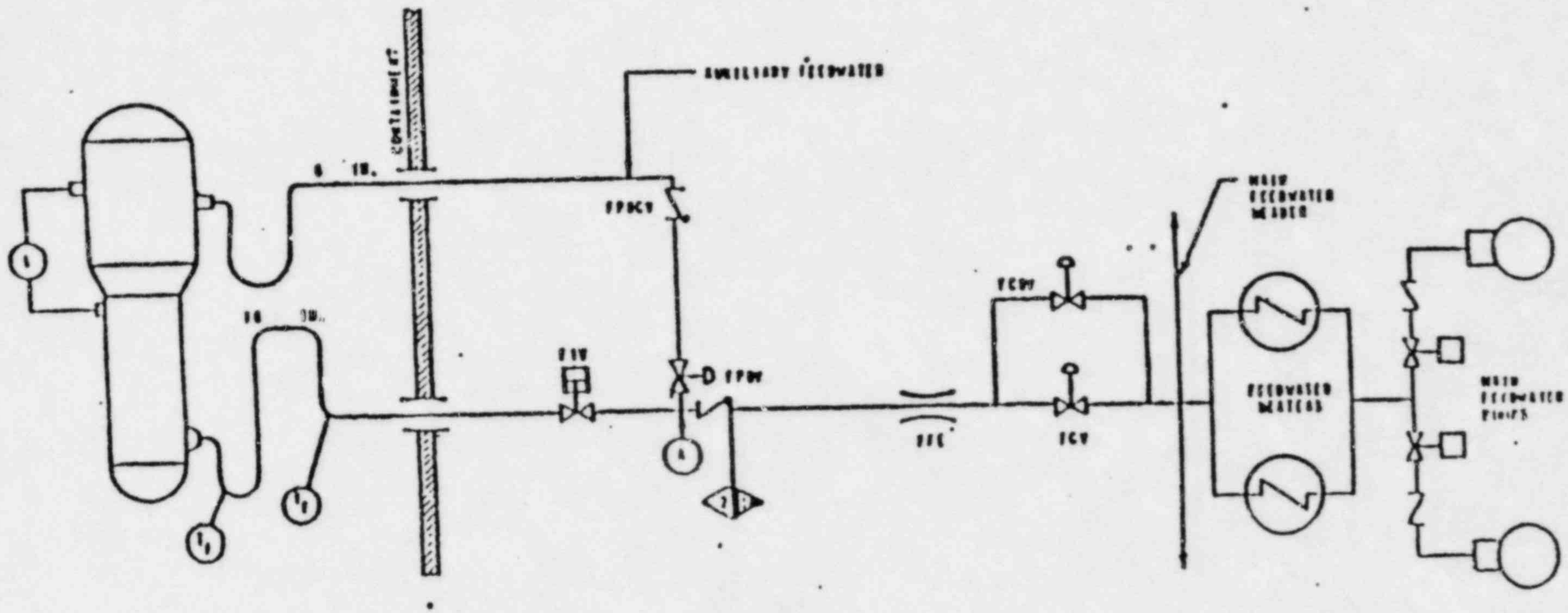
Q18: Please state that opinion.

A18: If these recommendations are adopted and implemented, and Commonwealth Edison Company installs the proposed check valves in the Auxiliary Feedwater System, the likelihood of occurrence of a KRSKO-type waterhammer event is reduced to an acceptable level.

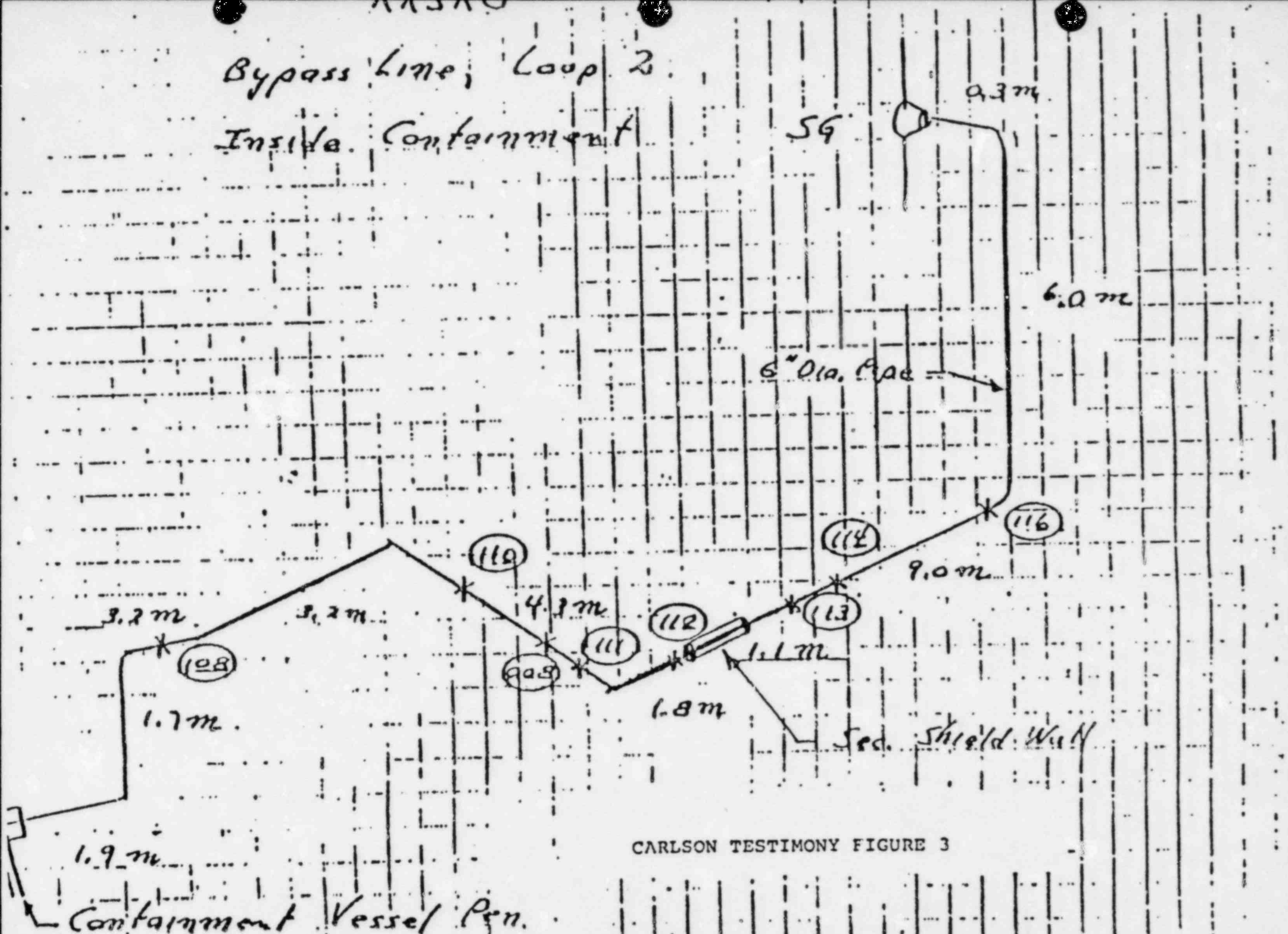


CARLSON TESTIMONY FIGURE 1

Byron Station Preheat Type Steam Generator



CARLSON TESTIMONY FIGURE 2

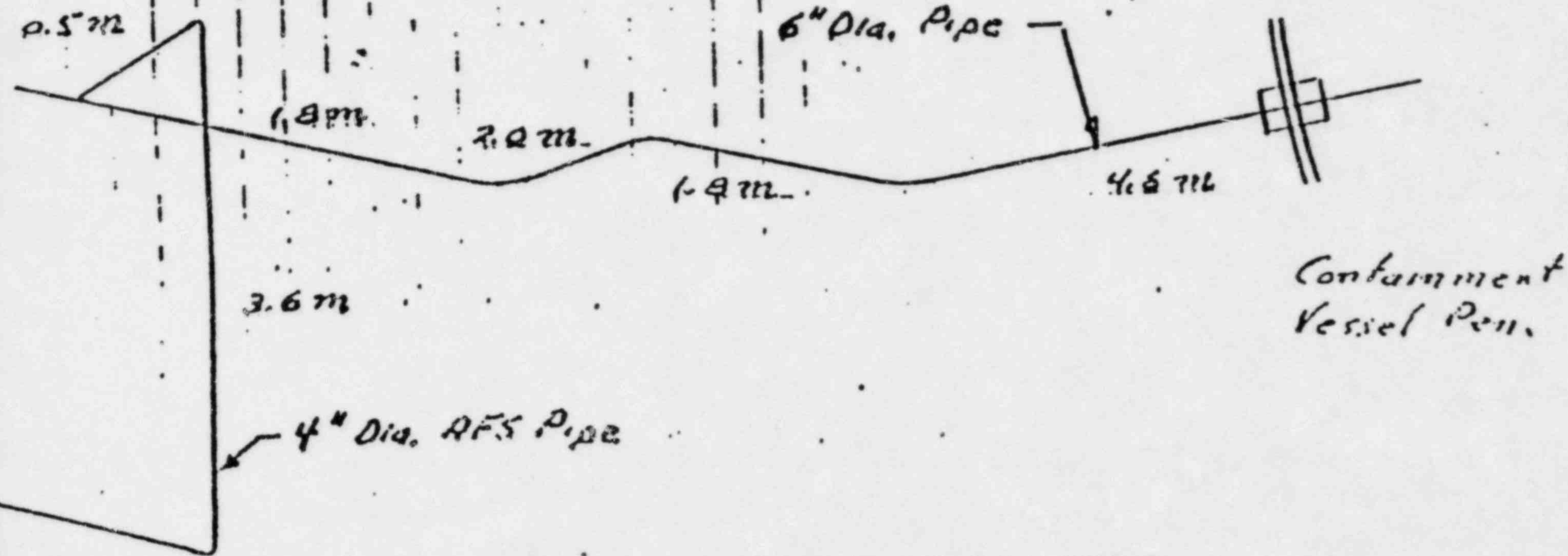


CARLSON TESTIMONY FIGURE 3

KRSKO

Bypass Line, Loop 2

Outside Containment



CARLSON.TESTIMONY FIGURE 4

MR. GOLDBERG: Judge, before we break, can I, if you have nothing further?

JUDGE SMITH: Yes.

MR. GOLDBERG: I brought to the attention of the parties during the recess a possible scheduling conflict between our waterhammer witness. He has another hearing at which he is scheduled to testify next week, and I ask counsel if they would object if they saw the hour hearing close together to have Mr. Circus join the present panel for the purpose of introducing his testimony and making him available for cross examination should it look like that the issue will not be fully tried by the ends of tomorrow's session.

Ms. Chavez indicated that she has considerable questions for Applicant witnesses but not significant testimony for Staff witnesses and I would just like to say that with the Board and party's indulgence perhaps we could try to accommodate this scheduling constraint.

MR. GALLO: Judge Smith. is it possible to go later this evening or what is the Board's disposition on that?

JUDGE SMITH: Yes, it is possible to go later this evening. However, it's going to be a long area and we simply aren't able night in and night out to go so long and still do our necessary preparation.

I can't deny that any one given evening but in my experience there is virtually always a reason why the regular closing time should be departed from.

MR. GALLO: What is the Board's preference for this evening?

JUDGE SMITH: Our preference for this evening is to adjourn soon. I want to point out that we do not have the use of this hearing room tomorrow and before I forget, no able bodied person capable of moving tables is permitted to leave the room before we do because we have to restore the room to the way the judge had it. We have to move to the magistrates courtroom. We will begin tomorrow at 8:30 rather than the usual 9:00 o'clock time. I recommend that we quit now because we have come to a discreet separation; but in answer to your question, yes, theoretically, we could proceed tonight but I don't see any reason why tonight is going to be stronger than any other night. It's going to be a long hearing.

MR. GALLO: Well, in response to counsel's suggestion, what he is saying is he wants to dispose of his witness before noon tomorrow, so he doesn't have to bring him back.

In that event, I would suggest that maybe we put Mr. Circus on out of order.

JUDGE SMITH: If he doesn't object, that is normally has been one of the things that the parties should discuss, because we don't really care in which order you present them, so long as the issues are presented.

MS. CHAVEZ: Your Honor, your Honor.

JUDGE SMITH: Yes.

MS. CHAVEZ: If Mr. Circus is presented tomorrow morning first thing, I have no objections.

JUDGE SMITH: All right. How long do you think that your cross examination would be?

MS. CHAVEZ: I think it would be concluded before noon.

JUDGE SMITH: Yes, it will have to be. We don't have access to the room.

I might say that I think you better think through your cross examination. Cross examination is very difficult and it takes a lot of planning. I see you have done a lot of planning, however; but if you see that you are not being particularly productive, just whatever advice I give you, usually you end up by helping your opponent by pushing a point home that you are not making any ground on and I don't think you want to do that.

All right. So we will take your witness tomorrow first thing at 8:30. This room has to be cleared out. Let's adjourn now until 8:30 tomorrow and we will meet in

Room 270, the magistrate's courtroom.

(Whereupon at 5:08 p. m., the hearing in the above-entitled matter was recessed, to reconvene at 8:30 a. m. the next day.]

NUCLEAR REGULATORY COMMISSION

This is to certify that the attached proceedings before the

ATOMIC SAFETY AND LICENSING BOARD

in the matter of: COMMONWEALTH EDISON COMPANY (Byron Nuclear Power Station, Units 1 & 2)

Date of Proceeding: March 3, 1983

Docket Number: 50-454-OL and 50-455-OL

Place of Proceeding: ROCKFORD, ILLINOIS

were held as herein appears, and that this is the original transcript thereof for the file of the Commission.

G. Allen Sonntag

Official Reporter (Typed)

Official Reporter (Signature)