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ON METAL COMPONENTS

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UNITED STATES NUCLEAR REGULATORY COMMISSION'S

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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BEFORE THE

U.S. NUCLEAR REGULATORY COMMISSION

ACRS SUBCOMMITTEE MEETING)
ON METAL COMPONENTS)

Conference Room D
EPRI NDE Center
1300 Harris Boulevard
Charlotte, North Carolina
Tuesday, March 15, 1988

The meeting convened, pursuant to Notice, at 8:30 a.m.

PRESENT WERE:

PAUL G. SHEWMON, Chairman of the Subcommittee
CHARLES J. WYLIE, Member
DAVID A. WARD, Member
AL IGNE, Cognizant Staff Member

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P R O C E E D I N G S

MR. DAU: Good morning, I'm Gary Dau from EPRI, it's a pleasure to welcome the Subcommittee to our facility here in Charlotte, and I think we have a good program laid out for you people to review, following both the NRC work and the utility industry.

I'd like to go over a few administrative items before the formal meeting starts. Bob Stone has drawn a map here showing where the restrooms are and basically it's right around the corner and located in our cross hallway here.

We have notified the receptionist this is to be an open meeting and anybody that shows up at the desk and asks for the meeting will be directed here. Luncheon arrangements have been made in our cafeteria down the hallway here and there will be a demonstration at the laboratory facility taking place right after lunch.

We understand the Committee would like leave by 2:30 this afternoon and we have adjusted our schedule to that. I think that's the only items I have and with that I'd like to turn it over to Mr. Shewmon.

DR. SHEWMON: Good morning, thank you.

This is a meeting of the ACRS Subcommittee on Metal Components. I'm Paul Shewmon, Chairman of the Subcommittee, and the other members in attendance are Dave Ward and Charlie Wylie on my right. We are here to review the sub-status of

the NDE tests of steel stainless -- cast stainless steel piping and other topics.

Al Igne on my left is the cognizant ACRS staff member.

Since we are a government body, the rules for participation in today's meeting have been announced as part of the notice of the meeting that was published in the Federal Register of February 29, '88. The meeting is being conducted in accordance with provisions of the Federal Advisory Committee Act and the Government and Sunshine Act. We do have a reporter and if you would speak loud enough so that he can hear you, we'd appreciate it.

Do you have any comments at this time?

(No response.)

DR. SHEWMON: Fine, then we'll proceed and I gues., it says here Steve Doctor is first on the agenda.

PRESENTATION BY STEVEN DOCTOR

DR. DOCTOR: Good morning everyone. I'm going to give an update on the status of work going on at PNL that is funded by the U.S. Nuclear Regulatory Commission. I have given a presentation on earlier progress at a previous Subcommittee meeting back in June of '86.

The presentation outline that I will be following will deal with these four topics.

I will first start out and review under the PISC III

Program, the centrifugally cast stainless steel round robin test that was conducted, some post studies that we have conducted on some of the data that we collected during that round robin exercise, some additional studies that we're doing looking at fundamental transmission properties through casting of the steel materials, and then of course the final item is to talk briefly about the PISC III Program that is currently in the planning stages right now and will be starting actual testing this coming fall.

As I indicated, the first thing I'm going to discuss is the centrifugally cast stainless steel round robin test as brought our under a NUREG CR document number 4970, and also published as PISC III Report Number 3. This was designed as a screening phase with the more detailed study of reliability of the material to be conducted as a part of the last topic under my agenda.

Now this initial screening phase was started, we had 15 specimens that currently existed at the time, several years ago when this was planned. They were approximately 400 millimeters long by 190 millimeters wide by 60 millimeters thick. There was a weld in the center of each specimen, the specimen contained either equiaxed or a columnar microstructure. There were 11 specimens that contained thermal fatigue cracks and this four specimens that contained no internal cracks. The crowns were ground but they were not

ground perfectly as I will show you in this next view.

There was a plate that was placed on the bottom of each of the specimens so that no one would know what was underneath there, whether there were cracks in there or not. As you can see up here, this is the crown region and it had been ground so that it was smooth but there were still some valleys left between weld passes. So it was not a perfect ideal surface.

The procedures that were followed; there were 18 teams that participated, they used a variety of procedures consisting of manual UT, they used automated UT, automated UT with some signal processing and then there was one we called non-UT or radiographic technique that was employed.

The most common technique employed a dual probe using a longitudinal mode at one megahertz. Each team basically spent one week performing their inspections and then they spent some time reducing the data, putting it onto report forms and turning it in for then the analysis.

You can summarize the various teams in this particular table from the report. We have used a notation here for M being for manual, A for automated, ASP for automated with signal processing and then of course the non-UT located here. In addition, you'll see over here that people used a variety of different decision criteria and sensitivity that they employed during the test. Some people worked at

what they called the noise level, in other words they would determine what the noise level was and they would set that as the particular height on their scope; other people used, for example, this 50% DAC right here; other people had a 20% DAC, other people used what we called data shape. They looked at the nature of the noise in terms of how it was displayed in an image and they looked at the signals from the defects and they tried to use the data shape as their discriminate for determining whether or not what they were looking at was purely a grain phenomenon or whether or not it was a phenomenon related to an actual defect.

This is a schematic -- I don't know if you can see that -- of a handout that was passed around. It's shown in two different dashed and dotted lines, I tried to use a different approach here in which the intended defects are shown in red, the box shows the zone around that that was used for scoring the results. If you count these up, you'll find that 11 cracks existed in these and I might point out that number 1 and number 14 basically have cracks that went almost completely across the entire defect -- or excuse me, across the entire specimen.

Now in terms of grading what we called the false call or where you call defects that result from the grain or metallurgical type of scattering, we've put in a total of 14 boxes that are shown here and this is how they are

distributed. Although there are four of the specimens that contain no cracks, others contain cracks that for example were clear over here to this side, so there was adequate room to put a grading unit in there to assess false call performance on that same specimen.

DR. SHEWMON: Does the box represent the areas they were supposed to look at, or what?

DR. DOCTOR: They were to look at the entire thing. That was our grading unit. In other words, we used these grading units to determine if they made any crack call that intersected with this box, we would classify that they made a false call in that box. If they made a false call in all 14 of these grading units, then they would have gotten a 100% score on false call performance.

Now before we get into the results, what I wanted to do is to report briefly on the destructive results. The destructive evaluation was actually conducted by ISPRA, they used the same procedures that were employed in the PISC I and PISC II exercises. Three specimens were destructed; one was Specimen Number 12 which was a blank and they verified by cross-sectioning this and a number of repeated examinations, there was no defects that were contained in that specimen. Specimen Number 1 was destructed, as I indicated, it was a defect that went the majority of the distance across that specimen. The maximum depth on it was 38% through wall.

Specimen Number 5 was selected because there was a high number of false calls that also existed in the grading unit that was on that same specimen, and they wanted to destruct this so they could look at the actual cracks and ascertain its through-wall extent, but also to evaluate the zone that was non-cracks to try and understand if there were any unintended defects that might be causing that.

This is a micrograph for Specimen Number 1. In this particular case we had an equiaxed structure on both sides of the weld. You can see the weld passes in the middle zone. In Specimen Number 12, this was the blank unit that had a columnar microstructure over here on the lefthand side and equiaxed microstructure over here on the righthand side. And then Specimen Number 5, as shown here, again it had a columnar microstructure on the left and equiaxed microstructure over on the righthand side.

What I would like to do now is to step through how they actually did a destructive evaluation on this with the next few viewgraphs. What this is a plot of right here is Specimen Number 5, and this is a plot of all the ultrasonic calls that were made by the 18 teams in this particular specimens. The point here is that the calls are being made pretty much uniformly all across the specimen, there is no great clustering in any one location. They wanted to look at this to determine how best to cross-section it.

This shows -- now if I can keep it consistent with the preceding one, this is the weld center line running through here, the intended defect is shown here. There were two -- well x-ray indications that were found. This is one shown there, a second one was shown over here. The second one was a false call made by the radiographic approach. It actually predicted one as being located over here but they ended up actually classifying it as not being a defect because of its location relative to the weld center line because it was outside -- well outside the weld zone region, but it clearly came out with a crack like type property and it was put into the matrix in terms of calling something as being there, and then you make a decision as to whether it's a crack or not a crack. This was called as being there but was given a non-crack type call.

This is a cross-sectional cutting then that was performed in which they basically sliced it into three pieces. They took that center piece then and did some ultrasonic scans on that, some radiographic examination. They then further sectioned it as shown here by these multiple slices, they did cross-sectional profiles and split things apart.

Looking at the specimen under the first cut, this is the kind and nature of scan that was generated using an ultrasonic normal beam across the specimen from the two different sides. You can see the presence of the crack

located here and here, so you can see where you're getting sound transmission and where you're getting back scattering of the sound. So this is the location of the intended defect. You can see that in this particular case, there is a fair amount of sound transmission that, you know, is occurring so it obviously has a fairly tight crack.

DR. SHEWMON: More on the right end, is that something you're going to ignore or is that --

DR. DOCTOR: You mean these --

DR. SHEWMON: Other end -- yeah.

DR. DOCTOR: I'm not sure. That's right near the edge of the specimen and that very well may be due to some kind of scattering sound path around there. I'm not sure why those are occurring out there quite frankly. They shouldn't be there. Ideally you should see the outline of this and you should see nothing here and nothing up here and of course you should just see this where the defect is located. I'm not sure what the significance of those are.

Let's move on to the results. The two performance metrics that were selected are the false call probability, that is the probability that one of these blanks grading units is classified as being cracked, there are a total of 14 that were in this particular study. The probability of detection and correct interpretation is the probability that a cracked grading unit will be classified as being cracked. So the way

that we actually come up with the estimates then is to, in the case of the false call probability, take the number that they classified as being cracked, divide that by the total number which in this case is 14, and then multiply it by 100. And correspondingly the same thing on the PODCI. Best performance will occur when the false call probability is near zero and the correct detection and interpretation is near one.

Now some of the things that you do before you jump in and analyze the results in great depth is to do some studies such as this in which we've plotted here for, in this particular case, probability of either detection or the false call probability, shown here by the two lines. In this particular case the solid line is the detection line, the dashed line is the false call probability. And we've done this as a function of our grading unit tolerance. In other words, in this particular case it's the axial width of the grading unit and in this particular case we're going circumferential tolerances of zero, five, ten and fifteen millimeters. In other words, this is the amount of extension that we made for the box as a circumferential direction. And what we wanted to see was whether or not if we selected a particular grading unit, whether or not we're at a point where it really didn't make any difference if we increased the size of it because we pretty much had all the correct calls. And that's what you see here, when you're dealing with extremely

small values of axial tolerance down here of around five millimeters, you can see that there's a fairly steep rise to the curve, but once you get out here to the nature of ten to fifteen, the curve has pretty much flattened off whether you're talking about false call probability or you're talking about the probability of detection of the actual defects. And you can see that there is no real strong relationship with regard to the circumferential tolerance, which is what one would expect because the tail ends of the crack are extremely hard to see and to define, so we're fairly insensitive to that.

What we ended up using on this was a fifteen millimeter tolerance for the axial and I think ten millimeter tolerance -- yeah, ten millimeter for the circumferential. So this is the box that was selected. But you can see that there's not a strong dependence, which is extremely important, for the grading unit that you're using.

DR. SHEWMON: Would you tell me what adds up to 100 in that? Apparently false call and correct calls don't add up to 100.

DR. DOCTOR: That's correct, it's whether or not people made a decision and put something in the box. If nobody put any decisions into a cracked unit box, then everything would be at zero and if they called all the blank units cracked, then that curve would correspondingly be up at

100. If you get all the cracked ones correct, then the POD would be at 100 and if you made no mistakes, the false call would be at zero.

What this shows in this particular case is that, let's say roughly 60% of the calls for detection were in cracked grading units and correspondingly roughly about 40% of the calls were in blank grading units. These were the calls that there were cracks located and it doesn't sum to zero -- or 100, it's whatever the calls are.

DR. SHEWMON: Okay.

MR. WARD: Steve, is there any way to express what this random calling would be?

DR. DOCTOR: I'll show you that a little bit later, but this curve is not designed to look at that particular phenomenon. What we're trying to do here is establish what is a reasonable size of grading unit that we should use with the data to tell us most accurately what is actually happening. And you can see if you select a five millimeter grading unit, you would be biasing things down fairly low. What that means is that changes in velocity and that that occurred in the material create a fair amount of uncertainty, particularly in the axial direction. With regard to the circumferential direction, if you detected something, you may miss the ends of it so you're fairly insensitive to that parameter.

One of the things we did look at was also the dB

response for the teams that reported things, with regard to a dB amplitude. We looked at the number of correct classifications for the defects. What we've plotted here then is the average in the range of the dB response as a function of the number of correct classifications. And one extreme we had out here, we had better than 90% of the people actually detecting this particular crack, and as you can see, the dB response average value is not a whole lot different from these others, plus the range of variability that we found with regard to that is extremely large.

What we were trying to see here was whether or not dB response was a prime requirement that they were using for making their determination. You can see there is a very slight, minor trend that you might classify except for the occurrence down here of these two points, but with the large error bars associated with the scatter of the data, there is no strong trend at all that the amplitude was actually being used as the prime discriminate for making that classification.

Another thing that was looked at was the number of calls that were made in blank grading units, and this is a summary with regard to each of the specimens. Of course 1 and 14 are not in there, those were not included because they did not contain any blank grading units. You can see from this that by far the majority of the crack calls in blank material occurred at twice as high a frequency as they occurred in

equiaxed material. So what this says is that the signals that were most difficult to discriminate against occurred more frequently in columnar material than they did in equiaxed material.

Now we can plot the results as a function of various specimens. I've put in the handout a complete series of all of the results. In terms of this presentation, I'm only going to go through about four of them, just to illustrate particular points because I just don't feel it's worthy to spend all the time devoting an analysis to all 15 at this particular time.

What we've plotted here is the number of crack calls that occurred as a function of circumferential position. These large vertically dashed lines then illustrate where the crack was actually located, so this was Specimen Number 1 where the crack went the majority of the distance across the specimen. And then we have decisions as a function of whether you were looking at the near side, whether you were inspecting from the far side or the solid line is where you were integrating the information from inspection from both sides.

I'll just put this up to show you that the peak value here goes up to close to 70% right in this one location, drops down to about 60. Over the majority of the crack, there's probably an average value that's in the neighborhood of about 40% of the people classified this zone as being

cracked.

Another example, this was Number 5 that was destructed. This one shows no real particular overall general trend. The classification here in the zone where the crack was located is very similar to this zone out here where the crack was not located. When we destructed this, of course we found a defect that was in this location, that was 28% through wall and no unintended defects out in this zone.

This is Specimen Number 12, this is the blank grading unit -- or blank specimen that had two grading units that were blank contained in it. You can see here that again we're getting in the neighborhood of 40 to 50% of the people who looked at this particular specimen classifying it as being cracked and it was verified by destructive evaluation, that it did not contain any cracks.

I've put up one final one then. This happens to be Specimen Number 11. It was the one that the people scored about 93% on that you saw in that dB response plot that we were showing earlier as a function of the number of people who made the classification. This happened to be a unique specimen, it had been subjected to special treatment in which it had been both thermally relieved and then mechanically stress relieved, the crack was bent open and then the specimen was bent back to its original shape. When people inspected this, and I'll show you some results later on, the actual dB

response on this particular specimen you'll find was slightly higher, but out in this zone here you'll find that the actual signals that they had to discriminate against were very typical of what they had to discriminate against in other specimens.

This I think shows the psychology of taking a test in which this one people really found that they had very high competence in it and that they were able then easily to discriminate against signals that in other specimens they ended up classifying as being actually cracks. And that's the reason you see this extremely low response in this zone here.

Well this shows I think that the properties of the crack are extremely important and now what I'd like to do is move on, and before I go into the final results, I just wanted to put up an example of one team's results to show you some of the things that you have to contend with.

What you see here is a whole series of classifications that a team made in terms of cracked and non-cracked decisions. As you can see, there's a large number of lines that go across the entire specimen, such as this one and this one. In this particular case down here, they classified one of these as being cracked, down here they classified one as being cracked on one side and the other being cracked on the other side and went the full length of the specimen.

Now let me put this up to show you that because of results like this, it's extremely difficult to extract and understand exactly what's been going on in terms of the round robin test. Other people, you know, in terms of their performance were able to classify things with a far smaller number of crack type calls that coincided with the intended defects and did not have -- when you have something that goes all the way across and then intersects one of your grading units and you end up classifying it as being cracked, and it also intersects one of your blank grading units, you end up actually nullifying it. Obviously the person was not seeing the defects, so one has to look at both false call and the detection probability and look at those two numbers in conjunction with one another.

Now as I indicated earlier, this was a screen type test and we used a small number of specimens. This is put up to show the error bars associated with the detection or behavior in cracked material versus the behavior in blank material; false call probability, probability of detection and correct interpretation. As you can see, those error bars are very large.

Now when we look at a plot such as this, you can see that if I put those error bars on, for example, performance right here, they would extend quite a distance in that direction and in that direction, so that in essence I would be

unable to discriminate most of these calls in this zone from one another. I would be able to distinguish those from these up here, however.

What we were intending to do with this was to try and find out if there were teams that were able to perform in this upper lefthand corner. What is in that upper lefthand corner, as you note, is a square. That was the results from the optimized radiographic exam that was performed in a laboratory using a linear accelerator under idealized conditions where they had removed the vacuum plate, put the film in contact with it, so those were extremely idealized conditions, the performance was there.

When that same radiographic technique was applied with the vacuum plate in place, that performance dropped down to here. Okay? So if you would try and take that to the field where you have double wall type inspection, you have water, you couldn't get the two meter distance that they were using, you couldn't use the linear accelerator that they were using, you would expect this performance to probably deteriorate substantially from where it is.

The rest of these dots then are all from the results generated by the ultrasonic inspections. What's shown here by this solid line is a line that would be obtained if one was using a random decisionmaking type process, so that you would make an equal number of correct and wrong decisions, things

would fall along this line.

So if you look at this, the idealized performance is as far away from this line as you can possibly get. You can see that these techniques that are located up in this zone are the fartherest way, excluding of course this laboratory type test. One can see from this that clearly it appears that there are doing better than random chance even taking into account the large error bars that we had in this -- they are doing better than random chance.

One looks at these up here and one recognizes that clearly in some of these cases at least you have to I think believe that people were seeing the defects. And if you go back and look at the original data, if they weren't calling defects all the way across but were simply finding defects and classifying some of them as being associated with blank grading units and some with cracked units, what one could conclude I think is that one is seeing the defects but one cannot discriminate against the non-defect type scattering.

Now that doesn't solve your problem, but it says at least that in this particular case with these thermal fatigue cracks, there were a number of people that were seeing basically all of the thermal fatigue cracks. And the thermal fatigue cracks are tight and difficult to see and I think that shows promise from the point of view of being able to see those. It doesn't help us for being able to discriminate at

this particular juncture in time, but that focuses in on what the problem is, the one we have to solve.

If you rank all the performances in a table such as this, what we've done is broken things out -- some people looked at things from one side, from the other side and then from both, and that's the reason you see more than 18 teams listed here. What we've done then is to show the FCP and PODCI and ask the question of what is the probability that this kind of performance could have been obtained purely by chance. And what we've done then is to rank these by that probability, of course recognizing the uncertainty that I indicated that we had earlier with regard to the actual quantification of performance. We have large bars, so you can't really say that this team is better than that team, you have too much uncertainty. You can probably discriminate from here half way down the list or so, but you certainly can't try and do it on any finer scale.

What we tried to do here was to look and see if there are any generic all around trends with regard to what people were doing with regard to, you know, achieving the best performance and if you look through this, you'll see that there is basically an inter-mixing of ASME levels, data shape, et cetera, that were actually used. There is no clear overall trend.

When you ask some of these teams, for example up

here that were using the ASME 50%, how did you actually make a decision, they said well we just got a feeling that this was a crack and this wasn't but they couldn't put their finger on actually a requirement that they had or decision process that they had for making that determination. It was kind of a feeling that they had more than anything else that they could put their finger on. So even though this ASME 50% is up here, you can't transfer that to anybody else. It was something that that person had in terms of an understanding of the responses, but they really didn't understand it themselves. Therefore it had to be considered very unreliable.

DR. SHEWMON: You don't have frequency or wave length on there except there was some spread in what they do, is that normal?

DR. DOCTOR: There was some spread but it was not very much. People did not go up much higher than one megahertz and some people went down to 500 kilohertz.

DR. SHEWMON: But going down to 500 did not help?

DR. DOCTOR: Did not help much, that's correct. The results that we did with SAFT were at 500 kilohertz in the shear mode and I'll talk more about those in terms of our post-analysis in a few moments.

I'd like to talk about our conclusions. First off, I want to point out there are a few cautions. This was purely a screening test, it contained only thermal fatigue cracks, it

only dealt with two types of microstructures, an equiaxed microstructure and a columnar microstructure. We also quantified the performance by the two parameters PODCI and the false call probability. And the point here is that both parameters must be used in terms of describing the performance. You can't use just a single one. This was a screening test and thus we had large confidence limits with regard to those two parameters.

Do not use this data for comparing the effectiveness of different procedures, it was not designed as such, it was simply trying to see whether or not techniques existed that would provide the kind of detection performance that we were trying to look and find so that we could have the problem solved. But in conclusion, there are some global trends that do exist and what I want to do is point out what I think are the relevant things that can be concluded from this.

In general, the inspection performance was rather poor. Some operator/technique combinations did show potential for detecting and classifying the material, however other operators using the same procedures did rather poorly.

HIgh false call rates made it difficult to ambiguously analyze results. As I showed you in that one plot, some people called cracks all the way across. There was such a preponderance of calls in a number of cases that it was extremely difficult to really understand what that team's

performance really was.

Specimen Number 11 that I showed you had much higher POD and lower false call probability. We believe this is related to the relaxation of crack tightness because of the thermal stress relieving and the mechanical stress relieving that was performed on that particular specimen. I think it points out the properties of the defect are extremely important insofar as detection is concerned.

In general, the false call probability was higher in the columnar than in the equiaxed material, 40 versus 23 percent numbers that I showed you.

Let's see, the single-sided versus both side inspection effectiveness could not be resolved due to the high false call probability in columnar material. This was a result of, as I showed you, the fact that we had in most specimens an equiaxed material on one side and columnar on the other and because of the high false call numbers that occurred on the columnar side, you couldn't really look at the single side access versus both side to effectively understand that.

Now the two radiographic laboratory inspection techniques that had been applied did show very good results, but it should be pointed out that these are not adaptable for field inspection.

DR. SHEWMON: This was the PISC group, so this was an international group done under semi-lab basis or fully lab

basis --

DR. DOCTOR: Fully lab basis.

DR. SHEWMON: -- and presumably not the third team in any given country.

DR. DOCTOR: That's correct, they were the best team in all countries, yes.

DR. SHEWMON: There are -- it seems to me there is an NRC regulation about -- I see reports that people go out to a plant and Byron was one, they couldn't get a signal back out of it. So there is variability in what is in the field. Is this primarily grain size or more columnar, or do you know?

DR. DOCTOR: Well I'll show you some of the work that we have done in regard to different specimens and we're in the process of trying to understand what actually happens in these various microstructures because when you propagate through these different microstructures, different things happen. And if you've got an intermix of different microstructures, it's like, you know, stacking up different filters and one filters out and tries to pass a band of frequencies and another one knocks out another band and if these two don't overlap, you end up reducing the signal very greatly. I'll show you some of the results a little bit later on that, in terms of our laboratory work.

DR. SHEWMON: Any questions?

(No response.)

DR. DOCTOR: Okay, what I'd like to do then is talk about the post-CCSSRRT study that we did. This was conducted at PNL and it involved the data base that we collected using the SAFT system. We digitized all the A-scans so we have that data base on storage.

We used a 500 kilohertz shear-wave transducer and the reason that was selected was for several reasons; Dave Cupperman at Argonne felt that was one of the best ways to perform an inspection because using the lower wave length, the shear mode should scatter and give you a stronger corner trap response and so we did some preliminary tests and said yeah that looks good, so we used it for all of the SAFT work, which we got similar results to other people in terms of the discrimination process. When I go through the spectrum to show you this I think you'll understand why.

We compiled data from defect zones and from defect-free zones. What I mean by that is in the grading unit we went into the zone of the grading unit where the defect occurred and we excluded the end parts of the defect to eliminate extremely weak signals from that zone. So we dealt with the center part of the cracks. So if a crack was three inches long, we might take the center two inches of it for example. And then the defect-free zones were basically all the blank grading units.

We performed FFTs on all the A-scans and we summed

the results together and sorted into these four classes. We looked at equiaxed, the columnar and both the high probability detections and the low probability detections. What I mean by that is if you go back to those curves that I showed you where people made classifications, we separated them out. If at least half the people made a classification there and that was twice the number of classifications that occurred in the defect-free zone, we considered that a high probability one, if not we put it in the low probability case.

And what I'd like to do is step through first off to show you a composite. This is the response from a sawcut in rough stainless steel. It's only put up here as an example so that as I step through this, you'll understand what I'm talking about. We plotted relative magnitude over here as a function of frequency and in this particular case two and a quarter megahertz transmission was used and the response and the defect are shown here. The non-defect response, in other words going to a zone adjacent to it where the defect was not located, you collect basically grain noise, and that's shown down here. When we subtract the two, the difference is the curve that swings through here and what you like to do is have that difference bet extremely high, but you would also like to have it be peaked here where the center frequency of the transducer is located.

Now if we take all the results from the spectrum for

all the specimens and we separate out into the defect and non-defect cases, what we have plotted is the defect and non-defect cases right here, the difference is down here. In this particular case, we're using a 500 kilohertz transducer and you can see the difference shows somewhat of a minor peak occurring right in here, but you can see that that's not much different and barely above the noise level, if you will. So from an overall composite standpoint, there's not much difference being shown here.

So then what we did is we went in and we looked at the results. In this particular case, this is for all the columnar ones. We looked at what the defect response was. You can see that one here being slightly higher than the non-defect. When you look at the difference you can see a predominant peak occurring here somewhat higher than what we saw when we collapsed all the columnar and the equiaxed microstructure information.

So then what we did is we said okay, there's a slight trend there, how does this break out when we look at the ones where people did a good job versus ones where it wasn't clear that they were detecting them. When we looked at the difficult ones, this is what we found. We found that in general, you still have that peak there but it hasn't been enhanced at all, it's at about the same level as what we saw when we collapsed all the information. If we contrast that

with the case where there was a high detection probability what you see here is an extremely large respon , for the defect versus the non-defect call, and this down here is the difference. You can see that extends up there extremely high, much higher than this base line noise.

So from this we conclude that at least in the columnar material where people had a high probability of calling something, in this particular case using our 500 kilohertz transducer it appears to us that they're getting a much larger response off of those flaws than what they were off of these flaws.

DR. SHEWMON: Why is it such a jagged curve? One could almost say if you used eight-tenth megacycles you'd do as well. It seems to be very periodic. Is it noise or is it real?

DR. DOCTOR: Yeah, our band width of our transducer probably extends out here, it was like a 60 or so percent band width. I would say from about 300 kilohertz out to around 700 kilohertz is the range. Once you get beyond that, you're looking simply at a noise phenomenon that's related to looking at two basically small amplitude signals. You're amplisizing extremely low noise levels, low information content.

So, you know, based on this, the results from the columnar material appear to be related to the response that one gets with regard to the amplitude, it's very evident

there's a difference there.

Now we looked at the composite results from all the equiaxed grained material, and again we see somewhat of a similar thing, however you'll notice here that we've got a quite high peak located down here at about 400 kilohertz. And we still have a peak occurring right here at about 500 kilohertz but this one at 400 is about twice the size of that. If one were using the 500 kilohertz informational, one would draw the conclusion that it's lower than this 400 kilohertz one, and it's obviously not the information to be using. So again we repeated the same type of analysis.

We looked at the composite spectrum of the difficult cracks and in this particular case what's interesting is that there's actually an inversion almost at 400 kilohertz for those. so that what we were seeing before must be due to the more easily detected ones and you do not see a very strong response occurring here at the 500 kilohertz for the center frequency that one would like to have and what one was seeing in the case of columnar material.

When we went to the easy cracks, this is shown here, you can see that we do get the peak coming back in here at about 400 kilohertz as to be distinguished from this case where we actually had almost the inversion of that looking at the composite spectrum for the difficult and the easy ones. You can't really conclude that that is in fact a good zone,

out here it's 500 kilohertz for this particular case and there's not a good response occurring either.

So the only thing we had left to do was to look at that Specimen Number 11 to see what kind of response we got from it, and that's shown here. It was actually on the equiaxed side and that was the one where people detected it with very high reliability, 93% of the people who saw that made a classification and in the non-cracked zone there was only a few percent of classification calls. And we looked at the spectrum of that and you can see that there's not a strong response there at 400 kilohertz but we do have a fairly sizable response right here at the 500 kilohertz. So in this particular case, for whatever reason, this one was giving us a very nice response at the 500 kilohertz range but if you look at the spectrum of this versus the others, it's not overwhelming. There's nothing in here to suggest that people should make a classification on this of 93% when you go back here to this case in the columnar material and have this kind of response occurring, and yet none of those cracks people even approached that kind of level.

So I think this shows some of the difficulty in terms of trying to understand this. It's related to the signal amplitude and it's related to signal to noise ratio, but that interrelationship and what people actually use in terms of a decisionmaking process is not well understood, it's

a very complicated matter.

So our conclusions that we've drawn from this is that we feel the detections were probably based on signal amplitude as the strongest piece of evidence that we've got. It wasn't the only thing, but in terms of the ones where people tended to find those, at least in the columnar case, that appears to be the largest trend, but that doesn't answer the question.

There is no simple filter, as we pointed out, in this that you could use. In the 500 kilohertz case that we were using, you would want to be right near that frequency for columnar examination and if you went to equiaxed it appears that perhaps you might want to be down at the 400 kilohertz range in order to pick up a number of those others, although even working there doesn't provide you with the ability to detect all the cracks in the equiaxed material.

The problem is not really one totally of signal to noise, and that's probably due to the spectrum of defects and noise are quite similar. As you look at these plots, they're quite complicated, but they also show that the spectrum coming off the coherent scattering from the grain structure and the amplitude of that approaches that which one gets off of defects.

So what is the bottom line of this? I think it shows that, you know, there's still a lot of work that needs

to be done to understand how to inspect this material and that you can't use just simply signal amplitude. YOu must try and understand when you're performing an inspection as to what's happening as the sound goes through a particular microstructure and optimize the inspection with regard to that particular microstructure.

What I'd like to go on and talk about is the coarse grained material inspection. The objective of this work is to evaluate the effectiveness of ultrasonic techniques for inspecting cast materials, to understand the physics of the problem of how sound propagates through that material, to assess methods to provide improvements for the inspections, determine the limitations of those solutions and recommend improvements to Code/regulatory requirements.

This task is part of one on the NDE reliability program which is going on at PNL. There are four problem areas that we're basically addressing, that consist of the far-side weld inspections, cast stainless steel weld inspection, dissimilar metal weld inspection and weld overlay inspection. All these are similar because they all deal with very coarse grained material.

And our approach as part of this is to carefully map the sound field transmission properties in going through this to try and understand what actually happens, can you get a coherent sound field propagated through this material.

DR. SHEWMON: Is the far-side weld stainless steel also?

DR. DOCTOR: Yes.

DR. SHEWMON: Okay.

DR. DOCTOR: We've had to go to a digital signal acquisition system because when sound propagates through this coarse grained material a number of things happen, you get scattering of the sound field, you get mode conversion, you get beam skewing, and all those lead to all these multiple modes coming through. In trying to capture that signal that's received on the other side, to understand what it means, is difficult. So what we found is that the best way to do that is to record it and then to actually map what actually happens at different locations, spatial locations. From that you can then determine what is the actual signal that you want to be tracking, because if you mode convert into a longitudinal and have twice the wave length, therefore you'll get confusing results.

What we have been studying is four different microstructures; the columnar and equiaxed which I have described in the previous studies, mixed modes and layered type structures, and I've got examples of these and I'll explain what we mean by that terminology in just a moment.

The status is we've completed some L-wave attenuation measurements using a naught degree probe. We've

also completed our L-wave field profiles at naught degrees and we have in progress the 45 degree L-wave field profiles. I've got a series to show you which I didn't have time to reproduce to put into the handout, on the 45 degree L-wave, which I think you'll find interesting.

Basically the system looks like this, in which we take a specimen and we attach a very small point receiver to the ID of it and then we scan a transducer driven by a tone burst at a particular frequency across the surface. We then gather that signal that's transmitted through it, we amplify it, we use a gated RF peak detector in the analog mode but now we just do an A/D conversion on that and store it in our minicomputer.

Now what I'd like to do is show you what kind of results we get from that. I might point out that this is done in this manner so that we're simulating what actually happens during inspection as if there is a defect located at this spot. This is the kind of sound field that that defect would actually be illuminating.

Let's just spend a minute talking about this one particular case because it's one that we obtained in carbon steel -- I'm going to show you a whole series of these and we'll spend just a minute going over what actually is being presented here. What we've shown is an aperture in which this is a circumferential pipe like this so that this direction is

in the circumferential direction and this is in the axial direction. Okay? And the dimension here, this is 75 millimeters or three inches, the dimensions here are about 115 millimeters or about four and a half inches.

What we've shown then is ranges of amplitude, zero is the reference here in red, orange then is the 1 dB contour, the green is the 2 dB. There's two shades of blue in here at 3 and 4, then it goes to this kind of maroon color at 6 and a brown color at 10 and a black color at 14 and a white color then is greater than this -- 20 dB and greater.

So this is what happens when we go into a piece of ferretic (ph.) pipe that again has a 16 millimeter thickness. This is the kind of response that we got using a probe at one megahertz and had a diameter of one and a half inches. So this is looking straight down through it.

Now let's step through some of the other microstructures. Here is an example of a columnar grain microstructure material that I've shown you results of in the CCSSRRT study. When we do our zero degree profile through that columnar microstructure, what we find in contrast -- perhaps maybe give you a little bit of an idea -- the effect of going through this coarser material of course is to spread the sound field out. You've lot a fair amount of -- the coherency has started to spread out, you can see in particular the brown level is much, much larger. If you go into this

maroon color, you can see it has grown. Specifically you've seen probably a little more growth in this direction than you have in the transverse direction.

If we look at an equiaxed specimen such as shown here, when you propagate the sound field through this, you can see that in fact there isn't as much degradation occurring with regard to again the results obtained in the carbon steel. YOu can see in the equiaxed structure, there's not much difference.

If we now go to the next, this is a columnar and equiaxed microstructure, it's a specimen that we obtained from Westinghouse, and if you look at this you can see that there's a predominance of columnar material, as we would describe it, occurring on the upper zone of it and the rather coarse grained more equiaxed type structure occurring down here towards the ID. This is the circumferential direction and the axial view of the same thing and you can see still they've got long columnar grains in this direction. Down here we have rather large, what we call equiaxed grains, they're just large grains that have equal dimensions basically in X, Y and Z. And we classify those as being equiaxed. In this particular case you can see more of a trend from the columnar to the equiaxed. When we propagated the sound field through this specimen, the is the nature of results that we obtained. Now this is looking straight down on it. You can see here in this

particular case that we're getting a much larger smearing of the energy in the circumferential direction for this material versus what we had in the columnar -- excuse me, what we had in the carbon steel. But you don't see a real large enhancement of spreading of the energy in this direction as what we had seen earlier for this case here, the columnar material. So this isn't as bad as that pure columnar form with regard to dispersion in this direction.

Okay, this was a specimen that we obtained from Southwest Research Institute and it's a very layered type of microstructure. If you look at it you can see very definitive layers going through this. You can see a fairly complicated structure, you can see some dendritic structure down here that almost goes completely through all. In this zone here, you've got, you know, dendrites occurring and then it looks like it goes into more equiaxed phase. And as you go across here it's a very complicated type of structure. These are two axial profiles, this one across this end and this one across the other end. You can see on this end you've got again this dendritic structure in the upper part, some very large coarse grained type structures that we classified as being equiaxed on the lower portion of it. Over here, it's somewhat difficult, it's hard to define it, the structure even gets fairly small there apparently in certain zones. It's hard to actually classify this in terms of, do you call this a

columnar and equiaxed, what kind of description do you use to accurately describe it.

I'm going to show you a profile tha s gathered and that was gathered in this zone right in h One of the things that we will be doing and we did not ... a chance to do prior to this meeting, is to gather profiles as we move across the surface, to try to better understand what happens as you go through these various zones.

DR. SHEWMON: Does the interface itself, the circumferential interface introduce attenuation or --

DR. DOCTOR: In terms of going through it at 45 degrees, I would suspect one would never see those. Perhaps looking down there may be something about those that's related to, you know, the power spectrum, you may be able to see those and enhance them. Probably in general at the one megahertz frequency that you're using, they're going to be pretty transparent unless you do something really to try and emphasize that particular aspect in the spectrum.

DR. SHEWMON: Magnification is such that the columnar diameter is a millimeter or several millimeters?

DR. DOCTOR: I don't know if you can see this, this is basically an inch right here, this dimension right here is an inch. So if you go over here you can see that these are roughly about an eighth of an inch. If you go and look at some of these large structures like that, you're talking

things that are in the half inch regime. This zone right here looks like --

DR. SHEWMON: The wave length is a lot shorter than the grain size then.

DR. DOCTOR: Wave length at one megahertz you're dealing with about 250/1000 -- quarter of an inch, quarter of an inch wave length. So this is smaller but some of these other things are clearly larger than the wave length.

This is the profile that we obtained using a zero degree probe going through that, that specimen at one location that I showed you. It's very apparent here that we're starting to pull this energy out and it's almost completely filling up this entire aperture that was scanned, showing what I think is, based on this kind of structure, a breaking up the coherency of the sound field, you're starting to pull in other lobes.

What the sound field profiling does, it allows us to look at it in and ask the question as to whether or not one can get through this particular microstructure a coherent sound field which is needed, because that's what you rely on with regard to ultrasound to make all your decisions. If you lose that coherency, you've got nothing to work with in essence. And we're trying to understand what happens and whether or not we can improve on this by changing frequency if one, for this type of structure for example, dropped down to a

lower frequency, you very clearly may be able to improve that, but you don't have any way of quantifying it without going through this kind of procedure to understand that.

DR. SHEWMON: That sort of structure only shows up with centrifugally casting where they pour in a jerky fashion but not in say valve bodies, or do you know?

DR. DOCTOR: I guess I don't know enough about static casting microstructures to be able to answer that. I've heard tell rumors that in those you get grains that are incredibly large, much larger than what you see in the centrifugally cast process, but I don't know whether or not you get this kind of, you know, intermixing of different layers of dendritic and equiaxed type structures.

Well one of the ways to look at this and try and understand in addition to the sound coherency, is what happens attenuation wise, because the one thing I haven't shown you here is at what gain levels this information was collected at.

What I have here is a table and the only thing I want to focus on is over here on the relative attenuation. What I've shown you is these four cases in the same order that I just described them and what we have shown here then is in decibels per centimeter, the attenuation for the longitudinal and for an SV wave. And you can see when we compare things versus carbon steel, in the equiaxed we had like a .69 dB per centimeter on propagation and roughly slightly over twice that

or 1.5 dB per centimeter for the SV wave.

As you go to columnar, you can see that you get an increase in attenuation, you go to the mixed diffuse and you get a higher increase and you go to this mixed layered structure, this last one, and you can see a much higher attenuation. And this is due to the breaking up of the sound field. When you fill out this kind of a plot, you can see the rationale for what's happening is that you're breaking the sound field up due to a variety of different processes and leading to the attenuation. But what we're trying to understand from these is what kind of coherency can we get through this kind of material and this tells us that we're probably going to have to increase the gain considerably to penetrate this material effectively.

Now I had indicated that we had done some work on 45 degree L-wave. This is an example here in carbon steel. The plate is curved like this, the microprobe is sitting here and we're scanning it again. This is the circumferential direction and that's the axial direction there. You can see a fairly nice sound field here, a little bit of a break up is occurring here, but that's not really much of an alternation from being basically a perfect sound field.

Now on 25 degree L-wave going into the columnar material, you can start to see some changes occurring, if I can slide those to adjacent. What we've plotted, I should

point out too, is we're putting the sound field in at 45 degrees and things are set up very precisely to ensure that, the center of our sound field is right there at 45 degrees. In this particular case when we're going into columnar material, what you find is that the center part of the beam is skewed up slightly higher up around say 48 degrees. You can also see that there's been slight shi:t, there's a starred formation or what I'd call another lobe occurring down here when you're trying to propagate through the columnar material.

When you look at the equiaxed type material at 45 degrees in the L-wave mode, you can see -- you're still at 45 degrees basically, maybe it's skewed down a degree or two, but it's pretty close, but you can see that the sound field has broken up quite more dramatically.

When you go to the layered columnar and equiaxed microstructure, in this particular case this specimen was thicker. Okay? It was like 75 millimeters thick versus the 60 millimeters, and that's the reason that we had to adjust the angles occurring over here. But surprisingly for going through this particular structure, we've got a very coherent sound field quite frankly, better than what I'd expected based on, you know, results in the naught degree penetration. And looking at the columnar and equiaxed when we went to this layered structure, I'd expected it to be much worse than what we were seeing, but the coherency is pretty good in this.

When we go to the mixed rather than the layered structure, this is back to the same thickness, you can see a skewing here, probably down around 40 degrees with regard to the center lobe, plus you're getting another fairly strong response that's only six dB down, occurring down here roughly in about 15 degrees, which probably means there's some kind of a referred direction located in that.

Furthermore, since things were set up carefully you can see that this beam has actually been skewed off to the right. It should have been located, you know, in the center and you can actually see a skewing that has occurred in that direction, so that you would think your beam was located here, but the center of the beam is really located over there, so it's giving you a shift.

Well what conclusions can we draw from this? The conclusions say that the microstructure is very important to UT inspection effectiveness and that when you get into these more complicated microstructures they create greater inspection difficulties due to the distortion. And what we're trying to do is to understand that distortion so that you can still get a coherent sound field through with known properties and then be able to use that information to actually determine the presence of defects and use the information in a reliable fashion to talk about the properties that the defect had, specifically the size of it. But if you don't, the skewing in

effect, you're going to place things in the wrong position, and that's extremely important. In another year or so I hope we'll have all these answers and be much further along in our knowledge than where we are right now.

DR. SHEWMON: Before we get into that, you said something about increasing the intensity of the beam, to what extent -- there's a lot of scattering, you didn't use those words but I think that's what you meant.

DR. DOCTOR: Yeah, that's --

DR. SHEWMON: How far can the operator do that?

DR. DOCTOR: Well this is really what I was referring to. This is an attenuation measurement and the difficulty is is that as you go around, as I showed -- let me see if I can pull it up real quick for you -- in this kind of a --

DR. SHEWMON: I understand that but my question is one of equipment, not one of --

DR. DOCTOR: Sorry, I misunderstood. You mean can an operator just increase the gain to compensate --

DR. SHEWMON: Well you said gain and I thought power. The power is fixed and the gain he can control if noise is a problem, is that it?

DR. DOCTOR: Right.

DR. SHEWMON: What limits the amount of power he puts in, crystal?

DR. DOCTOR: Well it's that and what is the output voltage from the pulser that he's using. And of course, depending upon how you want to drive it, you can do things like drive it at a particular frequency with a tone burster, reduces your performance in terms of range resolution, but it gives you better lateral type spatial resolution.

I guess the real question is is you have to I think understand whether or not you can propagate a sound field through coherently if you up the power regardless of the fact -- you can increase the power as much as you want but all it does is pull up the grain by the same amount. It isn't going to improve your signal to noise ratio, it isn't going to give you a better inspection. What you have to do is be able to get the sound field through in a coherent fashion and then optimize the power so that you can work as effectively as possible to reduce the coherent scattering with the maximum signal response.

DR. SHEWMON: So presumably when the people come back or the word comes back from the field that there are castings in this particular plant which can't be inspected because we can't get a beam through them, it's something like this?

DR. DOCTOR: That's right. And I think, you know, the more samples we can get and we can understand those cases, we'll be able to determine what we can do and be able to go

out and perform --

THE REPORTER: Excuse me, I can't hear you over here.

DR. DOCTOR: I'm sorry. I think all this data, I find it in general rather encouraging. Looking at some of these sound field profiles, I would have expected them to be much worse than what they actually have turned out to be. I'm much encouraged that we can perform effective examinations on the materials if we can understand exactly what's happening as the sound propagates through these materials.

I think the results from our round robin exercise -- it doesn't show the problem is solved, but when I was initially doing this work, I quite frankly was very pessimistic that we would ever be able to perform effective examinations, and looking at this data and the frequencies of calls in a number of the defect zones, I was quite surprised that we got as high performance as we did.

The problem is clearly not solved, but I think there's a lot of hope there and I think that through some of the work that we're doing, and I'm sure what EPRI is going to report on later, we're going to increase our understanding and do a much more effective job than what has been done in the past.

DR. SHEWMON: Thank you.

DR. DOCTOR: I do have a few more viewgraphs talking

on the PISC III. This is Action 4 and it's called Round Robin Studies on Austenitic Steels, and it's given the acronym AST. I'm a co-leader of this work with Hans Herkenrath from ISPRA Research Center. What the AST Program does, it describes a program for studies to be conducted in terms of capability, parametric studies and reliability, and I'll define what these are in just a moment. The program includes wrought stainless steel as well as cast stainless steel, and the plan describes specimen sets, test protocol and analysis methods for actually conducting this.

The planning for this is underway, specimens are being acquired and defects are being implanted, that nature of thing, for actually conducting this type of very in-depth study.

The program has three different sets of study as I'll call them; one is a capability. The objective is to identify procedures that have the potential to detect and size defects and to discriminate between flawed and unflawed materials. These will be specimens that will be circulated around from laboratory to laboratory so that people will be able to use some of the evolving technologies that are in laboratories and are not ready to go out and be tested in more detail through what we call reliability studies.

The parametric studies are designed to complement both the capability and the reliability studies and they're

really trying to evaluate the effect of important material and defect variables such as microstructure, such as defect time, the effects of crown and counter-bore with regard to the cast and wrought structures.

The reliability study is designed to measure in-service inspection performance under realistic in-field conditions on realistic cracks and evaluate human reliability factors. This last one human reliability factors, I'll only comment there that a separate action designed to try and gather information on human reliability and we're interfacing with that particular task for the reliability studies.

So this is really trying to determine capability of potential techniques, this is trying to look at the question of reliability under actual field type of conditions. So in this particular case, what one would do is have several sites and bring the teams into those sites to go through an inspection such as what one would encounter when going to a plant and actually performing an inspection.

The kind of matrix are shown here for the three studies, to give you an idea. The capability studies will be relative small specimens, let's say maybe a foot and a half in axial length and circumferential length perhaps 8 to 12 inches. The kinds of defects that are going to be put into these will be fatigue cracks, thermal fatigue cracks and mechanical fatigue cracks. The F here is for fabrication type

defects. The A down here is for artificial sharp planr reflectors. This was introduced in the parametric studies as a result of the PISC II results, to do a comparison between those artificial sharp planr reflectors and other type reflectors. As I indicated, parametric studies are going to deal with things like base material, crack characteristics and weldment geometry.

You can see it's a fairly substantial number of specimens that are being compiled. When you're dealing with this kind of an international study, you'll have as a result of the PISC II, if you use that as a measure, there are like 50 teams from around the world that perform inspections on those four blocks. So that gives one a tremendous data base to use to look at effectiveness of applying various technology and gives one a yardstick for determining what reliability one can achieve. You introduce typically a number of teams that are using quite similar procedures so that you can actually look at the variation of applying a similar procedure by various qualifications and various -- and qualifications of personnel as well as equipment.

DR. SHEWMON: Fatigue fabrication is lack of filling in the weld or porosity in casting, or --

DR. DOCTOR: What we were planning for for our fabrication defects were primarily lack of fusion type of defects. That was felt to be the most important, particularly

because if it occurred let's say down near the root of a weld it could be extremely important from the structural standpoint. It's condition should be found during pre-service and if it's found in-service, it may warrant, you know, a repair. It was thought to be one of greatest interest.

The reliability study, there's two different, if you will, groups, cast to cast and the other group is cast to wrought and a wrought to wrought series of specimens. Most of these are going to be a pipe to a component, principally an elbow type of specimen.

So you can see there's a substantial number of specimens being put together for this. It will be a very large data base and extremely useful in quantifying and understanding inspection in these austenitic stainless steels.

So what's the status? We had a call for intent to participate that was sent out in the fall of '87. There was a very large interest that was shown from that, which -- the reason this was drawn upon to give guidances to how much interest there was, should we go forward with this particular round robin test, and there was a large amount of interest shown so things are moving ahead.

We plan to start testing in the fall of '88 and there will be a final call for participation that will be sent out this summer. There's a Board meeting next month and it will be concluded there and then the final draft will be

prepared and mailed.

A schedule has not been established because it will rely primarily on what kind of a final participation we get that comes in, then we'll set up a schedule when people can actually perform the inspections, because they have to work around a number of other requirements. We'll lay out a schedule I would suspect to run probably for one to two years and then of course there will be instructive work and reporting the results.

And with that, that wraps up all the material that I had to present. I guess I'm pretty much on time. Are there any questions?

(No response.)

DR. SHEWMON: Thank you. The schedule calls for a break at this point, why don't we take one.

(A short recess was taken.)

DR. SHEWMON: Fire when ready.

PRESENTATION BY ALBERT E. CURTIS, III

MR. CURTIS: Well it was June 25, 1986 that we last talked to you, the ACRS Subcommittee for Material Components about our joint Westinghouse Owners' Group and EPRI Coordinated Program on ultrasonic examination of welded joints in centrifugally cast stainless steel pipes of PWR main coolant loops. We also obviously have some statically cast components included in our sample set that you will be

seeing later today and that some of you saw before when you were at our meeting in Pittsburgh on June 25, 1986.

The background, I think Steve Doctor did an excellent job of setting the stage. It's almost impossible to inspect some of these configurations, although we now feel that we have a lot more understanding, and hopefully you'll see why later today that we can do a much better job than was done even just a few years ago on cast austenitic stainless steel components.

WOG and EPRI started this program back several years ago, both bringing to the party if you will the aspects we thought we both could contribute and make the best possible program. The program elements I'll review with you in just a minute. The major objectives we had hoped to accomplish was the optimization and quantification of flaw detection and sizing capabilities for the in-service inspection of main coolant piping; interface improved flaw detection and sizing procedure with automated inspection data processing systems; and then demonstrate the improved flaw detection, sizing techniques and equipment and test samples representing actual field conditions and indeed part of the demonstration would be to this group of individuals from the ACRS.

We are on track, we are at the final stretch of our joint coordinated program and we have we feel accomplished the major number of our objectives.

A quick review of the four phased approach we took of the coordinated program was obviously we needed to fabricate test samples. And so the first thing we wanted to do was to try to determine what type of matrix flaws we should include in these samples and how we should put these samples together, and that was a joint effort between Westinghouse and EPRI, the Westinghouse Owners' Group people and the Westinghouse personnel along with Electric Power Research Institute people, Gary Dau and Dr. Behravesh and others, and some consultants.

Sources of pipe material, we had some material that Westinghouse supplied for us to fabricate these test samples and of course we did fabricate the test samples and in the last meeting, Dr. Shewmon, I know that you saw some of these samples that had been fabricated and we were actually fatiguing them and thermally cycling them to produce both mechanical and thermal fatigue cracks.

Phase II was to improve manual technique development to look to see what we could do to improve the manual techniques that are being applied across the industry today. Westinghouse and EPR[illegible]ked together in establishing technique requirements and then we had the manual technique development and Rick Rishel from Westinghouse will talk about that from the Westinghouse point of view and then Dr. Behravesh will talk about that from the EPRI point of view

later on.

Phase III, automated inspection, we had to go through equipment evaluation and demonstration and that has been done here at EPRI and they have been doing that for quite awhile, not only looking at what we can do with cast piping but all piping, wrought piping, BWR piping, carbon steel piping, but to factor the cast [illegible] material into this program. So they've evaluated [illegible] demonstrated the use of the automated inspection techniques. Now they're integrating this type of approach into the inspection regime for cast material and Dr. Behravesh will talk about that. And then la[illegible] we hope to have some field trials with the automated tec[illegible]ues and Mohamad will address that.

And last but not least, and we are here today doing this, is to demonstrate the capabilities that we feel we have improved upon and developed. And that's a joint effort again between Westinghouse and EPRI staffs and then we hope to in the near future -- near future -- within the next four to six months, develop the protocol for howe we would go about in training and demonstration utilizing samples that have been developed in the program that has been carried out.

As far as what are the end products, I'll just review those for you again; there are 75 test samples which represent actual field condition, potential flaw types, flaw orientations, joint configurations geometry, materials for use

in establishing personnel training programs and in demonstrations, and then of course demonstrate and quantify flaw detection and sizing techniques and equipment for in-service inspection of main coolant loop piping.

Now obviously we hope to factor all this into an overall long-term plan and that's to not only demonstrate we can inspect this pipe but make sure from a fracture mechanic's point of view we can detect flaws before they become a concern. We also, as I mentioned to you last time, Dr. Shewmon, I have a personal ultimate goal and that is not the purpose of this meeting today but once we demonstrate we know what we're doing when it comes to inspection, we'd like to look at why are we spending a lot of time and money inspecting this type of material when there may be other more critical components that we ought to be spending more time and money inspecting.

So rather than, as I said last time, telling you I don't need to do it because I can't do it, I'm going to say I can do it but I really don't need to do it for the following reasons. For instance, I don't have a problem, literature says there isn't a problem and experimentation says there isn't a problem, so why am I wasting my time inspecting.

We are doing this today, we've been working on this and I think you will be very pleased and I hope Dr. Doctor is pleased also with what he sees that we've done. And then of

course we've gone through and shown a leak before a break is applicable for the cast austenitic stainless steel material and we are -- we have completed and are working on this thermal aging question from Westinghouse Owners' Group point of view, which we will factor into this overall question later on.

That's my personal and Westinghouse Owners' Group ultimate goal. That may be down the road quite a ways, but that's where we hope to be heading.

So without any further ado, unless there's some questions for me personally, I'd like to introduce Don Adamonis, who will be speaking to you about the fabrication of the samples. Then Rick Rishel from Westinghouse will talk to you about the manual development work that has been done and then of course Dr. Behravesh will talk about the EPRI work and the automated development work that has been going on.

Thank you. Don.

PRESENTATION BY DON ADAMONIS

MR. ADAMONIS: Thanks, Al. Does everyone have copies of the set of overheads we'll be using here?

I'd like to speak briefly on the sample set that was developed under the Owners' Group Program. As Al mentioned, one of the deliverables from Westinghouse under this program was to provide a set of 75 crack test samples. Those samples have been completed, we've completed the fabrication and they

reside here at the NDE Center and you'll be able to see them this afternoon.

That test sample set represents a variety of material combinations. We varied some of the welding techniques, we've represented a number of joint geometries, we've included various defect types; thermal, mechanical, fatigue cracks. We've varied the defect sizes in terms of depth and length and the location along the length of the weld.

These samples were fabricated from nine ring weldments representing again different geometries, pipe to elbow type configuration. We've also included inlet and outlet nozzle geometries that include the bi-metallic, tri-metallic welds.

The overview of the parameters that we varied -- that came out pretty well actually -- we have a designation for the various pipe to elbow configurations. If you look at the designation for the first column, APE, it's a pipe to elbow weld, centrifugally cast pipe to a statically cast elbow welded with an automatic process.

Second set designation MPE, same material combinations, these were welded manually to represent the field weld.

The third set designated OPE, we varied the pipe material. This is some of the older vintage cast pipe where

the microstructure we'll see as we go through is more columnar in nature. All of the pipe microstructures that we look at are of the mixed variety, not necessarily layered but the mixed variety that Steve Doctor mentioned. This particular vintage of pipe demonstrates more of a columnar structure than equiaxed.

The FPE designation is a forged pipe. Again we varied the pipe material here, this is a forged pipe to represent those plants where forged pipe materials were used.

We've mocked up the pump outlet pipe weld where the inspection problem is further complicated by some overlay that was applied to smooth the transition, and I'll show some of these geometries.

And again the inlet and outlet nozzle configurations. We represented a number of different heats of piping material, again automatic versus manual welding processes were included in the matrix and the next to the last column on this overhead shows the distribution of types of cracks; mechanical fatigue cracks versus thermal fatigue cracks and I guess in 1986 you were able to witness in the labs in Pittsburgh some of the cracking process, so you're familiar with the process that was used for introducing the defects.

DR. SHEWMON: The forged pipe is plate that was then forged into shape?

MR. ADAMONIS: It's really an extrusion, it's from a large sheet and it's actually an extruded process, an extruding process. We call it a forged pipe essentially, but you'll see a rather fine grain structure as we go through some of the macrographs that we have in this package.

MR. CURTIS: By the way, Dr. Shewmon, based upon the comments at the June meeting in 1986, we did go through and categorize all the microstructures of these samples, so we have an accurate assessment of those. And that was done after that meeting based upon the comments of the Subcommittee. That has been done.

MR. ADAMONIS: After completion of an individual ring weldment, we sectioned the ring into various samples where the circumferential length varied from 8 to 10 inches, the axial length of the specimen varied from 18 to 24 inches. We would introduced a stress riser in the form of a notch whether we introduced the cracking mechanically or thermally, a notch was included. We would go through the cracking process and based on some calibration data that we had done, calibration and sectioning early on a number of cycles could be correlated with actual crack depths. So we're looking at samples that vary in length from 18 inches -- foot and a half to two feet -- 8 to 10 inches wide, that had cracks in them anywhere from one quarter of an inch to about one and two-tenths inches deep to -- and lengths of cracks about

eight-tenths to three and a quarter inches.

Welds in the primary loop which are represented by the samples are highlighted on this particular slide. We've mocked up the inlet and outlet nozzle to safe end welds and the safe end of pipe welds in the same mock-ups. If a particular plant were to have main loop isolation valves, there are samples in this set that mock those particular welds up. The elbow -- essentially all the elbow to pipe welds in the plant are mocked up and I guess the last area that we have also been able to cover is the pump to elbow weld.

DR. SHEWMON: Do many plants have isolation valves? That's in the primary piping, isn't it?

MR. ADAMONIS: In the primary loop. I don't think there are many, I can only think off the top of my head of about three.

DR. SHEWMON: I thought the Code prohibited it but obviously it doesn't.

MR. CURTIS: There's about three I think. There's about three or four plants with isolation valves installed in the primary loop. Most plants are putting nozzle bands in their steam generators so they can refuel and still work on their generators. But some plants, I think there's three or four of all the plants, that have the isolation. There's not a large number.

MR. ADAMONIS: But when you look at the various

material combinations that have been included in the program, the welding types and the joint geometries that we've managed to cover, we've covered essentially every area that you need to look at from an ISI point of view.

MR. CURTIS: No one is running with them though. I mean no one runs with them, they're issues during shutdown conditions, so you can refuel and work on your steam generators at the same time.

MR. ADAMONIS: Here are some sketches and they're illustrative of the joint geometries, joint configurations that we've managed to duplicate during the sample fabrication process. You can see on the pipe to elbow series, on one series we've primarily concentrated on representing the joint configurations, generally from earlier plants where the thickness of the elbow was thicker by a fairly significant margin than the pipe itself and the transition from elbow thickness to pipe thickness was made across the weld, making a rather difficult joint to inspect.

We've also in all cases -- and again these are illustrative -- but we've maintained as well as we could duplicate the counter-bores and ID surface geometry such that when performing inspections of these particular samples, the operator would be afforded the opportunity to try to discriminate between ID geometry and real defects, as operators are given that opportunity in the field.

The pump outlet to pipe is the one that I mentioned earlier where there is an overlay on the pipe side to take care of a transition that exists between the pump nozzle thickness and pipe thickness, and for the safe end wells, the outlet and the inlet safe end wells, all the material combinations are duplicated, the welding processes were duplicated as was used in the field where you have an inconel butting on the face of the 508 nozzle material. The ID of that nozzle is clad with stainless steel. We have an inconel weld to a stainless safe end and then the safe end is welded to the pipe in a similar or identical configuration for the outlet nozzle mock-up.

DR. SHEWMON: Now there have been cracks at nozzle transition, pipe transitions but only in BWRs, or have those been found in Westinghouse plants too?

MR. CURTIS: We have not found any in Westinghouse designed PWRs to date.

DR. SHEWMON: Okay. Let's hope it all has to do with the coolant chemistry.

MR. CURTIS: We hope.

MR. ADAMONIS: To finish up, just a few examples of the types of microstructures we found in the materials we've used for fabrications plants and we'll be concentrating here primarily on the centrifugally cast materials but you will also have an opportunity to see the microstructures of the

statically cast material as well.

This is a 360 degree ring section from a typical piece of pipe that we've used. I have some other viewgraphs that show this a bit more closely but we looked at the macrostructure, if you will, and we were looking at structures that are primarily, and throughout this program you'll find that we're looking at the layered -- not really the layered, but the mixed microstructure combinations that Steve talked about. We see equiaxed and we see columnar together, but we don't see it in the step fashion on the layered material that you talk about.

MR. WARD: Why? Is that because of the casting technique or is that something --

MR. ADAMONIS: It probably has something to do with it. The cooling rates, and I think it's probably not the worst case from an inspection point of view but it's not the best case.

DR. SHEWMON: What is the worst case?

MR. ADAMONIS: The worst case based on the data that we've looked at so far is this very rigidly layered mix.

DR. SHEWMON: Okay. When you said it isn't the worst case, I wasn't sure what "it" was. Go ahead.

MR. ADAMONIS: As you can see, the sections give us a bit of a close-up on this ring section that we looked at. We do have a microstructure that is primarily columnar for the

outer say two-thirds of the wall thickness and we go to an equiax zone on the inside. And as one goes around 360 degrees around this section, you see pretty much the same behavior.

Now just to move on to some individual test samples, we're looking at a test sample here in the APE series where welds were made automatically, they're pipe to elbow welds. On your right you see the statically cast fitting which is primarily equiaxed with some tendency toward columnar at this point.

And on the lefthand side we're looking at centrifugally cast pipe from a heat that's identified 156529. Now in this particular section of pipe, it's almost primarily equiaxed with some tendency -- some slight tendency toward columnar on the inside.

DR. SHEWMON: How much of a signal does the operator get from that kind of a transition in microstructure between the --

MR. ADAMONIS: You know, in the angle beam testing that we've done -- and we do primarily angle beam testing -- you don't see a definite reflection from that transition.

DR. SHEWMON: No, I meant the weld metal.

MR. CURTIS: He means the weld interface.

MR. ADAMONIS: From the interface? Not a great deal in this particular case. Where you see it most, where the interface signal in the weld and base material appears to be

most -- or a significant factor is on the bi-metallic, tri-metallic welds. On these particular welds it doesn't seem to be a factor. You need to contend with the geometry on the inside of these to some extent, but the biggest problems on these types of welds are the access limitations that are due to this OD configuration that you see right here. And in fact, we were rather successful, Rick will -- I don't want to steal Rick's thunder, he'll go into the examination results -- but in many instances we were able to penetrate the welds and see what I'll refer to as far side defects, the defects were placed on the pipe side and on the fitting side.

The same material configuration in terms of the pipe and the elbow are represented here. This particular macrograph represents a manual weld of these two sets of materials.

Now the next overhead, we'll see some of the older vintage pipe and you can see in this particular case, we do see more of a columnar structure on the centrifugally cast pipe. So you can see we do have a variety of microstructures represented in the heats of cast pipe material that we used. And even on the statically cast elbow side, there's some elongation of grains that you see in this particular case. So this might start to address the question you brought up with Steve earlier about what effect does cooling rates have on the microstructure of some of the statically cast products as

well. We didn't intensively go into that study, but I see from this particular overhead some elongation there that is likely to have something to do with cooling rates.

This particular macrograph is from one of the samples that includes the forged pipe material. You see a rather small equiaxed zone on the pipe side. Again we used the term "forged pipe" but it's actually extruded.

The pump to elbow weld is represented by this next overhead. We're looking at -- you can see in this particular zone the weld overlay that's used to accommodate the transition and thickness between the elbow and the pipe material and I guess based on some of the experience in the BWRs we can see how these types of overlays may further complicate the inspection problem on an already difficult situation but that particular configuration is also represented in the sample set.

And then the last few overheads I have to show are the safe end configurations where we have the -- this particular overhead is an inlet nozzle where we have the 508 material and we're looking at the weld to the statically cast elbow in that particular case.

In this case we're showing the entire configuration of an outlet nozzle safe end where we have the 508 material that's clad, the inconel weld to a stainless ring and then the automatic weld directly to the centrifugally cast pipe.

So just an overview, at your request from the last meeting, we went ahead and looked at the macrostructure, if you will, on all the samples and I believe we'll still be able to see some of that. And we do have -- feel as though we have a wide range of structure included in this sample set which makes it a good set to go ahead and proceed with our technique development and verification. And Rick will talk about some of the results we've been able to obtain in our manual studies of these samples.

DR. SHEWMON: Thank you.

MR. ADAMONIS: Thank you.

PRESENTATION BY RICK RISHEL

MR. RISHEL: What I'll be going over is the manual inspection results of this program, which is Phase II of the program.

In terms of the program status itself, the manual inspection program is complete. This included a literature search as well as manual examination program using various transducers and test instrument combinations on these 75 crack samples. In this particular program all 75 crack samples were examined with various, as we said before, various techniques, transducers and equipment. The final report on this particular inspection results will be completed by the end of March. This final report will include the literature search, a synopsis of that; manual examinations and results;

conclusions of the program; some recommendations or some things that I found during the program which I think is relevant and should be used to help develop some manual inspection procedures, some things to look out for in these particular procedures.

DR. SHEWMON: If somebody wanted to find a copy of that final report ten years from now, where could they do it? Who will get one, is this all confidential? No libraries except what?

MR. CURTIS: Well obviously all the utilities will have it and it would be our intention to provide that to -- I'm sure the Regional Inspectors would have it available to them.

DR. SHEWMON: So it would be available at the plants or in connection with the plants where it was germane?

MR. CURTIS: Oh, yes. Hopefully it would be documentation for widely used procedures on the material that we're inspecting, so there should be a file.

DR. SHEWMON: All right.

MR. RISHEL: And the last thing the report will include is a brief summary of results from the vendor qualification program that Union Electric did on these particular samples -- on a group of these particular samples.

In terms of improvement of inspection results; basically it involves six factors. These factors are not

unique in the NDE industry but they're just more important when you're talking about main coolant loop material. It is a more difficult examination, it's not as easy as carbon steel itself, so you have to put more emphasis on all six of them.

These include knowledge of the fabrication materials, what kind of material you're looking at, is it mixed, is it equiaxed, is it rod; adequate surface preparation, the best technique in the world won't find anything if you can't have double side access in some cases or you have poor surfaces to exam from or you don't have adequate coupling for your UT crystal. Knowledge of the nature of defects, what kind of defects could there potentially be out there, are they branched, where are they located and such as that. Additional operator training and experience, providing the operator the opportunity to look at crack samples with his procedure to gain confidence for himself.

Five, understanding sound beam propagation mechanism, beams distortion, beam skewing, understanding those phenomena.

And six, proper selection of ultrasonic test parameters and procedures, which in a way is associated with the other factors. I'll be talking to you in a little more detail on each one of these particular factors.

In terms of the knowledge of fabrication materials; what's generally known, the fabricator, year of fabrication,

fabrication process, material specification. These are essentially known for the fabrication materials. They're nice to know but they don't tell you important information for ultrasonic purposes.

What you need to know is the volumetric metallurgical characteristics. Is the microstructure columnar, is it mixed, is it coarse, equiaxed, fine grained. You don't know the actual thickness as well as the actual material velocity, all which affect the UT or the ultrasonic testing.

Problems associated with determining these unknowns: OD is typically the only accessible surface and there's a full range of volumetric metallurgical possibilities out there which are not all known.

In terms of samples which I don't have down there, there are increasingly a number of samples becoming available with these different microstructures.

Solutions to the knowledge of fabrication materials; there are programs in development, specifically funded through EPRI, on determining these metallurgical characteristics and developing ways of compensating for their effects in terms of angles, frequencies, things such as that.

In the particular program that I went through I made four calibration blocks of the material for these -- that represented some piece of material for the individual samples.

There was differences, surprisingly enough even in the forged pipe, when you went in two 180 degree directions on the pipe, the angle shifted from -- by about three to seven degrees. So centrifugally cast isn't the only thing that can raise some questions in terms of your angle beam. You have to know even on forged pipe what can happen. It was surprising from the microstructure, you couldn't see why it was affecting it but there was definitely a shift when you turn the transducer around 180 degrees.

So by having knowledge of the fabrication materials, you can compensate for your examination and perhaps locate your defects more -- better and improve your inspection.

In terms of the knowledge of the nature of defects, the potential service-induced mechanics, these were essentially provided by EPRI with their particular program, thermal and mechanical fatigue are potentially -- are potential mechanisms. Stress corrosion cracking, a very, very low probability of that. This is why we chose to make the samples of thermal and mechanical fatigue defects.

How are these important? Well it's nice to know from an ultrasonic point of view the size, position of these, the nature and the orientation of these particular cracks, whether they're axial or whether they're circumferential.

The next viewgraph shows a few of the typical cracks involved in this particular program. The top portion shows

thermal and mechanical fatigue cracks. As you can see -- you can't see it much on the right upper one, but the left upper picture shows a thermal fatigue crack in this one particular sample. As you can see, it's highly branched, there is an axial component coming out below it and there's a series of axial type cracks and it's also very, very meandering. Whereas in the mechanical fatigue cracks down below, essentially straight, no branches involved.

In terms of operator training and experience, the operator should understand refracted longitudinal waves. They're not the same as conventional shear. There's different modes going on there, reflections, mode conversions of the ID, things that the operator must understand and must be fully cognizant of.

Understand material effects on beam propagation, knowledge of some of the programs that are out on -- like Dr. Doctor's on the beam profile as it goes through the microstructure. Knowing about beam skewing and beam distortions.

Understanding the limitations of the particular event in terms of sizing, locating problems that may exist or perhaps can be compensated for after detection of indications.

And probably most importantly, experience at practicing UT procedure on cracked samples. Many of the operators haven't seen cracked samples and it's very difficult

for them to recognize the echo-dynamic patterns that exist unless they see something like that. They can also build confidence in their procedure and themselves also by looking at particular samples with cracks and finding out that they don't typically look like side drill holes or notches in most cases.

And lastly would be a demonstration of such skills, where they might have blind tests or whatever. But I believe in this particular case that practicing on cracked samples is probably the most important in terms of operator training and experience.

Understanding the sound beam propagation mechanism. Here you have beam distortion which is essentially disintegration of the beam cross-section. You may have beam splitting, two beams at perhaps different angles or positions, as Dr. Doctor showed. Beam skewing, you have a deviation of the beam from predicted. These are all effects, they could occur individually or in conjunction with each other.

And lastly, the selection of ultrasonic test parameters and procedures. In the inspection program that I went through, I must limit it because I'm basically the only one that did the examination so we don't have a round robin study or anything like that. What I tried to do was work through the back door per se, take the UT technique, I knew where the cracks were, try to develop a sensitivity based on

those cracks and more or less work backward in the operation.

In terms of forged stainless steel components, I found that false echo and transmit/receive probes, shear weight probes, 45 and 60, were very effective. All thermal and mechanical cracks were detected getting up to signal to noise differences of 20 dB or greater.

The better detected cracks were the near-side cracks. In other words, in the forged pipe itself looking from the forged pipe. The worse case were the far-side cracks. As you would expect, you get more noise associated with that because now you have a shear wave going through the weld into the, in this particular case a statically cast forging. The cracks though were detected, you did have to put up with the interface problem there. There you do have a continuous signal from the base metal to statically cast elbow interface.

In terms of reporting sensitivities in this particular case, if you looked at the signals from the cracks with respect to side drilled holes and notches, 50% DAC will not find some of the cracks, you had to go further down in reporting levels. In fact, for the false echo 45 degree, I think it was something on the order of 12 dB below the side drilled hole response that you had to go down to in order to detect all cracks. And this was an average value. So there was some above and some below. Most of those that required

the extra sensitivity were again those on the far side of the weld during the statically cast elbow.

In terms of lengths and depths for the forged stainless steel components, length sizing using 50% -- I used 50% half backs which is close to the 50% DAC as used in the field, basically undersized in all cases.

But in this arena you have the capabilities of doing more substantial dB drop sizing, down to 12 dB, 14 dB. You can get down further. The high signal to noise ratios of 20 dB allows you to do this.

In terms of depth sizing, fracture to fracture would probably be used in this case. I didn't try it, I limited myself only to dB drop and depth in terms of dB drop or amplitude drop again is undersize typically.

As I said before, on the forged, I did get an angle shift going from one axial direction to the other of 3 to 7 degrees, so this should be looked at. And you must know -- granted you're on forged pipe and you think well I'm going in at a 45 degree angle, well it could be a 42 or a 41, so you have to know your angle of that material.

THE REPORTER: I'm sorry, I can't hear you back here.

MR. RISHEL: Oh, I'm sorry. On centrifugally cast and statically cast stainless steel components, shear wave is really impractical. Due to the literature search I

concentrated basically on 45 refractor longitudinal waves. The ones that worked the best were the 45 refractor longitudinal waves frequencies of .75 to one megahertz. These are transmit/receive units and they were focused near the ID surface. They were successful in detecting both thermal and mechanical fatigue cracks although they did not detect hem all.

The biggest problem, and if you remember the previous presentation on the POP weld was the overlay side of that particular weld where there was a weld overlay on the pipe side. Inspecting from that side gave us the worst results and that's basically what dropped most of the transducers in terms of their percentage of detection.

I found that the better detections were gathered from the statically cast side of the weld. The .75 megahertz --

DR. SHEWMON: Does that mean where the defects on the statically cast material were easier to detect than those in the centrifugally cast, is that what you're saying?

MR. RISHEL: What I mean by that is the -- I'm scanning from the statically cast side, so all exams from the statically cast side were better than those exams that were from the pipe side or the centrifugally cast.

DR. SHEWMON: but that would have been true if you had started from the centrifugally cast side too. Then the

cast would have been easier -- the centrifugally cast defects would have been easier to find?

MR. RISHEL: No, this includes both far side and near side welds. So when I say all examinations from the statically cast side I'm talking about transducer locations, not crack location.

DR. SHEWMON: You've also said that it's easier to look on the near side and not the far side.

MR. RISHEL: That's correct, in the forged.

DR. SHEWMON: I'm not sure yet what you're telling me about the statically cast material, when that's -- whether that's always easier than the centrifugally cast material. Is that a fair statement, easier to find the cracks?

MR. RISHEL: In this particular case, yes, I found it much easier.

DR. SHEWMON: Okay, fine.

MR. RISHEL: Where I talk about the near side and far side, I should make this point, was in the forged stainless steel, I found that there was a difference.

In terms of looking at the attenuation from the statically cast -- when scanning from the statically cast side or the centrifugally cast side, there wasn't really a distinction between signal amplitudes, whether the crack was on the near side of the weld or the far side of the weld.

DR. SHEWMON: Okay.

MR. RISHEL: Also using this particular unit, it seemed that the mechanical fatigue cracks were more difficult to detect in this particular case.

DR. SHEWMON: More difficult than thermally?

MR. RISHEL: That's correct. But as I said before, the attenuation or the level of response were more or less the same.

In terms of just a quick percentage of the number of cracks that were found with respect to the total crack population, on the statically cast stainless steel using a .75 megahertz two element unit, about a 94% inspection -- it was able to detect 94% of the cracks in the blocks. Whereas for the centrifugally cast it averaged around 87%, so they're relatively close.

In terms of the responses with respect to the notch calibration, the notch in the calibration block, they were well within the 6 dB reporting level.

Okay, the safe end nozzle welds, in this particular case I primarily emphasized ID examination. This particular weld is accessible by reactor vessel inspection tools, so I looked at it from the standpoint well we should apply the best technique that we know is available. So I applied a contact 70 degree L transmit/receive, two megahertz unit and found that all cracks in the safe end nozzle welds were detected, getting signal to noise differences of greater than 27 dB, very, very

little noise, that's typically associated with bi-metallic welding.

Again we're talking about in terms of using a 6 dB drop technique for link sizing and underestimation of size, but the 27 dB signal to noise difference gives you the opportunity to go down further to 12 dB, 14 dB. In this particular case 12 dB performed much better for sizing the lengths. And depths, again a 6 dB underestimated -- typically underestimated the size.

In this particular case I would recommend crack tip sizing from the ID probably could work but you may have a little difficulty with the bi-metallic weld and seeing some noise from that interface.

Some of the things that I'm recommending -- a lot of it may be opinion, what I learned from this program. In terms ofl probes, the dual element probes, 45 degree longitudinal dual element, one megahertz probes are large, they're roughly two inches by two inches. That's a very large footprint which requires a large surface prepared area on the pipe or the elbow. Because of its large footprint, any surface irregularities could cause coupling problems, so liberal use of couplant is necessary. And you should watch out on the way this couplant is applied because I found that if you don't have couplant under the center portion of the beam, you don't see the crack, whereas if you do have it on the center portion

of the beam you do see the crack, but the noise level on the screen has not changed. So it's something that has to be watched for in scanning blocks or in the field itself.

In terms of test sensitivity, side drilled holes and notches are sometimes not sufficient when you're talking about a 6 dB drop technique. You have attenuation losses perhaps due to the differences between calibration block and the component, perhaps within the component itself. I found that the best method was just to run at a 5% to 10% noise level on the screen, record things that are greater than two to one and have some length to them. If a crack is there you're going to see it. If it isn't and it's in the noise level, then you won't see it. A manual operator cannot look into a noise level and reliably see something in there. It either has to appear above the noise level -- that's when you'll find it. You may increase the number of reflectors that have to be evaluated but your probability of finding a defect increases.

And again I come with the hands on training. I must emphasize this because some of the operators I now, and there's operators out there that just have not used procedure on crack samples. They should be trained on these particular samples, let them look at them, let them see the echo-dynamic responses from geometrical reflectors, metallurgical reflectors, cracks, side drilled holes, notches and see if they can see the difference. Sometimes you can't see the

difference between them.

In terms of sizing methodologies, amplitude drop are not totally sufficient for depth but for length they are. Although in the forged samples and using the contact methods from the ID, you can go to smaller dB drop or greater dB drop techniques. In terms of cast pipe or statically cast and centrifugally cast pipe, you really can't go down more than 6 dB because you're talking about signal to noise ratios on the order of 6 to 9 dB. So once you get a crack signal that gets near the noise level, you have a very difficult time reliably telling which one is the crack and which one is the noise.

Since -- but the lengths are a better estimation than the depth, although there is a tendency for undersizing to perhaps compensate for this.

In terms of depth sizing though, perhaps we may be better off just taking a length to depth ratio. We make blocks in the laboratory to be a certain depth based on the length. If you can assume a length to depth ratio in the field where you know the length better than you do the depth, perhaps this is the best way of sizing such as this until more advanced techniques such as automated systems are available.

And lastly automated data recording, processing and analysis systems. I think this is probably the way to go in terms of providing further improvements, greater signal to noise ratios, greater than the manual techniques. Some kind

of processing perhaps to filter some of the noise out, some analytical software will aid in further improving the results over and beyond the manual techniques.

And this leads me to my last viewgraph where we're basically looking at the future improvement in inspections of main coolant loop piping inspection. Manual techniques are available which can find cracks, thermal and mechanical. If you want to go further and perhaps find smaller cracks or you want to improve the signal to noise ratios then you have to go to the last segment here which would be automated data recording and processing.

And I might just want to add a few comments on the results of a vendor demonstration program that Union Electric of St. Louis, Missouri, put together. They brought in some different vendors to look at eight particular samples that we shipped out to them I believe last year sometime. They brought in vendors, Westinghouse reviewed the results. We didn't know who the vendors, that was kept from us. Of the eight particular cracks there were three particular groups that detected all of them. These were masked tests so that again emphasizes the fact that manual techniques can work if applied properly looking at all the parameters involved.

DR. SHEWMON: Could you help me on what -- what I'd like to talk about some is the spread of materials out in the field and the degree to which your results would depend on

that. There was -- there apparently is some test that must -- presumably is run by the licensee on new piping when they come back to the NRC and talk about what inspections they will do. And at least some of this -- and the Braidwood-Byron set was e that sticks in my head. Word came back and said basically we can't do an inspection because we can't get a signal through, and this caused waves for awhile.

Can you help straighten me out on what I do remember or should be saying about what is the test that the NRC requires the vendor or licensee to run and what fraction of the plants do or don't pass this and then where are we, what can they do if it doesn't?

MR. RISHEL: One, I don't know what tests the NRC requires be performed. I know they've done in the past fuel work based on zero degree L, whether sound can get in the material, based on a straight beam.

DR. SHEWMON. Can somebody help me? Maybe I have my story mixed but I didn't think so.

DR. BEHRAVESH: We have included some presentation on some of those tests of at least what we did at Braidwood.

DR. SHEWMON. Okay, it was the Braidwood site?

DR. BEHRAVESH: Braidwood site. It was work that was done at the Trojan site.

DR. SHEWMON: And these were particularly hard to inspect, is that why you got involved, or --

DR. BEHRAVESH: We were asked to go in there so it is correct that there was problemmatic areas.

DR. SHEWMON: And what standard test or survey of the piping then brought this to light? Was this something that is done on each class of pipe when it comes into service or why didn't we ignore it and go on? Yeah?

MR. LANCE: Maybe I can help you a little bit.

DR. SHEWMON: Would you identify yourself?

MR. LANCE: Oh, I'm sorry. My name is Jack Lance. We had during the licensing of the Seabrook stations requirements to show that we could inspect certain piping systems or ask for waivers against those inspections. It was pretty much accepted that the ferretic steel and the wrought stainless steel systems were not a problem and therefore we didn't have to do any demonstration, but on the cast stainless steel inspections we had to develop a program within the licensing arena or for our licensing submittal and then successfully demonstrate that we could inspect the cast stainless steel main coolant piping to some satisfactory level. It was not Section 11 criteria but I believe we finally settled on something that was being able to detect something on the order of 30% through-wall block or crack.

DR. SHEWMON: And how do you do this in unflawed piping?

MR. LANCE: Well we had some folks from PNL come in

as consultants, a group of them, I think approximately 12 or 14 NRC folks and the people from PNL came in with standards or with samples. One in particular that had an equiaxed structure on one side and a columnar structure on the other. And the inspectors and the techniques were blind -- I don't -- I guess they were blind tested, it certainly wasn't a qualification test.

Then we went out on the plant and we showed that we had similar attenuation on things like counter-bores, weld roots, both through angle beam where we could get it and straight beam attenuation. And we convinced ourselves as well as the regulators that we were involved in a program of similarities.

DR. SHEWMON: Is this something required on all new plants?

MR. CHENG: Yeah, on --

DR. SHEWMON: His name is Simon Cheng.

MR. CHENG: About four or five years ago I think we start requiring those demonstrations for the NTOL plants. I think what Jack was talking about was Seabrook, one of the NTOL, including the Braidwood. What we had done at that time is we required the licensee, the applicant, to demonstrate on their pipe that at least they can penetrate through their pipe and then get back reflection and perhaps, as provided by PNL, they can detect flaws of mechanical fatigue or maybe thermal

fatigue. We considered that one is acceptable because in future certainly they can penetrate the pipe compared to some of the older plants where they cannot penetrate the pipe.

DR. SHEWMON: And what fraction -- over that five year span, what fraction of the pipe have you had to grant waivers through because they couldn't go through it?

MR. CHENG: I think they went through almost every one. I couldn't answer how many plants we granted waivers.

DR. SHEWMON: But we don't know -- it wasn't 90% but was it 10% or --

MR. CHENG: I think most of them could demonstrate.

DR. SHEWMON: Okay, all right.

MR. RISHEL: Just to add, some of that demonstration is done by looking at counter-bores and things such as that, using the angle beam but in not all places you can detect counter-bores, so sometimes the angle beam is not useful in determining whether you can get through it or not because you don't have a reflector on the back side. And that's where there's some difficulty. Even zero degree sometimes can be a little -- if you don't have non-parallel surfaces or something like that, but in most cases a good angle beam examination to determine that would be to look for counter-bores.

DR. SHEWMON: Okay, thank you.

Mohamad.

PRESENTATION BY DR. MOHAMAD BEHRAVESH

DR. BEHRAVESH: I am Mohamad Behravesh from EPRI. I have a lot of sympathy for this gentleman sitting here, that he can't hear. In a different life I used to do something similar to what he does, so for most part I feel I must talk to him.

DR. SHEWMON: Okay.

DR. BEHRAVESH: But in any event --

MR. CURTIS: It's the Southern accent that gets him though.

(Laughter.)

DR. BEHRAVESH: Some four years ago when we started on this activity, it really was presented to us as something insurmountable, and in the process we have really been quite successful in meeting the challenge for the most part and in fact been able to advance our understanding of the fundamental processes that take place here.

But more than that, we have been successful in trying what we have learned in the field. As my presentation continues, you will see examples of that. But before I get into that, I want to give you a background on what EPRI's overall program dealing with cast material includes and what it involves.

The program is that of a component reliability and that's managed by Gary Dau. The questions are very general. I'll go over them. The general questions are when and under

what conditions do the properties of cast material make it potentially limiting to be used as a piping material in a plant. For example, what are the flaw sizes of concern and establishing in-service inspection requirements. As Al Curtis mentioned earlier this morning, there is a number of people who really believe that the inspection requirements may be too stringent as they are currently.

Also, identification and possible extent of in-service piping degradation mechanisms. And finally, coming up with answers to are there adequate and demonstrable NDE techniques for inspection of this material.

The remainder of the talk today will concentrate on the last bullet. I want you to be aware of the other bullets because of the work that's being done on the structural mechanics program.

But, several presentations have been made this morning, I think it is a good place to present to you at least what our understanding of what light water reactor experience is with this type of material.

Of all the information we have gathered to date tells us that this material has been basically trouble-free in the PWR service. Both cast stainless steel as well as -- centrifugally cast as well as statically cast components are susceptible to long-term ductility loss. That has not been a secret, but the other thing is that even aged pipe material

has been shown to be tolerant of significant flaws under design loading. This is all information that has been gathered. More importantly issues of stress corrosion cracking has been raised, the information that is given to us is that intergranular stress corrosion cracking and interdendritic stress corrosion cracking really are not a likely damage mechanism in cast material under PWR operating conditions.

And finally, flaws in cast material and welding defects are most likely areas of fatigue initiations and from the limited information that exists on fabrication of this material, we'll see that weld repairs during manufacturing and installations are (1) very common, but more so the control and documentation of these repairs are quite scarce and not adequate.

I would like to go and present to you some of the elements of the programs we have at EPRI that will address the inspection of cast material.

MR. WARD: Mohamad, could I go back to your last comment?

DR. BEHRAVESH: Sure.

MR. WARD: That weld repairs are common and they're not well documented. What's the significance of that?

DR. BEHRAVESH: Well if you were to look at a place that may be most likely to degrade or to have a flaw

initiated, perhaps it would be in these repair locations.

MR. WARD: Is there some experience that indicates that or is that just common sense?

DR. BEHRAVESH: I think combination of both.

MR. WARD: But I mean you've said that --

DR. SHEWMON: These are in static castings?

MR. WARD: Yeah.

DR. SHEWMON: Well static castings often have porosity in them and you chew out what you have to to replace it with sounder metal, but if there was for example more porosity there, that could be a place where a fatigue crack, except they're so over-designed you wouldn't expect it, but the reason they did repair there was because there were weaknesses.

MR. CURTIS: We have not experienced any flaws that led to leakage in any of these repair areas.

MR. WARD: Well that's what I was driving at. Your first comment is, you know, that you've had trouble pre-service, and I guess that includes this sort of thing.

DR. BEHRAVESH: Exactly, yes.

MR. WARD: Okay.

DR. BEHRAVESH: Now to go back and present to you some of the elements of the program we have at EPRI that is designed to address the inspection of cast material, we have work on use of wave scattering models to determine the

dominant grain structure in this material. Everyone has given you information how important that is. The reason for that is to be able to help with selection of the model of the sound propagation that you use, whether it be shear or longitudinal. We need to find what are the most appropriate inspection angles. That comes also from knowing the structure. There are artifact arguments in there that has to do with probe angles and how to come up with minimal side lobes. There is a lateral resolution argument that has to do with the width of the beam.

And to get a handle on any of these things, you need to know not only the structure but how that structure influences the sound that propagates to it. That has been -- that's an ongoing program. We know far more about this subject today than we knew four years ago, but we certainly are not there completely. That is, our understanding is far from complete.

We have been using Rayleigh and Lamb waves to detect deep cracks, particularly those that may propagate close to 20% -- to 20% of the outer wall if ever such a thing becomes problemmatic. Rayleigh waves can be used for an ID inspection as Rick mentioned to you in the nozzle case if you can get inside as well as on the outside of the pipe. And also we have had modeling of ultrasonic beam to tell us what happens in anisotropic material and how it affects the crack

and echos that we get from the cracks.

These are some of the fundamental studies that are ongoing.

From the outset, we knew that a lot has been learned and developed as part of the BWR inspection technology, so we have been trying to adopt most of what we have learned from that and to use it in this area. For example, we have had several inspection systems that have been quite successful, they are commercially available and we have been putting them to use on this problem. You will this afternoon as you go in the high bay, you will see a demonstration of this system that was basically developed for BWR inspection, it's called intraspect, it's commercially available, has been used in a lot of other fields besides NDE.

We have done considerable work in using ultrasonic feature analysis; that is, looking at a signature of a flaw and extracting features from it and trying to understand from those features what are the flaw characteristics. And this ties in with signal processing and actually there is hardware out there in the field that are no more complicated than what you see here. This is an entire system that can get a signature from a flaw, process it and give you far more information than was available before. You are basically looking at a compact PC with a pulser receiver board and a transducer that is coming and getting the result and you can

do the entire analysis on that. These are all commercially available and are being used and you see some examples of them this afternoon.

We have done considerable work in characterization of this material and as a result being able to optimize some of the parameters. You will see more of this presented, and also field application of technology for both cases of pre-service and in-service inspection and capability demonstration.

Now more details on all of these will be presented to you next by Frank Ammirato of the NDE Center, who will be giving you details of a lot of these because these are at the heart of our activity.

In summary, to give you a snapshot of where we are, I believe that our experience with this material is still limited. We know far more than we did before but it is still limited, but is improving fast. We are getting lots of good information which is helping us.

We see all kinds of variations in characteristics of this material, from plant to plant, from material to material, from component to component or even along the same component. So that should be no secret that what you know that works here, there is no guarantee that it will work in the next place.

We now know that we need to have very good reference

material in order to be able to see -- to determine what sensitivity we need and it is -- proper reference material is essential for the calibration and inspection of this material.

As I mentioned, an a priori knowledge of the material is very necessary in order to optimize the parameters and most of our work now and in the months and years to come will concentrate on characterizing this material before we attempt to test it. The more we know about the specifics of this material, the better chance we have in doing the credible examinations. Not knowing the material characteristics is almost like walking into a dark room and attempting to see what you can find.

The information that we have to date -- and I should emphasize that all the information that we have to date is limited to the samples we have worked with. So on the basis of samples that we have, we are finding out detection sensitivities of between -- good detection sensitivities exist for flaws that are somewhere between 10 to 40% through-wall, and that can be readily demonstrated.

DR. SHEWMON: When you talk about characterizing the material non-destructively, do you have any techniques aside from ultrasonic probes as you go into this dark room?

DR. BEHRAVESH: Not quite yet, no, we don't. We still like to make some ultrasonic measurements that will tell us about the material properties rather than whether there is

a flaw in there or not.

And also, most of the work that has been done are now published in five EPRI reports that I list in here but you have them in your handouts. I have included the front page of these reports in your handout so you can get a glimpse of what the reports are about and what is the concentration of them.

So at this time I would like to turn it over to Frank Ammirato of the NDE Center to give you details of the work that is done and pretty much set the stage for some of the experimental work that you will see this afternoon.

PRESENTATION BY FRANK AMMIRATO

MR. AMMIRATO: Thank you, Mohamad.

My outline this morning, I'll very briefly go over the background that has been covered already, I won't dwell on it. I'll talk about the NDE Center activities, some theoretical and experimental work done here to try to understand wave propagation in cast stainless steel. I'll talk about signal processing efforts to improve the quality of NDE data, the sample acquisition and characterization, particularly the Westinghouse Owners' Group samples that were just made available to us last year. I'll talk about some field trials that we've done over the last three years and then I'll talk about the demonstration that you're going to see this afternoon.

A little bit of an overview: The objective of NDE

activities here at the Center for cast stainless steel is really two-pronged. One is to improve the effectiveness of NDE, but in order to do that you really have to be able to evaluate the capability of NDE. If you make an improvement, you have to be able to measure what you did to make the improvement, particularly the influences of individual joint characteristics. We've heard several times this morning that that's very important, each joint is quite different and its influence on NDE is quite distinct.

It's a difficult problem as we all know. There's no general solution, NDE solution. By that I mean there's no one fixed procedure that works in every case. You have to know a lot about the particular joint.

Some results I'll show you later on I think will bear out that NDE can be effective in some specific kinds of grain structures and some specific kinds of joints.

The approach here at the Center can be characterized as three-pronged; theoretical and experimental work to try to understand both how waves travel through cast stainless, how you can use that information to figure out what the grain structure is and once you do that, pick out the best technique for the grain structure.

Signal processing and pattern recognition to improve the quality of the data. A lot of the data that you see from the field is noisy, difficult to interpret. Signal processing

can in some cases improve that and I've got some examples of that.

Field trials are very important. What works in the lab doesn't always work in the field and furthermore you learn a lot by going out to the field to find out what is the real situation. I'll talk about those too.

You've already heard quite a bit about what happens in cast stainless, beam skew, distortion, attenuation. There has been theoretical work done here at the Center and also other EPRI contractors to try to understand these effects. And each grain structure is very specific and we want to try to use that specific effect to try to identify the grain structure from measurements. If you know the grain structure, maybe you can have a compensation technique to correct your data and I'll talk about that a little bit later. Ray tracing is a useful example to take some of this knowledge and try to predict how the beam passes, behaving in the weldment. And I have an example of that also.

On the experimental side, we started about in 1985 some basic measurements of attenuation, velocity, beam skew, really trying to understand how bad the problem was. We worked a little bit with detection of machined reflectors but starting last year the Westinghouse Owners' Group samples became available and that gave us a chance to work with cracks in a large variety of grain structures, geometries,

configurations and so forth. You've heard about them already. We've used them here at the Center for several things. Transducer optimization; again, if we know the grain structure we can optimize the transducer but you need to do a lot of work to figure out what is the best combination of techniques for that configuration. Excellent signal processing test bed. You can try lots of candidate signal processing procedures and see what happens. Lately we've been going through our results and trying to come up with some detection performance data, how well did we detect each kind of crack and each kind of grain structure. I've got some preliminary results I can talk about a little bit later.

These are typical joints. This is an example of the ray tracing that I'm talking about and this is a model developed by Dr. Jung here at the Center just to illustrate what happens in a complex joint. This is one of the nozzle to safe end to pipe specimens from the Westinghouse Owners' Group samples and this is a calculation that Dr. Jung did, and each grain direction is represented by these little short straight lines and at each point the beam deflection is calculated, at least the new velocity is calculated and what you see is you think the beam would go this direction, it doesn't, it goes someplace else. So this is an illustration of what was mentioned earlier, the beam doesn't go where you think it's going.

DR. SHEWMON: Do you use Snell's law or something to say they'll always bend the same way instead of some bending the opposite way?

MR. AMMIRATO: Well they bend according to the elastic constant at that particular point and that is determined by the grain orientation, and that's what you have to know.

DR. SHEWMON: You show a fair amount of rotation inside that V-shaped gray area but it's always clockwise.

MR. AMMIRATO: It depends on the wave mode, depends on the wave mode and on the horizontal shear wave it bends the other way.

DR. SHEWMON: Okay.

MR. AMMIRATO: This is three but they're all different.

This is an example of location errors. We talked about beam skew and beam distortion. This is a simple experiment, a side drilled hole and it was located by just a conventional angle beam at two points. The calculated point was over here for this case and the calculated point for this was over here, there was considerable error. But if you knew, again the grain orientation, you could correct that data. I'll have some examples of how that can be done later.

Location is not the only problem of beam redirection, it's noise. We have lots of samples of noise.

Over here we have detection of a simple side drilled hole target. In carbon steel and forged stainless steel there's not much difficult at all, very strong signals. If you go to -- one of the worst cases, centrifugally cast coarse grain, you see the signal to noise ratio is not as good. In fact there's a factor of eight difference in gain from here to here and we still haven't really sharply detected that drilled hole.

More grain structures. I think it was mentioned earlier that this is really a tough one, the mixed kind, columnar grain and a rather sphere sharp layered boundary, but all of these except for this are represented in the Westinghouse specimens, columnar and equiaxed, fine equiaxed of course we have.

What we're trying to do is we're trying to make some incremental improvements. We know it's a tough problem and we're not going to solve it right now today. Typical performance for manual UT might be here -- this is a crack detection versus false call. This is the random call line. Typical manual guide might be here today and you saw some examples with Steve Doctor. We're just trying to go in this direction. If you just increase the gain, increase the pulse power, you're probably going to go that way, you're going to increase detections but also false calls. You want to go this way. Some of the waves are trying to go that way.

Automated systems, you'll see an example this afternoon during the demonstration where the automated systems just themselves are going to help view a more global picture of your data instead of manually scanning across the sample, you can get individual A-scans. Just looking at the pattern of those signals might help.

Optimize your technique. If you use a columnar grain structure, maybe you can pick out particular beam angle and frequency that would do the best job.

Signal processing, it definitely helps in some situations.

Training, it was mentioned before a lot of operators don't see cracks every day. These samples are now available so now that training is very useful. And field experience, trying to make small steps in the right direction.

An overall block diagram, and I don't want to go through the steps, I just want to make a few points. This has to do with defect location, those errors that I showed you earlier where you get the wrong location. This side has to do with the detection of defects, noise problems. Both have the same kind of approach, understanding the grain structure, pick the best technique for that grain structure and then compensate your technique to give you the best results. It's a pretty general approach.

Some examples of experimental measurements that have

been going on here at the Center over the last few years. There's an EPRI report that Mohamad mentioned that's got hundreds of these kinds of graphs in it and I'll leave it here if anyone wants to take a look at it. This is just one exa: In an equiaxed grain sample with a side drilled hole and ing at just a zero degree transducer going along this surface, you can see the amplitude trace and it peaks at the right place, right over the hole.

On the columnar grain structure it doesn't do that, it skews over. Expect a peak here but it peaks over there. This was gone through as a function of angle, as a function of frequency, as a function of grain structure. These kinds of beam redirection and beam skew data was collected.

Another parameter is the velocity. I already mentioned that the velocity changes as a function of angle relative to the grain, so that has to be known in order to make these calculations and corrections.

Skew angles are measured and plotted. You can see for each of the different grain structures, different frequencies, different transducer sizes, different transducer types, it's all collected in detail. And the reason this is all done is to make a parameter study. You want to make a parametric representation of the wave propagation. That's how that ray tracing was done. Given the angle of the grain, you can then predict the --

DR. SHEWMON: What is the grain size on the static cast, how does it -- where does it fall between your fine grain/coarse grain --

MR. AMMIRATO: Oh, I don't think I have the numbers for you, I really don't know.

DR. SHEWMON: Anybody ever looked at one? Why is -- is it just pure chance that the static cast looks either better than the fine or coarse centrifugally? Is the centrifugal always more mixed or is it -- yeah?

MR. JUNG: The centrifugally cast fine grain --

DR. SHEWMON: Identify yourself please.

MR. JUNG: My name is Peter Jung from ND Center. The reason why we made it as a fine grain is although we quote it as a fine grain compared with the other centrifugally cast or static cast grain size, but still it is considerably larger than conventionally --

DR. SHEWMON: But my question is a comparison with static cast which should also be pretty big grain size, shouldn't it?

MR. JUNG: Yes, static cast that we examined was approximately comparable size with CCSS fine grain in terms of amount of attenuation or some shape of the grain, et cetera. In that case, it appeared that it was just strictly size of the grain but it is a comparable but we tried to classify it on CCSS static cast. Normally those static cast stainless

could have some partially mixed type grains.

MR. AMMIRATO: This is an example of using this kind of data to correct location errors. This is an example of a columnar grain specimen, drill hole in the middle and an experimental measurement of location done all around the periphery of the sample and that's what these experimental predictions are, that's where you would have predicted the defect to be. With this parameterized analysis you can then go back and correct these points back to the true location, but you need to know the grain structure and grain orientation, it can be done.

We saw some beam plots earlier today and I just want to show you a few more. This was part of the experimental measurements to characterize grain structure, what happens in each kind of grain structure as a function of incident angle with the grain. Here you see a relatively uniform beam, the kind that Steve showed this morning, and here's a rather coarse example of beam splitting, two beams and over here this very severe attenuation. Again each grain structure has its characteristic, that's what we're trying to find out.

Each kind of grain structure has a particular effect in the frequency domain. Here you see four different frequencies, each kind of grain structure, these are just frequency spectra measurements to get an idea how to characterize each kind of grain structure.

This can all be summarized in a table, which I don't want to go into the details of but just to mention that we have each kind of grain structure; centrifugally cast, carbon steel, all the various parameters, velocity, skew, amplitude, beam profile. Each entry has a characteristic behavior.

I'd like to get into now the Westinghouse Owners' Group samples, what we've been doing with them in the last year.

We're using them for transducer studies, defect detection evaluation. The defects in these samples range from about 5% of wall thickness up to about 40% of wall thickness and a very large array of configurations, trying to figure out what can be detected.

As we mentioned before, signal processing test bed, training. The possibility later of performance demonstration or capability demonstration. We would like to get other industry teams to come in here and work with us with these samples to add to our data base of crack detection and just try to learn some more about it.

You'll see this this afternoon, this is all 75 specimens laid out in the high bay. One of each kind has been selected and put on the table for the demonstration this afternoon, so you'll be able to see some of these effects that I've already talked about in each kind of specimen, right after lunch.

Our characterization of the samples was the first job; both physical, weld profile, take a photograph of the microstructure, exhaustive manual UT, automated system UT and that's all put in a documentation folder which is kind of a euphemism, it's not very much of a little folder. All 75 specimens are catalogued in here. This does not include the automated data, that's on magnetic tapes now about this high.

I've copied one example packet of documentation which I think you can see later this afternoon, if you're interested.

The sample description you've already heard about, the different kinds of configurations; forged on one side, static cast on another or static or centrifugally cast on one side or the other.

Again, this is an example of some of the pictures that are in the documentation folder of the grain structure. We took an etched edge of each specimen, photographed it and that's in that folder for each specimen. I think you've pretty much seen all of these.

This is one of the samples that I showed the ray tracing model done on. These grain directions were all measured and then used for that ray tracing calculation.

DR. SHEWMON: What is FGSS?

MR. AMMIRATO: Forged stainless or extruded.

DR. SHEWMON: And the transition is a weld then?

MR. AMMIRATO: Carbon steel nozzle weld, forged stainless steel grain, weld, and then the pipe -- centrifugally cast pipe.

Some of the specimens have cracks on this weld, some of the specimens have cracks in this weld. So there's lot of different opportunities.

MR. WARD: When you talk about that pipe that's extruded, is that really extruded to final dimensions or is it extruded --

MR. AMMIRATO: I really don't know.

MR. CURTIS: I believe it's extruded to final dimensions, it's just cleaned out. It comes up nice.

DR. SHEWMON: Is it a two foot diameter extrusion?

MR. CURTIS: Yeah, it's thick.

DR. SHEWMON: It's a big guy.

MR. CURTIS: It's big.

MR. AMMIRATO: This is a reproduction of the cover sheet that's in this documentation folder for each specimen. A photograph, a sketch of liquid penetrant result, a photograph of liquid penetrant result, a typical automated UT scan of a crack, an etch of the specimen, some typical manual UT signals from the crack.

DR. SHEWMON: You point at that typical automated UT there, how -- does that show up on somebody's CRT or what?

MR. AMMIRATO: No, this is a processed image. This

is looking at the crack, this is the transducer positi n X and Y, sort of a plan view. I'll show you other displays like this, but this is the crack here.

DR. SHEWMON: I've lead such an under-privileged life that I've never even seen a typical one like that.

MR. CURTIS: Made your day.

MR. AMMIRATO: It's a typical picture you'll find in this book. I'll show you lots more of those. By the end of the day, everything will be typical.

What we would like to do -- don't know if we can -- is try to get these crack detection rate curves. We're pretty sure it's going to depend on the microstructure, forged is going to be easiest, static next and centrifugally cast maybe somewhere down there. But what you're going to see in the rest of my presentation is just composite results for various techniques. We've tried two, three, sometimes four and five techniques on one specimen and our results are going to be composite data. Also we have the data to do a technique specific, but we haven't done that yet. We also haven't found very much correlation with crack depth yet, as I'll show you.

We measured crack length very simply, just when it exceeded the noise level, that's where we started counting and when it dropped back we lost it. We scanned the entire specimen and just recorded the coordinates.

For the truth in our evaluations, we used the depths

supplied by the Owners' Group and we just plotted these just to see how they looked. This is the crack length versus depth and as I think Rick mentioned, that's how they measured depth by a correlation with length. My point is that the thermal and mechanical fatigue have a different length to depth aspect ratio. That's all that means.

We'll talk a little bit about our detection statistics and how we define the numbers just so we all understand. This is a rather specific definition, if the true crack length went from here to here, we looked at that with say four different ultrasonic techniques; technique 1 might go from here to here, technique 2 might be here, technique 3 might straddle the indication, technique 4 might be over here. We made a very specific definition of crack detection, did not allow for many tolerances at this point. You either got it or you didn't. If your indication that you measured, which is from here to here, we called that much a hit, that much a miss and that much an over call. And it's just the definition.

Now for example, if you detected the crack but because of beam skew or some measurement error or whatever it appeared over here, that was a miss. We can go back and redefine these any way we want, including some kind of tolerance in our grading unit but that has not been done yet. That's why it's still preliminary.

To show you what specimens have been looked at so

far, we're not finished with all the specimens, these are the nine types, a sort of qualitative measure of inspectability or the difficulty of inspection. One is the easiest and five is the toughest we think. You'll see we've done ten of the toughest and 24 of the easiest. So there's still quite a bit of difficult specimens yet that are not in our analysis yet. That'll be done in the next couple of weeks.

Results. We plotted our crack detection rate as defined by the little cartoon I showed you earlier, a very specific definition of crack detection versus crack depth and not too much correlation -- none. You see that crack detection rate went from 10% to about 100%, all over the board. And this is a mixture of the easy specimens and the tough specimens in here.

I plotted that a little bit differently again on one of these performance curves. The crack detection rate versus the false call rate. This is the type 2, this is the over call rate, not the crack miss, this is the over call rate. Closed circles are the specimens that have cast stainless on both sides, the open circles are the nozzle specimens that have some kind of forging in them someplace.

DR. SHEWMON: What was the mean depth or area of these flaws?

MR. AMMIRATO: Mean depth?

DR. SHEWMON: If you have a three inch wall thick, is

it on the average half way throu[illegible] or --

MR. AMMIRATO: Oh, they were distributed from 5% to 40%, it was a mixture.

DR. SHEWMON: Okay.

MR. AMMIRATO: Now the nozzle specimens --

DR. SHEWMON: Did the probability of detection rise to 100 on the 40% ones or was it independent of size?

MR. AMMIRATO: We haven't seen any correlation with size yet. Now the point I was going to make is that a lot of this data was taken on the nozzle specimens that have some forging someplace on it, so we can get to the crack through a forging, which I meant to say a composite result.

Again, the crack detection rate ranges from pretty much random to 100%, but in general it's sort of up in this side which is good, but you know, it's a very limited evaluation and laboratory experiment. But we have not included a lot of the tougher experiments. I expect those to show up down in here.

I'll talk a little bit about signal processing, which you will see demonstrated this afternoon, I'll just give you an introduction to it. The aim of it is to increase the signal to noise to help you with detection, and once you detect it to improve the classification; is it a crack or is it an interface signal or is it grain noise, what is it.

Three ways are being looked at and I've already

mentioned imaging, just making a picture of your data and use that to better interpret what you are seeing. Spatial averaging, it's a simple signal processing technique that takes advantage of some simple geometry which I'll explain in the next few slides. Feature based approaches, Mohamad mentioned this already, which uses the signal itself to try to understand what that signal is coming from, the signal rise time or its width or its shape or symmetry, those kinds of things. That's very well applied in the BWR case but we have not gotten to this very much for cast stainless but we're working on these first two up to now. But it's on the list.

The principle of spatial averaging, very simple concept. You have a crack that you scan in a direction parallel to it and the idea is that the grain noise is going to be -- the grain is going to be smaller than the crack length as you move across, and add up signals, average them together, the grain noise or other noise will smear out and the crack signal being at the same location will sustain and be reinforced. So you would just make a scan, average, make sort of a rolling average of the scans and do some reinforcement that way.

We tried this out on the Westinghouse Owners' Group specimens to see if it worked and here is one of these scans. This is an individual A-scan and this display is transducer position versus depth so it's taking these, turns them on edge

and stacking them up so you're looking down on top of a set of scans. And scan across the crack that way, parallel to it that way. And what you see on this side is the before and this is the after signal processing. And you can see in the A-scan the noise reduction, the crack signal is still here and here, but now you've eliminated a lot of these other signals which move around. So in the averaging process they get smeared out and you can see now this indication was here but it's pretty difficult to pick up from the rest of it and over here, it's sharpened up. So it worked in this case.

This is a technique that we applied to our field exams which I'd like to --

DR. SHEWMON: Do you have to know the sensitivity or the orientation of the crack for that or --

MR. AMMIRATO: Yes, it works best when you can scan parallel to it because then it's at a fixed time. Scanning perpendicular to it works also too but not anywhere near as well. In fact, even scanning parallel to it doesn't work all the time. I remember one example where it didn't help too much because the signal was already fairly strong, so it didn't really add anything. It's always going to help some.

Our field applications I want to talk about. I've been working on these since 1985 and these are really very important. It's already been mentioned that things like surface finish are going to kill you as happened here at the

Arkansas Power Plant. There was a stainless steel casting to be examined and we thought we knew what was the best technique to use and put it all in our tool kit and when we get there the surface is scalloped out by grinding and repairs and we couldn't do anything. So that's a simple thing that's just going to shoot you down.

To start off at Vogtle and took some automated UT collecting data and I'll show you one example later, again trying to scope out the problem. Trojan and Braidwood were done last year and we applied signal processing to data collected by commercial scientists and you'll see examples of that this afternoon. We'll go through again what was done. The data was collected by Intraspect 98 system by the utility's vendor, it was turned over to the NDE Center and we applied signal processing technique, this is the spatial averaging, to try to improve the data.

The joints that were examined at Braidwood, this area of this valve to elbow, there was a radiographic indication and the utility wanted some verification and confirmation with ultrasonics so they asked us to go in and apply some of the signal processing on their ultrasonic data as collected by someone else.

This is an example of the Braidwood data that was looked at with our signal processing system. This is an example, the signal was already pretty good, applying our

signal processing to smooth it out, sharpen it up. It was already reasonably a good signal.

DR. SHEWMON: Now there certainly wasn't a flaw like that in the Braidwood piping. What does this mean, Braidwood -- or was there?

MR. AMMIRATO: This is actual data from Braidwood.

DR. SHEWMON: Okay. How big was that flaw?

MR. AMMIRATO: This particular one looks like eight-tenths of an inch long.

DR. SHEWMON: Okay.

MR. AMMIRATO: But what's important is the next time when you go back there, you can look at this again.

MR. CURTIS: This is pre-service. Okay?

DR. SHEWMON: Pardon?

MR. CURTIS: It's pre-service inspection.

DR. SHEWMON: What is the post-service?

MR. CURTIS: That's yet to be seen.

DR. SHEWMON: Okay, so if the flaw is still there, we'll just watch it for awhile.

MR. AMMIRATO: And cleaning up the data helps you look at it next time a little bit better.

At Trojan we were asked to go in and do the same kind of thing on this ultrasonic data. There was a possibility of a snubber problem and some imposed strain on this hot leg elbow joint so we did an ultrasonic exam and

again the data was noisy and this technique helped to clean it up and helped them with their analysis. We did the same thing again, again the before and after. The indication here and here and you can see this noise, this noise is sort of -- a couple of causes, one is electronic pickup in the signal cables but that data is already there. So that averaged out as we moved across. Also there's the usual grain scattering and here's the indication in the before original data and here's the indication in the processed data. You can see just a cleaner image, cleaner picture.

DR. SHEWMON: You've shown that as a sharp crack. Do you have any idea whether it is that kind of shape or whether it's just a bunch of porosities there?

MR. AMMIRATO: No, you can't interpret this that way. This is a spec scan, so just as you move across the flaw you're going to see different locations and depths as you scan across it.

MR. CURTIS: I don't even think this is near a weld. I think this is in base material. Don, do you want to address that?

MR. ADAMONIS: I'm not sure, I think the confusion arises though from the sketch above.

MR. AMMIRATO: We scanned toward the crack so the indication is it appears as different depth as you get closer to it.

MR. ADAMONIS: That's right, but the configuration that you've drawn leads one to the conclusion that it is a planr defect and I don't think that's --

MR. AMMIRATO: Oh, no, that's just standard cartooning. There's an indication --

MR. CURTIS: Standard cartoonist can lead us the wrong way.

DR. SHEWMON: Thank you.

MR. AMMIRATO: This is that pump casing at Arkansas Unit 1. The area was in here and we just really couldn't do much with it, it was just too rough of a surface, and as mentioned before these transducers are quite large and you can see those this afternoon. You need a relatively smooth area over a larger region.

This is an example of really one of the first ones that was done at Vogtle, again examining a lot of welds trying to understand the field problems of this kind of work, what does it take to bring a system into service, that was an interesting thing, running cables, clamping scanners on pipes, that was a very useful experience.

I'd like to make some conclusions. I still believe there's really no single general technique for cast stainless steel. There's a logic tree you have to go through to pick the technique.

There are some specific conditions, I think I've

shown you some examples, where it does work in certain conditions.

The EPRI work and the work here at the Center over the last three or four years has I think lead to a very sound experimental and theoretical basis for understanding wave propagation in anisotropic material. The trick is to use that to first of all figure out what resources you have and then work backwards and compensate some of your measurements. That work is still in progress.

Signal processing can improve results. I've shown you some examples of field data that this was applied to and it did improve the quality of the data.

Field trials are valuable.

Preliminary detection statistics on the Westinghouse Owners' Group samples, and I say preliminary for several reasons, they're not finished yet and we don't have some of the more difficult specimens in there yet. It's a restrictive definition of crack detection and false call rate. There's no tolerance that has been allowed. It was done in the laboratory by someone who knew there was a crack someplace in this specimen. And it's composite result, three or four techniques thrown altogether.

Two sided access, if there is a forged part someplace in there, forged stainless or forged cast -- forged stainless or forged carbon steel, crack detection averaged

about 80%, false call of about 10%.

Two sided access where there's cast steel on both sides, the detection rate went down to about 60% and false calls came up to about 15.

The one sided access question is important. WE have that data but it has not been analyzed yet.

Back to our chart and I think Mohamad closed with the same comment that I think we are making small steps in this direction.

DR. SHEWMON: Thank you.

MR. AMMIRATO: I'd like to just tell you what we're going to see this afternoon if you're interested.

DR. SHEWMON: Let me stay with one thing, is it my understanding then that there is a pre-service inspection done on all welds and in the Braidwood and Trojan case they found indications and that's what's being followed or where EPRI came in to do additional work?

DR. BEHRAVESH: Not in Trojan, in Braidwood.

MR. CURTIS: Why don't you explain Trojan.

DR. BEHRAVESH: Trojan is an operating BWR and --

MR. CURTIS: PWR.

DR. BEHRAVESH: I'm sorry, PWR. And data that was collected, there was no credible pre-service data at Trojan to compare this to, so whatever data was collected last year was decided to let this constitute a base line now and in fact the

plant plans to look at the same region again next month.

DR. SHEWMON: Well was this part of a five-year inspection or ten year at Trojan?

DR. BEHRAVESH: We're talking about probably the ten year inspection.

MR. AMMIRATO: But there was a problem too in this particular joint because the pipe was displaced because there was a snubber problem. There was a symmetric displacement of the pipe, so they went to look at that joint to see if some damage had been done.

MR. CURTIS: And if I remember correctly, this is more of a casting type flaw in the body of the material itself and not a crack near a weld. Okay? When they were doing the exam, they saw this indication and further evaluated it and then called EPRI and so it doesn't even appear to be associated with a flaw in connection with a weld. It's something they found as they were doing the exam in the base material. The problem is the cartoon, the character if you will, kind of implies that there's a crack there and that's not the case I don't believe from the other data.

MR. WARD: But this was found just incidentally away from a weld but --

DR. SHEWMON: Something had bent it out of shape.

MR. CURTIS: Well they had gone through a thermal cycle on the piping, it had been a strut if I remember

correctly and because of that, they said this weld could have had some higher than normal stresses on it so because of that we'll do some augmented inspection. So they went in to do an inspection and while they were doing the inspection of the base metal they found this indication.

DR. SHEWMON: Was this in the feed water system?

MR. CURTIS: Yes, I think it had to do with the high cold water striation and the sparger line and that put the bending moment across that weld. So they wanted to inspect that weld and while they were inspecting the weld, they found in the base metal this indication which has been further evaluated.

So I'm not sure, you know -- I don't want to get you thinking there's a crack in that weld because it's not there.

DR. SHEWMON: Thank you.

MR. CURTIS: For them -- for their sake.

DR. SHEWMON: Okay. Go ahead.

MR. AMMIRATO: What you're going to see after lunch out in our high bay. You're going of course to be able to see all of our samples, get a close up look at them. We have three demonstration positions set up, one is manual UT and if you so care and have time you can actually do some scanning yourself if you want to try to illustrate some of the effects I've mentioned earlier today.

We'll move on to the automated UT, the Intraspect

98, a commercial inspection system, and we'll see some of the benefits of that data.

The next stop will be a signal processing system, personal computer system which is data acquisition, imaging and signal processing. This is the system that was used to analyze the data from Trojan and Braidwood that I showed you before. And you'll see some examples of the field data from Trojan and Braidwood and how this signal processing was applied.

That's after lunch.

DR. SHEWMON: Somebody want to tell us what we do for lunch?

VOICE: Yes. Through that door and down the hallway at the end is the cafeteria.

DR. SHEWMON: We're scheduled for an hour. Why don't we aim at half an hour and end up with 40 minutes from now or something if that sound credible, and we'll see how it goes.

VOICE: We'll lead you down the hallway to the laboratory, we'll not need to come back here right after lunch, the demonstration takes place in a different part of the building.

DR. SHEWMON: All right.

(Whereupon, the Subcommittee meeting was adjourned at 12:02 p.m.)

CERTIFICATE

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

Name: ACRS SUBCOMMITTEE MEETING ON METAL COMPONENTS

Docket Number:

Place: Charlotte, North Carolina

Date: March 15, 1988

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

/S/ William L. Warren

(Signature typed): William L. Warren

Official Reporter

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