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UNITED STATES NUCLEAR REGULATORY COMMISSION'S
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

AUGUST 23, 2001

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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MEETING

ADVISORY COMMITTEE ON NUCLEAR REACTOR SAFEGUARDS

(ACRS)

THERMAL-HYDRAULIC PHENOMENA SUBCOMMITTEE

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OPEN SESSION

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THURSDAY,

AUGUST 23, 2001

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The Subcommittee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B3, 11545 Rockville Pike, at 8:30 a.m., Dr. Thomas S. Kress, Acting Chairman, presiding.

PRESENT:

THOMAS S. KRESS	Acting Chairman
F. PETER FORD	Member
VIRGIL SCHROCK	Consultant
JOHN D. SIEBER	Member

ACRS STAFF PRESENT:

PAUL A. BOEHNERT

MEDHAT EL-ZEFTAWY

C-O-N-T-E-N-T-S

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

(8:30 a.m.)

CHAIRMAN KRESS: The meeting will now come to order. This is a continuation of the meeting of the ACRS Subcommittee on Thermal-Hydraulic Phenomena. I'm Tom Kress. I'm acting chairman of the subcommittee since the real chairman is out of the country for the moment. ACRS members in attendance are Peter Ford and Jack Sieber. Also in attendance is ACRS consultant Virgil Schrock.

The purpose of today's session is to review the resolution of issues associated with the Electric Power Research Institute Report TR-113594, "Resolution of Generic Letter 96-06 Waterhammer Issues". The Subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions, as appropriate for deliberation by the full committee.

Mr. Paul Boehnert is the Designated Federal Official for this meeting. The rules for participation in today's meeting have been announced as part of the notices of this meeting previously published in the Federal Register on July 30th and August 15th, 2001.

Portions of today's meeting session will be closed to the public to discuss EPRI proprietary information. A transcript of the meeting is being kept and the open portions will be made available as stated in the Federal Register Notice. It is requested the speakers first identify themselves and speak with sufficient clarity and volume so that they can be readily heard. We have received no written comments or request for time to make oral statements from members of the public regarding today's meeting.

If you recall we had a meeting on this subject previously, I forgot the date, in January was it? For the benefit of those of you who might not have been here, we had some problems with the resolution of the waterhammer issue that had to do with the test apparatus that -- to measure the quantity of air that got released and became an air cushion. We thought the results would be apparatus dependent.

In addition, I think we had some problems with the product of the heat transfer coefficient and area for the condensation to steam on the liquid surfaces. So today I think we're going to hear how EPRI intends to deal with those two issues. Who do I call on, Mr. Tatum to start the meeting?

First, I'll ask, do the members have any comments before we start? Virgil? No? Okay, with that, we'll turn it over to you.

MR. TATUM: Good morning. I just have a few introductory slides I want to present here primarily to -- it's been awhile since we met on this subject. I just wanted to in the way of introduction revisit what the issue is briefly and provide, I guess a perspective as far as where the staff is in terms of our review and whatnot. So let me go ahead here again with this first slide.

First of all, let me see, that's not the first slide, this is the first slide. There we go. Now, first of all, Generic Letter 96-06 the topic that we're talking about here has to do with waterhammer and the proposed or at least the accepted methodology in the Generic Letter was that that was part of NUREG/CR-5220 which is very conservative. I think everyone recognizes that to be the case.

And EPRI about two years after the Generic Letter was issued established a working group to try to come up with a methodology that would be less conservative but adequate for addressing the issue and it's involved a lot of testing, research, analysis and data and whatnot to try to come up with this methodology and EPRI and the working group have met with the ACRS Subcommittee now on two previous occasions.

Issues have been raised. The working group has gone and done additional research and testing and here they're back today for the third meeting to try to address the remaining significant issues so we can get on with our SE and resolution for the participating industry group, industry utilities anyway.

Just in the way of introduction, I'm Jim Tatum from Plant Systems Branch, one of the technical reviewers for the topic. We also have Gary Hammer, Walt Jensen, who are also involved with the review. Beth Wetzel is the Project Manager and the responsible SCS manager is John Hannon, Plant Systems Branch and George Hubbard is the supervisor.

Just to revisit the specific issue that we're dealing with here I've borrowed a couple of figures from the EPRI submittal. Basically, I think this is Figure 2-1, I think from Volume 2 of the report.

Essentially, what we're looking at, the issue boils down to if you have a LOCA or a main steam line break event in containment, what you have is the containment fan cooling units stop operating if you have a loss of power that is concurrent with that and the heat from the containment or from the accident, then is transferred to a stagnant cooling water system because if you lose power, of course, until the diesels are loaded, you don't have flow through the system.

And so the concern essentially boils down to whether or not during that period of time you have steam formation, and if you do have steam formation, whether or not there's a significant waterhammer concern as a result of that. Now, if you look at the typical fan cooler for a plant, and this is very representative, I think of most plants but you have a number of -- a series of heat exchangers basically that a fan or multiple fans will force the air through the heat exchangers.

You have a tube fin type arrangement and it tends to be very efficient in the way of heat transfer. So the concern is that as the fans coast down during the event, the heat from containment, from the containment atmosphere is effectively transferred into the fan cooler unit and the water in the tubes is contained in the tubes that has become stagnant will heat up and boil and in many cases you will get steam formation.

Now, there is some variance among the plants as to whether it's a closed loop system, whether you have a static head on the system, and those are plant specific details where the utility determines whether or not or to what extent they actually have boiling. However, the EPRI member utilities that are involved with this effort obviously, experience boiling or there wouldn't be a need for them really to participate in this group, per se, and they're trying to establish a way to effectively conclude that they don't have a problem or at least minimize any modifications that they would have to make to address the problem.

And they have found that by using the analytical approach, that's proposed in NUREG/CR-5220, that significant modifications could be required and by using what they've established as an alternate approach but apparently conservative, they would have to do much less and demonstrate that they would not have a problem in dealing with the event, should it occur.

Now, from the last meeting there were a number of issues that were raised. I've tried to characterize those here on this slide. Basically, I've broken them down into those that were raised by the

Thermal-Hydraulic Subcommittee last time around and those have been already mentioned I think for the most part. As far as the NRRL staff, you know, based on our review, we had a number of open items that we wanted to pursue further with the working group and we have done that and had additional discussion.

Also the EPRI group has made a couple of submittals; one, to address the HRS Thermal-Hydraulic Subcommittee issues and that was -- the submittal I think was July 10th that we all received. Then there was a subsequent submittal after that to address the NRC staff concerns. It was a separate letter that we received and we've had some opportunity to review that and have additional discussion with the working group about resolution of those items. But this was kind of the position --

MEMBER SCHROCK: Excuse me. Could you comment just a little more in depth on which part of the problem you've thought about this "h" for condensing heat transfer? Specifically, does it deal with the heat transfer by condensation during compression of the air/steam mixture in the column closure case. Is that the one that you're addressing?

MR. TATUM: Yes.

MEMBER SCHROCK: That is.

MR. TATUM: Yes, uh-huh. That was the ha -- it was the "h" from the "hA" term for the condensing heat transfer.

MEMBER SCHROCK: Yeah.

MR. TATUM: Yeah.

MEMBER SCHROCK: Well, I missed that meeting in January and as I read this new material it occurred to me that there ought to have been discussion and maybe there was and I simply didn't catch it in what I read, about the issue of using a constant value of h.

MR. TATUM: Uh-huh.

MEMBER SCHROCK: Is that going to get addressed here today?

MR. TATUM: I believe that's something that Altran is going to discuss. That was actually discussed to some extent I know with the staff and I think it was also discussed to some extent at the meeting, if I recall correctly. But I'll defer further discussion. I think we need to hear from Altran on that particular topic. It's one of the issues that's on the table.

MEMBER SCHROCK: Okay.

MR. TATUM: If that's okay with you. I'm not really -- you know, I'm interested as well in some of this final discussion on these issues.

As far as the current status of the technical review, this hasn't changed, this review comments. They remain the same as they were last time. We still believe that the effort that's been put forth by industry to establish the analytical methodology is a very good effort. They've done, I think, a good amount of testing, correlation of data and tried to make sense of the work that they've done and through the PIRT process have tried to establish where they need to focus their attention and resources. And I think for the most part, they've done a very good job and the staff is pretty pleased with the work that has been done to this point.

Also, we recognize that the level of expertise that has been involved in their selection of the expert panel members, I think was very good and it helped essentially to address many of the issues that have come up. So I want to go ahead and acknowledge that here at the beginning here. And having looked over the latest submittals and whatnot, you know, there still remains at least in our mind, we -- and I characterize these as areas of continuing review. We really haven't reached a conclusion. We probably need to think a little bit more in these areas.

And some of these areas are topics for discussion here today. They were recognized during the previous meeting and we still need to understand for example, I think in our mind the two major issues that we need to understand better are the air release fraction and the scaling of heat transfer surface are. But in addition to those, we have several other issues that we're still thinking about, still evaluating and still discussing with the working group and I've identified those here just so you know where the staff is with respect to our evaluation of the submittal and whatnot. These are the issues that remain open for us.

And having said that, I think we're ready to move onto the EPRI presentation and hear what they have to say about resolution of the remaining items that were raised at the last Thermal-Hydraulic Subcommittee meeting. So I guess, Vaughn, Vaughn Wagoner will be making the introductions and initial presentation.

MR. WAGONER: Thank you, good morning. I'm Vaughn Wagoner, Chair of the Utility Advisory Group for this issue that we are working with resolution of the Generic Letter. We're all set there? Okay, I guess by way of introduction just for the record, we have here with us today Dr. Peter Griffith and Dr. Fred Moody and Dr. Tom Esselman with parts of our expert panel as well as our consultant we're using on this, Greg Zysk, who's worked extensively on the analysis work itself.

Not here with us today is Dr. Ben Wylie. I think he's out somewhere in the wilds and was unable to join us today and also Dr. Avtar Singh from EPRI, who had worked with us from the EPRI perspective. So we're here today hopefully to address the remaining questions that have been raised relative to what we've been doing, present to you some of the results of additional testing, et cetera, that we've done.

Just by way if introduction, very brief, I just want to run back through a couple of things. How do I make slide changes? Okay, thanks. When we started into this after the Generic Letter came out and the concern was raised, several of us recognized that there were lots of information around on high pressure waterhammer phenomena, but there wasn't a lot around on low pressure stuff and there wasn't very much at all around on low pressure waterhammer where there was a potential for air release and cushioning and those kinds of things.

So recognizing what we had were events

that were occurring at atmospheric or sub-atmospheric or slightly above atmospheric pressures, we recognized that we needed to do some additional work to try to understand that phenomena that could potentially occur in the power plants. So we set about trying to do that, understand the phenomena and ultimately to understand how it relates to piping support loads because that's the analysis and that's the qualification process when it's all said and done.

And quite frankly, when we looked at it from just a pure waterhammer perspective, you take peak waterhammer loads, input them as static loads and then build pipe supports and frankly, that appeared to be the wrong thing to do. I don't have a PhD but my experience in a power plant has been is when we have waterhammers, the more you tighten up the system and the more rigid you make it, the more things you tear out of the wall. So it looked like the wrong thing to do, to go in and just start putting more steel in to address these peak Joukowsky type loads from these waterhammers.

So we started to look at it and say, "What makes sense"? So we went through and did the work. We've done modeling. We've done plant specific models and generic models to understand the phenomena from the time the pumps shut down and the fans coast down, till the pumps come back on with the power sequencers, et cetera. And we've looked at single coolers. We've looked at multiple coolers. We've tracked steam bubbles throughout the system and looked at how they interact. So we done that phenomenalogical study. Did I pronounce that right, and we're into the process.

And we've went through the -- we've looked at how then we can -- what the magnitude of those loads are and then how they translate through modeling into loads, into the structure that we can understand. And let's see, I'm sorry, we should be on the next slide. That's where we are. And so we went through that process and developed a user's manual that provides guidance for how a utility takes what we've learned and applies it to the plant.

It's not a cookbook, a 100 percent cookbook. It gives you a process and within that process there are places where you can use the information that's in the user's manual. It's backed up by the Technical Basis Report or there are places where you have to supply plant specific information because the process, it doesn't encompass every detail of plant specific. So there are some things that you've got to dig out.

But we've identified that based on comments from both technical and user friendly comments from review by staff and review by ACRS members and we have incorporated that and we've built a process flow chart. And if you'll look at the flow chart, we provide places where, "Do this step out of the user's manual. Here's one that's plant specific. If you get into this region, you've got to go pull the plant specific".

For example, model basic system hydraulics, that's a plant specific thing that you have to do. That's an input to get into the process. So anyway we've set the user's manual. Now, these have been outlawed in schools because kids point them at each other's eyes. My wife's a teacher.

But having -- like I say, we've set it up so that it delineates where you use the process and where there are plant specific inputs. So we appreciated that kind of comment. We've had it reviewed by utility folks. The utility folks can use it, can understand it. So I guess what I'm trying to say is we think we've built a process that, in fact, can be used by the utilities.

And that Technical Basis Report has got a number of topics in it. We've been through these with you and with the staff at various stages. We're going to come back and hit on two or three of the basic areas that we're talking about. Air release is one of them. Built within here in the scaling of "h" and "A" and looking at the -- how our test apparatus and our testing in general that's been done is applicable to larger pipe sizes and we're going to talk about those area.

One of the things I wanted to do before we get into that is just take a look at it from a perspective that as utility members we look at things a lot in a risk informed world and in an engineering applications world, what makes sense and I wanted to share with you where, frankly, I think we are in a what makes sense perspective. The first thing is, we're dealing with an event much less than 10^{-6} and frankly, when we looked at -- when we looked at the plants that are participating, even to get it up to 10^{-6} we had to assume the simultaneous occurrence of the LOOP and the LOCA over a 24-hour period.

Now, design basis is simultaneous. So to get a 10^{-6} in 24 hours, you take it down to the 30 to 60 seconds that this phenomena is occurring in we're up to 10^{-9}. So first off we're dealing with a probability of event in the first place that's much smaller than 10^{-6}. We're into the 10^{-9}, some plants up to the 10^{-13} range. Of course, that's why separating or getting rid of simultaneous LOOP/LOCA there's other efforts going on within the industry and the regulation to throw that out as a design basis event, period, and that's why, because we're dealing with such a low probability.

But that's the starting thing. There's already margin in the capacity of the pipes, as you know. There's ASME Code margins and things like that. We're dealing with pressure impulses that we're calculating in 600 psi range with a burst test capability of tubes and piping of over 3,000 psi. So there's a huge margin even if the phenomena does occur to bursting. And then what's really got to happen is, we've either got to burst something or we've got to shake it so badly that it deforms and bursts.

And frankly, folks, there just ain't enough energy in these low pressure events to make it happen. We just don't seem to be able to get there from here. Inadvertently, these systems have been banged a lot during start-up. And you have a shut-down system, you do LOOP testing, the service water pumps shut down. The system drains down. You fire them back up. We don't have auto flow controls that we'd like to have and we bang these things and they get banged a lot.

Those are close to Joukowski-type loads because that's just water hitting water, no steaming, no bubbling, no air release, no anything that goes on in there. And the systems have withstand it and have for years and years and years. And, frankly, the more flexible the system, the better they stand it because the energy is dissipated by the pipes dancing around. We've watched them, we've video taped them. And the pipes dance around a little bit and you go on about your business.

So the bottom line is, we think between the structural margins that are inherent in the design, we've got the low energy that's available and this really 10^{-9} probability event that we're looking at, there's no way that we'll ever compromise a safety function. The bottom line is we've got to deliver cooling for -- post-accident cooling, we've got to deliver the cooling through the containment and we've got to maintain the integrity of the containment because these pipes are part of containment boundary and we just don't see any way that we're going to violate this.

Now, we can argue a little bit about is the air really 52 percent or 48 percent or stuff like that, but frankly, we think that we're at a big enough picture where we banged them close to Joukowski type stuff, nothing happens. The thing is going to boil, there's going to be some amount of cushioning. We can argue about exactly how much, but frankly, we think we're there. We think we understand the phenomena, that we're not going to violate a safety function.

And with that, I guess I'll turn it over to --

CHAIRMAN KRESS: In those events you say were pretty much the Joukowski banging water against water, why didn't those have air in them?

MR. WAGONER: Well, what happens, there's no LOCA, so there's no heat.

CHAIRMAN KRESS: Okay.

MR. WAGONER: No boiling. It's just you know, the containment is sitting there 80 or 90 degrees, 95 degrees maybe.

CHAIRMAN KRESS: Okay, you didn't boil off first.

MR. WAGONER: That's right, that's right.

CHAIRMAN KRESS: Okay, appreciate that.

MEMBER FORD: Vaughn, forgive me, I'm

learning here. In your remark you said early on in operations you got a lot of this banging and bucking around, and therefore, that is where you came up with the 10^{-9} originally or a 10^{-6} frequency. How would your argument change if you made the same -- made the same argument 30 years down from licensing when you might have environmental degradation in your piping, I mean, fatigue, a crack of some sort or vibration induced fatigue crack, would you then be so sure that you wouldn't have a problem?

MR. WAGONER: Well, two responses. One is the frequency was not determined by the early testing. That frequency actually has nothing to do with this testing. It's just a frequency looking at the combined probabilities of a small, medium or large break LOCA and a LOOP event the loss of offsite power.

MEMBER FORD: Okay.

MR. WAGONER: So that frequency came from looking at that phenomena, I mean from those events. Secondly, in several cases because -- and frankly, because of the Generic Letter, we looked at the -- I know of several plants that looked at -- because the piping moves around, we did fatigue analysis. We actually measured displacements at critical areas and looked at fatigue and usage factors over the rest of the life of the plant. It's not a concern.

And then the systems like this, depending on plant specifics, may be monitored for things like erosion and stuff like that. So they would always be in a position to have maintained at least their design basis through the life of the plant. So my engineering response would be, not an issue.

MEMBER SCHROCK: I'm not clear on your response to Tom concerning Joukowski type events that occur routinely. How does this occur? Do you have vacuum voids in the system occasionally? What -- how does that happen?

MR. WAGONER: What happens is particularly at coolers that are above sea level, whatever sea level at the plant above the water level, and we do loss of offsite power testing, so when you do loss of offsite power testing, the plant goes black and for 20 or 30 or 40 seconds, however long it takes the diesels to fire up and in the load sequence to tie your pumps back on. And so during that black time, then God makes the water drain to seek, you know, the gravity level.

So during that time, you can get voids that form in the system and then when the --

MEMBER SCHROCK: You're imagining these

voids to be pure vacuum.

MR. WAGONER: Yeah, or close to it, yes, otherwise there would be leaks in the system.

MEMBER SCHROCK: That's what I wonder about.

MR. WAGONER: Well, if you had leaks in the system, we'd have water in primary containment, because that's where the concern about leaks would be. And we don't have leaks in the primary containment the service water.

MEMBER SCHROCK: But you have gas in the water.

MR. WAGONER: Okay. So it would be some release but it wouldn't be any release from boiling because the stuff typically would not boil at the temperatures that it would be at.

MEMBER SCHROCK: I guess my reaction to your explanation is it's a little too broad brush to believe that it's truly Joukowski level pressures.

MR. WAGONER: And I wouldn't argue with you on that but there has been some measurements of -- some pulse measurements and --

MEMBER SCHROCK: Okay.

MR. WAGONER: Okay? Any other questions? With that, I'll quit and -- I guess I would say at this point, that handout was the non-propriety portion.

MR. BOEHNERT: All right, we're going into closed session now.

MR. WAGONER: Yes.

MR. BOEHNERT: All right, go to a closed session transcript.

(Whereupon, the Subcommittee went into closed session.)

(12:52 p.m.)

CHAIRMAN KRESS: I guess one of the main things we need to do now is decide what to present during out one hour and 40 minutes to the full committee so that you can convince them as well as us things are okay. So is there -- I do think you need to answer the three questions; the R evolved during the various conditions, the "h" and along with the "h" the scale-up question. So is there -- the question is how to condense that down to an hour and 40 minutes, including the time that is going to get eaten up by the questions of the full committee members.

And keep in mind, we'll have Graham Wallis back and we'll have George and Dana here, so like 50 percent of the time at least.

MR. BOEHNERT: Let me stop you a second. The staff, did they have any concluding comments or any concluding presentations comments.

CHAIRMAN KRESS: Yeah, that might be well worthwhile before we totally decide on what we can.

MR. HUBBARD: This is George Hubbard. John Hannon had to leave but the -- you know, from the staff's standpoint and, you know, taking a management perspective in looking at the risk versus the burden of this issue, I think the question that comes up is has EPRI provided a methodology in which is either conservative or reasonably is reasonable assurance that a utility can take the information, do their calculations and then apply the various what is the gas or air that's released, what is the steam volume, and go through and make a reasonable assessment of what are the loads on the pipe and do they need to make a change or add steel as Vaughn says.

The thing that I think we're seeing is that we see that the -- there is a methodology there. There may be a few questions there as Jim Tatum mentioned earlier. You know, we've got a few things. We're still going through to make sure we've got it straight in our mind but I think our view is there is a proposed methodology that in the most part, we think provides a justified way to determine whether you need to add steel and if there are some things in there that aren't real straightforward, when we write our safety evaluation, we'll put some restrictions on how you apply this TBR.

But the question being is, is this methodology that the plant's going to use. Is it, you know, reasonable or conservative? Yes, I know from listening to all the discussions we can always do more to get a better test data, make the test a little more conclusive, but we're looking at it is, the -- with an event that is low, the LOCA or main streamline break with a loss of offsite power, the -- you know, how far do we have to go? And I think we're seeing that for the most part it probably is. You could take the methodology with maybe some caveats and apply it.

MEMBER SCHROCK: In the risk question, don't you have to ask also what is the consequence?

MR. HUBBARD: Yes.

MEMBER SCHROCK: So the risk is very low but the consequence is very high; isn't that true?

MR. TATUM: This is Jim Tatum.

MEMBER SCHROCK: If you lose the fan cooler, you jeopardize containment.

MR. TATUM: No, this is Jim Tatum. There have been plenty of tests done I think to show the robustness of containment. So the containment fan coolers really it's not a foregone conclusion that because you lose the cooling medium, you have a break in the piping system, that you've really significantly impacted safety. You may --

MEMBER SCHROCK: Why was the issue brought forward to begin with?

MR. TATUM: That was one of the considerations. The other consideration that we were concerned with was by-pass of containment through the piping system itself. That was a possibility. And if you look at, you know, containment by-pass, that would be another plant specific analysis but in fact, dose assessments, I think, you would find not to be a significant or overwhelming compromise to public health and safety.

So, you know, when we consider this and of course, our thinking has evolved over time as well but in looking at the current picture, I think, when you recognize what is the risk associated with the LOCA main steam line break and you combine that with loss of offsite power, and then you look at, well, okay, if that did happen, what would be the consequences? Is it likely that you would or could fail containment, is it likely that service water, if that's a system that's providing cooling and you have a failure in the system and it's going into containment, is it likely that you lose the cooling function of that system or do you have means of isolating that break in containment which typically plants do have plenty of capability available to them to isolate them so that you don't lose the service water function and then when you put together the robustness of containment design as we have seen over other considerations, other issues that we have gotten into with containment, and the by-pass leakage sought, I mean, overall I don't see a terrible -- terribly large threat to public health and safety when you put all this together and that's why I think George Hubbard in his assessment is looking at trying to balance here what the industry is proposing, looking at these other factors and asking ourselves the question when is enough enough for this, you know, recognizing that it could be a substantial expenditure to the industry as we've, I guess we've had meetings, I guess it was with Calvert Cliffs, wasn't it, that explained that if they take credit for air, it's quite a reduction in the cost to them in addressing the problem.

And so there can be a substantial cost to industry. Obviously, additional testing would involve not only cost to industry but also more time and the question in our minds is, well, given all these other factors, is all that really warranted. And that's really a management decision but I think we're thinking that given what the industry has done, we're pretty pleased at least with the methodology and justification that's been put together. As I mentioned earlier, we do have some open items that we want to have further discussion on, make sure we have a clear understanding and if we feel that any of these raise what we would call significant concerns in our minds, I think our view would be to address that somehow in the safety evaluation to have restrictions on how this methodology would be applied or some criteria for when it would be applied, approach it in that manner.

CHAIRMAN KRESS: In making a safety evaluation, one could see the standard Chapter 15 like safety evaluation or one could -- using the methodology to get the pressures and so on or one could see the risk analysis to compliment that, where what I think I hear you saying is that if one did a risk analysis that the risk importance worth of the fan cooler is probably pretty small and really it's not doing much for you in the first place from a risk standpoint.

MR. TATUM: Right, I think --

CHAIRMAN KRESS: And would that be, you think, considered in the safety analysis that --

MR. TATUM: Well, I think we can't avoid having some discussion.

CHAIRMAN KRESS: It's not an easy analysis to make because you've got all the different plants and you're talking about a Generic Rule, how to deal with a Generic Rule in a generic sense and you're mixing risk space into the terministic space.

MR. HUBBARD: I think the thing is -- and I'm not the risk expert, as I understand risk, you know, this Generic Letter was issued because we saw it as a compliance issue.

CHAIRMAN KRESS: It was a compliance issue.

MR. HUBBARD: Right.

CHAIRMAN KRESS: And that's --

MR. HUBBARD: Now, when you start factoring in the risk aspect --

CHAIRMAN KRESS: You're mixing apples and oranges a little bit.

MR. HUBBARD: Right, then you've got to look at, okay, if you have this waterhammer, are you really going to fail that pipe? And you get into the codes where you get into the faulted condition as opposed to the design condition and then when you start, is the pipe going to fail, the -- that's when you start getting into the risk and probably not. You know, you're going to get shocked. It's going to be moved around but are you going to get the containment back. I guess my feeling is the pipe is probably going to stay intact.

You know, you could argue, no, it isn't but that all goes into the risk factor, you know, in determining, okay, of it fails what are the consequences and, you know, put the risk number with it. This was -- you know, they're looking -- they've got a design to consider this load in here and, you know, that's designed. Then you go to risk, and, you know, it's a little different.

CHAIRMAN KRESS: Well, do you guys have enough guidance to figure out how to condense this into a presentation? I don't know what to tell you other than I'm sure they'll want to hear about the new test results and why we should believe the percentages of air and they'll want to hear that "hA" argument. So you'll have to figure out how to really condense those down.

DR. ESSELMAN: The discussion today, I think, is helpful both in figuring out how to condense it but also I think the detail that we need to have that we can augment this with before then and augment it before the final report.

CHAIRMAN KRESS: I wouldn't leave out the low frequency risk argument because that goes a long way in my mind to -- as to how I view the importance of the problem and so I wouldn't leave that out but I wouldn't -- you know, you're going to get a lot of questions like, how do you know what the frequencies actually are and -- the argument of the initiating frequency of LOOP and LOCA is good enough, I think, you don't even have to factor in break probability. It's probably low enough there to say that this is really -- not really significant in risk base and I wouldn't leave that argument out because that's convincing to a lot of the members.

I think you have to go over the tests and how they're run and what the results mean but I would certainly try to focus and the "hA" argument was, in my mind, a little shaky. I think you did go a long way in convincing me on the conservatism in the air release part. But I'm still not convinced on the "hA" part. I'm not sure it matters what much but I would -- I don't know how time you have but I would pursue this jet argument and the question of how much entrainment you actually get because I think this is an entrainment heat transfer question.

And if the entrainment is effected by the velocity and the pipe size and scale-up, then I think the -- I think you could certainly add to your argument if you had arguments along those lines that would help convince me. I don't know what you can do between now and the full meeting along that line. Are there other comments from the --

MEMBER FORD: I just got a brief one. I've given it low sensitivity of your Delta P to the gas contact and "h" and all this, maybe these questions about modeling become more of an academic issue. However, I have big concern. No one seems to be talking about integrity of the welded carbon steel piping that's been exposed to oxygenated water for 20 years and you will have a large delta P not to be cushioned that much due to waterhammer.

So whether this degraded piping, it will be degraded to a certain extent, can stand it.

MR. BROWN: This is Tim Brown from Duke Energy. We have -- service water system is in our ISI program. It's also in our raw water inspection programs. So we go to great pains to look at that system and I think everybody is having raw water piping problems and in fact, we're thinking about replacing some of ours. So that's something we do look strongly at.

MEMBER SIEBER: Probably the weakest point is the expansion joints --

MR. BROWN: Yes, at the --

MEMBER SIEBER: -- between the headers and the components that it connects to because where the failures occur, they usually fail there.

MEMBER SCHROCK: Is that where you'll see the pressure spike?

MEMBER SIEBER: The pressure spike goes throughout the system. Another weak -- you don't have it in the fan cooler but anything with a tube sheet there is usually a lot of force on a tube sheet in a waterhammer. You know, they start these systems up and even though they're partially throttled when they start them up. It's quite similar to the kind of situation that you're talking about during a LOCA. You actually don't run the fan. You know, the motors will burn out on the fans because the containment pressure is too high. And so the only thing -- the only reason this issue exists is because the service water system goes down, all these valves are open and you start that pump again and everything rushes through and when it hits the resistance, that's when it collapses.

DR. ESSELMAN: Today we can't focus, I think only on these three issues. I think we need to step back and consider the big picture because they haven't had the benefit --

MR. BOEHNERT: Well, I was going to

suggest that maybe we'll have the staff give an opening to set the stage and talk about that and then we can go into the specific issues on the table.

CHAIRMAN KRESS: See if -- possibly we won't have time for this issue on the agenda.

MR. BOEHNERT: What, like two hours?

CHAIRMAN KRESS: Yeah, I think it would be better if we had two hours.

MR. BOEHNERT: Okay, I'll try to do that.

CHAIRMAN KRESS: I think there was something potentially dropped off of the September agenda I heard.

MR. BOEHNERT: Well, we've pretty much been through that.

CHAIRMAN KRESS: Oh, we've already done that.

MR. BOEHNERT: Yeah, we've been there --

CHAIRMAN KRESS: Oh, we've already taken that step.

MR. BOEHNERT: But there still may be time because I think one of the issues is a little shaky and they may not take all their time, in fact, the one just before us. So we may be in good shape here.

CHAIRMAN KRESS: I think we can --

MR. BOEHNERT: I think we have the time

available, so it shouldn't be a problem.

CHAIRMAN KRESS: Okay.

MR. BOEHNERT: The agenda is kind of light.

CHAIRMAN KRESS: See if we can get a little more time.

MR. BOEHNERT: Sure.

CHAIRMAN KRESS: I think it's going to take -- and you know, we want this to be the last meeting here.

MR. BOEHNERT: Yeah.

MR. WAGONER: That we all agree on.

CHAIRMAN KRESS: With that I'm --

MR. BOEHNERT: You're going to adjourn the meeting?

CHAIRMAN KRESS: Yeah, unless -- I don't hear any opposition. I declare this subcommittee meeting adjourned.

(Whereupon, at 1:09 p.m. the subcommittee meeting concluded.)

CERTIFICATE

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

Name of Proceeding: ACRS Thermal Hydraulic Phenomena Subcommittee

Docket Number: (Not Applicable)

Location: Rockville, Maryland

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

Rebecca Davis

Rebecca Davis
Official Reporter
Neal R. Gross & Co., Inc.

INTRODUCTORY STATEMENT BY THE ACTING CHAIRMAN OF THE SUBCOMMITTEE ON THERMAL-HYDRAULIC PHENOMENA
ROOM T-2B3
TWO WHITE FLINT NORTH
ROCKVILLE, MARYLAND
AUGUST 23, 2001

The meeting will now come to order. This is a continuation of the meeting of the ACRS Subcommittee on Thermal-Hydraulic Phenomena. I am Tom Kress, Acting Chairman of the Subcommittee.

ACRS Members in attendance are: Peter Ford and Jack Sieber. Also in attendance is ACRS Consultant Virgil Schrock.

The purpose of today's session is to review the resolution of issues associated with the Electric Power Research Institute (EPRI) Report, TR-113594, "Resolution of Generic Letter 96-06 Waterhammer Issues". The Subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions, as appropriate, for deliberation by the full Committee. Mr. Paul Boehnert is the Designated Federal Official for this meeting.

The rules for participation in today's meeting have been announced as part of the notices of this meeting previously published in the Federal Register on, July 30 and August 15, 2001.

Portions of today's meeting session will be closed to the public to discuss Electric Power Research Institute proprietary information.

A transcript of the meeting is being kept and the open portions will be made available as stated in the Federal Register Notice. It is requested that speakers first identify themselves and speak with sufficient clarity and volume so that they can be readily heard.

We have received no written comments or requests for time to make oral statements from members of the public regarding today's meeting.

(Chairman's Comments-if any)

We will now proceed with the meeting and I call upon Mr. James Tatum, NRC Office of Nuclear Reactor Regulation, to begin.

EPRI/Industry Collaborative Project to Support Resolution of GL 96-06 Waterhammer Issues

Vaughn Wagoner, CP&L, Chairman, Utility Advisory Group
Dr. Peter Griffith, MIT, Chairman, Expert Panel
Dr. Fred Moody, Consultant, Expert Panel
Dr. Ben Wylie, University of Michigan, Expert Panel
Dr. Avtar Singh, Project Manager, EPRI
Dr. Tom Esselman, President, Altran Corporation
Greg Zysk, Altran Corporation

NRC/ACRS Meeting
August 23, 2001

1

Program Objectives

- Understand the behavior of the system during the transient.
- Provide methodology to assure pressure boundary integrity – focus is on piping support loads.
- Minimize modifications to plant systems.
  - Adding supports or strengthening existing supports, if not necessary, will not increase overall plant safety.

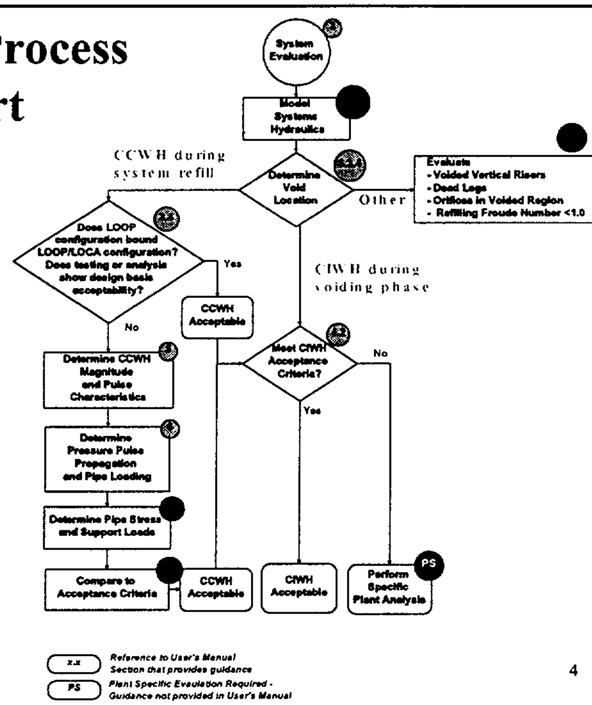
2

User's Manual

- Provides guidance for the evaluation of waterhammer events resulting from postulated LOOP/LOCA or MSLB.
- Not intended to replace individual plant analyses, but to provide a methodology that can be used in individual plant analyses.
- Contains a flow chart to describe the evaluation process.

3

Analysis Process Flow Chart



4

Technical Basis Report

The topics in the TBR include:

- Introduction
- Event and System Description
- Risk Perspective
- Technical Approach and Scope - PIRT
- Plant Waterhammer Experience
- Air Release
- Condensation Induced Waterhammer
- Method of Characteristics for CCWH
- Rigid Body Model for CCWH
- CCWH – Test Description and Results
- LOOP Versus LOOP/LOCA
- Pulse Propagation
- Structural Loading Model

5

Risk Considerations

- The probability of the postulated initiating event (LOOP and LOCA or MSLB) is much less than 10^{-6} per year.
- Risk of Pipe Failure
  - Significant margin exists in the capacity of pipes to resist burst due to internal pressure
  - Support failure and subsequent deformation would be required to challenge the pressure boundary integrity.
- Piping systems have withstood many LOOP-only events during testing.
- The overall structural margin in the plant, the generally limited energy available in this event, and the very low probability of occurrence, provide good assurance that safety functions will not be compromised.

6

Objective of Meeting

Address Issues raised by the ACRS T/H Subcommittee at our last meeting:

1. Test apparatus for determination of air release fraction.
2. Determination of the "h" in the "hA" term
3. Scale-up of the test data.

7

EPRI/Industry Collaborative Project to Support Resolution of GL 96-06 Waterhammer Issues

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NRC/ACRS Meeting
August 23, 2001

Proprietary 1

Objective of Meeting

Address Issues raised by the ACRS T/H Subcommittee at our last meeting:

1. Test apparatus for determination of air release fraction.
2. Determination of the "h" in the "hA" term
3. Scale-up of the CCWH test data.

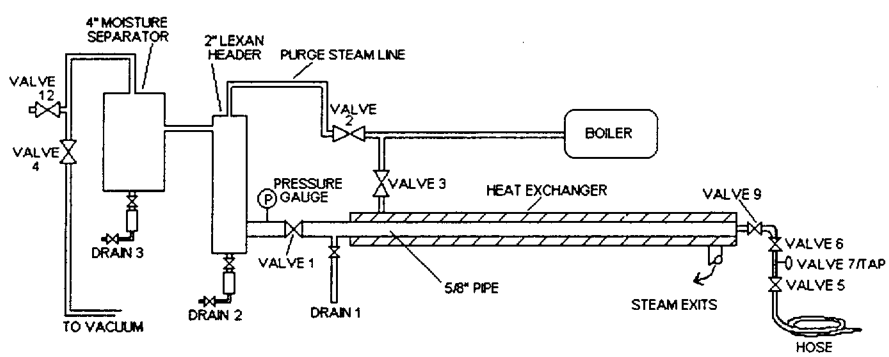
Proprietary 2

Air Release

- Dissolved non-condensable gases will be released from the water in a voiding system and will enter the steam voids.
- This gas will pressurize during a column closure event and cushion the impact.
- Air release will occur due to depressurization and boiling.

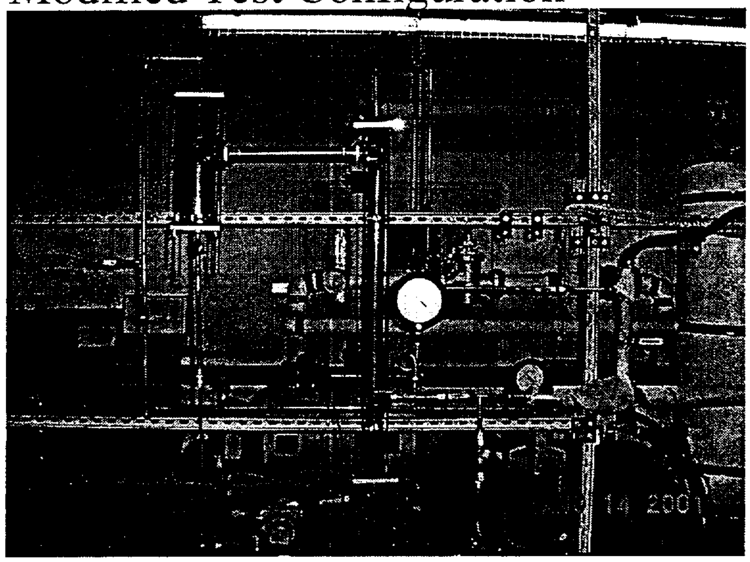
Proprietary 3

Modified Test Configuration



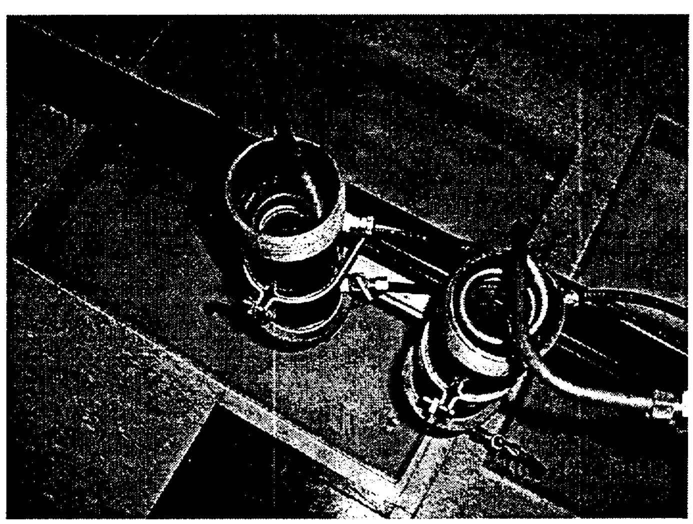
Proprietary 4

Modified Test Configuration



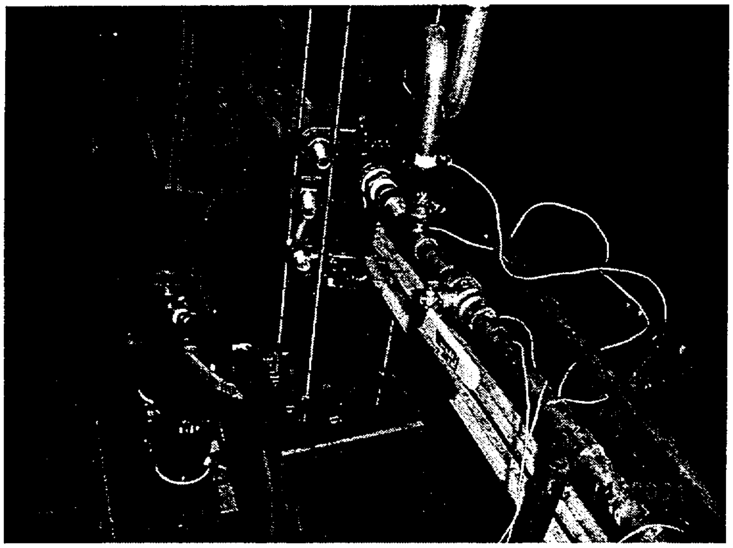
Proprietary 5

Modified Test Configuration



Proprietary 6

Modified Test Configuration



Proprietary 7

Test Parameters

- Tube Diameter and Length
- Tube Orientation
- Header Orientation
- Steam Temperature
- Steam Pressure
- Water Properties
- Time

Proprietary 8

24

Tube Diameter and Length

- Test Conditions : A 10 foot long 5/8" unfinned copper tube was tested.
- Plant Conditions : Typical fan cooler tubes range in size from ½" to 7/8" and are often finned. Fins would transfer more heat, increase the boiling, and evolve more gas. Fan cooler tubes are typically 40 feet long. A longer tube will transfer more heat during a longer transit time and evolve more gas.

Tube Orientation

- Test Conditions: A horizontal tube was tested.
- Plant Conditions: Fan cooler tubes are oriented horizontally.

Header Orientation

- **Test Conditions:** A vertical header was tested with a single tube entering the header and with various amounts of water in the header.
- **Plant Conditions:** Fan cooler tubes either drain or discharge to a header that contains trapped water. Multiple tubes will enhance the air release from the water in the header.

Proprietary 11

Steam Temperature

Test Conditions: High temperature and low temperature heating steam was tested. The low temperature steam was supplied at approximately atmospheric pressure to the jacket of the heat exchanger. The high temperature steam was supplied at approximately 40 psig.

Plant Conditions: These temperatures are prototypical for many LOCA events. The minimum steam pressure of interest is atmospheric and typical LOCA peak pressures are approximately 40 psig. Higher temperatures and pressures would increase the boiling and evolve more gas.

Proprietary 12

Initial Water Pressure

- Test Conditions : The pressure of the water in the test section was lowered to 15" Hg (7.5 psia) as steam was added to the jacket.
- Plant Conditions : This is somewhat higher than typical in an open loop plant (1-2 psia) and somewhat lower than typical in a closed loop plant (approximately 20 psia). The initial pressure is secondary as a method of gas release in comparison to boiling.

Water

- Test Conditions : The tests were performed using "normal" tap water (approximately 10 ppm oxygen). The oxygen content was measured for each test.
- Plant Conditions : The gas content of this water is typical of that in service water systems.

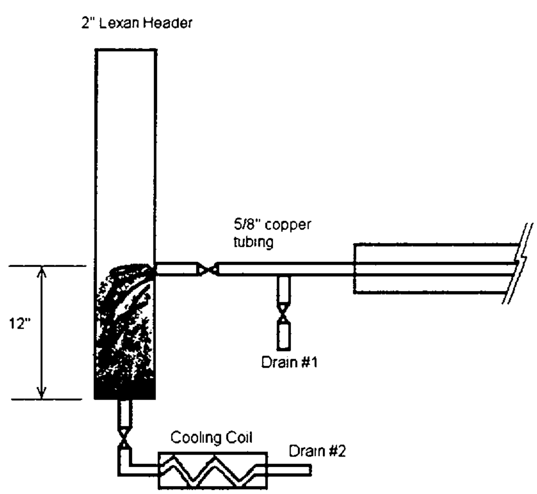
Time

- **Test Conditions :** The test section was heated for 30 seconds.
- **Plant Conditions:** The time of the tests is prototypical for the LOOP/LOCA transient. Pump restart typically occurs between 28 and 35 seconds following the occurrence of the LOOP.

Proprietary 15

Description of Air Release Testing

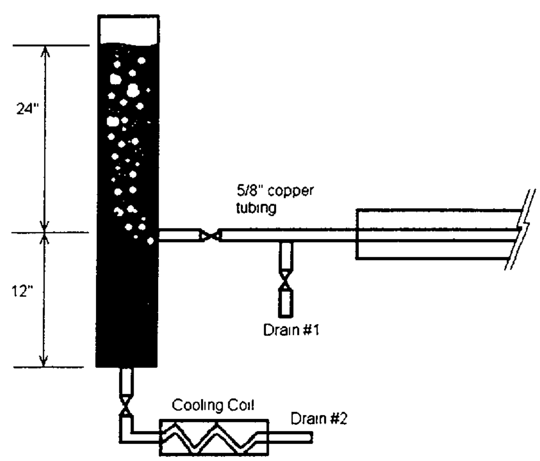
- Test Sequence 1 – Draining FCU



Proprietary 16

Description of Air Release Testing

- Test Sequence 2 – FCU with a Vertical Header

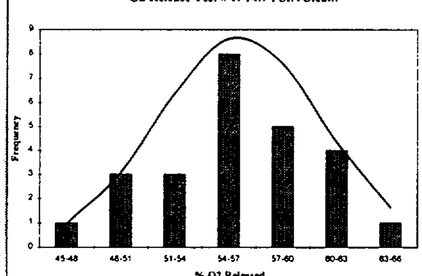


Proprietary 17

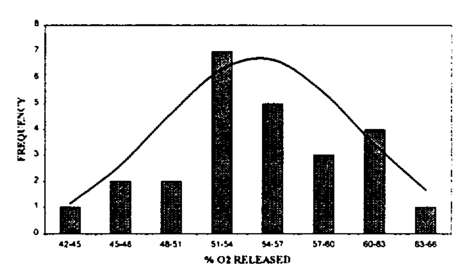
Air Released: Sequence #1

In test sequence 1, the case that represented a draining FCU, the dissolved oxygen content of the water initially in the tube was reduced by approximately 50%.

O2 Release Test # 1: 14.7 PSIA Steam



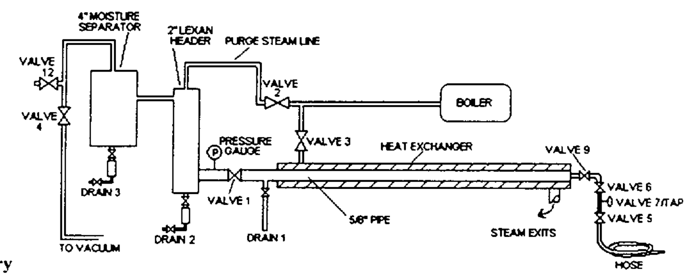
O2 RELEASE TEST#1 (40 PSIG STEAM)



Proprietary 18

Air Released: Sequence #2

- In test sequence 2, a similar amount of gas is released for the water that was initially in the tube.
- The gas released from the water in the header is conservatively represented by the water that spilled into the moisture separator and drain 3, approximately 24%.
- More gas was released by the water that remained in the header, approximately 46%.



Air Released: Sequence #2

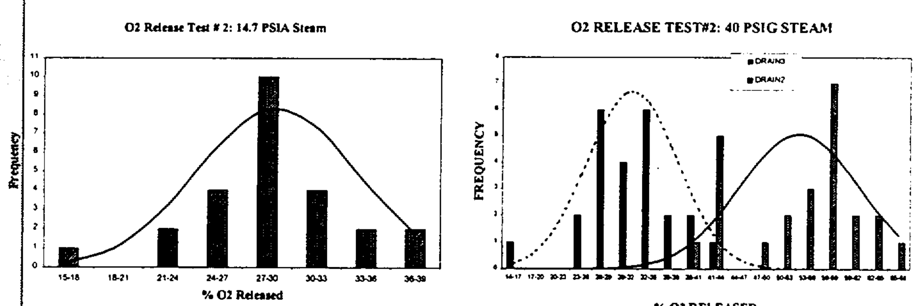
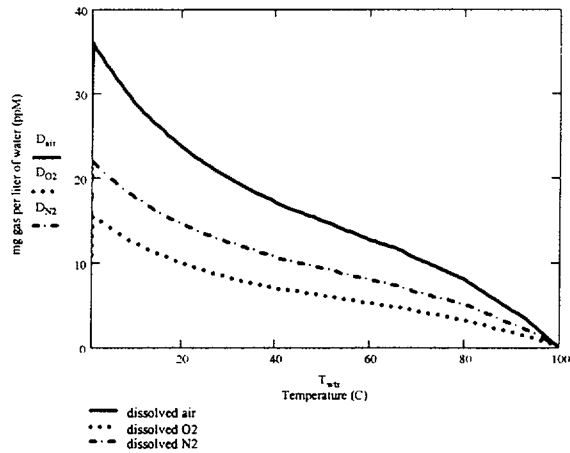


Figure 6-5 and 6-6: Distribution of Air Release Test Data for Sequence #2

Application to Plant Model

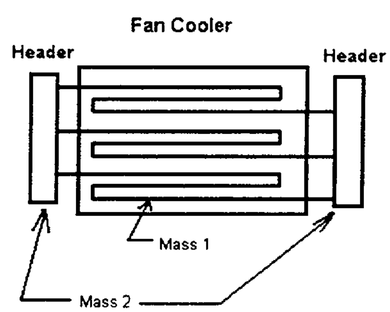
Determine initial air concentration for the water in the heat exchanger tubes and header. This should be based on plant specific temperature, pressure, and dissolved air data as shown in the following figure (Henry's Law) for one atmosphere.



Proprietary 21

Application to Power Plant

- Determine mass of water that will boil in the heat exchanger tubes (Mass 1).
- Air evolved into the void is 50% of the air in this water mass.
- If the heat exchanger has headers that drain, then the calculation is finished.



- **If the heat exchanger has headers that remain full:**
- Determine mass of water in the heat exchanger headers and attached piping through which steam can pass (Mass 2 in).
- Air evolved from Mass 2 is 24% of the air in this mass of water.
- Total air evolved is the sum of the air released from Mass 1 and Mass 2.

Proprietary 22

Air Test Additional Points

- The equilibrium point of air concentration for depressurization alone is not reached within the time period of the transient. Boiling is the significant contributor to the gas release.
- The drains from the header and moisture separator were equipped with coolers to decrease the temperature of the exiting water to approximately room-temperature (95 to 100°F) for the purpose of measuring the dissolved oxygen. The temperature at the time of measurement is recorded.

Proprietary 23

Air Test Additional Points

- The draining velocity for a horizontal 1/2" tube is approximately 0.5 ft/second, which would drain the 10' tube in approximately 20 seconds. Boiling initiated within the first 2-3 seconds of steam addition. Substantial amounts of the tube was heated and degassed. If the tube had been longer or if the heat transfer occurred more rapidly, more heating and degassing would occur. The 50% air release value based on the sample of water at drain 2 was chosen as a conservative value.
- The header extended 12" below the tube. This was sized so that in the draining FCU case, all the water in the tube could collect in the header.

Proprietary 24

Air Test Additional Points

- In Test 2, it is likely that some water drained back into the tube from the header as the voids condensed there when the steam was shut off. However, the release from this mixed water in the header water was conservatively not used.
- The water blown out of the header into the moisture separator had little mixing with the water in the tube. To be conservative, the smaller amount of released dissolved gas for test sequence #2 in the moisture separator was used.

Proprietary 25

Air Test Additional Points

- Dissolved oxygen was used as an indicator of overall air evolution under low pressure boiling conditions. Air and nitrogen will behave similarly. Consideration must be made for the initial concentration of each gas based on temperature and pressure.
- The air released from the lowest temperature steam (212°F) provided the lowest amount of air release (24% at the header drain). The higher temperature steam (255°F) provided 53.4% and 31.3% release from the header and moisture separator, respectively. The 24% release value was chosen as a conservative lower bound from the test results.

Proprietary 26

Air Test Additional Points

- The thermal-hydraulic conditions tested are typical of the actual plants. Test parameters were prototypical or were selected to make the results conservative.
  - Tube Diameter and Length
  - Tube Orientation
  - Header Orientation
  - Steam Temperature
  - Steam Pressure
  - Water Properties
  - Time

T

GL 96-06/EPRI INITIATIVE

INTRODUCTION -- BACKGROUND INFORMATION

- GL 96-06 WATERHAMMER & NUREG/CR-5220
- EPRI INITIATIVE PROPOSED 8/98
- ABOUT 24 PLANTS/12 UTILITIES PARTICIPATING
- TBR PRESENTED TO ACRS T/H SUBCOMMITTEE (11/99; 1/01)
- NRR REVIEWERS
  - JIM TATUM, NRR/DSSA/SPLB
  - WALTON JENSEN, NRR/DSSA/SRXB
  - GARY HAMMER, NRR/DE/EMEB

John Hannon

George Hubbard

GL 96-06/EPRI INITIATIVE

<u>REMAINING ISSUES FROM LAST MEETING</u>

- ACRS T/H SUBCOMMITTEE:
  - \+ LIMITATIONS OF AIR RELEASE FRACTION TEST APPARATUS
  - \+ DETERMINATION OF “h” FOR CONDENSING HEAT TRANSFER
  - \+ SENSITIVITY OF “SCALING-UP” TEST DATA TO PLANT DESIGN

- NRR STAFF:
  - \+ PRESSURE RISE TIME PLOT WITH & W/OUT AIR IN VOID
  - \+ PLANT DESIGN VS. TEST APPARATUS FOR AIR RELEASE
  - \+ PULSE RISE TIME USED IN RBM
  - \+ SINGLE VS. MULTIPLE WATERHAMMER PULSES
  - \+ FLUID STRUCTURE INTERACTION -- ATTENUATION
  - \+ STRUCTURAL DAMPING VALUE USED FOR ANALYZED LOADS VS. MEASURED LOADS

GL 96-06/EPRI INITIATIVE

LATEST SUBMITTALS:

- JULY 10, 2001; REVISED TBR SECTIONS (ACRS ISSUES)
- AUGUST 9, 2001; LETTER RESPONSE (NRR STAFF ISSUES)

NRR REVIEW COMMENTS

- GOOD EFFORT BY THE INDUSTRY TO ESTABLISH ANALYTICAL METHODOLOGY; NOTABLE STRENGTHS INCLUDE:
  + PIRT
  + TESTING & DATA COLLECTION
  + ENDORSEMENT BY EXPERT PANEL MEMBERS

GL 96-06/EPRI INITIATIVE

NRR REVIEW COMMENTS (cont.)

- AREAS OF CONTINUING REVIEW -- THERMAL HYDRAULICS
  - \+ DETERMINATION OF AIR RELEASE FRACTION
  - \+ SCALING OF HEAT TRANSFER SURFACE AREA
  - \+ PRESSURE LIMITATIONS ASSOCIATED WITH CIWH DATA

- AREAS OF CONTINUING REVIEW -- MECHANICAL/STRUCTURAL
  - \+ PULSE RISE TIME PREDICTION
  - \+ SINGLE VS. MULTIPLE PULSE LOADING
  - \+ USE OF DAMPING VALUES; 2-3% (TYPICAL) VS. 0.1%

Objective of Meeting

Address Issues raised by the ACRS T/H Subcommittee at our last meeting:

1. Test apparatus for determination of air release fraction.
2. Determination of the "h" in the "hA" term
3. Scale-up of the CCWH test data.

Proprietary 1

Steam Compression and Condensation

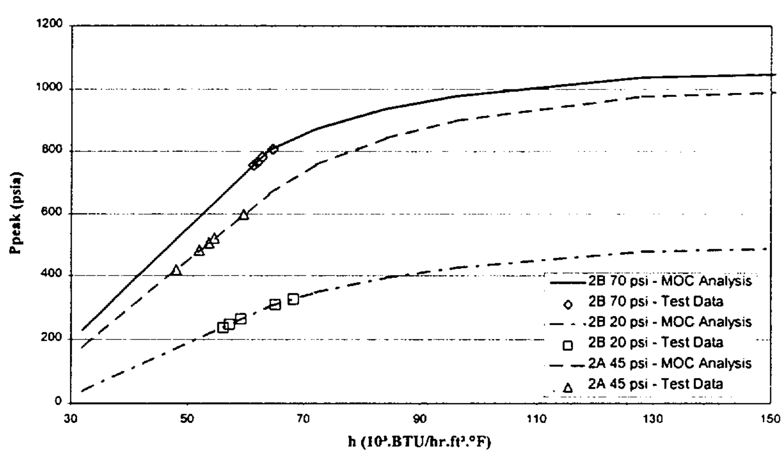
- During the final closure of the void, steam in the void will compress and pressurize.
- The mass of steam is reduced by condensation on water surfaces.
- Heat transfer from the pipe walls is not significant and is neglected.
- Condensing surfaces of the water is irregular but is taken to be the projected flow area of the water (A).
- Using the constant area (A), heat transfer coefficients (h) were determined from the test data to be up to 64,000 BTU/hr ft^2 F (hA = 2,652 BTU/hr F for 2" pipe area) to match the test data.
- The h coefficient was increased to 72,000 BTU/hr ft^2 F for Rigid Body Model (RBM) predictions.

Proprietary 2

Heat Transfer Coefficient from Test Data

- *h* was varied from 32,000 to 150,000 BTU/hr ft^2 °F in the MOC analysis and the waterhammer pressure calculated.
- The test data is compared to that MOC calculation.
- As *h* is increased, the column closure event becomes less dependent on the heat transfer at the steam/water interface, and the event becomes inertially dominated.

Heat Transfer Coefficient Sensitivity

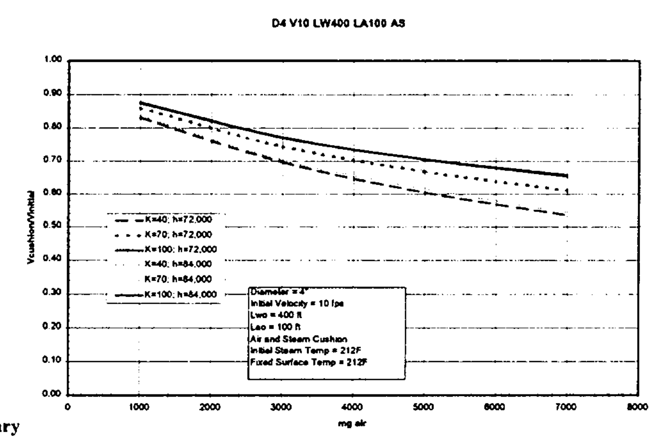


hA Sensitivity for RBM

- For plant application, the Rigid Body Model (RBM) was used to develop a series of curves showing the effects of void compression for various conditions.
- To assess the effect of variation in the hA on the RBM predictions waterhammer parameters, h was varied from 72,000 BTU/hr.ft^2.°F (h_{rec}) to 84,000 BTU/hr.ft^2.°F (25% above the largest h_{test}) in the Rigid Body Model equations.
- RBM curves were prepared for air and steam cushioning.

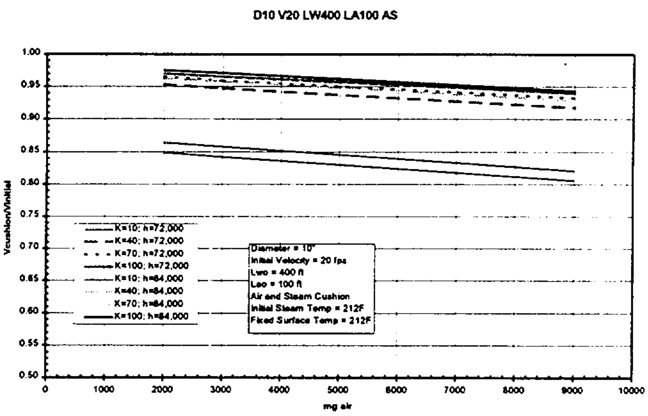
hA Sensitivity for RBM

For a 4" diameter pipe, the cushioned velocity calculated using h = 84,000 BTU/hr.ft^2.°F increases by approximately 1% of the initial velocity for the low K case (low pipe resistance model). The change is less for the other cases.



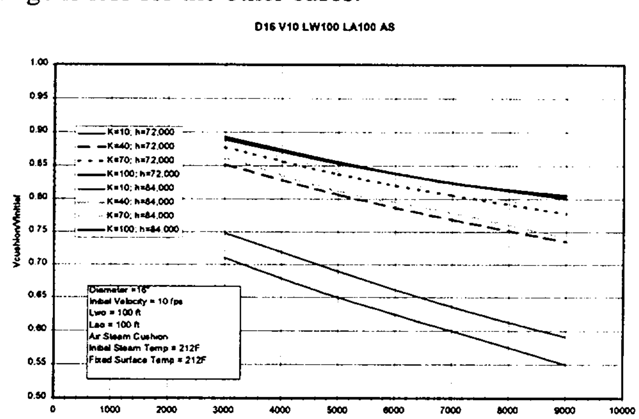
hA Sensitivity for RBM

For a 10" pipe, the cushioned velocity calculated using *h* equal to 84,000 BTU/hr.ft^2.°F increases by approximately 2% of the initial velocity for the low K case (low pipe resistance model). The change is less for the other cases.



hA Sensitivity for RBM

For a 16" pipe, the cushioned velocity calculated using *h* equal to 84,000 BTU/hr.ft^2.°F increases by approximately 3 to 4% of the initial velocity for the low K case (low pipe resistance model). The change is less for the other cases.



Pipe Diameter Effects

- Basic flow equations are employed to show that the pipe friction effect on water flow is negligible and independent of the flow area (or pipe diameter).
- Noncondensable gas compression is also independent of the pipe area.
- However, removal of the steam by condensation is determined predominantly by heat transfer to the water interfaces.
  - Heat transfer on turbulent water surfaces is velocity dependent and not diameter dependent.
- Therefore, the heat transfer to the water tends to occur as a uniform heat flux, which also is independent of pipe flow area.

Pipe Diameter Effects (cont.)

- Water motion, gas and steam state properties, and condensation heat transfer only depend on the length scale in the flow direction, but not on the cross-sectional area or pipe diameter.
- It follows that the tendency of the hA product to remain constant is supported by:
  - the fact that the area A cancels from all the equations
  - the simplified condensation modeling shows that the condensing coefficient h is influenced by the turbulent velocity and thermodynamic state properties, but not the pipe diameter.