DR. SANJOY: That was the clad temperature.

CHAIRMAN WALLIS: No, this is the steam. It is the other way around, it is getting cooled as it goes through the grid?

DR. HOCHREITER: Right. This is the steam temperature, 93 inches, again I should have drawn an arrow here, but the flow is up this way.

CHAIRMAN WALLIS: So what cools it?

DR. HOCHREITER: The droplet breakup here. The turbulent mixing, droplet breakup.

CHAIRMAN WALLIS: Now, these droplets --

DR. HOCHREITER: Increased convection.

CHAIRMAN WALLIS: These droplets are hitting your probe, then?

DR. HOCHREITER: The droplets are hitting the grid.

CHAIRMAN WALLIS: Not hitting the probe?

DR. KRESS: What was bothering me is that this supposes that every grid you hit the droplets get smaller, and then they get smaller again. I could never rationalize this.

DR. HOCHREITER: That may not be true, because you may reach a minimum size where most of the drops can pass through the grid. Where most of the drops can pass through the grid.

DR. KRESS: But then you wouldn't see the effect.

DR. HOCHREITER: There is still a convective enhancement that is caused by the spacer, particularly a spacer like this. So you are going to get a higher interfacial heat transfer between the vapor and the drop.

MR. SCHROCK: Do you have thermacouples on the grids?

DR. HOCHREITER: Yes.

MR. SCHROCK: You are not showing us those?

DR. HOCHREITER: I'm not. Most of these grids will end up being quenched.

MR. SCHROCK: Yes, that is what I was going to suggest, that your cooling occurs between the grid and the steam going through and not in a change in mixing conditions downstream of that.

DR. HOCHREITER: Well, I know there is a change in the mixing conditions downstream, I know that from single phase tests.

MR. SCHROCK: But you can't convince me that the predominant effect is in the region downstream of the grid, without showing me the temperature on the grid.

DR. HOCHREITER: Well, for most of these tests --

MR. SCHROCK: They are quenched.

DR. HOCHREITER: For most of these tests the grid --

MR. SCHROCK: But that is a lot of surface area compared to the drop surface area.

DR. HOCHREITER: I know, I agree, I agree. And that is something that we are going to have to sort out from the data. And, really, we've talked about this with the NRC.

We have purposely kept these tests at a low temperature, because it is the beginning of a test period, a long test period, one very large expensive rod bundle.

What we planned to do, and Steve had it on his slide, is go back after we run our separate effects decomposition of disperse flow film boiling, and run higher temperature tests, because there we will definitely have the grids hot.

And we do have some data, but it is limited, where the grids are hot. And I can't honestly answer whether you see exactly the same effect, or not, without going back and looking specifically at that data.

MR. SCHROCK: But you are convinced that the predominant effect is the enhanced heat transfer between drops and steam downstream from the grid, not enhanced heat transfer in the grid, from wall to steam?

DR. HOCHREITER: Well, actually, liquid film is --

MR. SCHROCK: Well, the liquid film is the wall to the vapor.

DR. HOCHREITER: Yes. Right now, yes, I am.

DR. KRESS: Larry, I conclude that in order to get that enhanced heat transfer, that you have to have more droplet surface area, which means you have to break them up.

Actually the heat transfer of a given drop between the steam and drop wasn't much, when I tried to make the calculations. So that is, once again, I come back to I never figured out how we kept making the droplets smaller each time.

DR. HOCHREITER: Well, Dr. Schrock has a very valid point.

DR. KRESS: Yes, it could have something to do with that grid, yes.

DR. HOCHREITER: And the amount of surface area. You get two benefits, if you would, in that case. One, the surface area benefit, because the grid does have a huge surface area.

The second benefit is that the relative velocity is much higher for the interfacial heat transfer, because the grid is not moving.

MR. SCHROCK: And the third is that you are in a thermal entry region.

DR. HOCHREITER: Right.

MR. SCHROCK: Very close to the beginning of it.

DR. HOCHREITER: That is right.

MR. SCHROCK: All at a very high heat transfer coefficient.

DR. HOCHREITER: That is right.

CHAIRMAN WALLIS: What does your grid thermocouple show?

DR. HOCHREITER: For most of the tests the grid thermocouple, once you start to get water through here, will quench. So it will come down --

CHAIRMAN WALLIS: The grid thermocouple is way down there.

DR. RANSOM: Larry, have you modeled these using COBRA/TRAC, or --

DR. HOCHREITER: Yes.

DR. RANSOM: What does it show in terms of these temperatures?

DR. HOCHREITER: We get a behavior like this.

DR. RANSOM: It would be very instructive to see some comparisons.

DR. HOCHREITER: We have done those, we do get a behavior that is like this.

DR. RANSOM: You do get that kind of superheat being predicted?

DR. HOCHREITER: Yes. If anything we tend to overpredict the superheat.

DR. RANSOM: How about other NRC codes? Like RELAP-5, what does it show?

DR. HOCHREITER: I cannot answer that, I don't know. But in this case, at this higher elevation, you do see more of an effect on the grid, even on the vapor temperature, including the rod temperatures.

The higher you go, of course the power gets higher. This is around the peak power location. Again, this is a thermocouple downstream of the grid, thermocouple upstream of the grid.

And when I said these tests are quasi-steady, I mean, these temperatures are really fairly steady for hundreds of seconds. And you don't see that in a normal reflood test.

Again, the reason for it is because we've been running these at a constant power. But here is almost 200 degrees C difference, upstream and downstream.

And you see the same picture for the vapor. The vapor is almost constant. This is almost a steady state test, that starts to drop off sooner because it is at a lower elevation.

CHAIRMAN WALLIS: And no one has tried to analyze these?

DR. HOCHREITER: We are analyzing these, the NRC is going to be analyzing these.

CHAIRMAN WALLIS: I really don't think that is the way to do it, they should be analyzing them right now, not waiting.

DR. HOCHREITER: This is at the -- past the peak power location, almost at the exit of the bundle. And, again, this is the temperature downstream of the grid, and this is the temperature upstream.

The temperatures, of course, are lower now because the power has dropped off.

DR. KRESS: You have cosine type distribution?

DR. HOCHREITER: No, it is two straight lines.

DR. KRESS: Two straight lines?

DR. HOCHREITER: From .5 to 1.5 peaking factor, and 1.5 occurs at about 108 inches, and then from 1.5 down to .5 at 144 inches.

DR. KRESS: Yes, that would be easier to analyze, anyway.

DR. HOCHREITER: And that is one of the reasons it was chosen.

DR. SANJOY: If you take the precursory cooling into account, does the advance of the quench front follow any sort of conduction quench front advance? You would have to work out the entrainment, and all this sort of stuff.

DR. HOCHREITER: We had a student that just finished at Penn State, that made improvements to the COBRA/TF inverted annular, annular, and entrainment models. We had him run his calculations against FLECHT test, which have a cosine power shape, and these rod bundle tests.

And he got excellent agreement with these five bundle tests. There still are issues with the code. One of the issues is what do you choose for T-min, minimal film boiling temperature.

These tests indicate that it should be lower than the models that are typically in the code. If you make that adjustment you could match the quench fronts very well.

So it was actually a combination of both of those things.

CHAIRMAN WALLIS: How much water is being drained out the top of the hole?

DR. HOCHREITER: Quite a bit. The qualities, if I remember correctly, are around 50 percent.

CHAIRMAN WALLIS: So half the flow coming out of the top is water?

DR. SANJOY: T-min would also depend on the material?

DR. HOCHREITER: Yes.

DR. SANJOY: That is the problem.

CHAIRMAN WALLIS: It depends on the velocity, too. It is not just a magic number.

DR. HOCHREITER: We have run experiments, again, as part of the program, on different cladding materials. We built a small furnace and we took inconnel, built a four foot heater rods, basically, and basically oxidized the inconnel. And we got T-min values, basically, with a dunk test.

And then we took zircaloy, fresh zircaloy, and zircaloy with different oxidation thicknesses, which we could characterize, did the same thing. Yes, there is quite a bit of difference.

We took the inconnel samples, we roughened them, and again you get a higher T-min value. So this is something that is going to have to be nailed down.

CHAIRMAN WALLIS: Which means that all fuel elements which have an oxide layer are going to be different?

DR. HOCHREITER: That is right. But those are usually low power fuel elements, not limine.

Again, what I'm ecstatic about with this data is the steam temperature measurements that just slowly, slowly come down towards saturation. We never saw that in any previous test, ever, anywhere in the world.

DR. RANSOM: Never saw what?

DR. HOCHREITER: Steam temperatures remaining superheated and then slowly coming down to a saturation temperature like this. Usually it goes plunk.

DR. RANSOM: You don't see any quench, you don't think?

DR. HOCHREITER: That is right. Now, this is at the very top of the bundle, the flow is most highly dispersed.

MR. SCHROCK: It looks almost like it sort of tries to quench, and then hesitates, and then tries again.

DR. HOCHREITER: Yes, in here.

MR. SCHROCK: Right, those shelves.

DR. HOCHREITER: Yes. And so, again, my interpretation of the data is take the tops.

DR. RANSOM: You have the same number on that 1096, is that a run number?

DR. HOCHREITER: Yes.

DR. RANSOM: But when I look at the printed version it looks different out here where these, near the tail end.

DR. HOCHREITER: I don't know what you mean.

DR. RANSOM: I guess you've gone over it with a pen, and smeared it up, that is what it looks like.

DR. HOCHREITER: With the green, you mean?

DR. RANSOM: Right, the green.

DR. HOCHREITER: Yes, I did, to make it

more dramatic.

DR. RANSOM: But when you look at the printed one there are more distinct shelves.

DR. HOCHREITER: Yes.

DR. RANSOM: There, as it comes down.

DR. HOCHREITER: That is very true, that is very true. You can see them in through here.

DR. RANSOM: Yes.

CHAIRMAN WALLIS: I don't think your model is going to predict those shelves.

DR. HOCHREITER: I don't think so either.

MR. BOEHNERT: What are you attributing this to, Larry?

DR. HOCHREITER: What am I attributing what to?

MR. BOEHNERT: This fall off of superheat cooling?

DR. HOCHREITER: The quench front is coming up but it is so highly dispersed that there is just not a lot of liquid there, okay? There is obviously liquid in the flow, that is really what causes this, okay?

MR. BOEHNERT: But you are saying you've never seen these many tests before?

DR. HOCHREITER: But I've never seen it

persist for as long a period of time. Because we always use these aspirating steam probes and, you know, so you are sucking steam, hopefully steam, into the thimble, where you have a shielded thermocouple. And you provide a torturous path, hopefully, to separate out the liquid.

Well, hopefully doesn't cut it. Now, a couple of reasons. One, you do get liquid in there, when you get it in there, it hits the probe, it quenches. These were larger thermacouples, which is probably part of the problem. These are much smaller thermacouples.

Again, the other thing is you have a decay power, so the whole transient is compressed. And you get a lot more liquid up there, sooner, than you do in these tests.

CHAIRMAN WALLIS: Did you do separate effects tests on your probes to see what they actually measure in a controlled flow?

DR. HOCHREITER: We have not, no. I think we did something like this in the FLECHT SEASET program. We used bare thermacouples in the FLECHT SEASET program, but it was at the very end of the particular, in a small 21 rod bundle.

And we had, Ralph and I designed a lot of steam probes that didn't work, okay? So it is rare that you find one that does. And we had shielded thermacouples, we had self-aspirating thermacouples, and then we had bare thermacouples.

Now, bare thermacouples worked the best. I think it is just a question of providing the smallest target to the drops.

DR. SANJOY: There was some CARS measurements made at Lehigh, John Chen made them?

DR. HOCHREITER: Yes. So he basically took what we had done in FLECHT and did it in a smaller rod bundle where, again, he was aspirating, pulling a vacuum and sucking --

DR. SANJOY: No, I meant he was also using random scattering to look at temperatures.

DR. HOCHREITER: That I'm not aware of.

DR. SANJOY: I don't know if he ever got it to work.

DR. HOCHREITER: I really can't answer that, I don't know.

DR. SANJOY: Then he had an independent measurement, completely.

DR. HOCHREITER: Right.

DR. SANJOY: NRC funded it, so we should be able to dig up what --

DR. HOCHREITER: No, we have the reports, and I looked at those reports, I just don't remember that being reported.

DR. SANJOY: Okay.

DR. MOODY: What is the one inch per second?

DR. HOCHREITER: It is one inch cold flooding rate into the bottom of the bundle.

Now, we have the laser illuminated camera. And this was positioned at the 93 inch elevation. And this is plotting the mean diameter versus time after reflood. This gives you an indication of where the quench front is, okay?

And as the quench front is moving up along these elevations, the mean diameter from the distribution of the drops that we measured with the camera, is slowly increasing.

And then as the quench front gets very close to this 93 inch elevation, this basically falls off. So we are measuring drops, entrained drops, roughly four to six inches below the quench front, with this camera system. We have never been able to dot and plot it.

And you get a whole history of these drops. When we did these, tried these types of measurements in the FLECHT SEASET program, as Steve indicated, we would maybe get 50 drops.

DR. KRESS: Where would you locate a grid along that?

DR. HOCHREITER: This is above a grid, if I remember correctly.

CHAIRMAN WALLIS: So one location?

DR. HOCHREITER: Yes, one location. I'm going to show you above and below in a minute.

DR. RANSOM: Larry, what Webber number do those correspond to?

DR. HOCHREITER: I can't tell you that, I have not calculated that.

DR. RANSOM: You really need to extract some of that data out of this.

DR. HOCHREITER: Well, we will, we will. We will be able to do that because we will do the -- at least it is going to be a bundle average steam velocity, and we can calculate that.

DR. KRESS: By looking at that change in droplet size you could probably extract how much turned into steam.

DR. HOCHREITER: Exactly. But you have to remember --

DR. SANJOY: There is not much change.

DR. HOCHREITER: You have to remember --

DR. KRESS: That is what I was thinking, there is not much of a slope there.

DR. HOCHREITER: You have to remember that these, the measuring system tends to bias you towards smaller sizes.

DR. KRESS: It probably does, yes.

DR. HOCHREITER: Because we cannot see the drops that are behind the rod, and we are looking through the gap. And the gap, I think, is 122 mils. And in the camera system you have to put boundaries, you put into the software boundaries. So it is actually less than 122 mils.

And then the software package with the system basically rejects parts of drops, or any drop that touches the boundary. So you tend to get a bias here, probably, of smaller drops.

DR. SANJOY: These are about 15 thou, right?

DR. HOCHREITER: Right.

DR. SANJOY: What is 122 mils?

DR. HOCHREITER: Well, roughly eight times this.

DR. SANJOY: This is a Sauter mean?

DR. HOCHREITER: This is just mean, I'm

going to show you Sauter mean next. Sauter mean is a little larger. There is more scatter, too, which I cannot explain right now.

DR. RANSOM: Sauter mean is the diameter that gibes you the same surface area?

DR. HOCHREITER: It is a surface area --

CHAIRMAN WALLIS: Actually it is a volume to surface.

DR. HOCHREITER: A volume to surface, so it comes out with a D, yes.

These are the number of counts. This is just to show you that we had a lot of counts.

CHAIRMAN WALLIS: This is counts per second?

DR. HOCHREITER: This is counts for each diameter size that we got, okay? And we -- I don't have the total number of counts, but it is typically like 5,000.

So the number, we threw anything of 20 or less. So to calculate this diameter, whether it is a Sauter mean, or the average diameter, where you are using data that has about 51 counts.

CHAIRMAN WALLIS: Presumably over a period of time?

DR. HOCHREITER: It is, but it is rather

short. Total counts, total, for that window.

DR. SANJOY: But there is seconds after reflood?

DR. HOCHREITER: Yes, these are seconds after reflood.

DR. SANJOY: How big are your windows?

DR. HOCHREITER: THE time window? I think it was about, I'm guessing, 20 seconds.

CHAIRMAN WALLIS: So there are very few counts per second.

DR. HOCHREITER: Yes. I don't really know the exact number.

DR. SANJOY: But it is off that order, because you go one, two, three, four, five, six, six in 100 seconds, roughly, of those.

DR. HOCHREITER: Yes. Now, if we look at the distribution, and you should correct your slide, this is below the 110 inch grid, this is the distribution we are getting, this was the mean, okay? And the mean was 18 mils.

CHAIRMAN WALLIS: That is a log scale?

DR. HOCHREITER: Yes. Actually we found most of this fits a log normal distribution.

CHAIRMAN WALLIS: What are these weird ones which are off scale?

DR. HOCHREITER: They are weird. They are weird data, which I cannot explain at this time.

DR. SANJOY: So these are log normal distribution, really?

DR. HOCHREITER: Yes.

CHAIRMAN WALLIS: Except for the weird ones.

DR. HOCHREITER: Except for the weird ones. This is above the grid, the one below the grid was 0.18 something. This is the size above the grid, the size has decreased.

The other thing, at least it seems to me, that this distribution is tighter than the one below the grid.

DR. SANJOY: But, you know, as you said, you may be biasing your data because of the window.

DR. HOCHREITER: I know, I know. You have to consider that.

MR. SCHROCK: There is a huge resonance of 10 to the minus 2 inches. Resonance.

CHAIRMAN WALLIS: Those are the weird ones.

MR. SCHROCK: It looks like a neutron scattering.

CHAIRMAN WALLIS: Well, it is not a log

scale, is it?

DR. SANJOY: Well, it could be that there is a preferred size.

MR. SCHROCK: It could be.

DR. HOCHREITER: I don't have an explanation for these points.

DR. SANJOY: If you look at this data set there is also that little bump.

DR. HOCHREITER: The next plot just is axial plots of the vapor temperature. So the green is at the beginning of the test. The solid squares are at 350 seconds. So, I mean, I just drew a colored line through here, so you can see it better.

And this is a turn-around, so you have some data here, you have point that is low here, these points are high here, points in here. Some of the thermacouples in the steam probes do behave differently, because this one is low, these two are basically together, these three are basically together.

By and large you don't see a large radial temperature gradient across the bundle, because you are sampling three different subchannels here, in the bundle.

Each one of these thermacouples is in the center of a different subchannel. They come in from the side.

DR. SANJOY: So now this is by axial location?

DR. HOCHREITER: That is right, this is temperature versus axial position.

DR. SANJOY: And the temperature --

DR. HOCHREITER: Or three different times.

MR. SCHROCK: Okay.

DR. HOCHREITER: This is at the beginning of the test, this is at 350 seconds, this is at turn-around. Now, this is my drawing of --

MR. SCHROCK: I don't understand how you are showing turn-around on temperature versus location.

DR. HOCHREITER: This is the clad temperature turn-around, this is the steam temperature distribution at the time that the clad temperature turns around.

CHAIRMAN WALLIS: Where does it turn around?

DR. HOCHREITER: At the upper elevations, up in here. And I don't remember what the time is, I would have to go back and look at the time.

DR. BAJOREK: It is about 800 seconds or

so.

DR. HOCHREITER: Yes, something like that.

DR. SANJOY: 350 seconds, when you say 350, is 350 from the start of reflood?

DR. HOCHREITER: Right.

DR. SANJOY: But when you say turn-around, what do you mean, is that something like 800 seconds?

DR. HOCHREITER: Yes, I should have put a time in here.

Now, the plot that Dr. Kress was talking about looks something like this. Again, this is temperature versus elevation. These are the heater rod temperatures, these are the spacer grids, these are vapor temperature measurements.

CHAIRMAN WALLIS: So the zigzag is used as spacer?

DR. HOCHREITER: Yes. You get cooling, and then you get recovery, cooling, recovery, I'm not too sure why this drops down, and then and so forth. Then you have --

DR. SANJOY: Where is your flux peak?

DR. HOCHREITER: It's in here, very close to this. Yes, I don't know why this is --

CHAIRMAN WALLIS: What are the expectations of the code, Steve? Are you going to model these mountains?

DR. BAJOREK: Yes, we think that in the long run this code has to be able to get the cladding profile, and be able to get the dips following each of these grids. And that is going to require us not only to get the rod to the fluid heat transfer correct, the interfacial heat transfer correct, and be able to get what I will call the delta D, or the change in the droplet sizes it encounters one grid to the next.

DR. KRESS: We'll need that, because there is 150 degree difference there.

DR. SANJOY: What time is it?

DR. HOCHREITER: This is at the peak temperature turnaround time. This is around 800 seconds. It is actually -- I can tell you that more accurately.

DR. RANSOM: Larry, the turn-around time is when the peak clad temperature starts to go back down?

DR. HOCHREITER: Yes. It is more like 400 seconds.

DR. SANJOY: Four hundred seconds?

DR. HOCHREITER: I'm just going based on this.

DR. SANJOY: And where does the peak clad temperature occur, is it at the maximum flux point?

DR. HOCHREITER: Yes, it is up in here.

DR. SANJOY: Somewhere there. So I don't understand this, Larry. The peak temperature there, that you are showing, is about 850, 870, or something.

DR. HOCHREITER: I see what you are saying, yes.

DR. SANJOY: So wouldn't you expect that unless the turn-around is just before the peak?

DR. HOCHREITER: Ralph, do you remember the exact location of the peak power?

DR. ROSAL: 108.

DR. HOCHREITER: 108 inches?

DR. ROSAL: Yes, we have it.

DR. HOCHREITER: All right, I would have to convert that to meters, because this was in -- I don't really know, it is before this grid.

CHAIRMAN WALLIS: This initial temperature, what is that? The initial temperature of everything?

DR. HOCHREITER: This was the initial temperature of the test.

CHAIRMAN WALLIS: Everything is at that temperature, it must be just the peak?

DR. HOCHREITER: It is the peak. There

was a 20 PSI test, I've got a similar set of plots for 40. Do you want me to walk through those plots?

CHAIRMAN WALLIS: Is there anything new?

DR. HOCHREITER: Not so much, no.

CHAIRMAN WALLIS: So are you going to, then, show us some predictions, or something?

DR. HOCHREITER: No.

CHAIRMAN WALLIS: There is a COBRA/TF here, on one of these.

DR. HOCHREITER: I don't think so, there shouldn't be. If there is, I screwed up.

I do want to show you, if you go ahead in the package, this is the steam probe behavior. When you are at the center of a subchannel, and when you are in the gap.

This experiment has a vapor temperature measured in the gap, versus this experiment, same conditions as the vapor temperature measured in the center of the subchannel.

CHAIRMAN WALLIS: So you are going to show that, too, in the code? It is going to be a two dimensional code, a three dimensional code?

DR. BAJOREK: No.

CHAIRMAN WALLIS: There is a big difference.

DR. SANJOY: What is the vapor velocity?

DR. HOCHREITER: I cannot give you an accurate number on that.

DR. SANJOY: It is most likely, though, that things are fairly well mixed, aren't they?

DR. HOCHREITER: Well, your vapor velocities are going to be the highest in here.

DR. SANJOY: Right.

DR. HOCHREITER: Okay? Vapor velocities are the highest in here, and they are going to be the lowest right in here.

DR. SANJOY: That could be just the radiation effect, or something.

DR. HOCHREITER: I don't think so. I really don't.

CHAIRMAN WALLIS: So it is much more readily quenched in the one position than the other?

DR. HOCHREITER: Well, you have more liquid here than you do here.

CHAIRMAN WALLIS: And the one that is quenched, I'm trying to figure out which is which. The center line is --

DR. HOCHREITER: The one that is quenched is the one that is in the center. You have a non-uniform temperature distribution within the subchannel.

The temperatures are going to be higher in the gaps than they are in the center of the subchannel. CFD calculations show that, because the velocity distribution is highest in the center of the subchannel, lowest in the gap region.

So if nothing else changes, the vapor in here is going to be at a higher temperature than here, simply because of velocity. It is lower in the gap region compared to the center.

Now, should a computer code like TRAC-M account for this? No, I don't think so.

CHAIRMAN WALLIS: Well, if it is averaging, it is going to average over a pretty wide range of --

DR. HOCHREITER: Well, there is more area here than there is here.

CHAIRMAN WALLIS: What is it going to say the temperature is?

DR. HOCHREITER: What TRAC-M is going to say the temperature is?

CHAIRMAN WALLIS: So 600 or something, between --

DR. HOCHREITER: TRAC-M is going to give you a more accurate estimate of the temperature in here.

DR. SANJOY: It would be an area average.

CHAIRMAN WALLIS: I guess it doesn't matter, there would be enough coefficients in the code that it will correct for it, anyway.

DR. HOCHREITER: Well, I wouldn't even try, but this is just something that people should know about.

DR. BAJOREK: Larry, I think what you are pointing out is, the TRAC-M, we would be shooting at getting like a mass weighted average across the bundle, and that is about the best we will do with that.

What the tests are pointing out is the potential need, in the future, for looking at subchannel effects. In something like that we would want to start looking at coupling TRAC-M with the COBRA/TF, or something like a VIPER, if it is important for the Staff to be able to predict the differences across the bundle, like that.

DR. SANJOY: Are the clad temperatures higher in the gaps, too?

DR. HOCHREITER: We don't know, because we have a single thermocouple at some position. We don't know the azimuthal position of the thermacouples.

Also the interior of the rod is boron nitride-filled. So you tend to smear out azimuthal differences.

DR. SANJOY: But you are getting the inconnel temperature, right?

DR. HOCHREITER: The inside temperature of the cladding is measured.

DR. SANJOY: So some of it is --

MR. SCHROCK: Larry, how did you explain this quench that occurs and persists for 20 odd seconds down here?

DR. HOCHREITER: Big drop, big drop.

MR. SCHROCK: Well, I can see it is a big drop, but what is going on there, how does the steam suddenly go to saturation well --

DR. HOCHREITER: The steam doesn't, the steam doesn't.

MR. SCHROCK: What is that?

DR. HOCHREITER: The thermocouple does. A drop hits the thermocouple and quenches it. The steam temperature is up here.

CHAIRMAN WALLIS: Is there one drop for that whole period?

DR. HOCHREITER: It could be more than one.

DR. RANSOM: What it looks like is an

inverted annular flow, almost, over the mass concentration of liquids more in this channel.

DR. HOCHREITER: No, you just got hammered by a bunch of drops.

DR. RANSOM: Well, that is what I said. But essentially inverted annular flow, where you have a higher concentration of liquid in the center of the channel.

DR. HOCHREITER: Right, you have more drops.

DR. RANSOM: That is right.

DR. SANJOY: But it could be ligaments, it could be anything.

DR. HOCHREITER: I don't think so, not at this time.

CHAIRMAN WALLIS: Is this just downstream of a spacer?

DR. HOCHREITER: This is at 100 inches, so this is downstream of a spacer.

CHAIRMAN WALLIS: So you've got drops coming off the spacer, preferential streaks?

DR. HOCHREITER: Yes, but it is pretty far downstream of the spacer.

MR. SCHROCK: So it looks as though there is not much liquid getting to that level until a little bit after 200 seconds. Then all of a sudden --

DR. HOCHREITER: Well, this I think, the fine hash, here, I think is liquid.

DR. RANSOM: 25 seconds is a long time.

DR. HOCHREITER: That is liquid coming.

DR. RANSOM: But there is a precipitous change at 210 seconds, or something like that.

DR. HOCHREITER: Right. Well, there is one here, too.

DR. RANSOM: Well, that one is short.

DR. HOCHREITER: Yes, but this is liquid.

DR. RANSOM: Sure.

DR. HOCHREITER: All of this is liquid, liquid, but whammo, you got hit, you try to recover, you got hit again. You try to recover, you got hit again.

CHAIRMAN WALLIS: It got really soaked for a long time.

DR. HOCHREITER: Yes, try to recover, got hit again, and slowly dried out, okay? Almost got here, but you got hit again. And, finally, you dried up.

Now, the steam temperature, what we are concerned about is the steam temperature. This is not the steam temperature. The steam temperature is up here.

That is what I said, you draw an envelope over these spikes, that is about the best you can do, okay? That is the best you can do.

So if your code comes along and predicts the tops of these, down to here, you are doing a real good job.

DR. SANJOY: But you don't even know if the top is the steam temperature.

DR. HOCHREITER: No, but it is the closest thing to the steam temperature.

DR. SANJOY: Yes, but the code doesn't have to predict it because, in fact, it may be halfway to the steam temperature, it could be the full way, you don't know.

DR. HOCHREITER: If the code is predicting a temperature down here, it is wrong.

DR. SANJOY: That is wrong, yes.

DR. HOCHREITER: But if the code is predicting a temperature here, it is wrong. If it is predicting a temperature up here it is wrong.

DR. SANJOY: Maybe.

DR. HOCHREITER: No, it is wrong. I mean, this is probably hotter than the rods.

DR. SANJOY: Well, we don't want to do

that.

DR. RANSOM: Larry, if I --

DR. HOCHREITER: It has to be in the vicinity of this data.

DR. RANSOM: Larry, other investigators have used a shielded thermocouple that more or less kept the liquid away from the thermocouple so you more or less measure the steam temperature. Would that be worth trying?

DR. HOCHREITER: I did try that, and what happens is you have a larger target, because it is shielded. So you get more liquid hitting it.

DR. RANSOM: In a cold shield?

DR. HOCHREITER: That is right. I tried aspirating these things, where you cut holes in the sides so the steam magically flows through, and it flows out the top. The steam didn't know that, and the water just hit it.

So, really, I really think the best thing are as small as you can get them, the thermacouples.

CHAIRMAN WALLIS: Well, let's let the radiation now, when the guy is in the gap, you've actually got more rods than you show there. It is looking sideways, it sees a lot more view factor of rods than it does in the other cases, more heat leak by radiation in the single light case.

DR. HOCHREITER: I think the argument would be, I mean, this sees nothing but a sea of rods.

CHAIRMAN WALLIS: Does it? It sees the outside world looking straight down, and straight up, and straight sideways. More southeast and west, it sees space.

MR. SCHROCK: But his scale is misleading, because the actual clearance between the rods is quite small.

CHAIRMAN WALLIS: At least it would explain the quenching.

DR. HOCHREITER: This is very true, we have not done that, that is one of the things that we have to do with this data. Because this actually goes back to -- I don't think I wanted to do that.

CHAIRMAN WALLIS: I think if you look at a lot of details you are going to find so many of these anomalies.

DR. HOCHREITER: Yes, but this goes back to, I think, what Dr. Schrock was saying, in terms of the accuracy of the data. You have the accuracy of the instrumentation, but you have a large uncertainty, which is really imposed on the data.

And the radiation effects in here are one of them. This behavior is another.

CHAIRMAN WALLIS: Is this consistent at different locations? I mean, if you went to 125 inches you might find the story was reversed.

DR. HOCHREITER: We only ran this one test. We did not run other tests. We talked about this and decided the most representative place for the thermacouples for these steam temperature measurements was more into the center of the subchannel because you are, in effect, sampling a larger fraction.

CHAIRMAN WALLIS: If that is true of all locations of the probe.

DR. HOCHREITER: I can't answer that.

MR. SCHROCK: You've got some apparent recovery times that are almost unbelievable, I think.

DR. HOCHREITER: Well, the scale, though, is -- look at the scale.

MR. SCHROCK: Yes.

DR. HOCHREITER: The sampling time is --

MR. SCHROCK: Have you calculated what the recovery time ought to be?

CHAIRMAN WALLIS: The trouble is swept away very quickly.

DR. HOCHREITER: Well, it is also followed by a burst of superheated steam.

CHAIRMAN WALLIS: But it is swept away, right?

DR. HOCHREITER: Yes. Again, looking at the drop -- I'm skipping ahead. This is the drop data. Again, this is a 40 PSI test. This is below the grid, and you have a mean of .025 inches.

DR. SANJOY: Why is there so much more scatter here, than the other one?

DR. HOCHREITER: I don't know. And this is above the grid. I think the grids are shaping the drop distribution. Now, I did not think about drops agglomerating downstream of a grid, okay?

I don't know if that is happening at all, or not. But, clearly, when you are passing through a grid, you are tending to, I think, to shape the distribution.

CHAIRMAN WALLIS: That is a very big drop on the right-hand tail, there.

DR. HOCHREITER: Over here?

CHAIRMAN WALLIS: Yes.

DR. HOCHREITER: It is probably too big.

DR. SANJOY: The camera didn't reject that one?

DR. HOCHREITER: No, but it probably should have.

DR. SANJOY: Ten to the minus one inches, one-tenth of an inch.

DR. HOCHREITER: This would still be within the subchannel.

DR. SANJOY: I thought you said it was .122 inches, your subchannel? I mean, your camera would reject anything --

DR. HOCHREITER: So this is .01, this is .1.

DR. SANJOY: Oh, okay.

CHAIRMAN WALLIS: But still a .05 inch drop is pretty big.

DR. HOCHREITER: Fifty mils, yes.

DR. SANJOY: How many millimeters is that?

DR. HOCHREITER: A little more than one, one and a quarter.

Now, one of the questions that was asked, I think by Dr. Banerjee, what are we learning that is new? This is the kind of data we got in FLECHT SEASET, okay?

This was taken with high speed movie cameras, which mostly failed, because we ripped the film apart. You take 400 feet of this film at 2000 frames a second. This was a successful test, we got 101 drops.

We then paid an employee to basically go frame by frame, shining this on a wall, paying for the changes in his eye prescription, as he would count the drop sizes, and we would get distributions that are something like this.

CHAIRMAN WALLIS: Not so different from what you got now.

DR. HOCHREITER: No, it is really not that different. Except now we get a lot more data for a long period of time. This is only for six seconds, okay?

DR. BAJOREK: Yes, but we are also going to be able to get it above and below a grid for comparable flows.

DR. HOCHREITER: I think that was a little bit out of order. But here were, again, the axial profiles for this test. Again, these are the grids. I have the grid wall temperatures plotted here.

Here is one of the grid wall temperature. So this is indicating that part of the grid is still hot, part of the grid is wetted. Most of the time, particularly at this time, when the quench runs at this elevation, the grids have wetted.

And then you see the saw-toothed curve that you get from the heat transfer performance of the grid.

CHAIRMAN WALLIS: Again, that is reversing steam probe in certain locations, it is really cold.

DR. HOCHREITER: Yes, you have one thermocouple quenched here, the other two are okay. These are all together, together, together, this one is quenched, this is at the end of the bundle, these are all together.

DR. SANJOY: That is a snapshot it time, right?

DR. HOCHREITER: That is correct.

DR. SANJOY: So one could be quenched.

CHAIRMAN WALLIS: So explaining this may be harder than getting the data.

DR. HOCHREITER: Boy, I hope not. Now, contrast that to an axial temperature distribution from FLECHT SEASET. This is temperature versus elevation, this is the behavior. And you don't really see a spacer grid effect.

Now, the bundle was not instrumented specifically to look for it. So it is really not too surprising that you don't see it. But the spacer grids that are in these tests are very simple grids. Half the blockage that these grids are.

But you have to instrument it to find it, and that was not done, because it wasn't considered that important.

CHAIRMAN WALLIS: The agency is going to have to decide what kind of code assessment is appropriate for this sort of data.

DR. HOCHREITER: Well, what would be very interesting to me would be, if someone predicts these tests very well, okay, with the codes. And then predicts these tests very well.

DR. BAJOREK: And predicts FEBA Test 223 and 234, which were comparable tests, where they took a grid in and out.

DR. HOCHREITER: With or without a center grid. If you are going to predict this test, you are going to have to have a spacer grid model in there, that is going to somehow recognize this geometry.

And then to predict these tests, you are going to have to have a spacer grid model in there that somehow recognizes the FLECHT grid geometry.

DR. SANJOY: You'd have to do that for the pressure drop, anyway, it is for some loss factor, or something, right?

DR. HOCHREITER: Yes.

DR. SANJOY: So, I mean, it could be related to that.

CHAIRMAN WALLIS: Who is going to do this work?

DR. HOCHREITER: Look at all those hands flying.

DR. BAJOREK: We will be doing that, that will be the staff.

CHAIRMAN WALLIS: Will I still be on the ACRS when you finish?

DR. BAJOREK: How many more years are you going to be doing this?

(Laughter.)

DR. HOCHREITER: Now, what Steve indicated, currently what is planned to do in the program, is do some interfacial drag experiments over a range of flows and powers, and pressures.

This is to be used to aid in the model development for advance plant audits that the Staff is doing right now. We are presently installing a steam boiler, actually Penn State is doing this for the program, and then we will run steam cooling experiments with and without droplet injection, to create, basically, steady state dispersed flow of film boiling tests, where we can decouple the problem from the quench front.

The steam cooling tests will also give us a reference convective heat transfer.

CHAIRMAN WALLIS: It will be interesting to see how steady your steady state is.

DR. HOCHREITER: Well, that is true, that is true, because this is not going to be straightforward.

Once these are done we will also be looking at more severe reflood tests with variable flow rates, higher temperatures. Again, the higher temperatures are primarily to drive the grids to a higher superheat temperature for a longer period of time. Really, to address the point that Dr. Schrock brought up.

And then there has also been talk about doing top down film boiling experiences. But this part of the plan is pretty much agreed upon.

CHAIRMAN WALLIS: What is a top down film boiling experiment?

DR. HOCHREITER: These are tests where you would actually bring the flow in from the top, and it would simulate the reverse flow period at the end of blowdown. It is still dispersed film flow boiling, but you now have a reverse flow.

And this is typical of, certainly, most four-loop plants, where you get a reverse flow as the pressure is coming down during blowdown. Now, we can't go to really high pressures, we can only go up to maybe 60, 70 feet, but at least we can capture the effect.

DR. SANJOY: That is at fairly high pressure, that happens?

DR. HOCHREITER: Well, it is typically 100 PSI, and we are not going to be able to get to 100 PSI.

DR. MOODY: You would do those on the same geometry?

DR. HOCHREITER: Yes.

DR. RANSOM: Larry, what do you expect to get out of the droplet injection test? You want to get a steady state, is that the idea?

DR. HOCHREITER: Yes. And I specifically want to get very detailed subchannel vapor temperature measurements.

It is doubtful that we can move the camera around during a test, because this -- it is very, very delicate. You have to set this thing up very -- I'm not going to say, set it up and fix it very hard.

And we've observed that as you heat the facility up the bundle can twist. And, remember, you are only looking through the gap. So the area, the viewing area can change.

So we've had to come up with an arrangement, basically, lets the camera flow to move with the housing as much as possible. But if we could get somebody to give us some more money, we could put more of these cameras in different positions.

But it is a very expensive system. When we purchased it, it was approximately 70 to 100,000 dollars. But it has really given very good data.

DR. RANSOM: So you just have one window, where you can take --

DR. HOCHREITER: No, we have windows -- we have a total of six --

DR. RANSOM: You only have a camera at one of the windows?

DR. HOCHREITER: We only have a camera at one of the windows. Now, what we did in the reflood test is we moved the camera, repeated the test conditions, and we would do the same thing here.

So what you are relying on is the ability to reproduce the conditions test to test, and then you move the camera at different elevations.

MR. SCHROCK: Is your camera working full frame? Is the image on the film occupying the whole frame?

DR. HOCHREITER: Yes. In fact you get two subchannels, or two gaps. So you have -- it sees a rod, and then sees a gap on either side of the rod. And that is about as much as we can open it up, and still get the resolution we want to get.

CHAIRMAN WALLIS: How many drops does it see at a time, is it just one?

DR. HOCHREITER: No.

CHAIRMAN WALLIS: Several, none?

DR. HOCHREITER: I don't know what you mean.

CHAIRMAN WALLIS: Well, you've got an exposure, once you get an exposure and the thing zaps.

DR. HOCHREITER: It will take a scan. You will basically put it in a thousand by a thousand pixel plate, if you think about it as a plate. And then it counts all the drops.

CHAIRMAN WALLIS: But isn't it like a flash photograph in digital form?

DR. HOCHREITER: In a sense, yes.

CHAIRMAN WALLIS: But the short exposure, and zap --

DR. HOCHREITER: Yes, very short, yes.

CHAIRMAN WALLIS: -- and then you get some blobs here and there?

DR. HOCHREITER: And you count them, and you reject some, and you count them, and they go into a bin, you've a bunch of bins that are set up. Then you just keep counting, and you keep filling the bins.

CHAIRMAN WALLIS: The machine can count them?

DR. HOCHREITER: Yes.

DR. BAJOREK: Larry, isn't it that it takes two frames very close together --

DR. HOCHREITER: That is for velocity.

DR. BAJOREK: Yes, to get the velocity, but it also gauges whether the droplet is coming at you, because based on the blurb between the two photographs, or whether you have one that is moving with the stream, that is how it is screeding those out?

DR. HOCHREITER: Well, but that is for velocity mode. When you do exactly what Steve said, for getting the droplet velocity, we've gotten some velocity measurements, but we found that there was a problem.

We were not getting accurate drop size measurements when we put the camera into the velocity mode. So we opted for getting accurate drop sizes. When we looked at the droplet velocity data that we were getting, it was actually all over the place.

CHAIRMAN WALLIS: All over the place?

DR. HOCHREITER: Yes, there was no rhyme or reason.

CHAIRMAN WALLIS: Velocity is an important variable in the code.

DR. HOCHREITER: I understand that, but it was a cloud. This may have been because we were downstream of a grid.

DR. SANJOY: You weren't getting enough separation?

DR. HOCHREITER: No, I think we were just getting a wide range of velocities.

CHAIRMAN WALLIS: That is that true? rue.

DR. HOCHREITER: A very wide range of velocities.

DR. SANJOY: Well, it would be turbulent.

DR. HOCHREITER: It could be. But I think downstream of grid accented that problem, okay? And then we had this, again, problem with the software.

CHAIRMAN WALLIS: It was telling you something very important.

DR. HOCHREITER: I agree. And one of the things that we are going to do is fix the system so we can get better velocity data, as well as drop size data.

MR. SCHROCK: You get kind of density waves, you have wetting on the thing that sweeps the batch of water off, and --

DR. HOCHREITER: Yes.

MR. SCHROCK: -- high density two phase mixture goes sweeping downstream. You see that go by rather left to chance as to what you are photographing.

Are you getting -- and then the drops in this time period between those sweeps probably smaller, and moving at lower velocity.

DR. HOCHREITER: That could be.

MR. SCHROCK: But I think that the pulsating nature of it is probably important.

DR. HOCHREITER: Well, like I said --

MR. SCHROCK: -- heat transfer characteristics.

DR. HOCHREITER: Well, it depends on the frequency. But the flow is unsteady. I mean, you can, you set up steady boundary conditions, but the flow is still unsteady, okay? And that is not going to change.

Some of the problems we had was that we would get oscillations that were superimposed on, again, this unsteady flow. And they were really due to the facility. So we had to, basically, figure out why. And we threw a lot of data away because of that.

Now, what I'm hoping here, when we do these droplet injection tests, we have to be careful because I don't want flashing to occur in these injectors. But I also don't want condensation to occur, such as the pressure takes a dive.

So these are going to be pretty delicate to set up. You would like the water to come out of these injectors saturated at the system pressure.

DR. MOODY: You made quite an argument about that, and I thought liquid jets breaking up into the range of droplet size. You also said some intriguing things about this camera you used.

It takes pictures on a regular photographic film?

DR. HOCHREITER: It is a digital camera.

DR. MOODY: It is a digital camera, I mean, you are getting --

DR. HOCHREITER: This stuff gets stored in the software, and you are probably asking for more detail than I can answer.

DR. MOODY: It was just a curiosity point. So you get a really fine resolution?

DR. HOCHREITER: It does.

MR. SCHROCK: It gives you a very clear picture, 1000 by 1000.

DR. HOCHREITER: And we calibrated this, like I said, on a milling machine, and we had, I think they are called rectals, they are like pieces of glass that have known images machined in them, of different sizes, so we could get a calibration curve for the camera system.

DR. MOODY: Which one threw the film apart? You mentioned something about --

DR. HOCHREITER: Those were high speed movies that we took 20 some odd years ago, as part of the FLECHT SEASET program.

DR. MOODY: Okay.

DR. HOCHREITER: And you could only put 400 foot roll of film into these. These are high cam cameras, and most of the time you basically destroyed the film.

DR. SANJOY: That is not always true.

DR. HOCHREITER: Most of the times we always destroyed the films, because we didn't do a very good job.

CHAIRMAN WALLIS: Because it is going so fast, it is the mechanical forces on the film.

DR. HOCHREITER: It rips it apart.

MR. SCHROCK: Well, that is the design. I mean, the film is a tape that rotates the prism. I mean, it is like a belt drive.

DR. HOCHREITER: Well --

DR. SANJOY: If you get it up too fast it rips.

CHAIRMAN WALLIS: So you are going to go through your conclusions now?

DR. HOCHREITER: Yes, sorry. We think we have constructed a facility which is flexible. It is low pressure. We've added seven new features to the facility. We've tried to take advantage of, basically, the lessons learned in previous reflood and other two-phased flow experiments, and enhanced the instrumentation in the facility, and the data that we can generate from the facility.

And the tests have been basically designed to provide answers for code model development, as opposed to address licensing questions.

The FLECHT SEASET program was really designed to address licensing issues. So you would run tests up to 2,200 degrees fahrenheit and, of course, you destroyed your heater rods doing that.

We are not doing that in this test

program. We are specifically designing experiments to give us data that can be used to either verify or develop component models which would go into an advanced code, like TRAC-M.

And we have been working hand in hand with the NRC. In fact, the conditions for our experiments basically come from the NRC. So the idea here is basically to improve the models in the NRC codes, and then the NRC codes will be used for audit calculations.

And I think there really is a need for this, because these days, again, the vendors are pushing the envelope in terms of allowable peak cladding temperatures, and kilowatts per foot.

CHAIRMAN WALLIS: What is the measurement of improvement, reflood models?

DR. HOCHREITER: If they can match this data and previous data.

CHAIRMAN WALLIS: They measure this in terms of less uncertainty, or less scatter, or some measure of deviation within the experiment?

DR. HOCHREITER: Yes, less uncertainty.

DR. SANJOY: The answer to the question is that you are getting better droplet data, that is one of the main things, compared to previous experiments?

DR. HOCHREITER: Better steam temperature data, better void fraction data. Well, consider what is there. Better mass flow and mass balance data.

CHAIRMAN WALLIS: It may make you more confused about the theory, so the theory could, eventually, end up being --

DR. HOCHREITER: Well, clearly, I don't know if we've done it a disservice, or what, but these have an effect, and most codes don't model it.

MR. SCHROCK: Well, I think there is no question that you've proven that those things have an effect. I worry about the fact that the data are still being collected from the viewpoint of being able to get some kind of time averaged information about drop size and distribution.

Whereas what you see in the movie that you showed us, is a pulsating flow. And the effect of the pulsation is not being addressed.

DR. HOCHREITER: Not trivial.

MR. SCHROCK: And I think it is important.

DR. HOCHREITER: These flows are unsteady. I mean, like I said, you run the tests as being steady state, or quasi-steady state. But the flow itself is unsteady. That is not going to change.

DR. KRESS: It doesn't look like it is

high, near your --

DR. HOCHREITER: It is steadier as you go up the bundle.

DR. KRESS: Yes.

DR. HOCHREITER: The most unsteady portion is going to be right at the quench front, I would agree with that.

DR. KRESS: But that would be important to determine the drops.

DR. HOCHREITER: Because it determines the liquid fractions carried up.

DR. MOODY: The spacers are terribly significant, you mentioned. And as far as something you said, several times, that the droplets really break up as they go through the spacers. What is your current thinking of the mechanisms, causes of breakup?

DR. HOCHREITER: Well, there is separate effects data that we looked at. And, again, this is roughly 20 years ago, because we put in droplet breakup models in the COBRA/TF.

We did this as part of the FLECHT SEASET program. And we ran little bench tests at Carnegie Mellon, where we took a blow torch and heated up a grid strap, and we dropped drops on it, and measured the chattering of the drops, and we measured the drop sizes.

And we ran tests for different thicknesses of the strap, different diameters of the drops. And we developed, basically, a correlation for this. And it was in terms like Dr. Ransom said, the Webber number, droplet Webber number.

And that model went in the COBRA/TF, and that was used as part of the FLECHT SEASET program when we looked at evaluating the effect of full blockages, and spacer grids. But these were simple grids, because there was no data on this type of a geometry.

DR. MOODY: That is primarily a velocity effect then, isn't it, that causes a breakup?

DR. HOCHREITER: If you get droplet Webber numbers, I think, greater than 80, you would start to shatter drops. And this was consistent with measurements that people had taken where they would drop drops on a heated surface, and then photograph what would happen.

If the droplet Webber number was smaller than that, you would basically bounce, the surface tension could hold the drop together. But when you had a sufficient inertia, the drop had sufficient inertia, you would hit the surface, the drop would shatter into a population of small droplets.

DR. MOODY: Thank you.

MR. SCHROCK: I would like to ask you to calculate HA over MC for your thermacouples, and tell us what it is, some time.

DR. HOCHREITER: Okay.

DR. RANSOM: I have a couple of quick questions. What are your plans for preserving this data for future use? And the reason I ask that question is a lot of the reactor safety data is starting to disappear because of the way it was stored, and preserved in the past.

The second one, is this gravity-fed?

DR. HOCHREITER: No, these are forced flow tests.

DR. RANSOM: Forced flow with a positive displacement pump, or --

DR. HOCHREITER: Actually what we did was we had a pressurized tank that we would inject the flow, using a pressurized tank.

DR. RANSOM: But how do you maintain a constant flow rate?

DR. HOCHREITER: We have a flow control valve.

DR. SANJOY: But that brings up the point of --

DR. HOCHREITER: Let me go back and answer his first question. In the contract we have to supply, to the NRC, this data on CDs, which they will put into the data bank.

DR. SANJOY: But that brings up the question that many situations you have, essentially, gravity fed systems, where you do get strong oscillations.

DR. HOCHREITER: Right.

DR. SANJOY: And a lot of the phenomena change with the oscillations, because you -- there is ligaments of liquid behind --

DR. HOCHREITER: It goes all the way up.

DR. SANJOY: -- and then it goes whoosh, out. The entrainment completely changes with the oscillation.

DR. RANSOM: Well, I notice you have a downcomer, well you have a downcomer in the diagram you have in this report. I was wondering if you plan to use that? Yes, short an external downcomer?

DR. HOCHREITER: Not at the present time.

DR. KRESS: These oscillations that you see always tend to delay the time in which you have the peak clad, and actually lower it. So if you had correlations that didn't have those in it, you would still be somewhat conservative, I think, in terms of regulatory space.

So I don't know how important it is to actually get those kinds of oscillations.

DR. HOCHREITER: I've seen mixed bag on these. The oscillations can help you, the oscillations can hurt you.

CHAIRMAN WALLIS: I can see some sophisticated vendor coming in and saying, we've designed our system to have oscillations at much lower peak clad temperature.

MR. SCHROCK: Therefore we are conservative, and therefore okay.

CHAIRMAN WALLIS: Maybe it is time to go back to Steve? Thank you, Larry, that was very interesting, indeed.

DR. SANJOY: We should really visit some of -- why didn't we visit the facility?

DR. HOCHREITER: More than welcome to come. I would not come on a home football weekend unless you want to stay here and then drive up.

DR. BAJOREK: Well, originally that was our plan, to have this meeting up at Penn State. But the problem there was budgetary. The Staff wasn't able to continue the program at the end of the year.

There is a continuing resolution now that is preventing us from continuing some of these programs and initiating new ones.

MR. BOEHNERT: And it is also impacting our travel budget, too.

MR. SCHROCK: Well, is it planned to do it in the future?

DR. BAJOREK: I hope so, yes. I think it is a lot better to see the facility, rather than looking at the movie, and the confusion, is that a light, or is that a rod? You know, seeing it first-hand.

And also, you know, I thought it was very informative to look at the output from the laser camera, and the output from an optical camera at the same time.

And what was very interesting is that the laser camera seemed to be picking up a lot more. And you can watch that, and when somebody says, the carryover for action is about 75 percent, yes, you almost see that in the movies itself, even though you look at a meter, or Ralph can help us out with that and show us, yes, you are still sitting up there well above anybody's estimate of T-min, while you are seeing all of these droplets.

CHAIRMAN WALLIS: Now, if you could measure velocity, as well as population, you could then calculate flow rate, and compare it with the flow rate, and --

DR. BAJOREK: Right, we are getting carryover, you are getting the carryover from that, you know what you are putting in, you are separating it, so you are getting a steam flow rate coming out.

Now, if you get to the droplet velocities above the grid, okay, we are going to get the relative velocities, and that is going to help us get at the interfacial heat transfer part of this.

DR. HOCHREITER: We are going to try to get that software fixed. But we've discovered this during the testing. And the vendor said, yes, you should have these upgrades, which only cost umpteen dollars, which of course we did not have, and we have to send back a camera, and the computer system, which meant we would have to stop testing. So we opted to test.

DR. SANJOY: Were Those Oxford lasers?

DR. HOCHREITER: Yes, you are familiar with the same spiel?

DR. KRESS: As I remember the calculation, those droplets reached terminal velocity very fast. So that if you know the steam velocity, and the droplet size distribution, you could make a pretty good estimate of the distribution of velocities.

And that may be a mechanism for agglomeration. They have different velocities, the droplets did.

DR. BAJOREK: I think the question a couple of hours ago, what have I learned here today? First, there is still a lot of work to do.

Most of this data that Larry was talking about were obtained June, July, and August. And there hasn't been a tremendous opportunity to compare these to previous results, compare it to one test to the other, and a lot of it has been sorting out are these tests valid, I mean, are they good, of the type of quality that we expect to get?

And our conclusion right now is yes. We are seeing a lot of interesting things in the data that we don't have an explanation for, at this point. But that is where kind of the fun begins.

Now, I think in terms of things that we've talked about today, that we need to incorporate, and work into this overall project, the first one I would characterize as bias and uncertainty.

I think the questions that we've had a few times now, if we change a reflood model, how do we know we are getting any better? I think we owe it to you to define, in much better terms, what models we are focusing our attention on, and as we start to tinker with some of these knobs in the code, are we having an effect?

And I think the only way of doing that is taking the models we have now, obtaining a bias and uncertainty from some preliminary assessments, making the changes, and hopefully you are going in the right direction, and then bias is becoming smaller, and the uncertainty likewise dropping.

I think we --

DR. MOODY: Can you make copies of this for us?

DR. BAJOREK: I guess. We think it is very clear that the spacer grids, their design differences, and their effect on the transient, are key. This is really what is dominating the vapor temperatures, the clad temperatures.

And in terms of model development, my suggestion is that this be given one of the top priorities. TRAC-M does not have spacer grid models at this time. And it is clear that we've got to take this data, the egg crate data from FLECHT, where you can see a little bit more of the dips downstream of the rods.

So 318.05, I think, was too high a temperature to see some of those. But that in FEBA it tried to develop spacer grid models that will help give us this change in droplet size, as we go up the bundle.

CHAIRMAN WALLIS: What do the vendors have for spacer grid models?

DR. BAJOREK: The Westinghouse model, I'm just trying, I want to make sure I'm not giving away, this is an open meeting, and I don't want to give away proprietary models.

CHAIRMAN WALLIS: But they do have spacer grid models?

DR. BAJOREK: Yes. I put that into the COBRA TRAC. It was based on the Carnegie Mellon data, it does take a look at the droplet size coming to the grid, and how it would break up as it passes the grid.

But we need to get that capability in TRAC-M. Now, one of the things that I also was thinking about, as we went through the presentation today, we are getting a lot of very good information on the dispersed droplet film boiling type of regime, what the grids are doing to things.

We are going to get better information down near the quench front, and that is where these more detailed DP cells are going to help us quite a bit.

We've got to think and be fairly clever, as we are going through additional tests, and evaluating these, on how we can identify inverted annular flow, and what is the flow, excuse me, the heat flux split near the quench front.

That has been a nagging problem in some of the reflood models. Because what we need, in order to get our model correct at the PCT location, we have to know how quickly we eat up the vapor very close to the quench front.

MR. SCHROCK: What does IVA mean?

DR. BAJOREK: Inverted annular.

MR. SCHROCK: And q-double-prime split, you are talking about --

DR. BAJOREK: Heat flux.

MR. SCHROCK: -- heat flux to liquid, and heat flux to vapor?

DR. BAJOREK: Yes.

CHAIRMAN WALLIS: There was very little that Larry said that helped me with the inverted annular, he is talking about droplets and all that, that has nothing to do with inverted annular, supposedly the liquid is in the middle, and the film is on the wall.

This is only a very short length of the --

DR. HOCHREITER: Yes, but we ran tests at six inches a second.

CHAIRMAN WALLIS: Right.

DR. HOCHREITER: So we do have that data.

CHAIRMAN WALLIS: Okay.

DR. BAJOREK: So that data is in there. We need to think more in terms of how we --

CHAIRMAN WALLIS: You didn't show us that today?

DR. HOCHREITER: No.

CHAIRMAN WALLIS: Why?

DR. HOCHREITER: Why didn't I show you that?

CHAIRMAN WALLIS: I'm assuming because it wasn't any good.

DR. HOCHREITER: No, that is the wrong assumption.

DR. KRESS: It was too good to be true.

DR. BAJOREK: Actually they are very good in that you get the inverted annular flow regime, and it is persistent over a very long period of time. FLECHT 317-01, which is the one a lot of people use, get crunched in the 20 seconds.

But I think in your test, Larry, it stayed inverted annular for a couple hundred seconds?

DR. HOCHREITER: That is correct.

DR. BAJOREK: So they aren't as fun as the dispersed droplet because with all that water, those probes quench right away. And we haven't gotten to the point of trying to evaluate the DP cells, and what there might be some type of a void distribution.

Just, you know, to elaborate on a couple of points. When, and we owe you this, I mean, we have to develop this. When I say bias and uncertainty, one of the things that I want to recognize is that previous reflood experiments had the idea that, hey, if you knew VIN, your flooding rate, you would essentially be interested in what would be the heat flux from the rod, because in your code assessment you would look at the predicted versus measured.

And in some cases you see vendors say, well, my bias is in terms of a delta PCT. And I think as Larry mentioned, if you do it that way, you really cover over all the processes. You may get the PC right, but you haven't a clue whether it was because there were compensating errors through your calculation.

As we go through the development of what we are going to call these mechanistic reflood models, what we need to do is to break these into as many individual components as we can, look at the models we have now, look at the ones we intend to develop, and try to determine bias and uncertainties for things like components of the heat flux below the quench front; components of the film boiling heat flux up near the PCT location, how much was convective, how much was due to a convected enhancement with the droplets, if there is any drop to wall impaction try to characterize that.

I think a very, very important aspect, as Larry pointed out, is what is the entrainment rate at the quench front, and how much of that, eventually, gets carried over out of the bundle.

Very small deltas in how you predict that can have a very drastic impact on your steam temperatures higher up in the bundle. And I think as we saw from the spacer grids, we need to be able to characterize what is the variation of droplet size, as it approaches and passes through a grid.

CHAIRMAN WALLIS: It seems to me that you need a full time analyst at NRC doing all this?

DR. BAJOREK: In fact we do have one person right now, his mission is to start putting these interim reflood models into the code. But it is a full time job just putting those in.

And over the course of, probably, the next year characterizing these in setting things up, hopefully, in an automated way that we can get some quantified measures.

CHAIRMAN WALLIS: So you are short of hoping that the mechanistic model is going to be a fair representation of what is going on. And that is something we don't really know yet.

There may be mechanisms which we don't know how to model yet, that should be in the code. It is not just building on someone's fantasy of what happened there 20 years ago. There is a lot more information now. So you may have to change your thinking about some of the models.

DR. BAJOREK: I think that is why we need to look at the data, and develop some new fantasies on what we see in there.

And I think, as I mentioned, we think in terms of what we've seen, the tests that spacer grid models have to be at the higher priority. I think, as we mentioned earlier, what do we do now if a vendor, or somebody comes in with a different type of model, which has different mixing veins, different blockage.

This may be reason, in the future, where we might want to start working in some other types of small scale separate effects test, to where we might be able to more easily vary things like the mixing vein geometry blockage, and things like that, that I mentioned, the inverted annular flow split.

MR. SCHROCK: What is the subscript R, there, radiation?

DR. BAJOREK: Radiation.

MR. SCHROCK: Radiation to what, drops, or radiation to --

DR. BAJOREK: To the film. At least in my simplistic way of looking at it, right now, heat flux is split between something that goes to the liquid --

MR. SCHROCK: I see, it is just for that term, there, you are talking about. Yes, inverted annular.

DR. BAJOREK: Radiation, perhaps some contact of the waves, and the rest going into the vapor phase. But one, how do you characterize that, and what is the split.

DR. SANJOY: You don't think the flow

oscillations should be taken into account during gravity reflood?

DR. BAJOREK: Right now I'm not convinced that the oscillations that we saw in those movies are necessarily something that is an artifact of what would happen if you had a constant reflood, versus what is going on in that facility, where you know that for those early tests, the controller was trying to keep up, and it was pulsating at the inlet. Larry?

DR. HOCHREITER: Well, I think for the movie we showed, I don't think there was strong pulsations.

DR. SANJOY: No, I'm talking about the real reactor situation, the code has to handle a situation where everybody understands that there are large oscillations. And everything you said here could be of much less important than those oscillations.

So how are we going to account for that?

DR. HOCHREITER: It is not clear that the reactor does oscillate, it is not clear to me. There have been some large scale tests, and you don't see a lot of oscillations.

DR. BAJOREK: I thought they did see them in CCTF, Larry?

DR. HOCHREITER: For selected tests, not every test.

DR. SANJOY: Well, maybe there should have been an assessment of that problem, then. I thought that there were oscillations, but maybe there are some that --

DR. BAJOREK: I think there were in some of those CCTF experiments.

DR. HOCHREITER: In some, not in all.

DR. BAJOREK: And I think in terms of how we would approach that, first try to get models that work good under very well established boundary conditions. And I think we are getting out of this an easy power shape, you know the inlet conditions.

If we get models that work good there, try them out on CCTF, and SETF, other tests where you -- ACHILLES would be another good one, tests with a downcomer, where you can see if they are doing adequately for gravity reflood.

DR. SANJOY: Did they see oscillations in the WINFRED experiments? We will have to look at those. They were done, what, about ten years ago?

DR. BAJOREK: About that. I guess I'm not real familiar with that, except for the test that was the international standard problem, where they got a large burst of the non-condensibles.

DR. SANJOY: I know that early '80s, anyway, there was quite a bit of concern about these oscillations, and the modeling of them. And the reason was that they strongly affected entrainment.

And to first order the main thing that matters is how much is entrained, it is the balance between what is carried out, and what you put in. And that depends, really, it determines how fast the front goes.

Now, since that time the problem seems to have sort of vanished, I don't know why. Whether that was just neglect, or there was a reason to say it wasn't important.

But I think it would be worthwhile, at least, having an assessment as to whether it is important or not. Because it could have an effect on the test program, also.

I agree with you that first you should be able to handle the steady state. But the phenomena during oscillations could be quite different, because you tend to leave a lot of liquid up there, where it gets caught in the vapor, and it gets carried out.

So the entrainment correlations, everything change. Maybe not, but --

DR. BAJOREK: Well, let me see if I can try to find out what --

DR. SANJOY: What is known bout it.

DR. BAJOREK: -- why the problem has gone away. I thought I heard, at one point, that the heat transfer was improved when you had the gravity reflood, and the oscillations. So maybe that --

DR. SANJOY: But entrainment got worse. At least I remember in some cases.

CHAIRMAN WALLIS: So you will have to respond to this oscillation issue, it is not going to go away.

DR. BAJOREK: That is all I have.

CHAIRMAN WALLIS: I think it has been very good to get results from this experiment. We have been looking forward to getting some results, for some time.

Also hearing that the Staff has ideas about how to use them. And I believe what is going to happen here is that there won't be any letter from the ACRS, or anything like that. But I will give a report to the full Committee at the December meeting.

So I would need input, then, from you folks by the end of November. Is that a reasonable thing, go back and write up comments which I can then

-- your comments will actually be handed out to the full Committee. They are for publication, which I'm sure they will be.

MR. SCHROCK: Would you ask him to give us copies?

CHAIRMAN WALLIS: Yes, I would like copies of your --

Are there final remarks that members of the subcommittee would like to make at this time, before we recess?

DR. MOODY: I was just going to mention, on page --

CHAIRMAN WALLIS: I think you need to bring your mike up.

DR. MOODY: This is in the PSU ARL report, rod bundle heat transfer, that we all got a copy of. I just want to say, I think you are a little too restrictive on page 29, when you make a statement in the middle of the page.

From this point forward temperatures must be in absolute units. I don't think you have to say that. I think you can take whatever units. Do you recall anything like that? Okay, you have some heat transfer equations, conduction and convection, getting a temperature. Probably one of your students.

DR. HOCHREITER: No, we are having an endless battle on units, temps, and so forth.

DR. MOODY: Well, I think the thought was you had to use absolute, and you don't have to.

DR. HOCHREITER: No, I agree.

CHAIRMAN WALLIS: Radiation expression?

DR. MOODY: There wasn't a radiation expression in there.

DR. HOCHREITER: Let us check that out.

CHAIRMAN WALLIS: There is a lot to be said for having agreement on units. When you come to a massive code, which -- we have a great deal of difficulty with vendors who come here with mixed units, and you can never be clear on what units are actually encoded in the code itself, or whether or not they have mixed them up, and whether the conversion factors are all right.

If you have a consistent set of units all the way through it is much more reassuring. You will get the NASA problem with Mars.

Anyone else?

DR. RANSOM: One thing I didn't hear anything about today, but was the single phase pressure drop analysis that they have in the report, which seemed to bring up a number of issues that I think ought to be resolved, in a way.

Why it doesn't approximate the velocity situation very closely, and I know at one point they talk about frictional pressure drop, but don't mention entrance effects, which clearly would have an effect of increasing the frictional pressure drop.

But I guess my conclusions, in general, I sure would like to see a little more analysis, you know, to go along with this data. I'm not -- I know you've said that is what you plan, and I hope you will do it.

DR. HOCHREITER: We've actually done some more, particularly on the pressure drop. We had a student that just is completing his thesis, where he set up a CFD model. They modeled a fraction of the model, plus the spacer. And he actually got very good agreement with the measured pressure drop data.

He is now comparing it to some of the single phase transfer data that we got from the facility. He did find a pressure drop relationship in, I think, Tong and Wiseman's book, that gave a better agreement for the bare rod bundle pressure drop than what we were seeing when we would go to the Moody chart.

So I think -- I haven't had a chance to go back and look at that particular correlation, but I know it gives higher friction factors. And this is really what we are seeing when we reduce the data.

And I do think it is due to exactly what you said, which is entrance region downstream of the spacer grid. Because the upstream tap is going to be in that region.

CHAIRMAN WALLIS: Ready to recess? All right, we will now recess until 8:30 tomorrow morning. Thank you all very much.

(Whereupon, at 5:10 p.m. the above-entitled matter was recessed.)

## CERTIFICATE

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

Name of Proceeding: Advisory Committee on Reactor Safeguards Thermal-Hydraulic Subcommittee

Docket Number: N/A

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.

/s/ Rebecca Davis

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

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
THERMAL-HYDRAULIC PHENOMENA SUBCOMMITTEE MEETING:
**NRC-RES ROD BUNDLE HEAT TRANSFER TEST PROGRAM/**
**FRAMATOME ANP-RICHLAND S-RELAP5 LB LOCA CODE**
NOVEMBER 12-14, 2002
ROCKVILLE, MARYLAND

**DRAFT PRESENTATION SCHEDULE**

Contact: P. Boehnert (301/415-8065) ("pab2@nrc.gov")

| TOPIC | PRESENTER | TIME |
|---|---|---|
| **November 12, 2002** | | |
| I. Introduction | **G. Wallis, Chairman** | 1:00 p.m. |
| II. NRC-RES Rod Bundle Heat Transfer Test Program - Status | | |
| A. Introduction | **S. Bajorek, RES** | 1:10 p.m. |
| B. Rod Bundle Heat Transfer Program Status | **L. Hochreiter, Penn. State U.** | 1:30 p.m. |
| | **BREAK** | 3:00 p.m. |
| C. Concluding Remarks | **S. Bajorek** | 5:00 p.m. |
| III. Recess | | 5:15 p.m. |

**November 13, 2002**

| TOPIC | PRESENTER | TIME |
|---|---|---|
| IV. Reconvene **Open** | **G. Wallis, Chairman** | 8:30 a.m. |
| V. Framatome-ANP Richland S-RELAP5 Realistic LB LOCA Code **Closed** | | |
| A. Introduction | **Mr. Holm** | 8:40 a.m. |
| B. Momentum Equation<br>• Straight Pipe<br>• Bends/Elbows<br>• Area Changes<br>• Multi-Junctions<br>• Cross-Flow<br>• 2-D Model<br>• Cold Leg/Downcomer Connection<br>• Downcomer/Lower Plenum Connection<br>• Pump<br>• Added Mass | **Mr. Carlson** | |
| | **LUNCH** | 12:00 p.m. |
| B. Momentum Equation (Cont.) **Closed** | | 1:00 p.m. |
| C. General RELAP-5 Questions **Open** | **Mr. Martin** | 2:45 p.m. |
| D. Selection of Node Size **Open** | **Mr. Martin** | |
| E. Critical Flow **Open** | **Mr. O'Dell** | |
| F. Statistical Analyses **Open/Closed (as necessary)** | **Mr. O'Dell** | |
| VI. Recess | | 6:00 p.m. |

**November 14, 2002**

| **TOPIC** | **PRESENTER** | **TIME** |
|---|---|---|
| VII. Reconvene **Open** | **G. Wallis, Chairman** | 8:30 a.m. |
| VIII. Framatome-ANP Richland S-RELAP5 Realistic LB-LOCA Code - Summary of Methodology **Closed** | | |
| A. Requirements & Capabilities | | |
| B. Changes to RELAP5 to Create S-RELAP5 | | |
| C. Assessment & Ranging of Parameters | | |
| D. Sensitivity & Uncertainty Analyses | | |
| **LUNCH** | | 12:00 p.m. |
| IX. NRR Presentation - Safety Evaluation Report for S-RELAP5 Realistic LB LOCA Code | | 1:00 p.m. |
| A. Code Review Results | **R. Landry, NRR** | |
| B. Uncertainty Analysis Methodology | **Y. Orechwa, NRR** | |
| C. Staff Parametric Studies | **S. Colpo, NRR** | |
| D. SER Conclusions | **R. Landry, NRR** | |
| X. Framatome Response to NRR Presentations **Open/Closed (as necessary)** | | 4:00 p.m. |
| XI. Subcommittee Caucus **Open** | | 4:45 p.m. |
| 1. Comments on Meeting Presentations | | |
| 2. Follow-on Actions | | |
| 3. Decision to Bring Review to ACRS/ Instructions to Presenters | | |
| XII. Adjourn | | 5:00 p.m. |

PENNSTATE

# Penn State/US NRC Rod Bundle Test Facility and Reflood Heat Transfer Program (RBHT)


L.E. Hochreiter
Mechanical and Nuclear Engineering Department
The Pennsylvania State University
(814)-865-6198
lehnuc@engr.psu.edu

PENNSTATE

# Program Background

- RBHT Contract was initiated in November 1997 with the Nuclear Regulatory Commission Office of Research.
- Is a joint program between the College of Engineering and the Applied Research Laboratory (ARL).
- Principal Investigators

  Dr. L.E. Hochreiter

  Dr. F-B. Cheung

  Dr. T.F. Lin

PENNSTATE

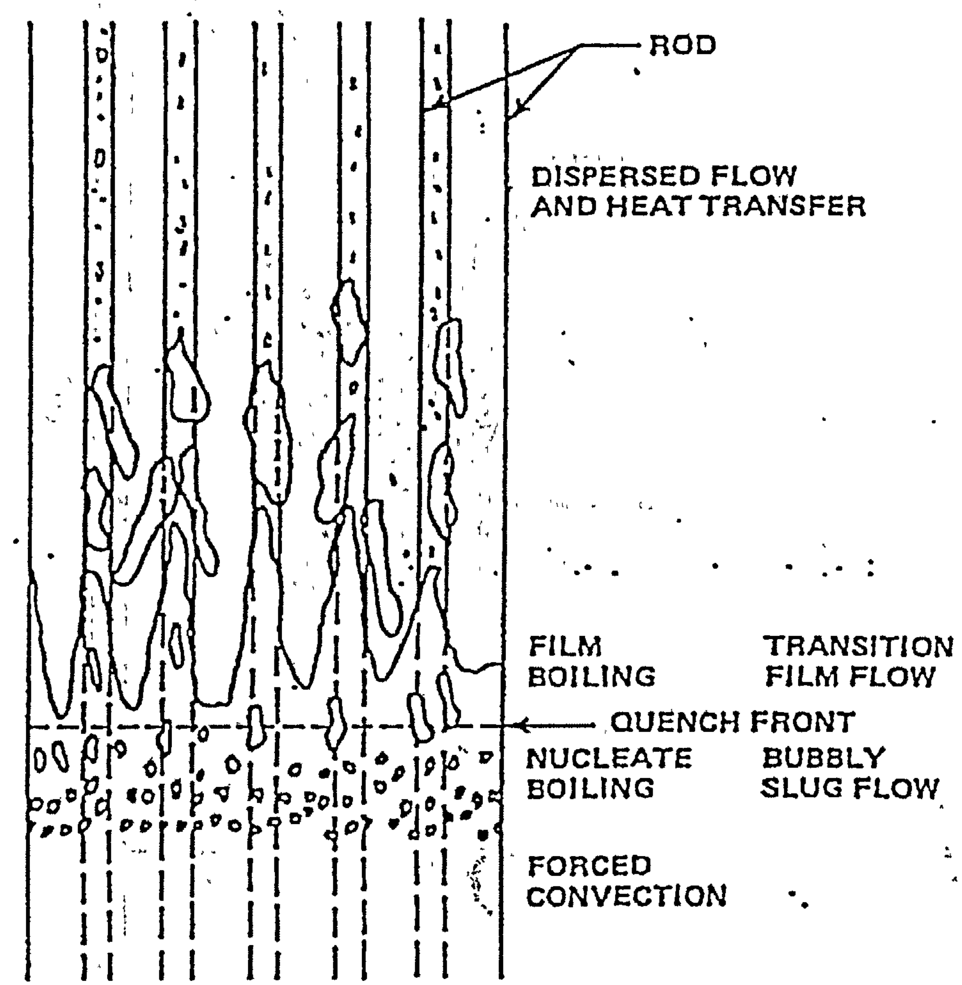
# Background

- Loss of Coolant Accident (LOCA) is the most limiting design basis accident for PWRs.
- LOCA can limit the peak kW/ft values as well as the allowable power shapes for the plant operation.
- LOCA is a 'calculated' accident, the performance of the safety systems in mitigating the accident depends on the computer models used.

# Peak Cladding Temperature (PCT) is calculated to occur during the Reflood period of the transient.

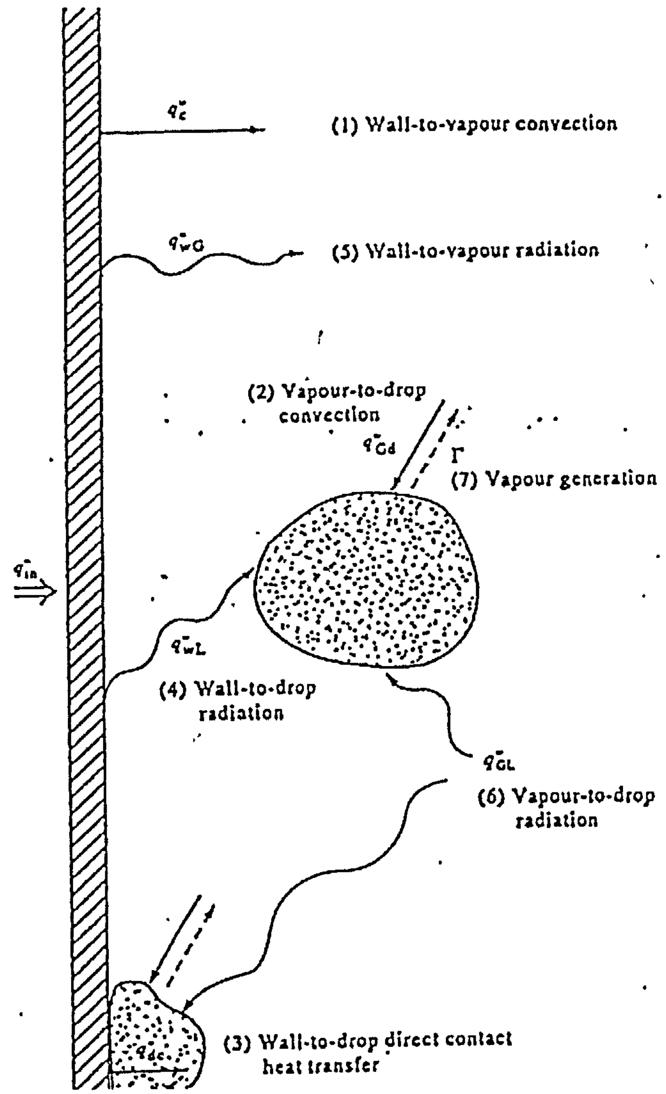
- Heat transfer rates are the smallest.
- Several different heat transfer mechanisms control the heat transfer.
- Flow is highly dispersed and non-equilibrium with superheated steam and liquid droplets.
- Quench front progresses up the fuel rods as the core quenches.
- Reflood is also the most limiting LOCA period with Best-Estimate codes.

# Flow Regimes During Reflood



PENNSTATE

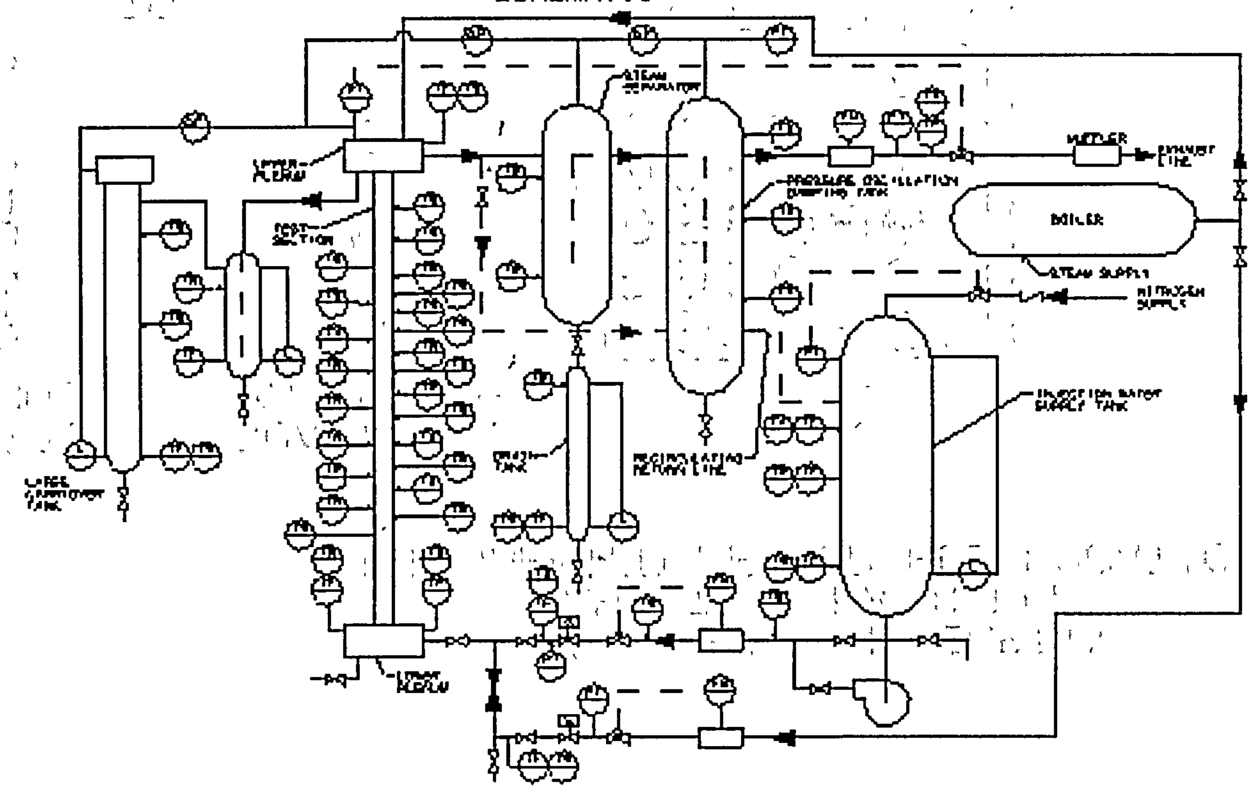
# Reflood Heat Transfer Phenomena



PENNSTATE

# System Schematic with Instrumentation

PENN STATE UNIVERSITY
RBHT-TEST FACILITY
INSTRUMENTATION
SCHEMATIC

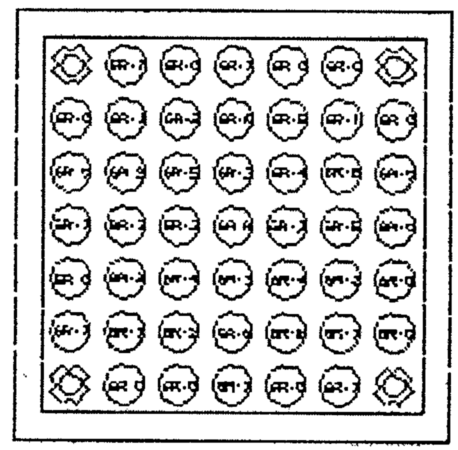


PENNSTATE

# RBHT

PENN STATE UNIVERSITY
RBHT-TEST FACILITY
INSTRUMENTED HEATER ROD LOCATIONS

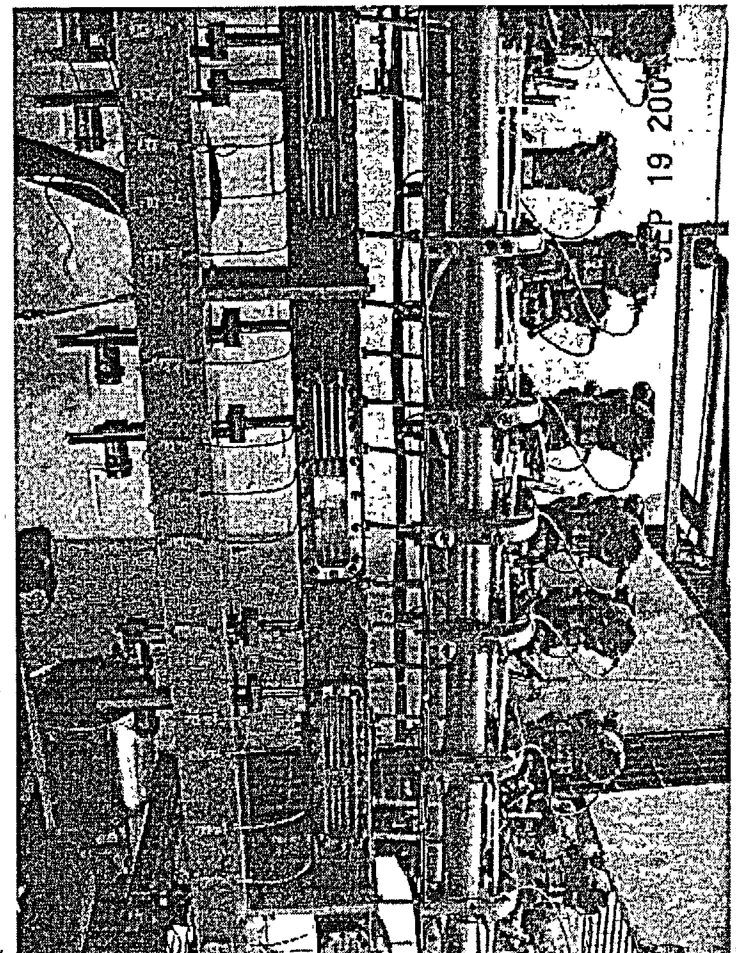
| GROUP NO. | QUANTITY HEATER RODS |
|---|---|
| GR-0 | 14 |
| GR-1 | 4 |
| GR-2 | 4 |
| GR-3 | 5 |
| GR-4 | 3 |
| GR-5 | 2 |
| GR-6 | 3 |
| GR-7 | 6 |
| GR-8 | 4 |
| TOTAL: | 45 |



GR-0 UNINSTRUMENTED
GR-1 THRU 8 INSTRUMENTED

PENNSTATE

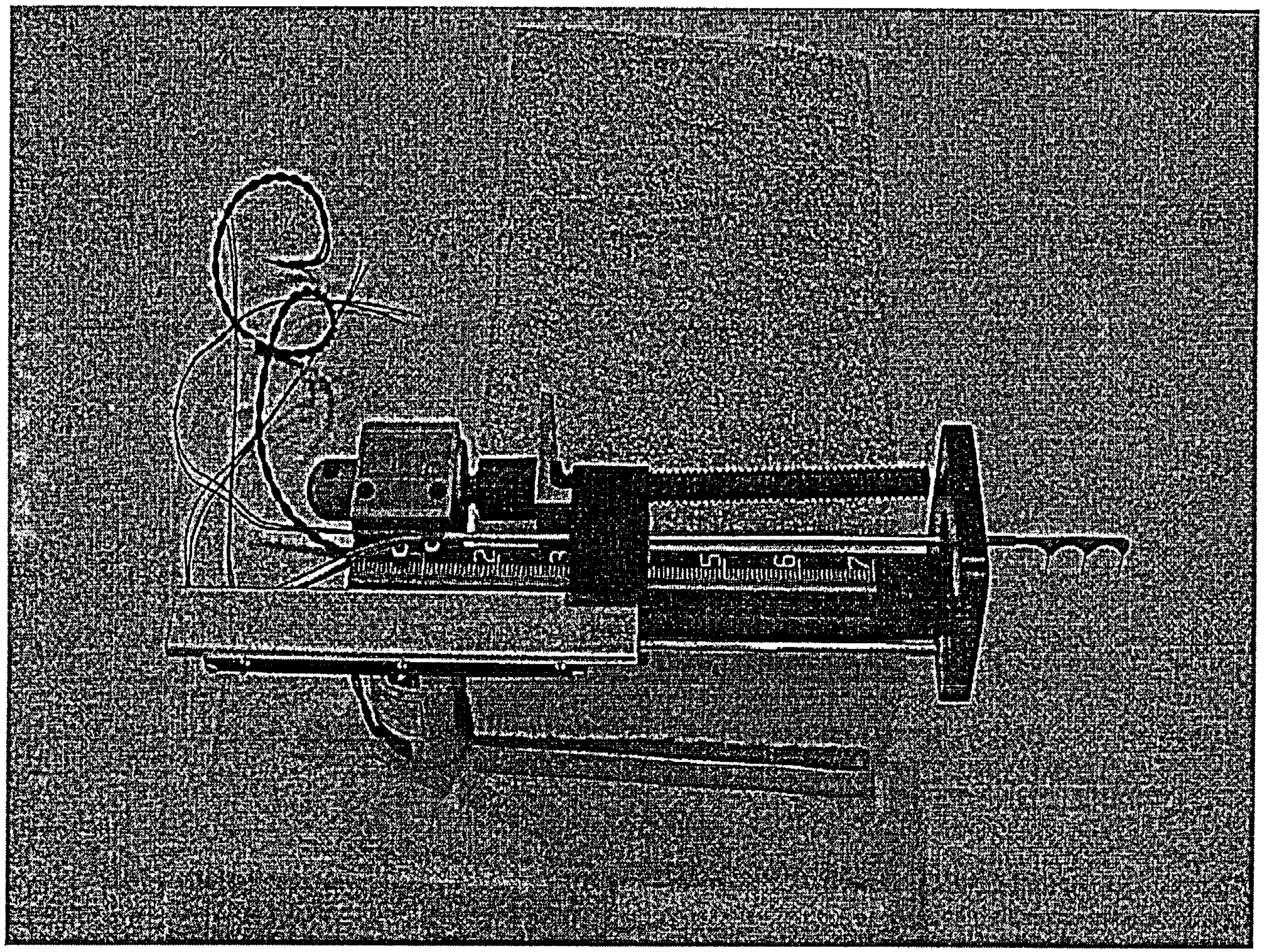
# RBHT



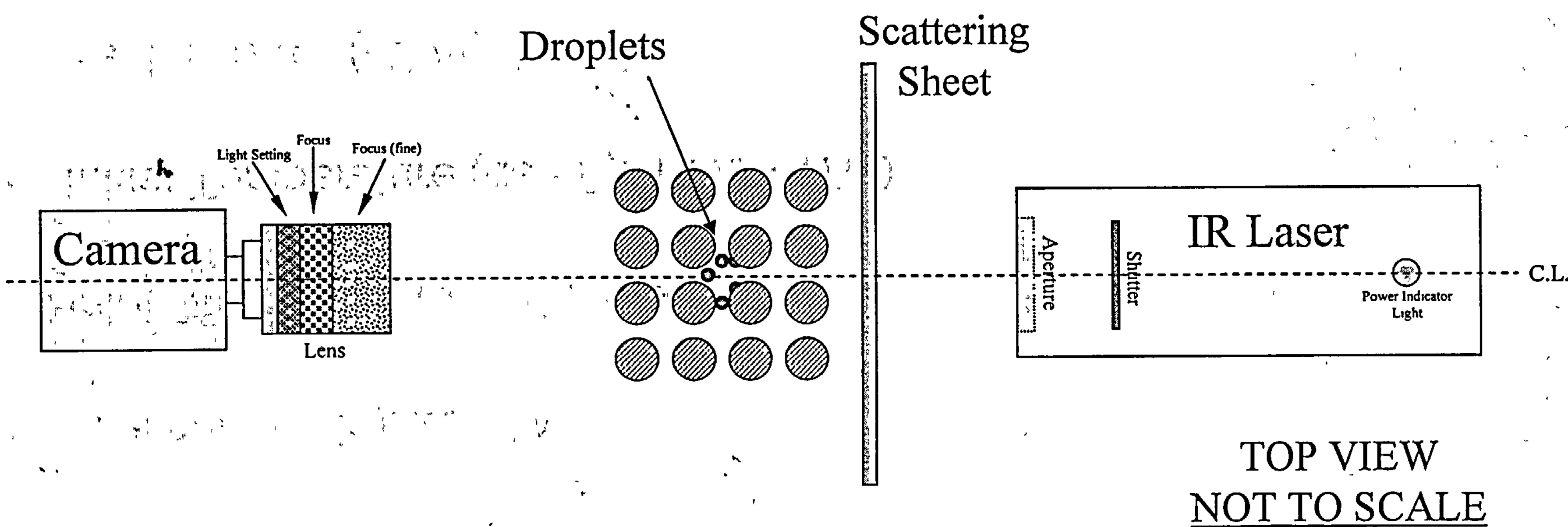

Flow Housing Instrumentation

PENNSTATE

# RBHT – Steam Probe Rake



# Laser Illuminated Digital Imaging System Setup



PENNSTATE

# RBHT Matrix

- Flooding Rate (inch/s): 0.54 - 10
- Pressure (psia): 20 - 60
- Inlet Subcooling (deg F): 20 - 150
- Initial Temperature (deg F): 1200 - 1700
- Peak Power* (kW/ft): 0.4 - 0.7

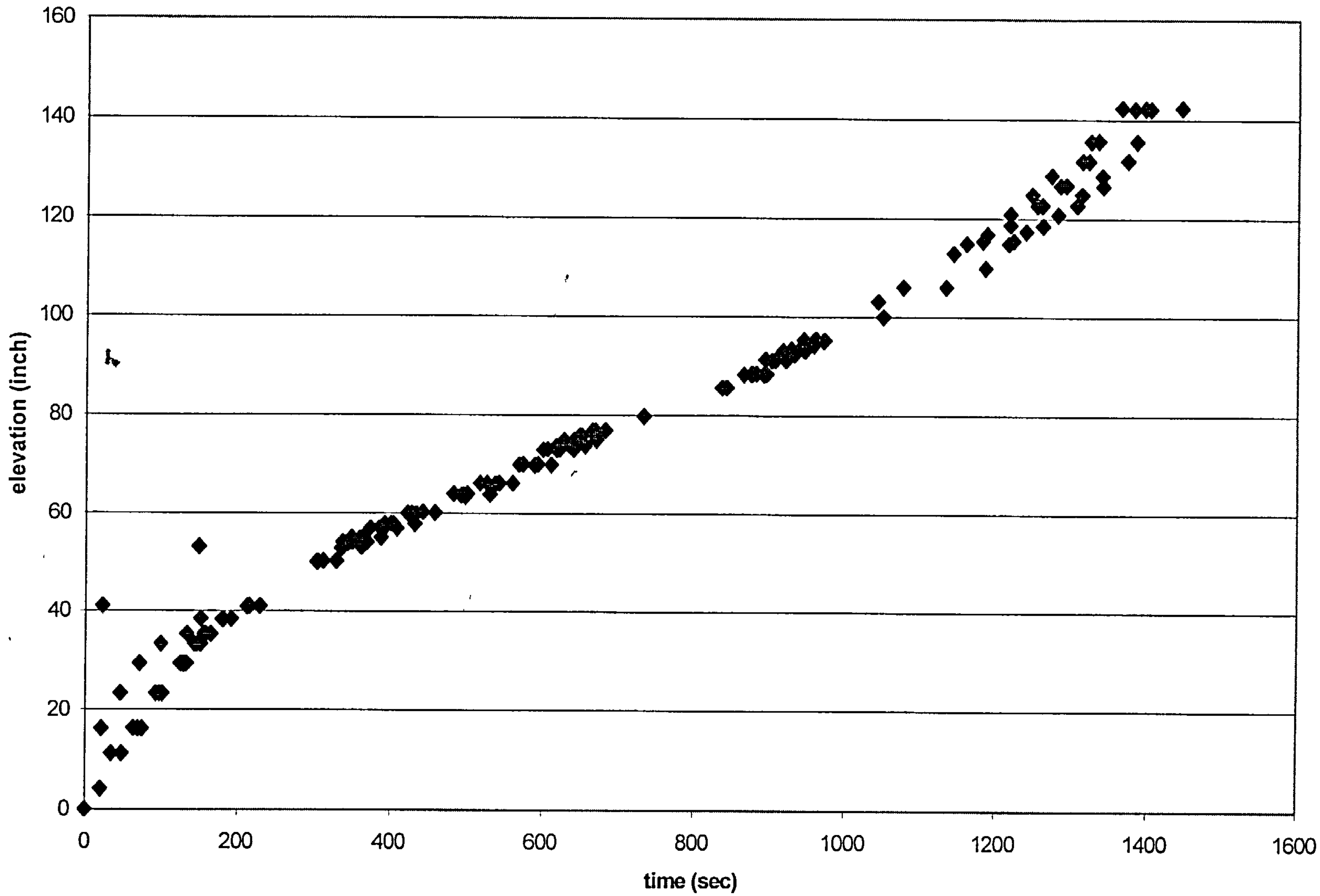
* *Power was held constant, did not decay.*

PENNSTATE

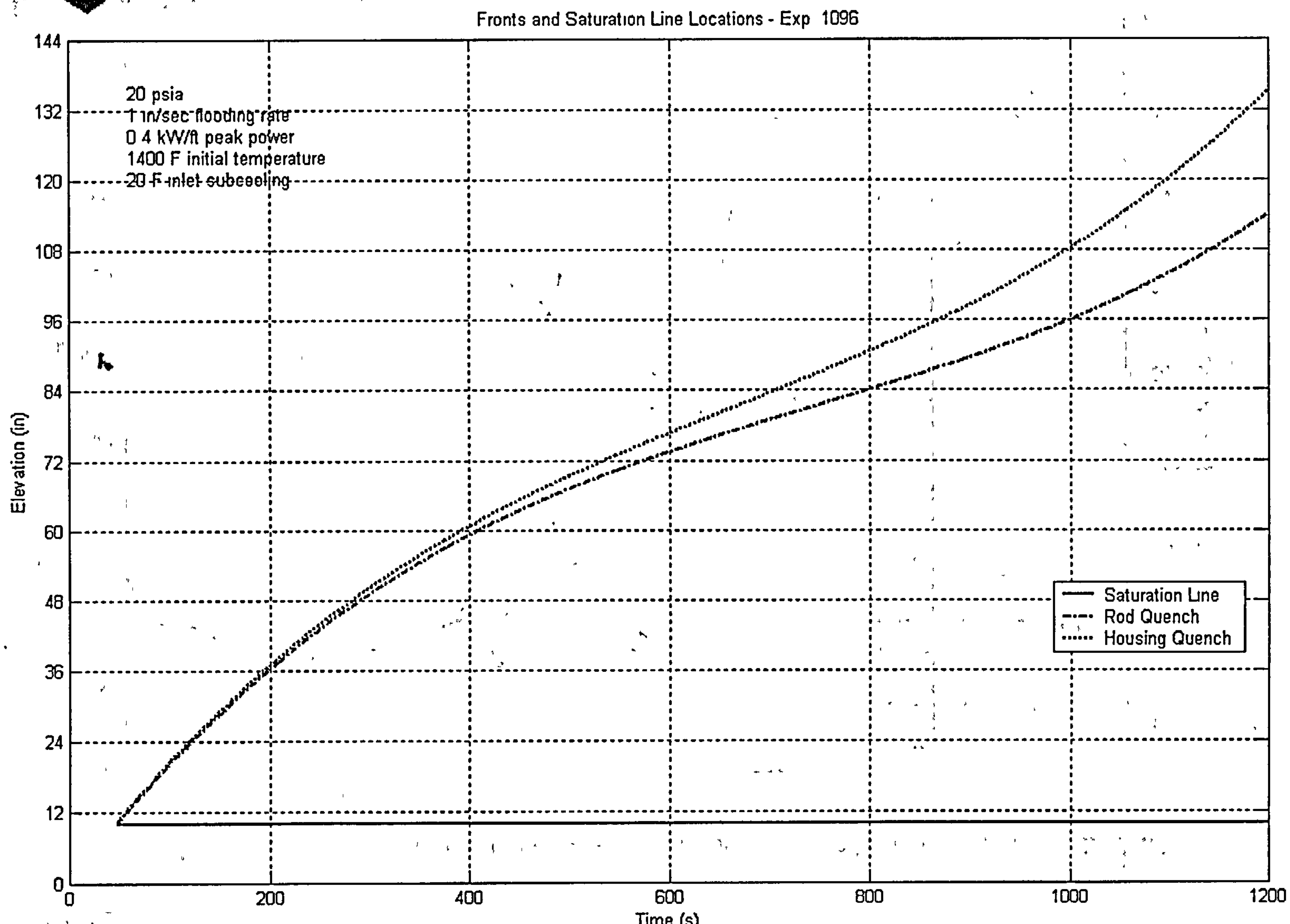
- Spacer grids can have a significant effect on the heat transfer due to
  - convective enhancement
  - grid quenching
  - entrained droplet break-up

PENNSTATE

RBHT, Experiment 1096, 20 psia, 1.0 in/sec, 1400 F initial temperature, 20 F subcooling



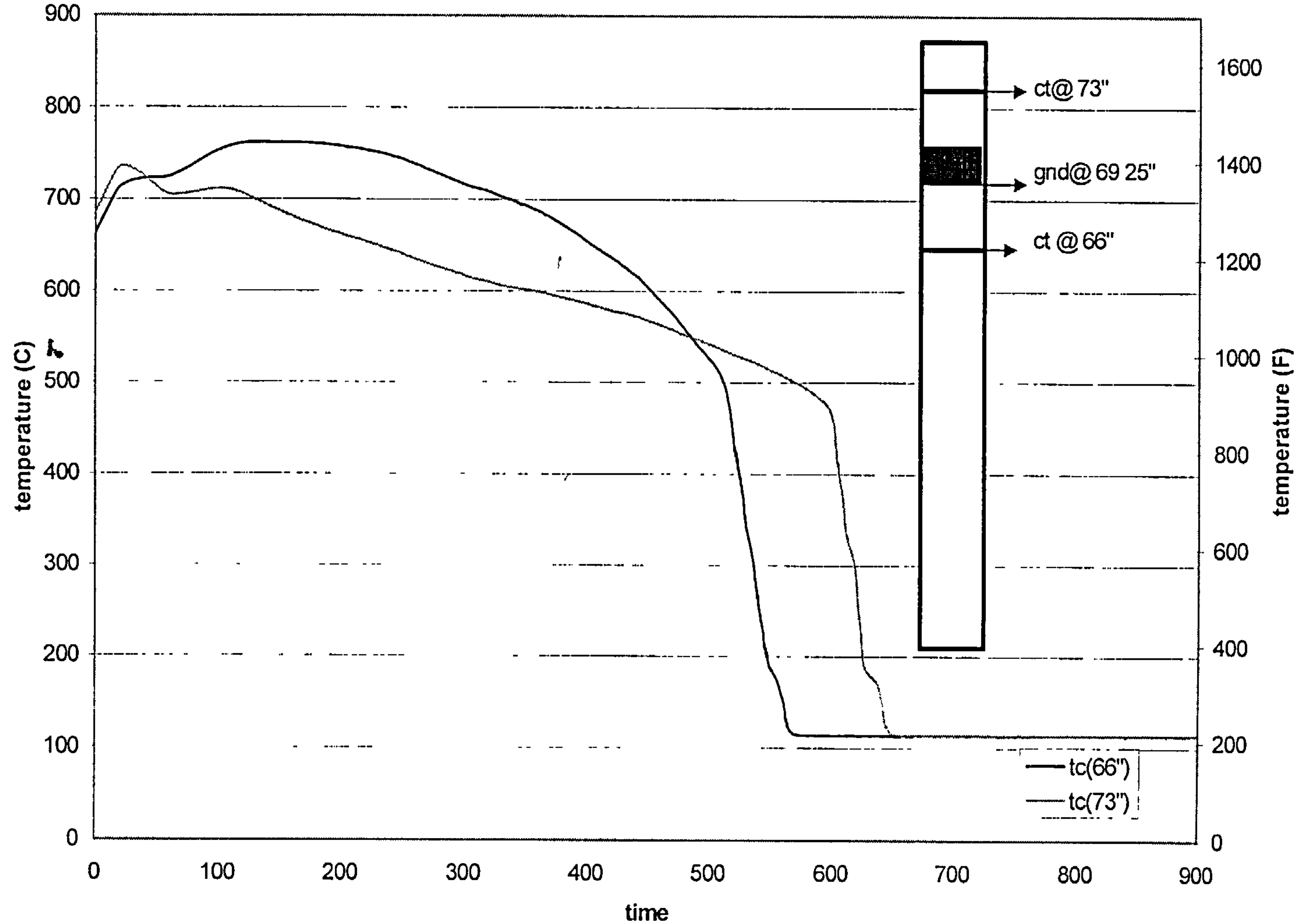
PENNSTATE



Fronts and Saturation Line Locations - Exp 1096
20 psia
1 in/sec flooding rate
0 4 kW/ft peak power
1400 F initial temperature
20 F inlet subcooling
Elevation (in)
Time (s)
Saturation Line
Rod Quench
Housing Quench
144
132
120
108
96
84
72
60
48
36
24
12
0
200
400
600
800
1000
1200

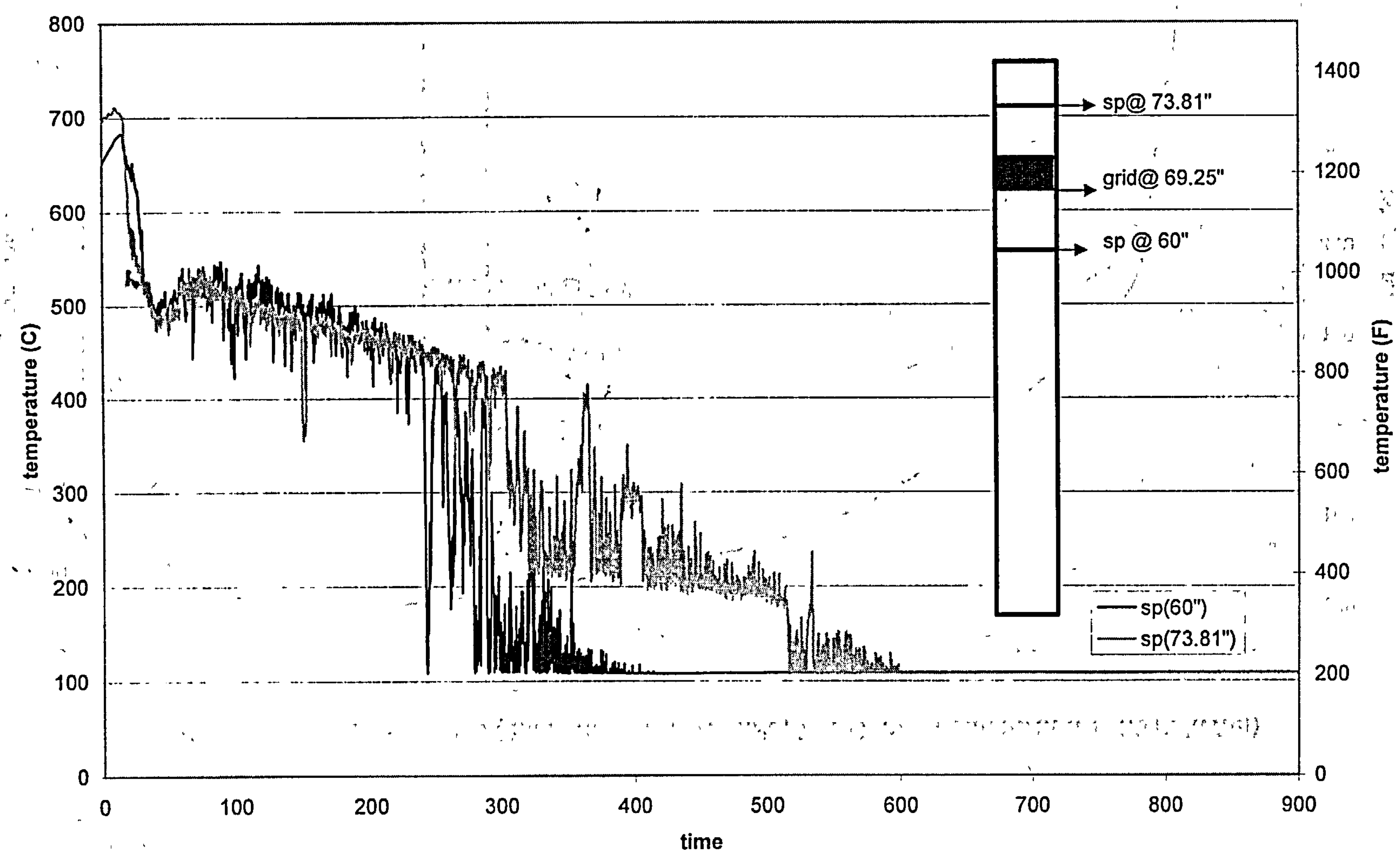
PENNSTATE

Clad Temperature, Exp 1096 (2.54 cm/sec, 137.9 kPa, 760 C initial temperature, 1.312 kW/m)



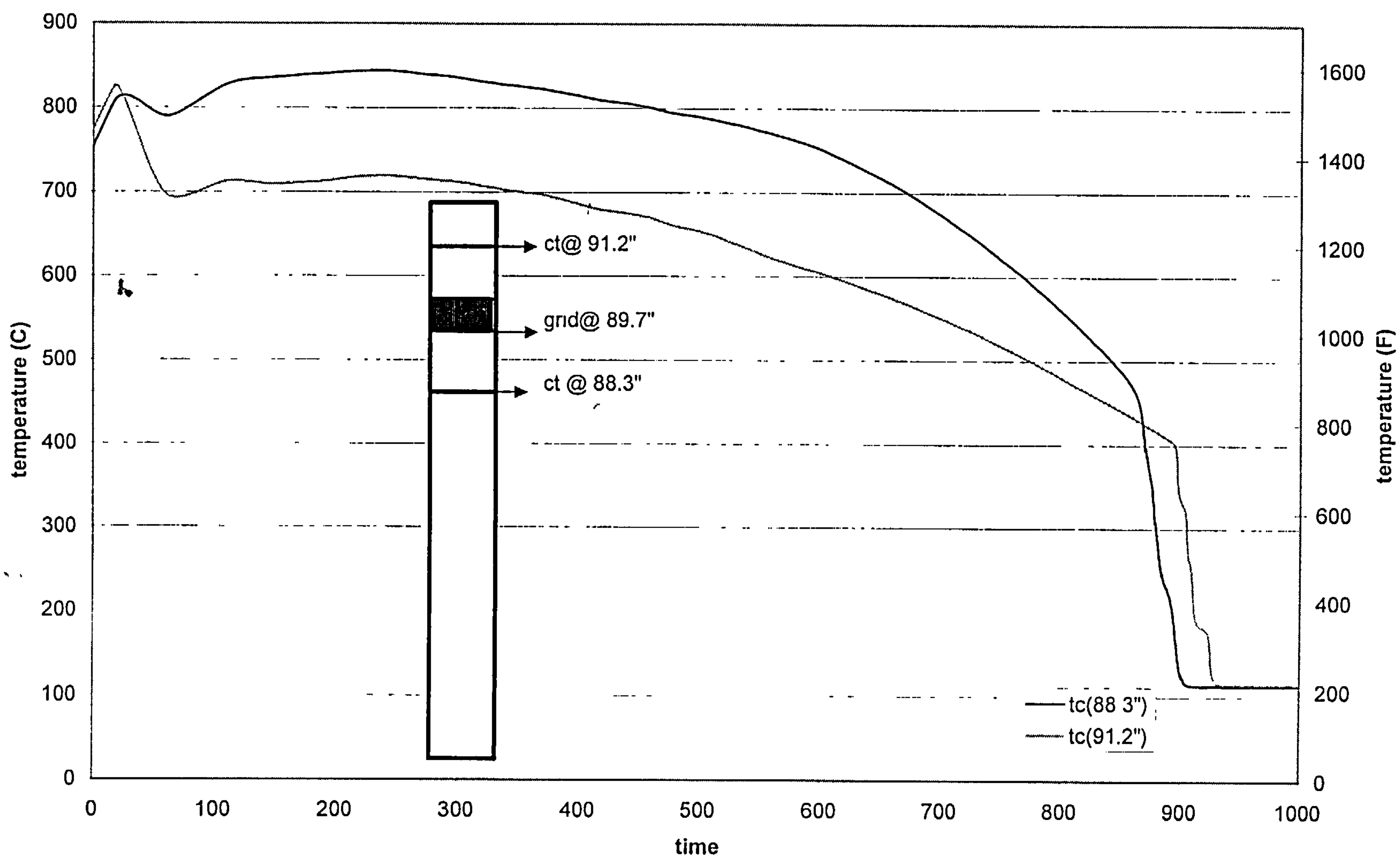
PENNSTATE

**Steam Temp, Exp 1096 (2.54 cm/sec, 137.9 kPa, 760 C initial temperature, 1.312 kW/m)**



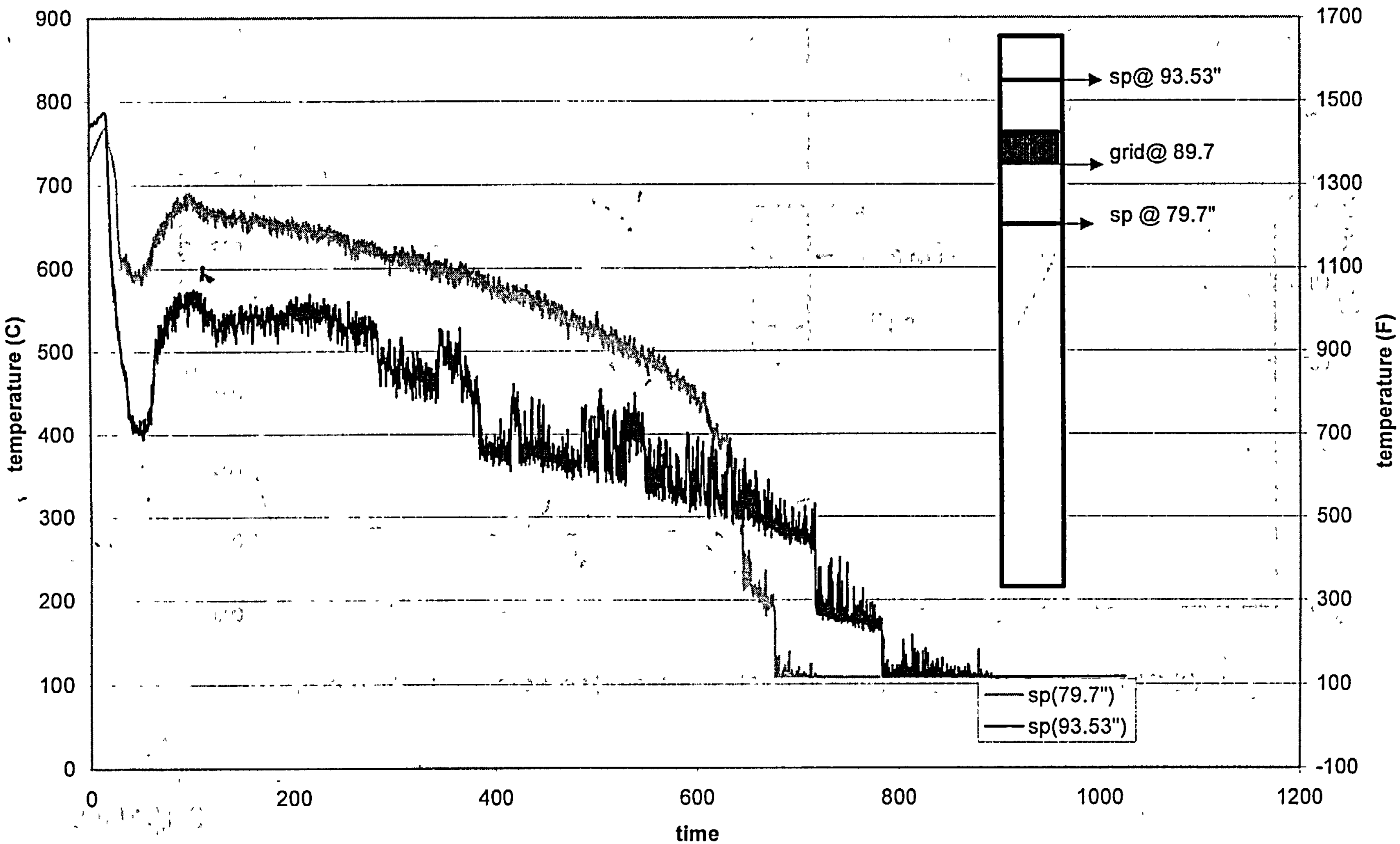
PENNSTATE

Clad Temperature, Exp 1096 (2.54 cm/sec, 137.9 kPa, 760 C initial temperature, 1.312 kW/m)



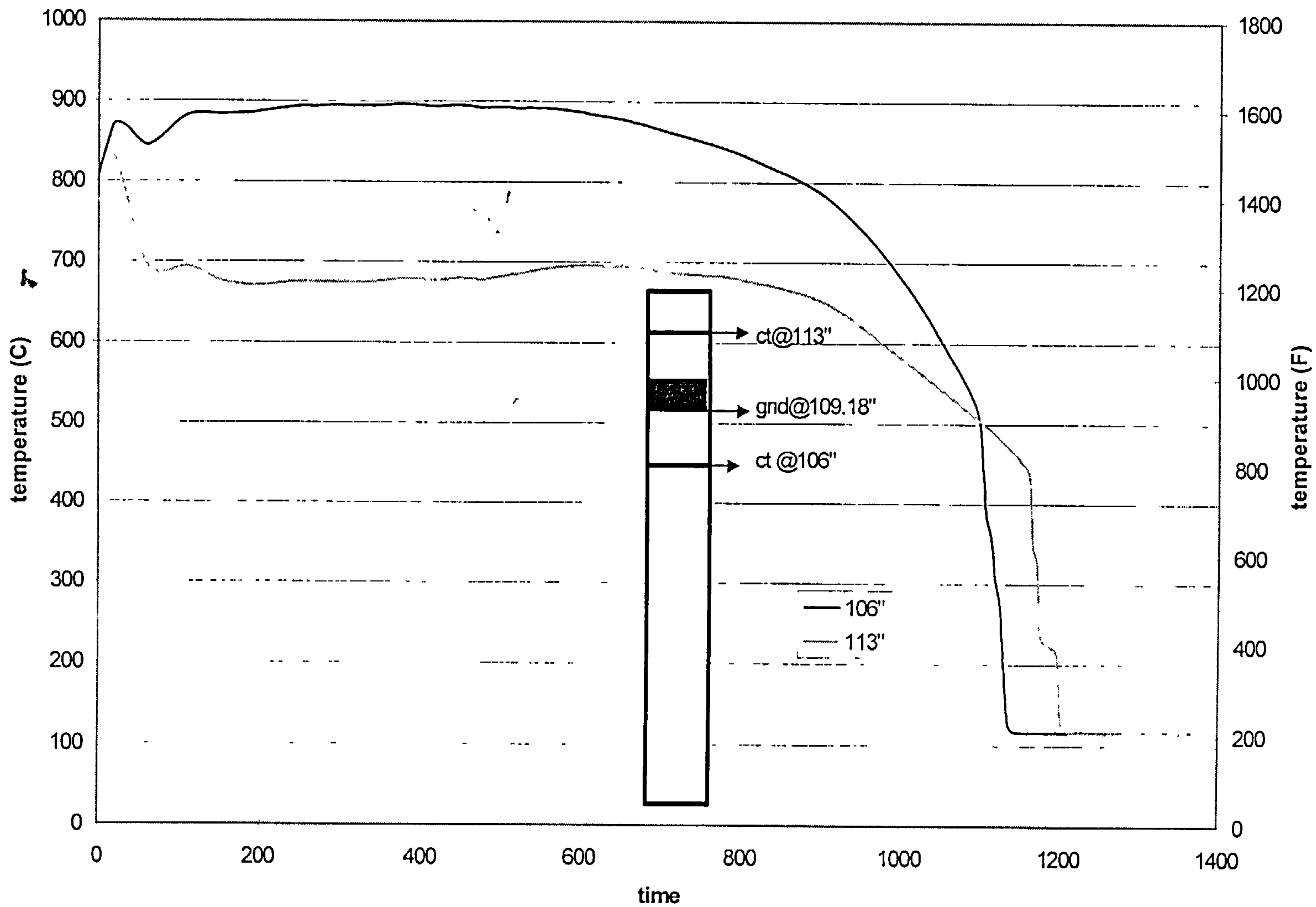
PENNSTATE

Steam Temp, Exp 1096 (2.54 cm/sec, 137.9 kPa, 760 C initial temperature, 1.312 kW/m)

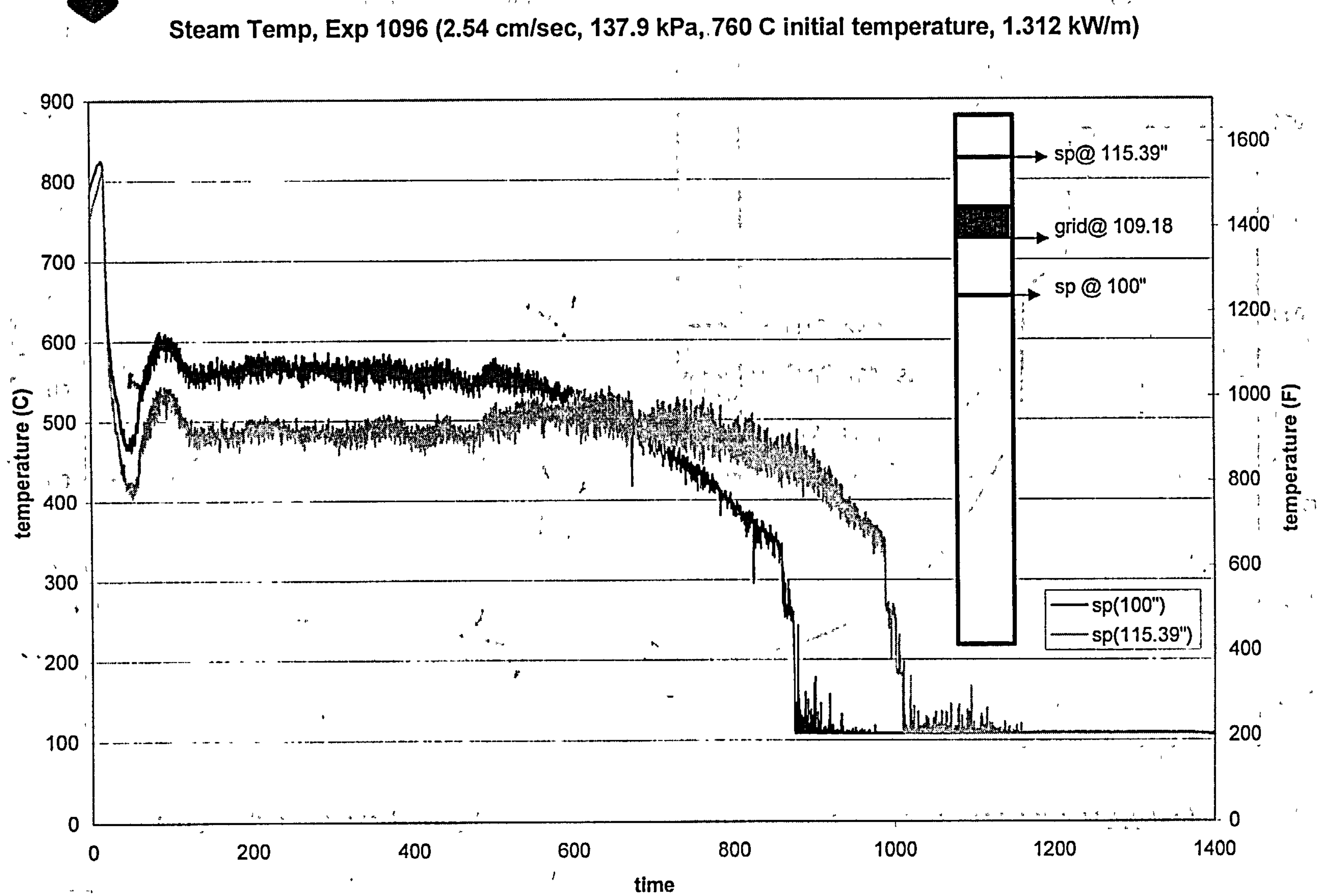


PENNSTATE

Clad Temperature, Exp 1096 (2.54 cm/sec, 137.9 kPa, 760 C initial temperature, 1.312 kW/m)



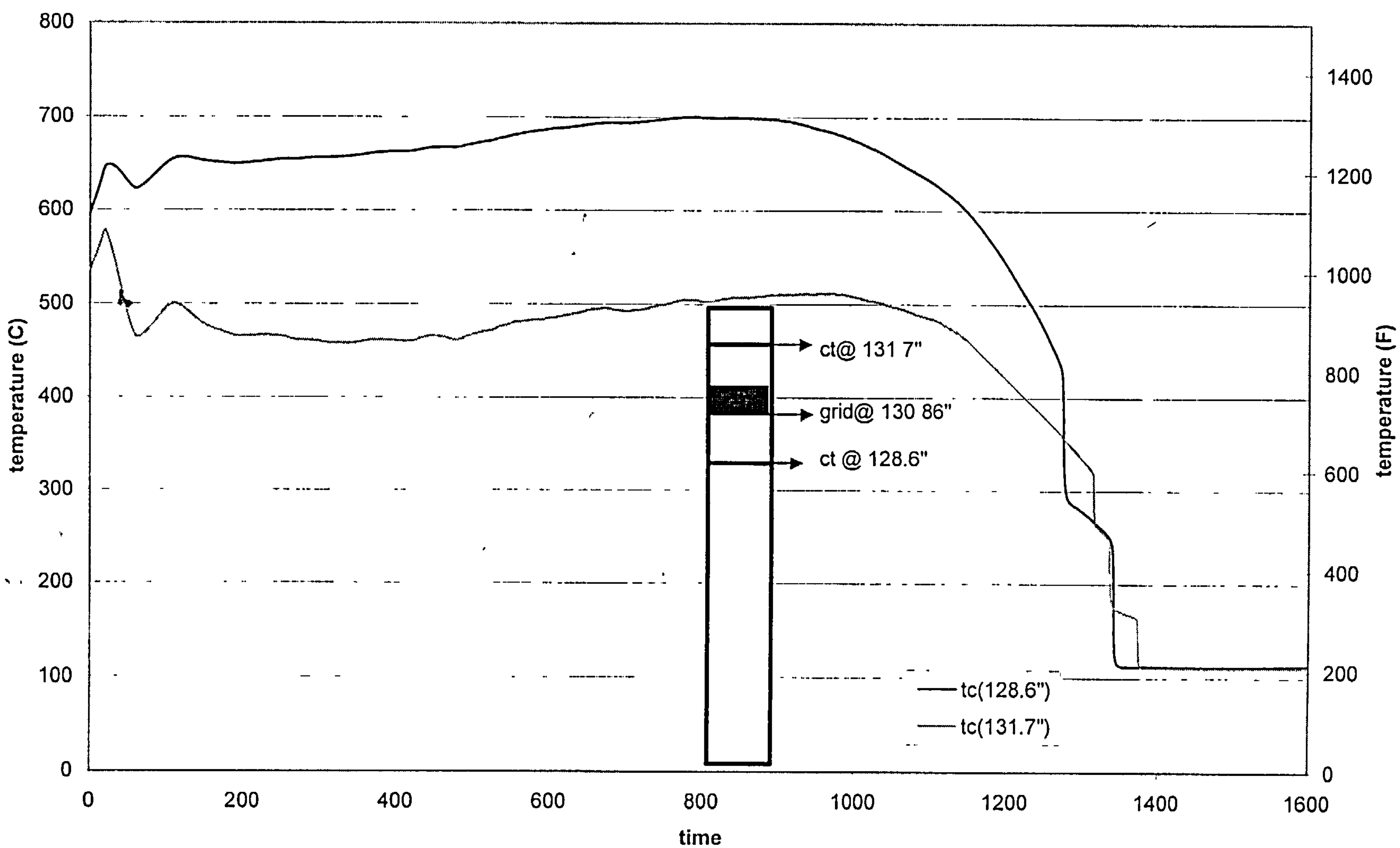
PENNSTATE



Steam Temp, Exp 1096 (2.54 cm/sec, 137.9 kPa, 760 C initial temperature, 1.312 kW/m)
temperature (C)
temperature (F)
time
sp@ 115.39"
grid@ 109.18
sp @ 100"
sp(100")
sp(115.39")

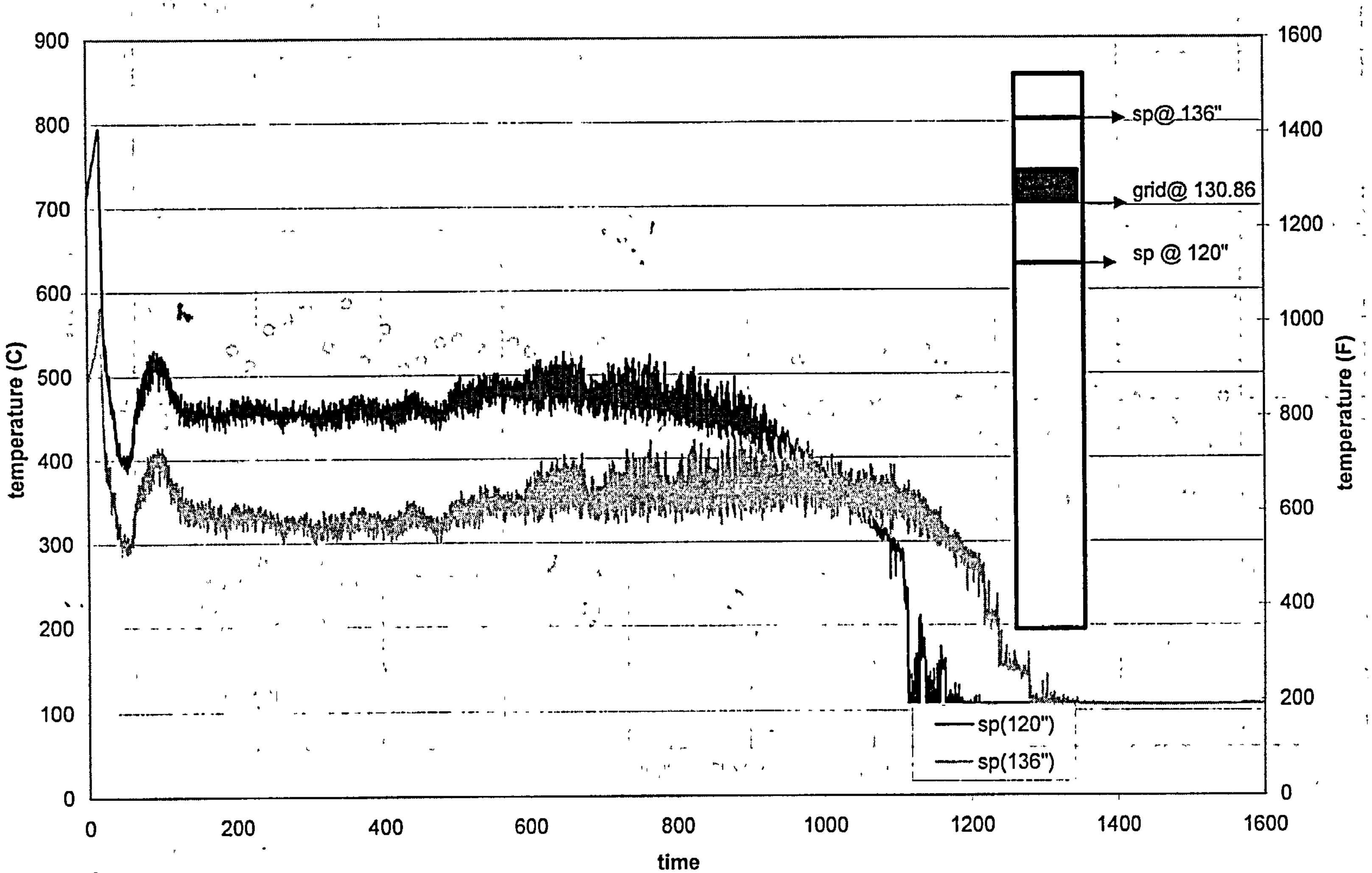
PENNSTATE

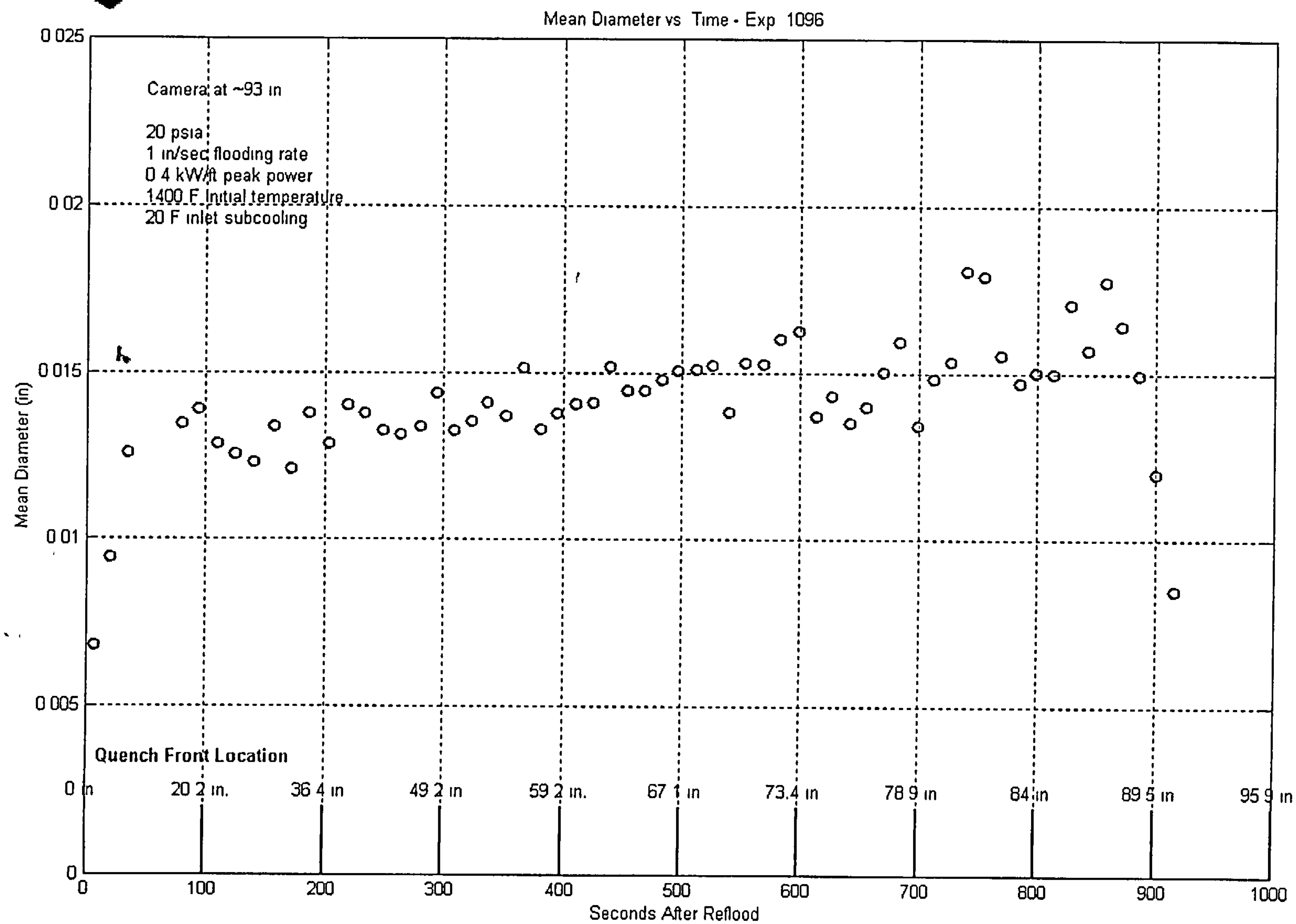
Clad Temperature, Exp 1096 (2.54 cm/sec, 137.9 kPa, 760 C initial temperature, 1.312 kW/m)



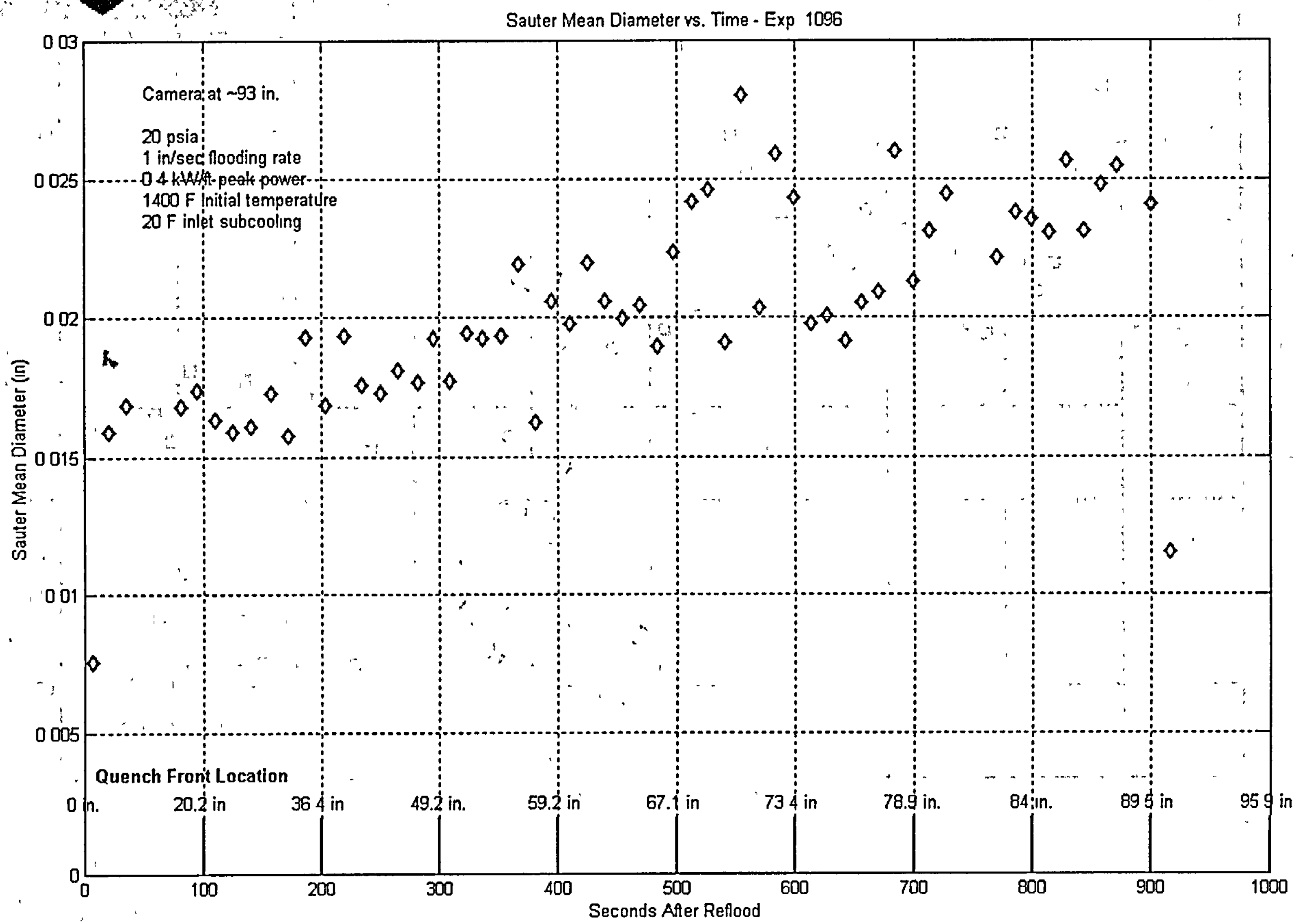
PENNSTATE

## Steam Temp, Exp 1096 (2.54 cm/sec, 137.9 kPa, 760 C initial temperature, 1.312 kW/m)





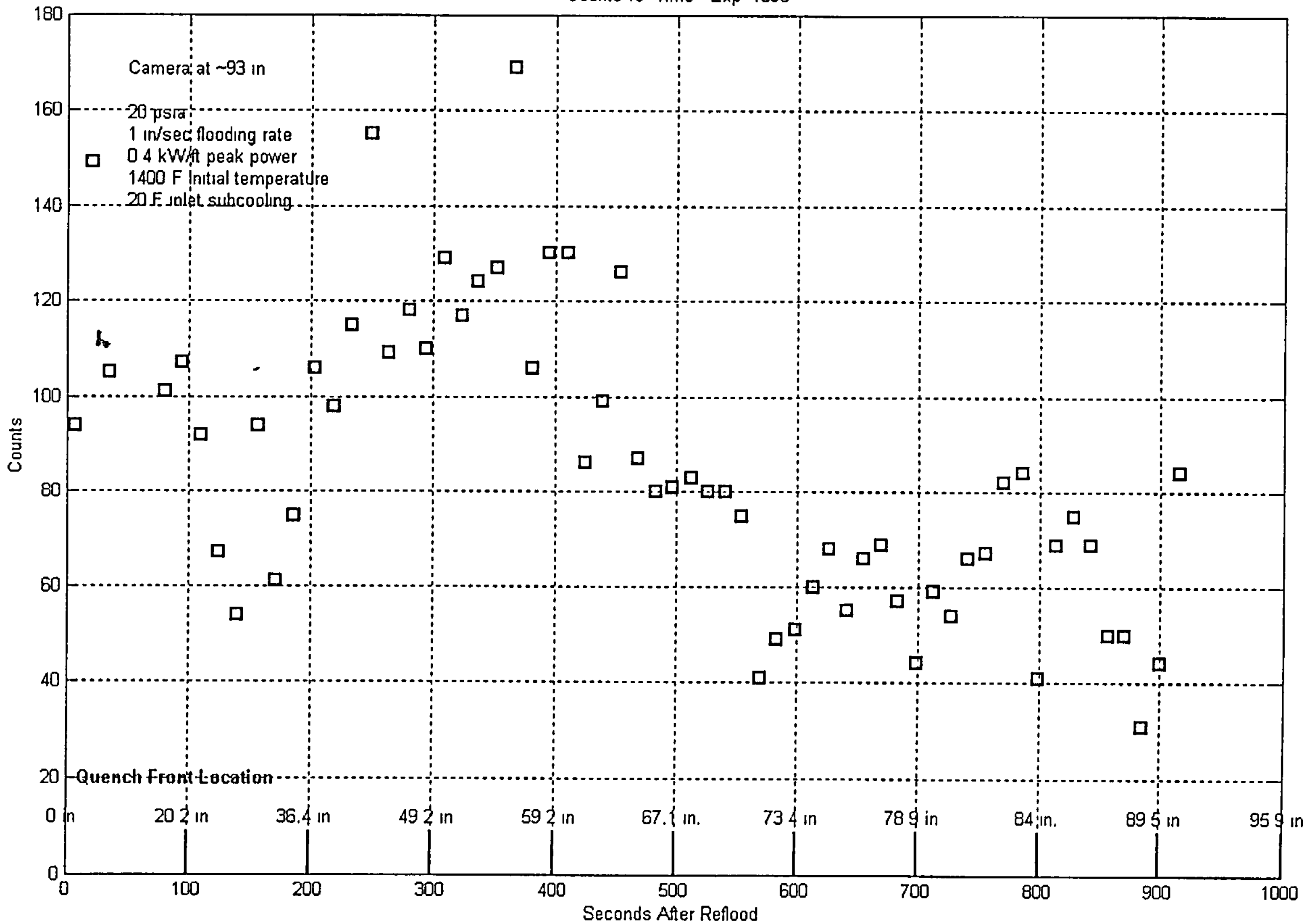
Mean Diameter vs Time - Exp 1096
Camera at ~93 in
20 psia
1 in/sec flooding rate
0 4 kW/ft peak power
1400 F Initial temperature
20 F inlet subcooling
Quench Front Location
0 in
20 2 in.
36 4 in
49 2 in
59 2 in.
67 1 in
73.4 in
78 9 in
84 in
89 5 in
95 9 in
Mean Diameter (in)
0 025
0 02
0 015
0 01
0 005
0
0
100
200
300
400
500
600
700
800
900
1000
Seconds After Reflood



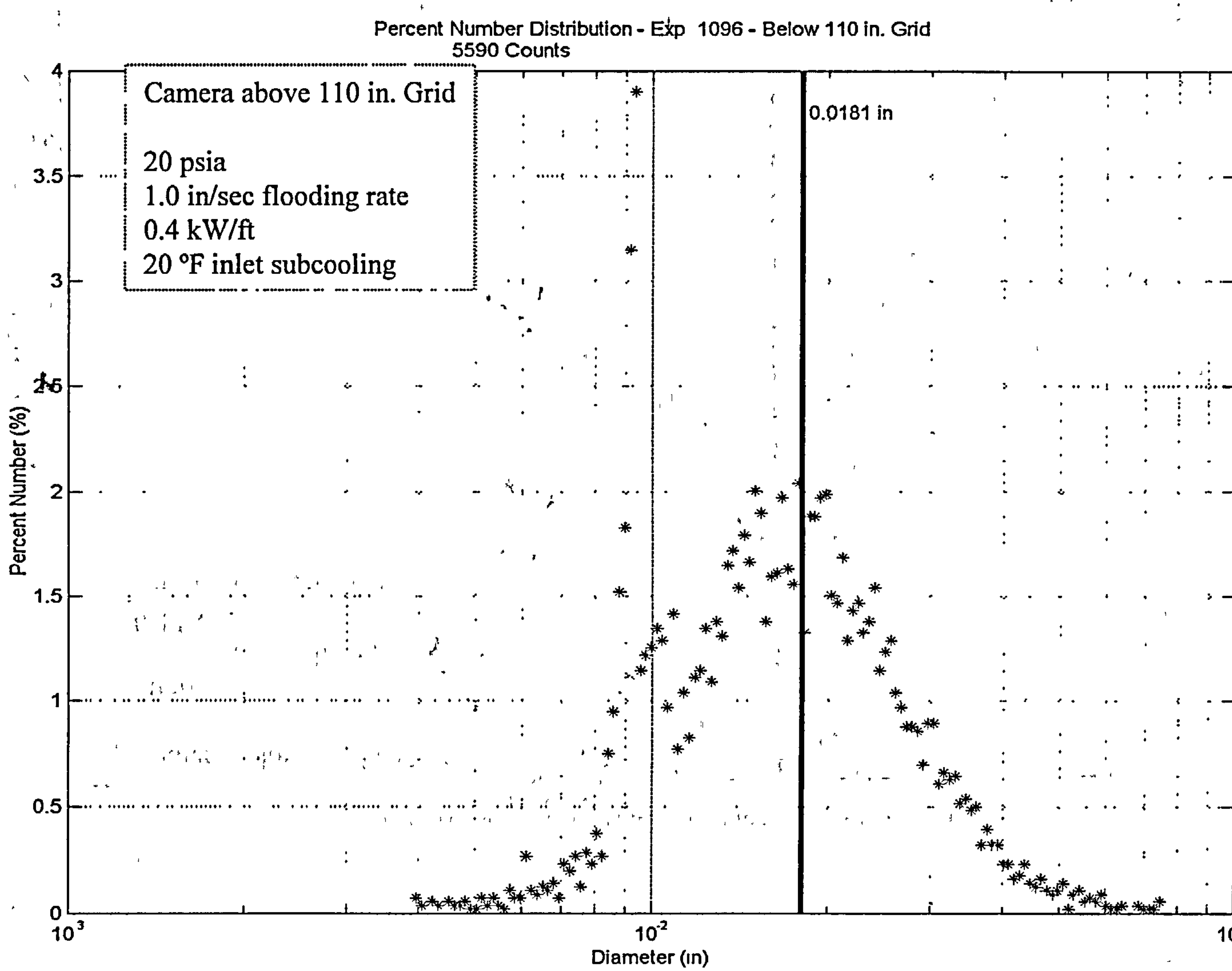
Sauter Mean Diameter vs. Time - Exp 1096
Camera at ~93 in.
20 psia
1 in/sec flooding rate
0 4 kW/ft peak power
1400 F initial temperature
20 F inlet subcooling
Sauter Mean Diameter (in)
0 03
0 025
0 02
0 015
0 01
0 005
0
Quench Front Location
0 in.
20.2 in
36 4 in
49.2 in.
59.2 in
67.1 in
73 4 in
78.9 in.
84 in.
89 5 in
95 9 in
0
100
200
300
400
500
600
700
800
900
1000
Seconds After Reflood

PENNSTATE

Counts vs Time - Exp 1096

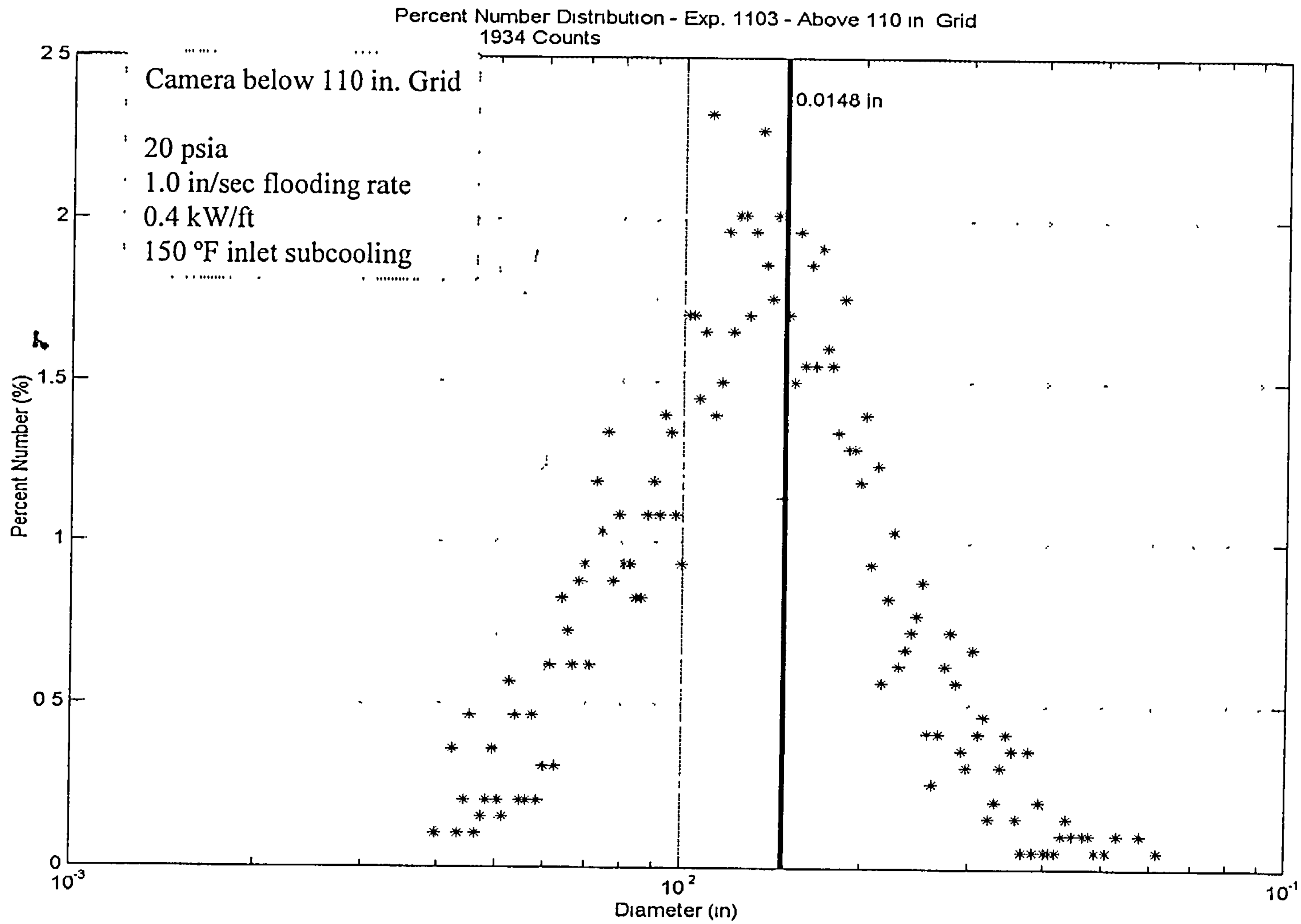


PENNSTATE



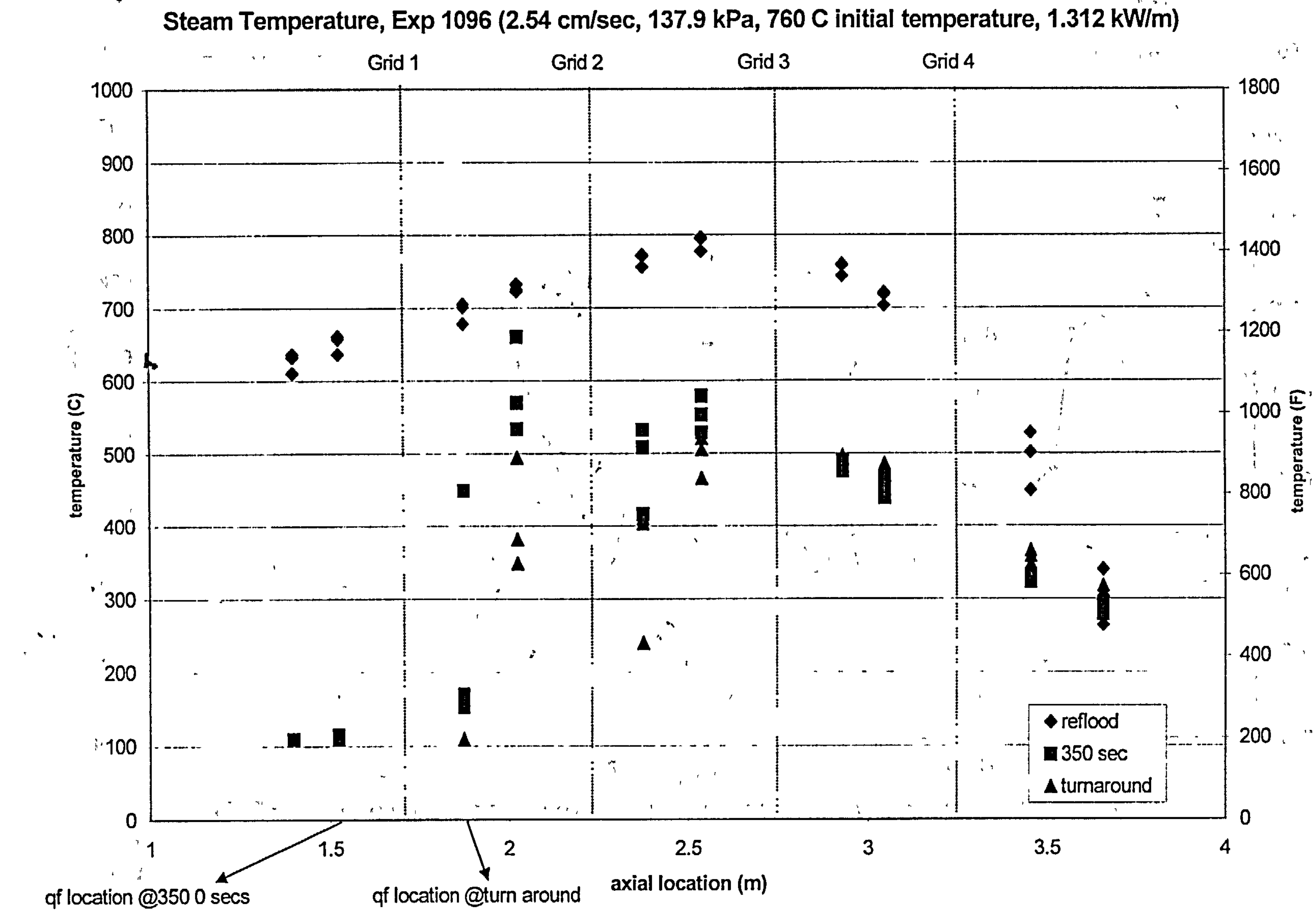
Percent Number Distribution - Exp 1096 - Below 110 in. Grid
5590 Counts
Camera above 110 in. Grid
20 psia
1.0 in/sec flooding rate
0.4 kW/ft
20 °F inlet subcooling
0.0181 in
Percent Number (%)
Diameter (in)
0
0.5
1
1.5
2
2.5
3
3.5
4
10^-3
10^-2
10^-1

PENNSTATE



Percent Number Distribution - Exp. 1103 - Above 110 in Grid
1934 Counts
Camera below 110 in. Grid
20 psia
1.0 in/sec flooding rate
0.4 kW/ft
150 °F inlet subcooling
0.0148 in
Percent Number (%)
Diameter (in)
2.5
2
1.5
1
0.5
0
$10^{-3}$
$10^{-2}$
$10^{-1}$

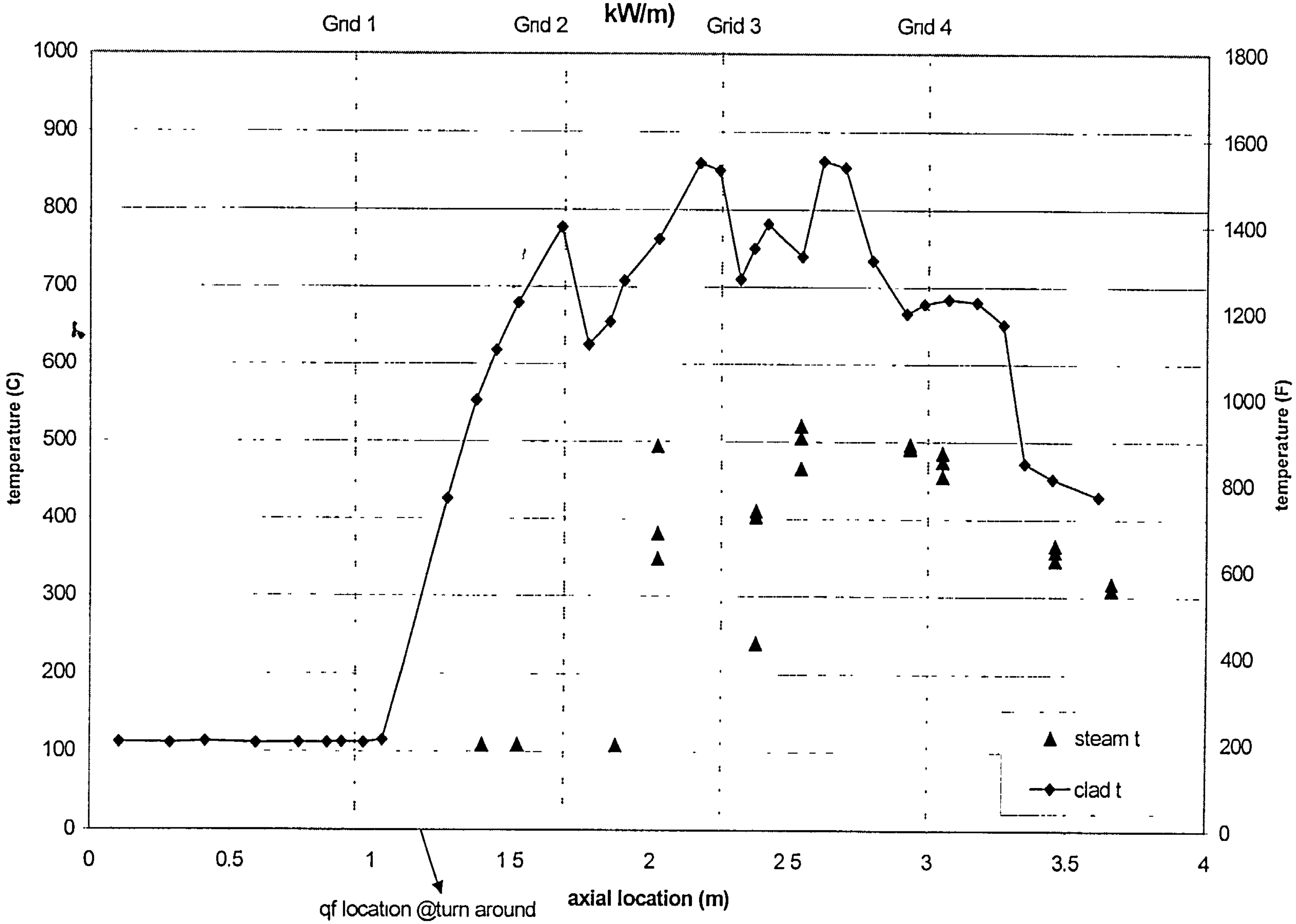
PENNSTATE



Steam Temperature, Exp 1096 (2.54 cm/sec, 137.9 kPa, 760 C initial temperature, 1.312 kW/m)
Grid 1
Grid 2
Grid 3
Grid 4
temperature (C)
temperature (F)
axial location (m)
reflood
350 sec
turnaround
qf location @350 0 secs
qf location @turn around

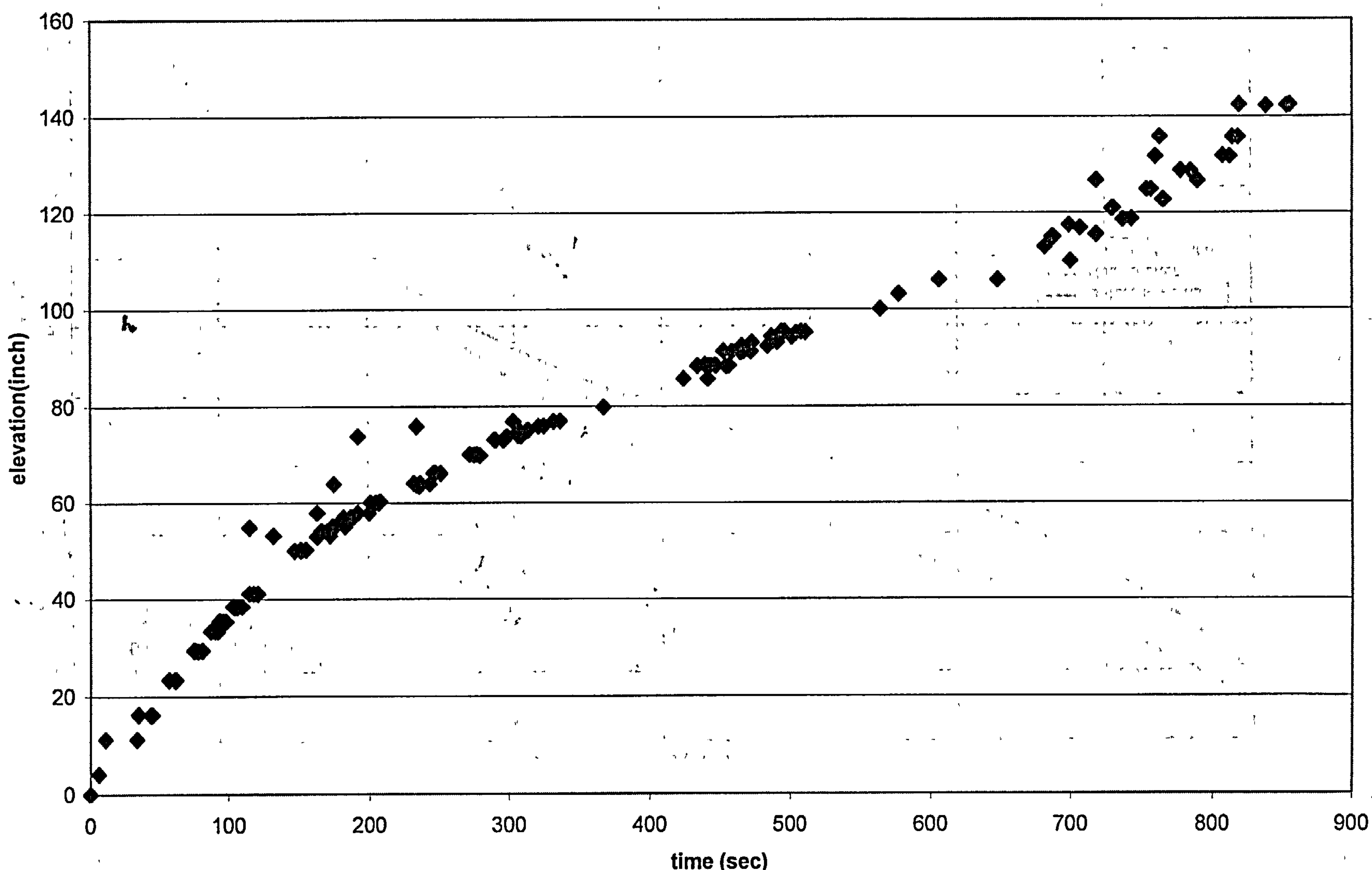
PENNSTATE

Temp@ turnaround time, Exp 1096 (2.54 cm/sec, 137.9 kPa, 760 C initial temperature, 1.312 kW/m)



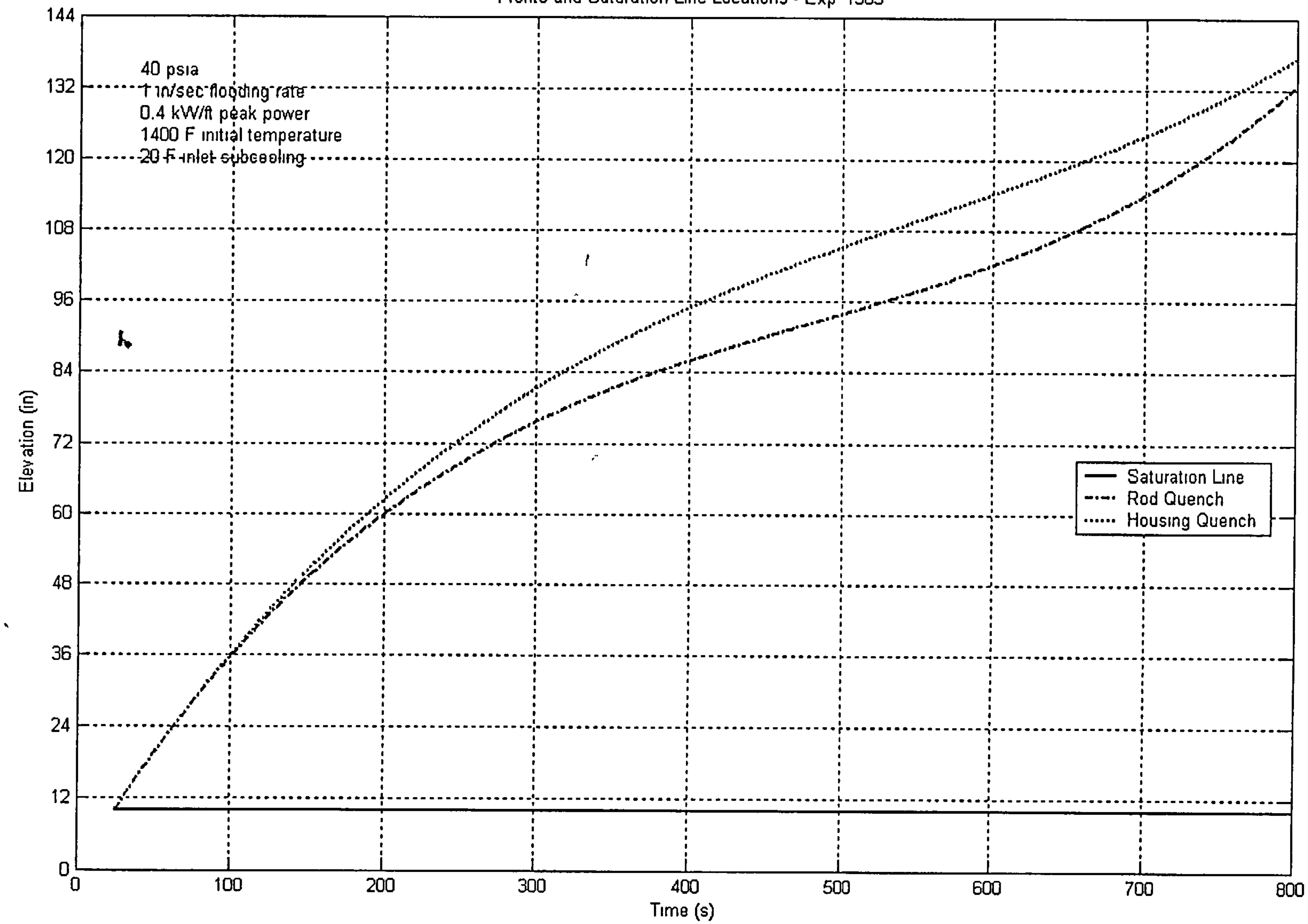
PENNSTATE

RBHT, Experiment 1383, 40 psia, 1.0 in/sec, 1400 F initial temperature, 20 F subcooling



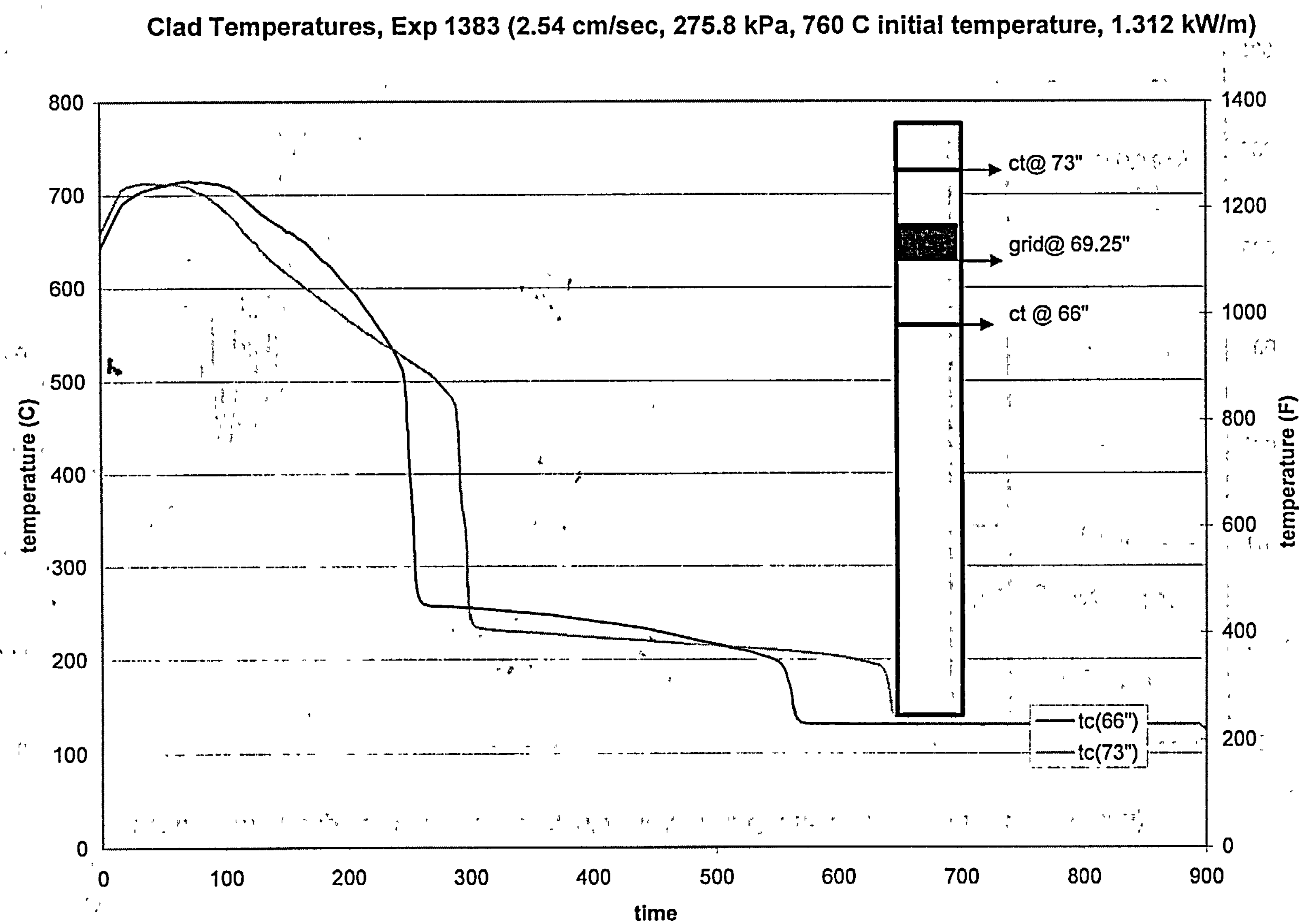
PENNSTATE

Fronts and Saturation Line Locations - Exp 1383



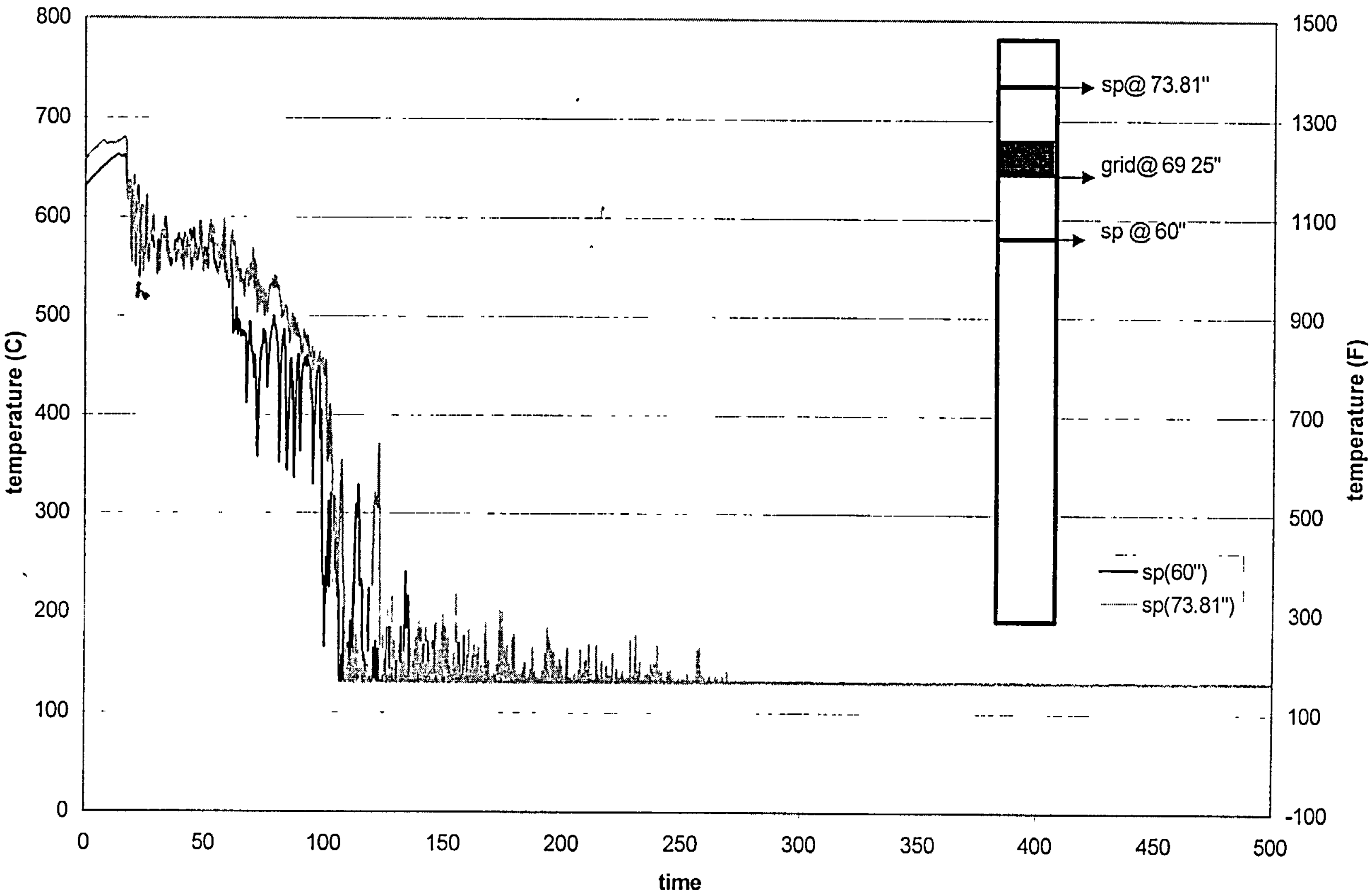
PENNSTATE

1855



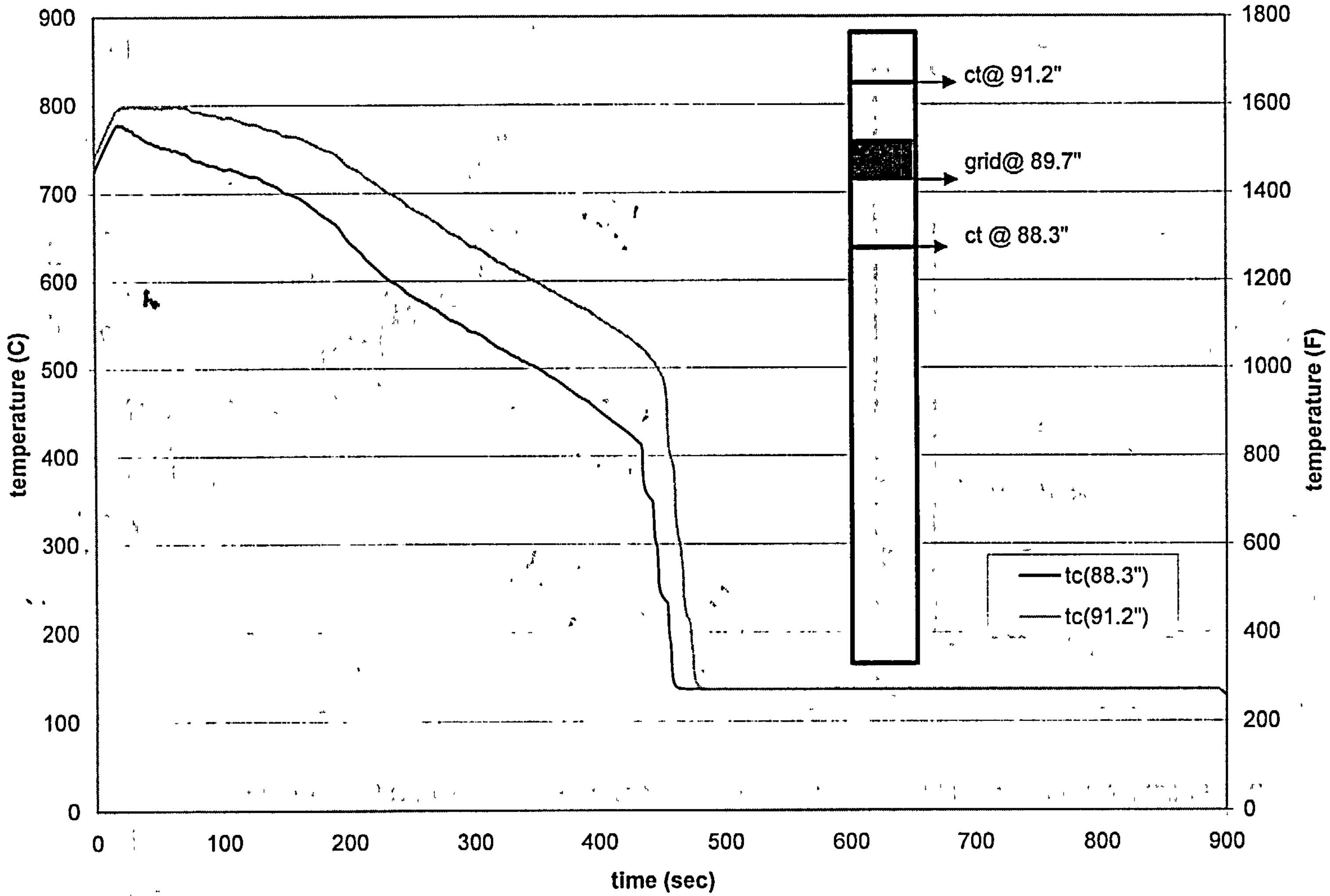
PENNSTATE

Steam Temp, Exp 1383 (2.54 cm/sec, 275.8 kPa, 760 C initial temperature, 1.312 kW/m)



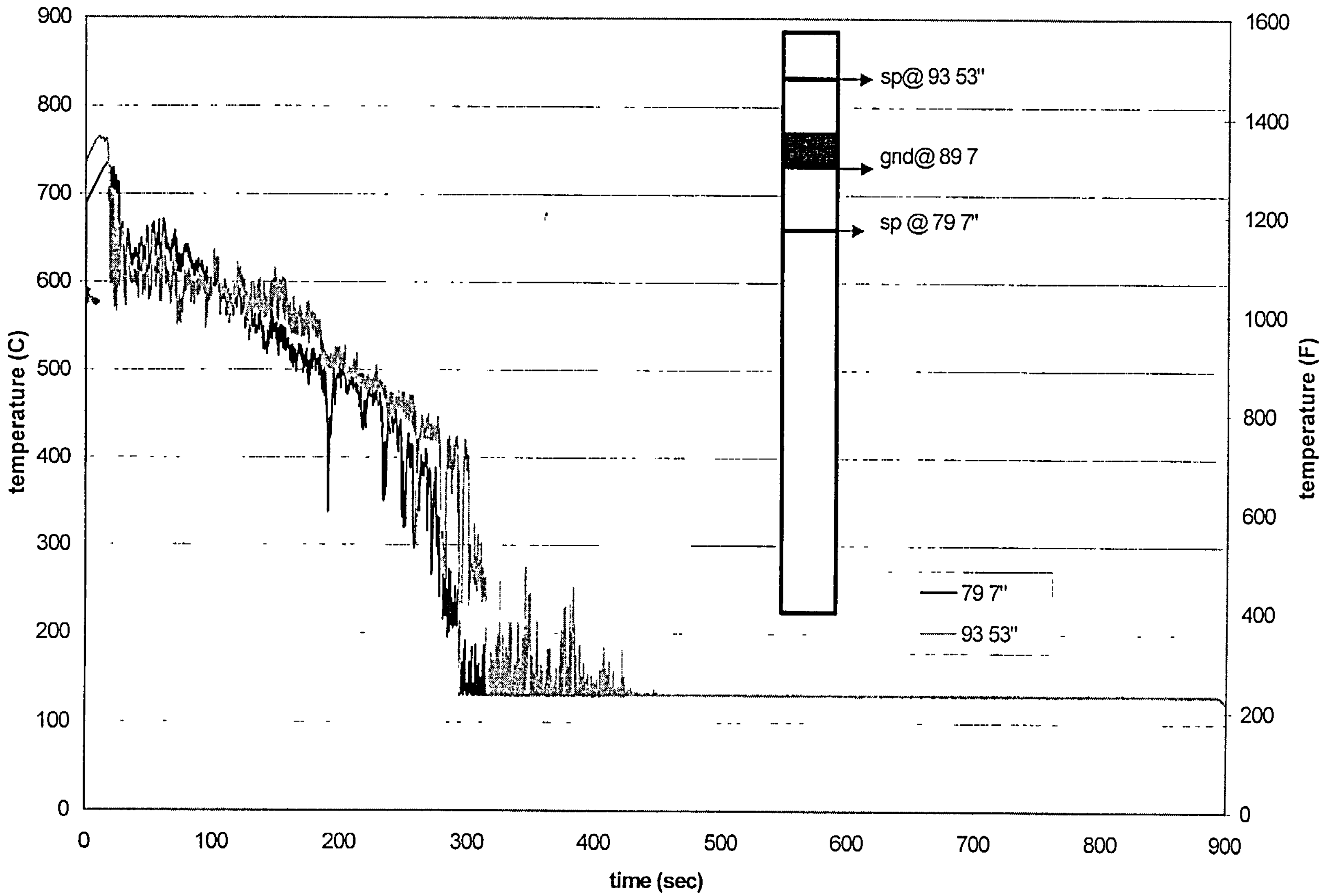
PENNSTATE

Clad Temperatures, Exp 1383 (2.54 cm/sec, 275.8 kPa, 760 C initial temperature, 1.312 kW/m)



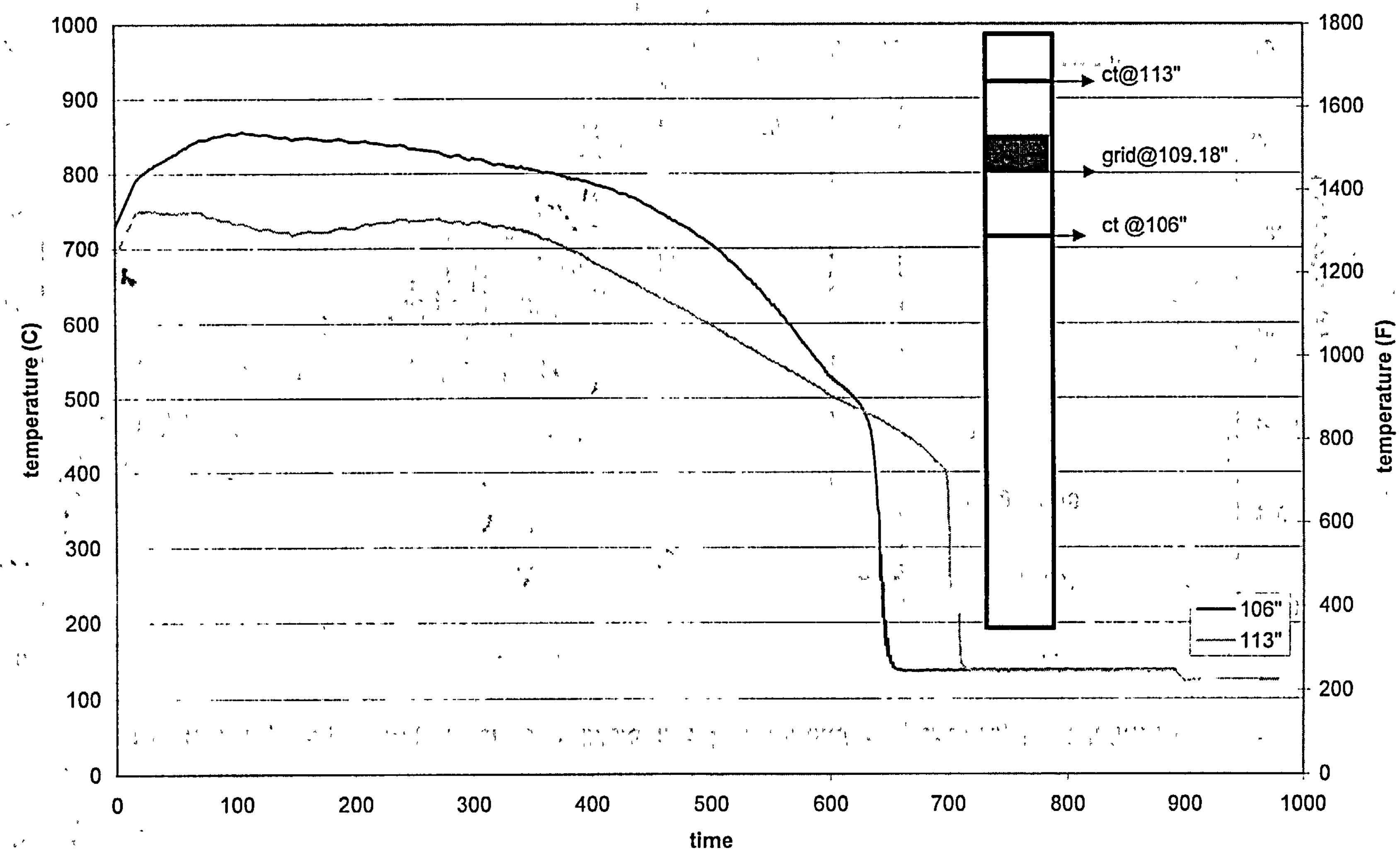
PENNSTATE

Steam Temp, Exp 1383 (2.54 cm/sec, 275.8 kPa, 760 C initial temperature, 1.312 kW/m)



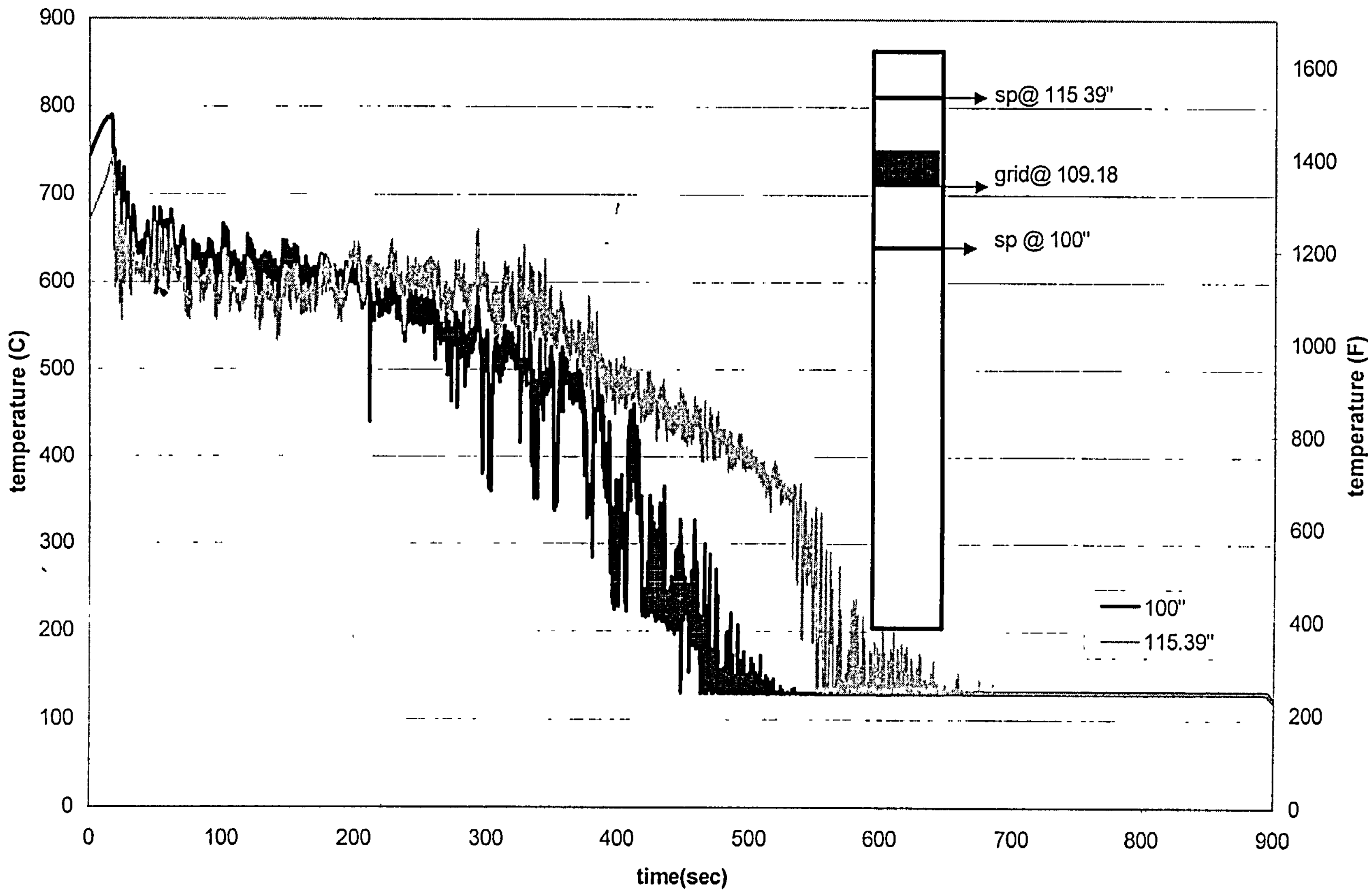
PENNSTATE

Clad Temperatures, Exp 1383 (2.54 cm/sec, 275.8 kPa, 760 C initial temperature, 1.312 kW/m)



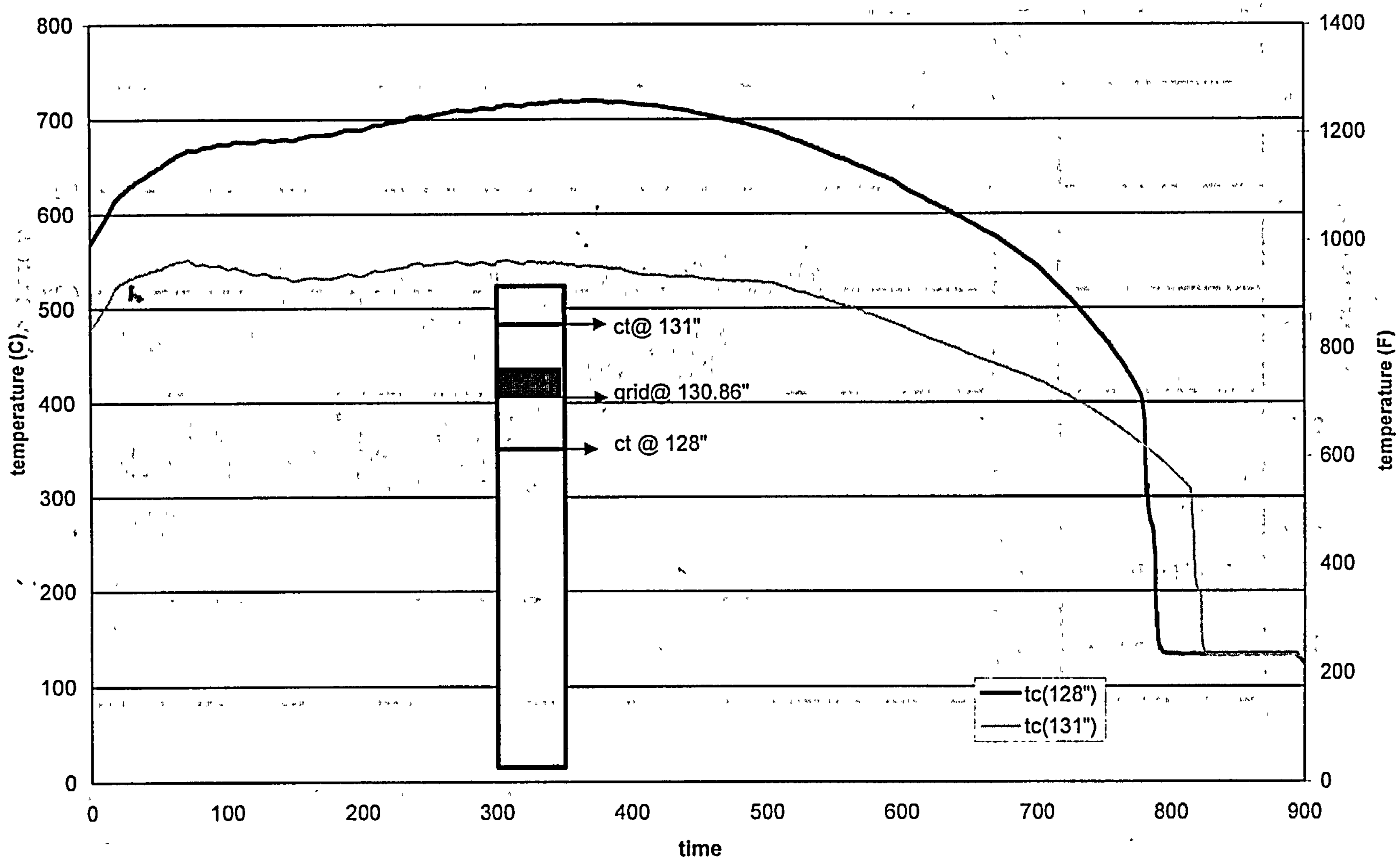
PENNSTATE

Steam Temp, Exp 1383 (2.54 cm/sec, 275.8 kPa, 760 C initial temperature, 1.312 kW/m)



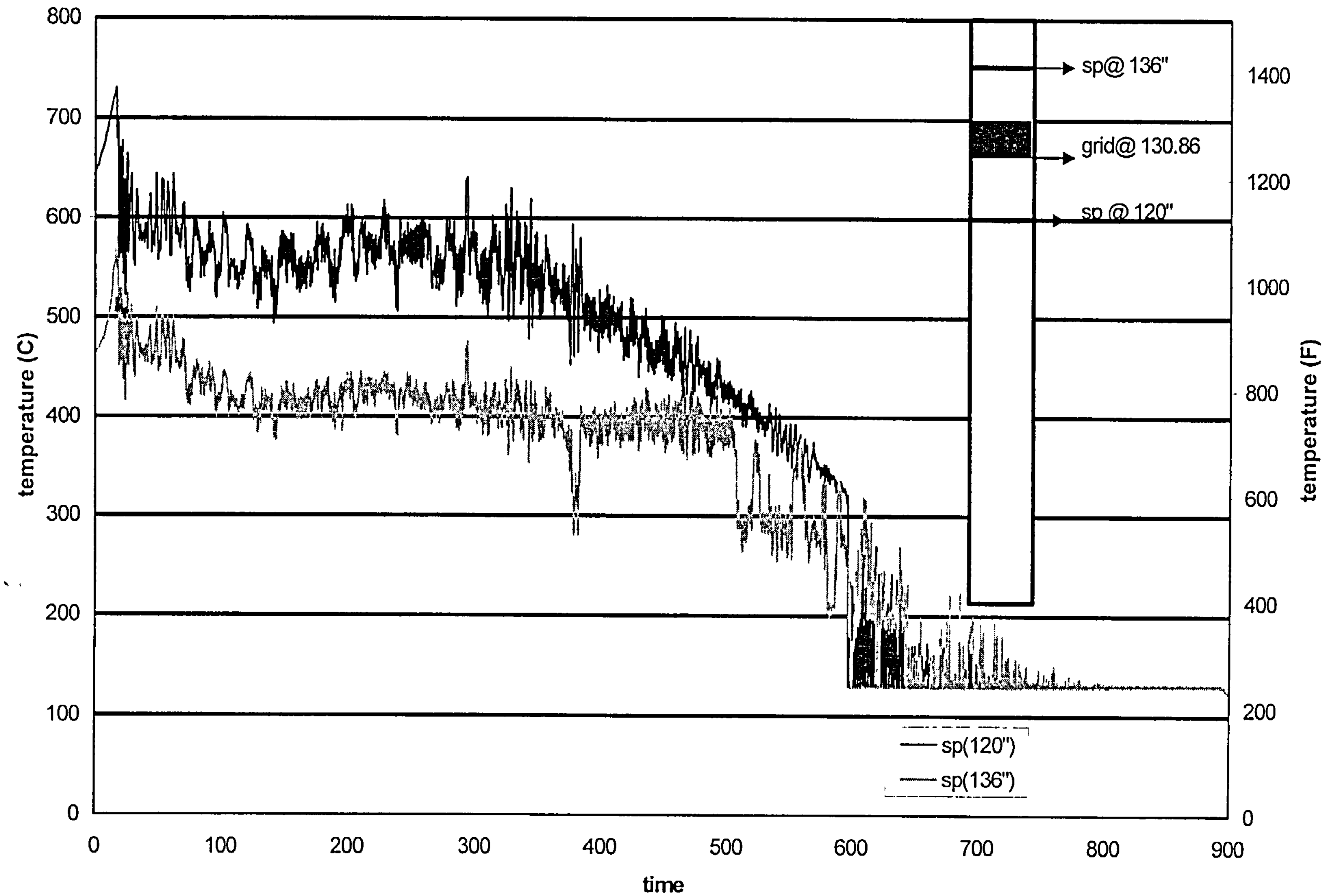
PENNSTATE

**Clad Temperatures, Exp 1383 (2.54 cm/sec, 275.8 kPa, 760 C initial temperature, 1.312 kW/m)**

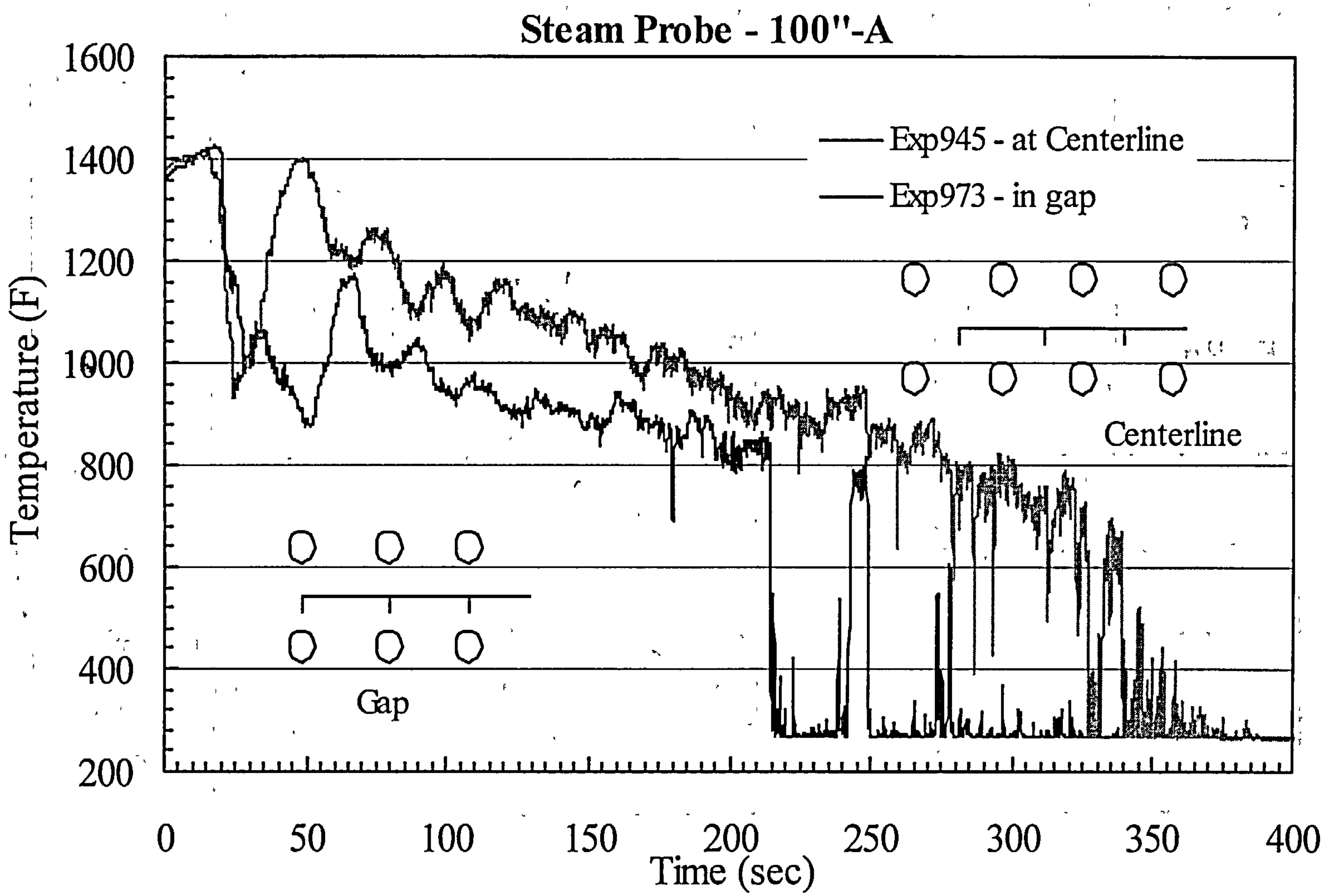


PENNSTATE

## Steam Temp, Exp 1383 (2.54 cm/sec, 275.8 kPa, 760 C initial temperature, 1.312 kW/m)

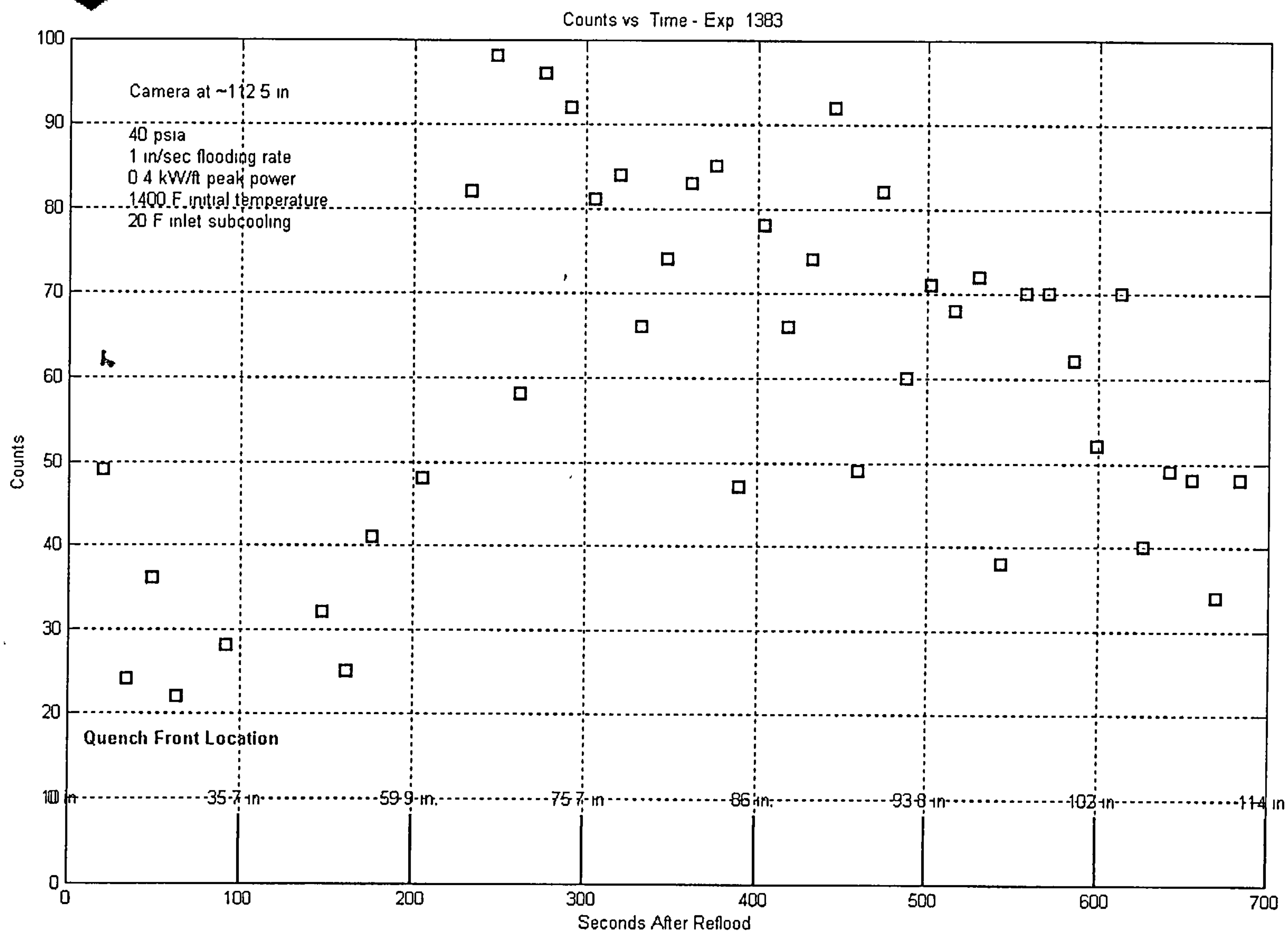


PENNSTATE



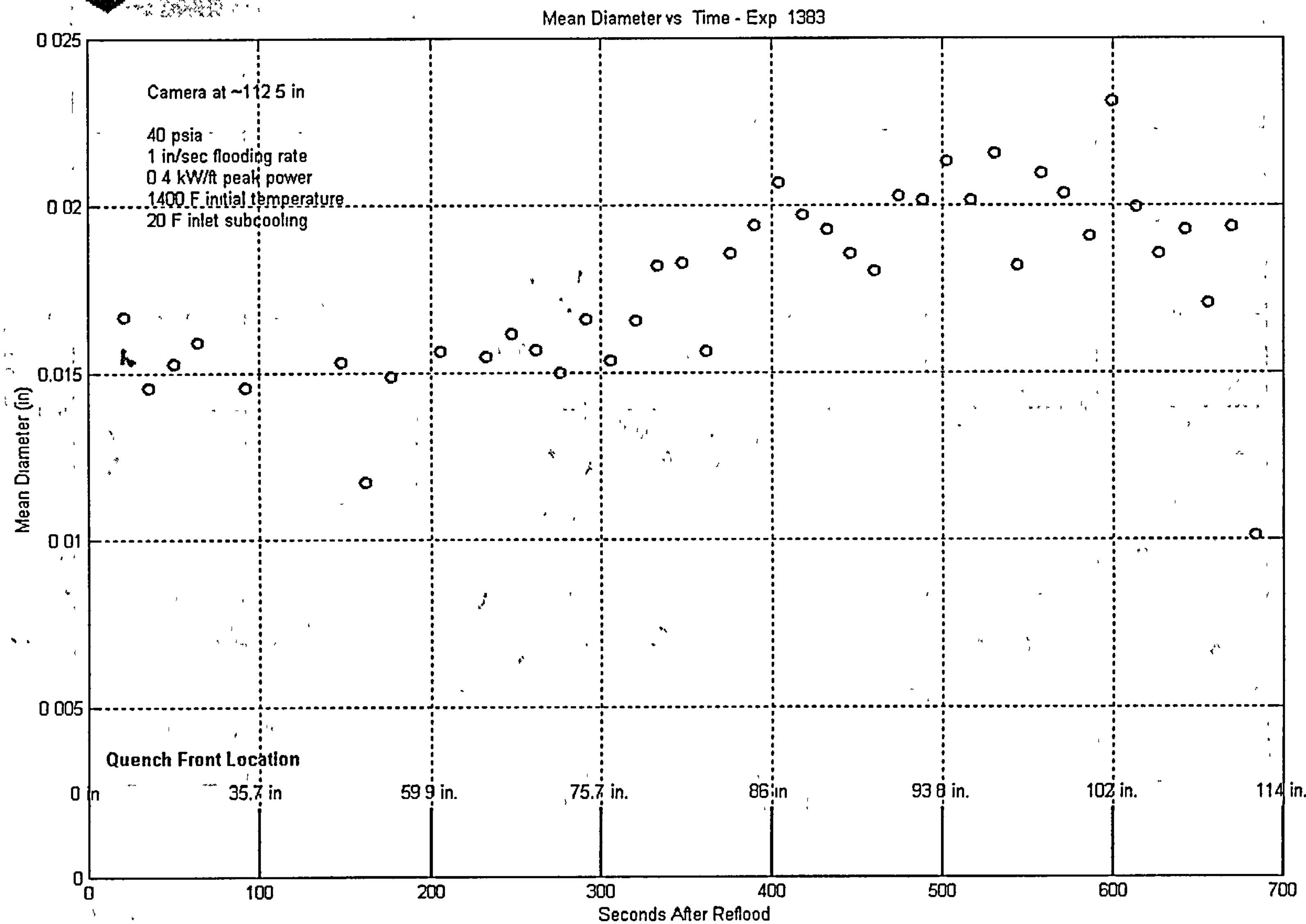
Steam Probe - 100"-A
1600
1400
1200
1000
800
600
400
200
Temperature (F)
0
50
100
150
200
250
300
350
400
Time (sec)
Exp945 - at Centerline
Exp973 - in gap
Centerline
Gap

PENNSTATE

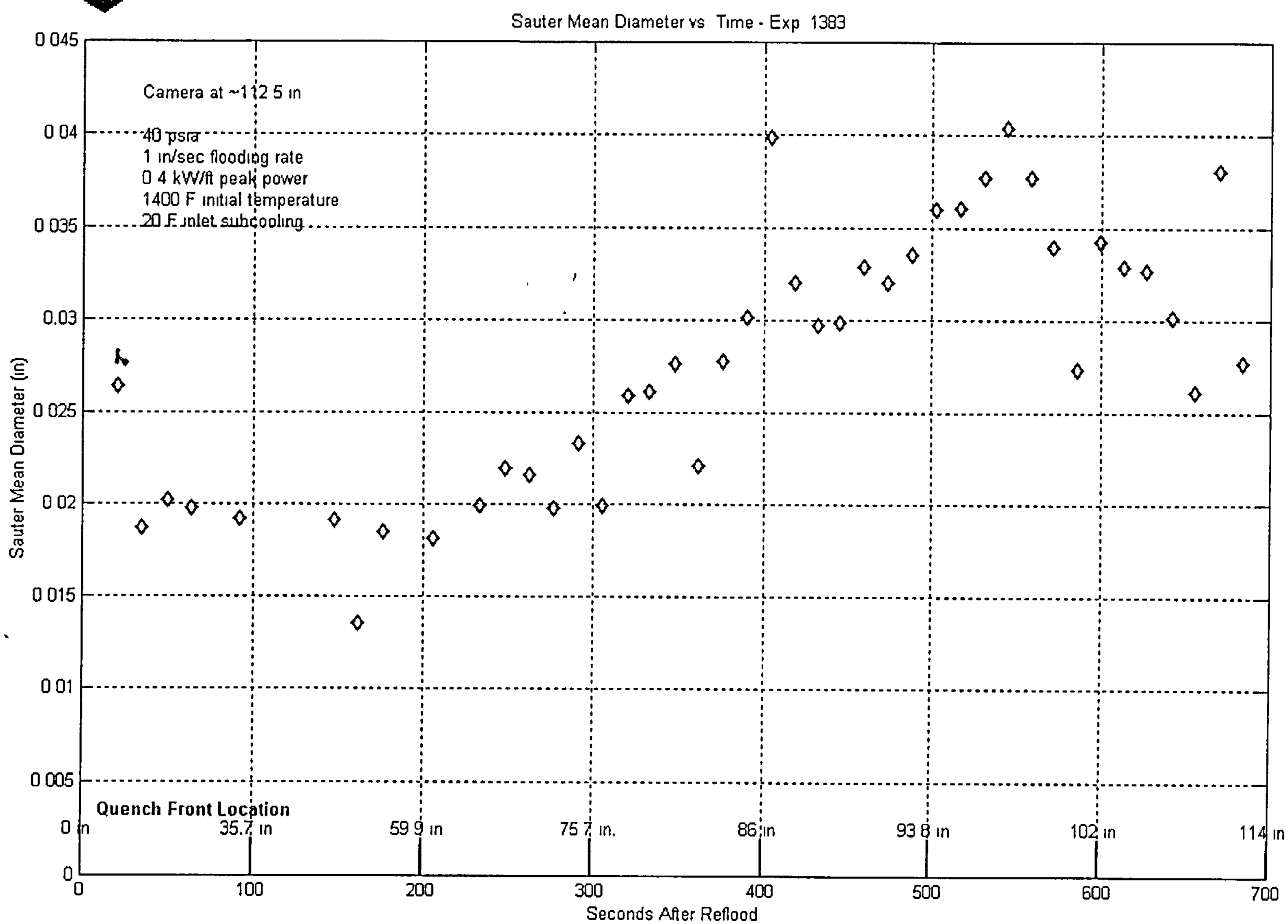


Counts vs Time - Exp 1383
Camera at ~112 5 in
40 psia
1 in/sec flooding rate
0 4 kW/ft peak power
1400 F initial temperature
20 F inlet subcooling
Quench Front Location
10 in
35 7 in
59 9 in.
75 7 in
86 in.
93 8 in
102 in
114 in
Counts
Seconds After Reflood
0
100
200
300
400
500
600
700
10
20
30
40
50
60
70
80
90

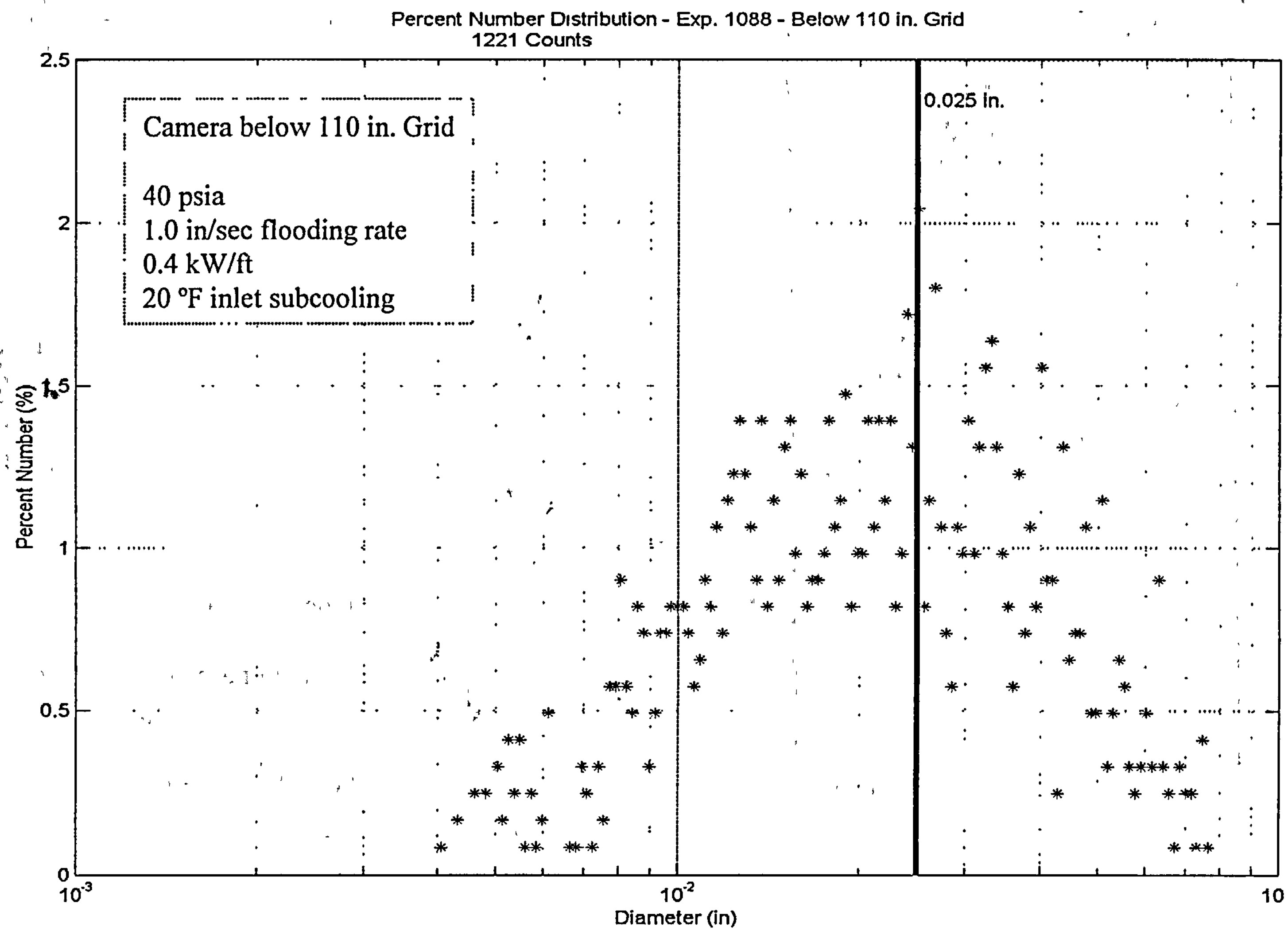
PENNSTATE



Mean Diameter vs Time - Exp 1383
Camera at ~112 5 in
40 psia
1 in/sec flooding rate
0 4 kW/ft peak power
1400 F initial temperature
20 F inlet subcooling
Quench Front Location
0 in
35.7 in
59 9 in.
75.7 in.
86 in
93 8 in.
102 in.
114 in.
Mean Diameter (in)
0 025
0 02
0.015
0 01
0 005
0
0
100
200
300
400
500
600
700
Seconds After Reflood


PENNSTATE
1855
Sauter Mean Diameter vs Time - Exp 1383
Camera at ~112 5 in
40 psia
1 in/sec flooding rate
0 4 kW/ft peak power
1400 F initial temperature
20 F inlet subcooling
Sauter Mean Diameter (in)
0 045
0 04
0 035
0.03
0 025
0 02
0 015
0 01
0 005
0
Quench Front Location
0 in
35.7 in
59 9 in
75 7 in.
86 in
93 8 in
102 in
114 in
0
100
200
300
400
500
600
700
Seconds After Reflood

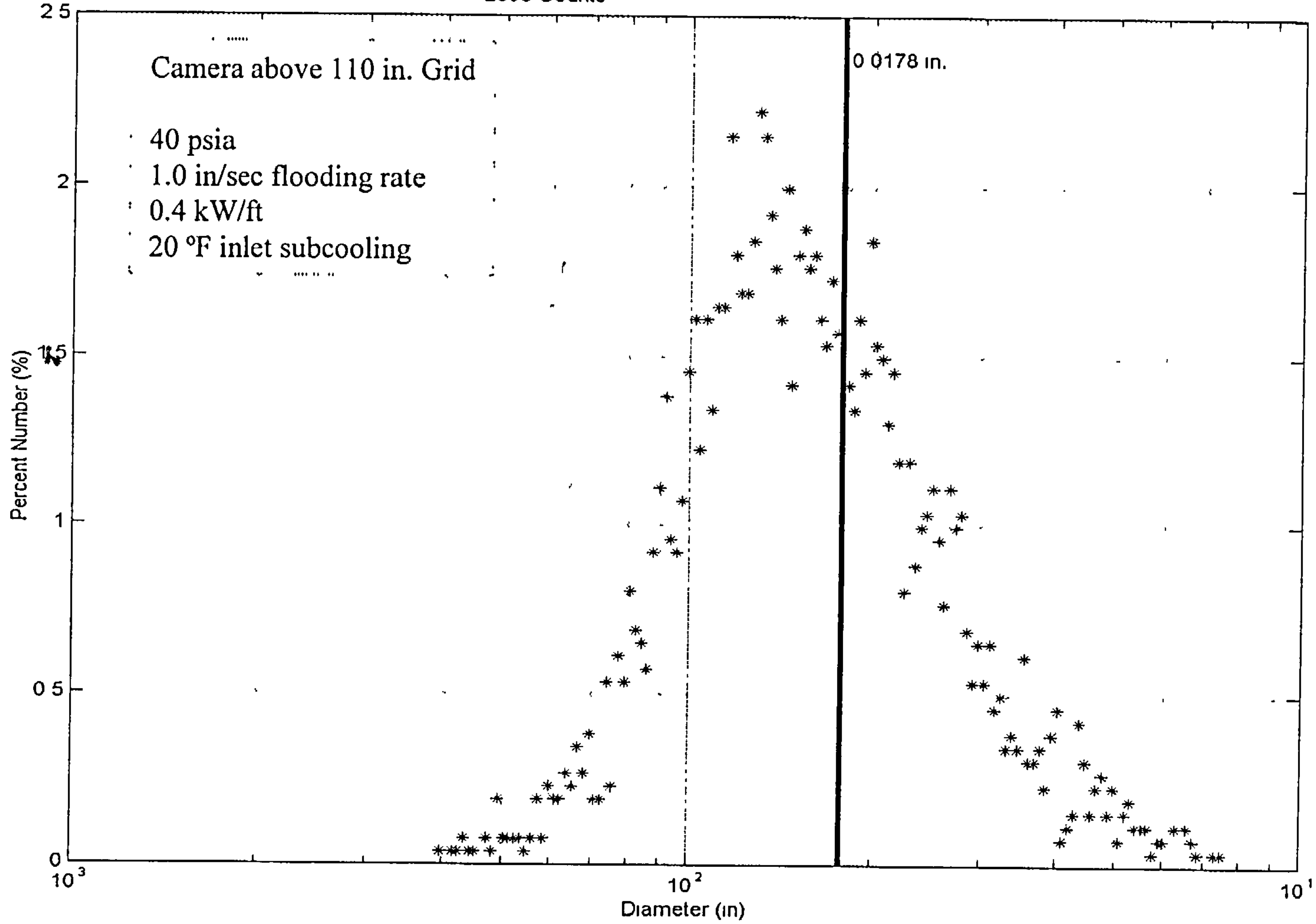
PENNSTATE



Percent Number Distribution - Exp. 1088 - Below 110 in. Grid
1221 Counts
Camera below 110 in. Grid
40 psia
1.0 in/sec flooding rate
0.4 kW/ft
20 °F inlet subcooling
0.025 in.
Percent Number (%)
Diameter (in)
2.5
2
1.5
1
0.5
0
$10^{-3}$
$10^{-2}$
$10^{-1}$

PENNSTATE

Percent Number Distribution - Exp 1383 - Above 110 in. Grid
2608 Counts



PENNSTATE

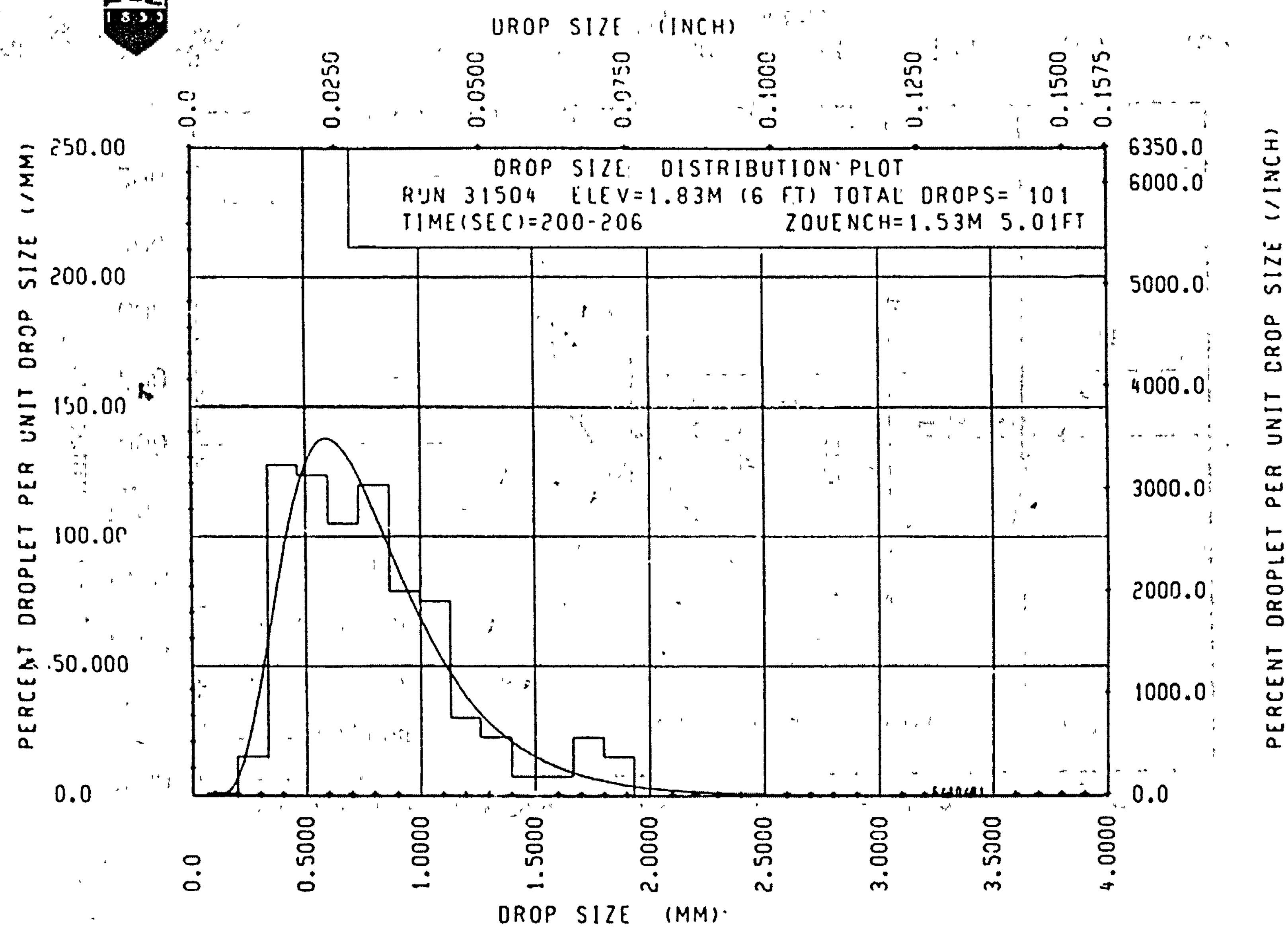
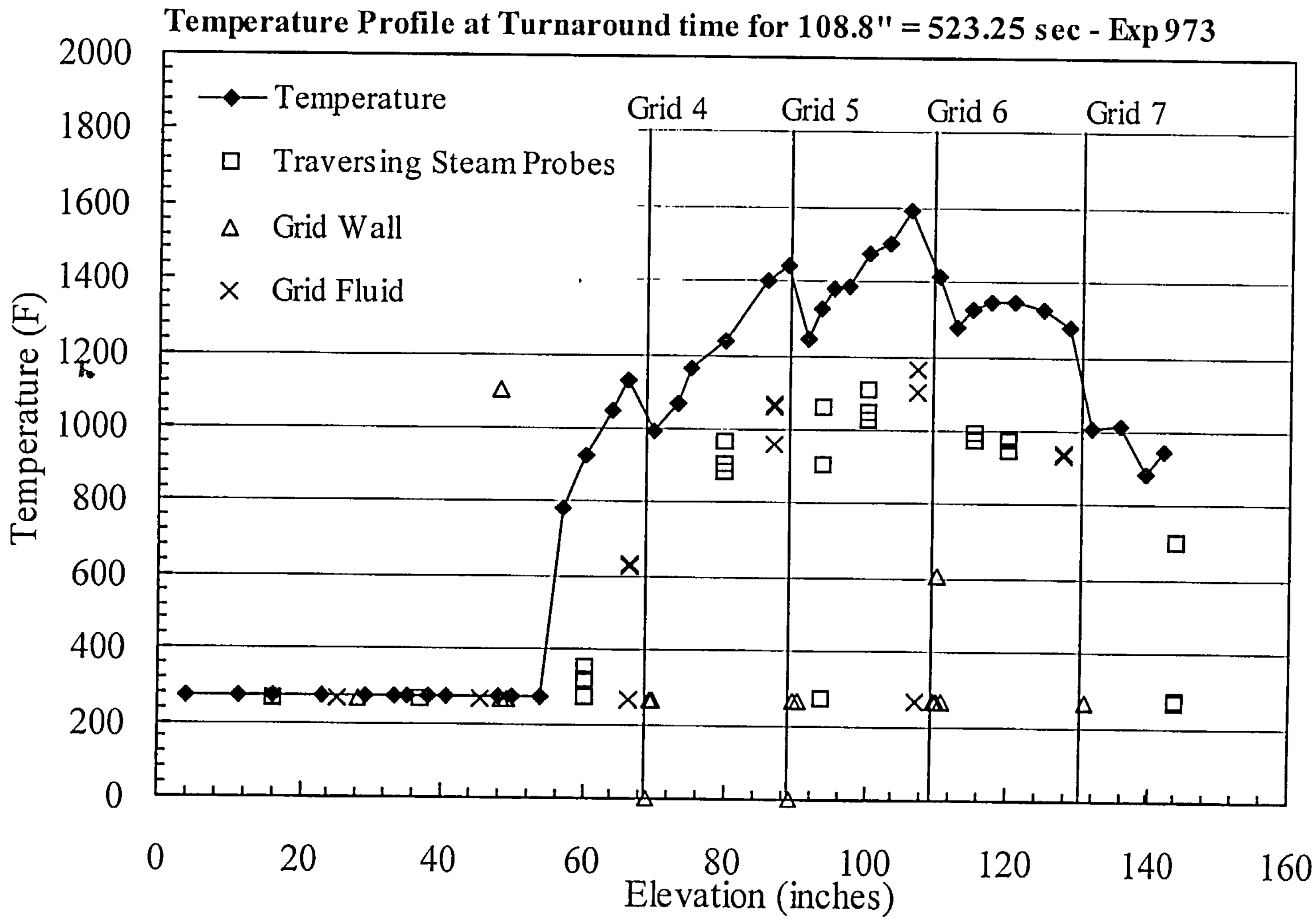


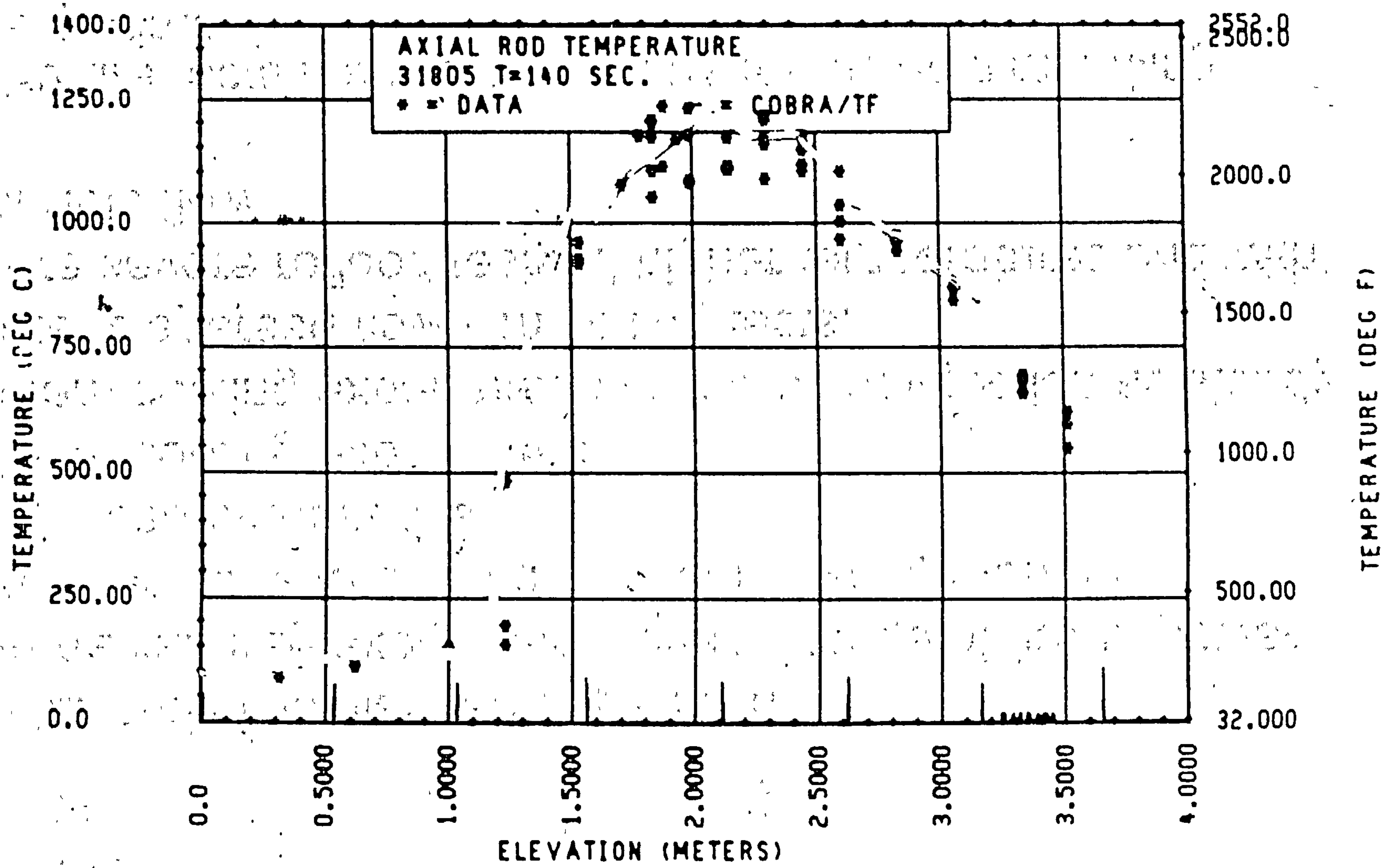

Figure E-8. Drop Size Distribution Plot, Run 31504

PENNSTATE



Temperature Profile at Turnaround time for 108.8" = 523.25 sec - Exp 973
Temperature
Traversing Steam Probes
Grid Wall
Grid Fluid
Grid 4
Grid 5
Grid 6
Grid 7
Temperature (F)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
160
Elevation (inches)

PENNSTATE




Steam Probe Location

PENNSTATE

# Future Program

- Currently it is planned to perform:

-Interfacial drag experiments over a range of flows, power and pressures to aid in the model development for advanced plant audits.

-Steam cooling experiments.

-Steam cooling experiments with droplet injection as steady state" dispersed flow film boiling tests.

-More severe reflood tests at higher temperatures and with variable flow.

- Future tests may also examine top down film boiling experiments.

PENNSTATE

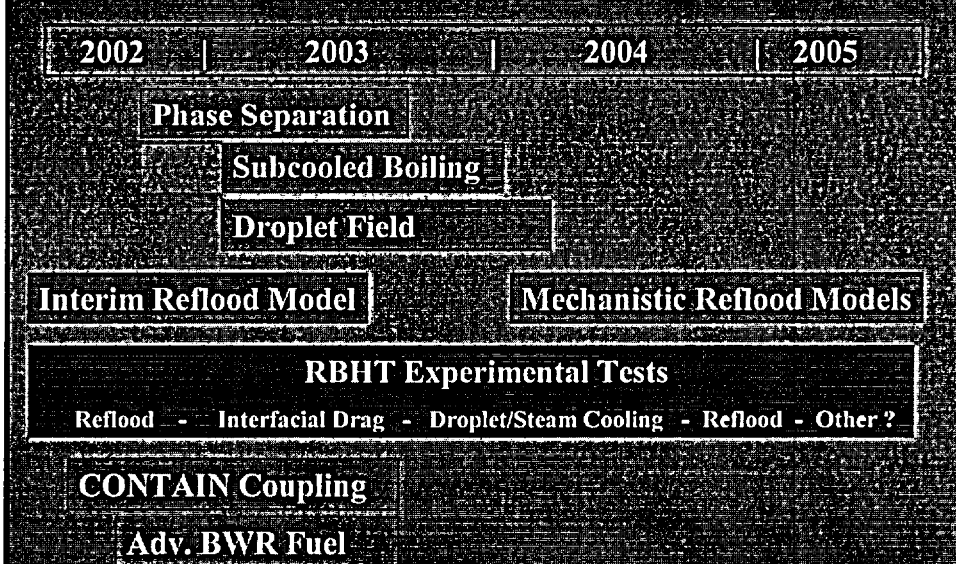
# Conclusions

- RBHT has been constructed as a flexible, low pressure, rod bundle test facility.
- Several new features have been added to the RBHT facility to provide additional detailed thermal-hydraulic data.
- Experiments have been performed in a separate effects test mode to isolate particular phenomena.
- RBHT Program is structured to improve the reflood models in the NRC safety analysis codes.
- Improved NRC codes will aid them in audit calculations and risk informed regulation.

# Major Test Series

- Transient forced reflood tests (complete)
- Interfacial drag tests
- Steam cooling / droplet injection tests
- Transient (high temperature) forced reflood tests

# TRAC-M Model Development



# NRC/RES Rod Bundle Heat Transfer Program Status

Stephen M. Bajorek
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

Meeting of the Advisory Committee on Reactor Safeguards
Thermal-Hydraulic Phenomena Subcommittee

November 12, 2002

## INTRODUCTION

- The Rod Bundle Heat Transfer (RBHT) test program was initiated in 1998 to provide detailed information to enable development of mechanistic thermal-hydraulic models for the reflood period of a LOCA.
- Processes of interest:
  - Dispersed droplet film boiling
  - Entrainment at quench front
  - Inverted annular film boiling & transition boiling
  - Spacer grid effects
  - Drop size, break up, and evaporation rates

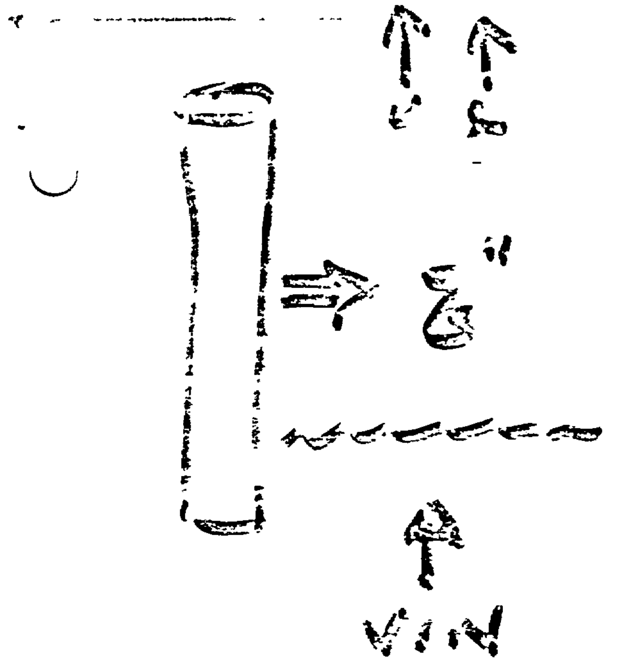
Q. What have I learned?

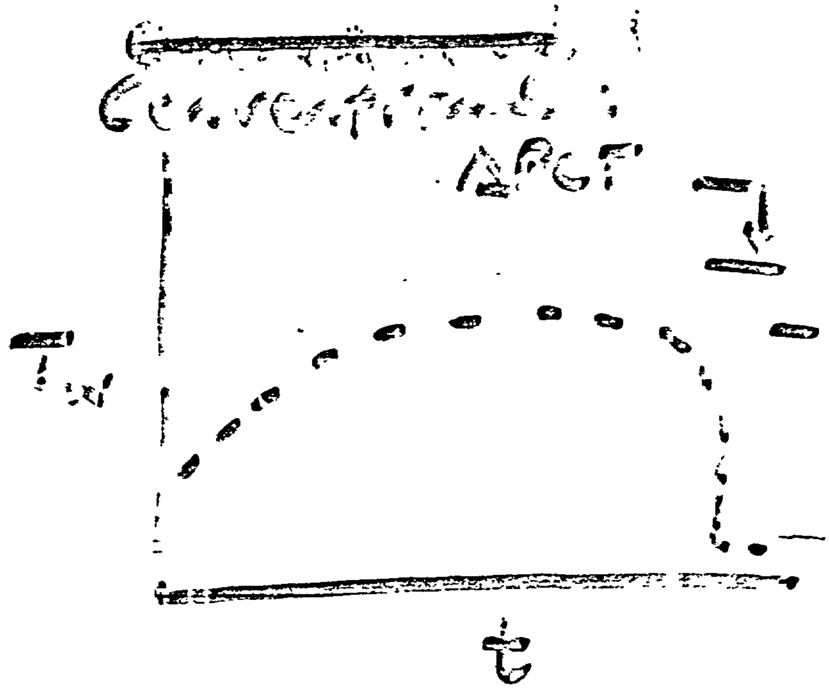
A. Three issues need to be addressed w/ RBHT & model dev.

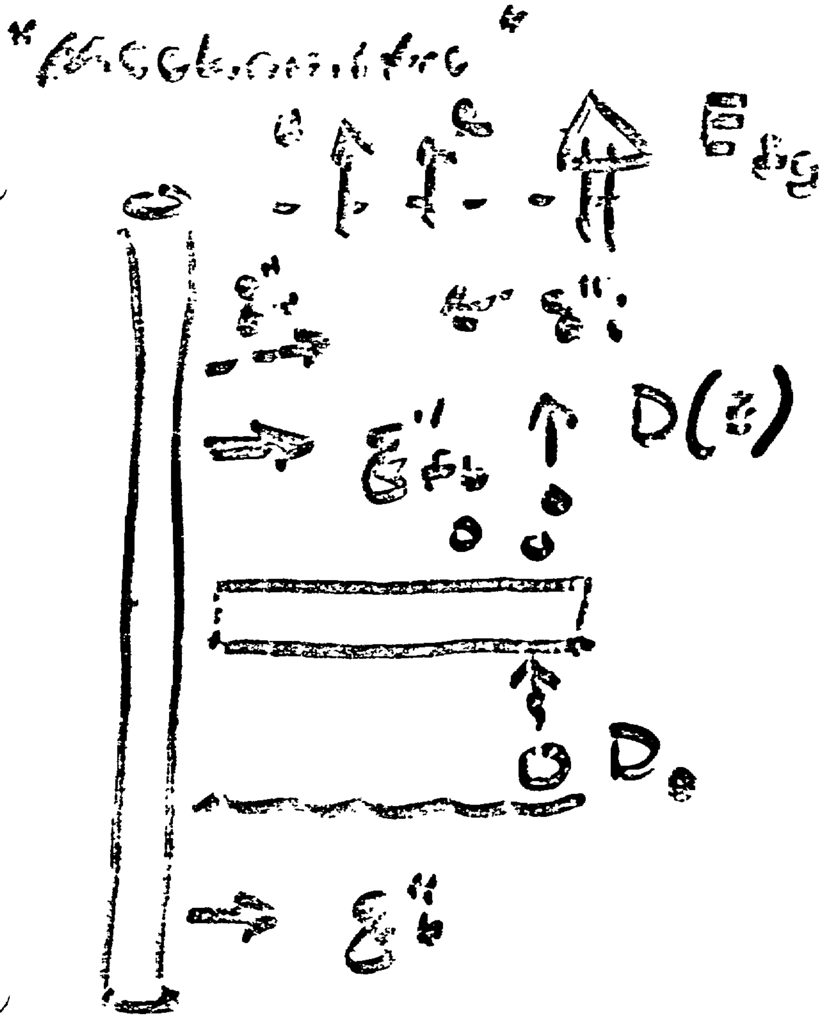
→ Bias & Uncertainty of indiv. models!

→ Spacer grid models, design differences are key!

→ IVA $\varepsilon''$ split ?




Obtain $\bar{E}$ and $\sigma$ for:

$E''_b$

$E''_{fb}$ and $E''_c$

$E''_i$

$\bar{E}_{fy}$

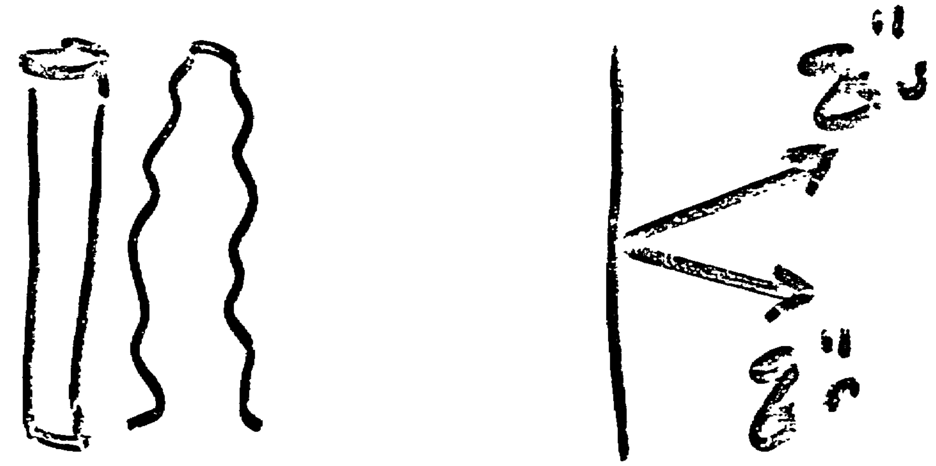
$\Delta D(z)$

etc.

# Spacer grids

- * First order, should be high priority
- * What is $\Delta D(\theta)$ and how does it depend on design?

## IVA Film Testing



$T(\theta)$ near dB?

INTRODUCTORY STATEMENT BY THE CHAIRMAN OF THE SUBCOMMITTEE ON THERMAL-HYDRAULIC PHENOMENA
11545 ROCKVILLE PIKE, ROOM T-2B1
ROCKVILLE, MARYLAND
NOVEMBER 12, 2002

The meeting will now come to order. This is a meeting of the ACRS Subcommittee on Thermal-Hydraulic Phenomena. I am, Graham Wallis, Chairman of the Subcommittee. The other ACRS Members in attendance are: Tom Kress, and Victor Ransom. ACRS Consultants in attendance are: Sanjoy Banerjee, Fred Moody, and Virgil Schrock.

For today's meeting, the Subcommittee will discuss the status of the NRC Office of Nuclear Regulatory Research's (RES) Rod Bundle Heat Transfer (RBHT) Program underway at Pennsylvania State University. Tomorrow, we will continue review of the Framatome ANP-Richland S-RELAP5 realistic code version and its application to PWR large-break LOCA analyses. Portions of this meeting will be closed to the public for discussion of information considered proprietary to Framatome ANP-Richland Incorporated.

Mr. Paul Boehnert is the Cognizant ACRS Staff Engineer for this meeting.

The rules for participation in today's meeting have been announced as part of the notice of this meeting previously published in the *Federal Register* on October 23, 2002.

A transcript of this meeting is being kept, and the transcript 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.

**(Chairman's Comments-if any)**

We will now proceed with the meeting and I call upon Dr. Stephen Bajorek, from the NRC's Office of Nuclear Regulatory Research, to begin.