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BRIEFING ON HYDROGEN CONTROL IN THE
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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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BRIEFING ON HYDROGEN CONTROL IN THE SEQUOYAH CONTAINMENT

Room 1046
1717 H Street, N. W.
Washington, D. C. 20555
Thursday, August 14, 1980

The Subcommittee met, pursuant to notice, at 10:05a.m.

BEFORE:

JOSEPH M. HENDRIE, Commissioner (Presiding)
VICTOR GILINSKY, Commissioner

STAFF PRESENT:

D. ROSS
B. DIRCKS
M. MALSCH
W. BUTLER
R. RUBENSTEIN
E. HANRAHAN
C. TINKLER
E. CASE
B. BERNERO

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PROCEEDINGS

COMMISSIONER HENDRIE: If we could come to order, Commissioner Bradford will join us directly. The Chairman is off taking some well-deserved rest.

The Commission meets this afternoon to hear a briefing from the staff on the progress of their consideration of hydrogen control matters for the Sequoyah nuclear plant. We have in hand a draft staff position. This is the first meeting at which we have gathered on this subject.

There are other meetings scheduled down the line. I regard this first set of discussions on the subject of the draft as an appropriate getting started point on a subject which will undoubtedly take a number of discussions by the Commission with the staff, and indeed on down the line, because there are a number of staff review efforts still to be complted.

We have the executive director, Mr. Case, Mr. Ross, Mr. Rubenstein, Mr. Butler, OPE, and the general counsel at the table. Let me start off and throw it to you, Bill, and you can farm out the task as appropriate.

MR. DIRCKS: I can farm it out right away to the man on my left, Denny Ross, to pick up that burden.

MR. ROSS: If I could have the first slide, please.

(Slide.)

MR. ROSS: As Dr. Hendrie said, we are here to talk about hydrogen control measures for Sequoyah. As we continue on to the next slide --

(Slide.)

MR. ROSS: -- we will be discussing sources of hydrogen, what might happen if it burns, some possible countermeasures, some possible contraindications to some of these countermeasures, and then some conclusions.

Next slide.

(Slide.)

MR. ROSS: If you look -- reverse it, please.

(Slide.)

COMMISSIONER HENDRIE: I kind of took a fancy to it the other way. It allowed freer interpretation.

(General laughter.)

COMMISSIONER HENDRIE: Out of the containment, into the vessel. Now what are you going to do?

(General laughter.)

COMMISSIONER HENDRIE: I have been there before. I can give you a long lecture on what to do about that.

(General laughter.)

MR. ROSS: Maybe you can cut it into three pieces, according to how much hydrogen, how much core reaction. If you took the top path here, it is more or less what present policy is. The hydrogen that is generated, it follows the

Regulation 50.44, which does not produce much hydrogen in the containment. We don't believe there would be any structural problem.

The bottom trail is the more adverse side, where you assume that you have a complete reaction there.

COMMISSIONER GILINSKY: Are you assuming a large containment up there?

MR. ROSS: No, no. That number is for Sequoyah.

COMMISSIONER GILINSKY: Oh, I see.

MR. ROSS: Even less for the large dry -- the bottom trail with 100 percent core metal-water reaction could produce temperatures uniformly and slowly relative to a detonation could produce a 200-pound pressure, which again would lead to containment failure, and that path we did not pursue further either.

Actually, the containment would fail from other mechanisms as well if the core melted. From the hydrogen viewpoint, though, the Sequoyah containment would not withstand 100 percent core metal-water reaction. The middle trail is the one that we are prepared to discuss today where you would have rates and amounts of hydrogen analogous to what happened at TMI II, not exactly, but analogous, perhaps up to two-thirds core metal-water reaction.

If burning adiabatically, this could produce a containment failure, and there may be some countermeasures, and we will be discussing those.

Okay, next slide.

(Slide.)

MR. ROSS: This is a simplistic adiabatic calculation. This has been done several different ways by several different people. You get pretty much the same answer. This shows about a 35-percent core metal-water reaction, 300 kilograms of hydrogen produced, and following the initial state column, where we reduced the hydrogen, burn it, and then look at the temperature increase and the attendant pressure increase, it comes about 68.6 psia. You get different numbers, some 67, some 70. This pressure is above the predicted failure pressure, as calculated in several different manners. So this would establish the need to go further.

Had this number come out within the containment capabilities, and had the amount of hydrogen been considered a reasonable amount analogous to TMI II, then we might well have stopped, but it didn't, so we press on.

Next slide.

(Slide.)

MR. ROSS: The structural analyses that were done and that were discussed in the report that Dr. Hendrie referred to are several. TVA has supplied one. A consultant to the staff, Ames Laboratory, has provided one.

R&D Associates from Los Angeles have done one.

Next slide.

(Slide.)

MR. ROSS: The results -- the calculation was approached differently, and we have different answers, but in summary, the difference is not significant. The TVA calculation produced 33 -- I will go down the yield pressure numbers. The 33 psig yield pressure, the Ames Laboratory consultant at 36, and the R&D Associates at 37, the nominal containment design pressure being 12.

These represent numbers two and a half to three and a half the nominal design basis. We don't think it is particularly significant whether it is 27 or 36, considering the difference in assumptions. The research number shown at the bottom is 34. Failure pressure is about 40 or so psig.

Okay, next slide.

(Slide.)

MR. ROSS: I mentioned countermeasures. TVA has made a proposal for three phases of hydrogen control measures for Sequoyah.

Let's go to the next slide.

(Slide.)

MR. ROSS: The Phase I, the short-term effort is a proposed distributed ignition system. They would install and are in fact actively -- beginning to install a series of 30 glow plugs within the containment. That is distributed as shown on the chart here, and with the specified capabilities on power and seismic design and remote control.

Tests are under way both on endurance of the igniters as well as the onset and completion of ignition of hydrogen mixtures that they would provide.

Next slide.

(Slide.)

MR. ROSS: This is a schematic of the containment. There is a rough division of the containment in the horizontal direction, the upper compartment being about two-thirds or so of the volume; the lower compartment, where the reactor system is, being about one-third to one-fourth, and they are mainly connected through the ice condenser.

Most of the glow plugs are proposed to be installed in the lower compartment, where most of the hydrogen should be released, a few in the ice condenser plenum themselves, and three in the upper volume.

Okay, next slide.

(Slide.)

MR. ROSS: Endurance tests I mentioned are in progress. They are also doing tests to determine how efficient the igniter is in a steam air-hydrogen-mixture. These tests are ongoing, and we do not have the conclusions from them yet. There exists what is known as turnery diagrams, where the triangle has sides being percentage by mixture -- volume of air, hydrogen, and steam.

A locus of detonation or flammable limit would exist on the turnery diagram. This should explore a portion of the turnery diagram for the particular igniter being proposed.

As you will see later, the staff is supporting similar confirmatory work at Lawrence Livermore Laboratory.

Next slide.

(Slide.)

MR. ROSS: Going beyond the present phase, a number of improvements in the igniters are proposed, so they can be activated individually instead of collectively. More and better hydrogen and oxygen monitors and the various upgrades are shown here.

COMMISSIONER GILINSKY: What is the use of the igniter? Suppose we go back to the short-term. They can be turned on manually from the auxiliary building. What indication --

MR. ROSS: The only words we have so far would be following a LOCA. Now, the safetey analysis that TVA -- actually, I guess it filed it today -- would discuss that. We have reached agreement with them on that, on the necessary and sufficient conditions to turn it on. It could be, for example, an indication of inadequate core cooling, or it could be high hydrogen concentration, or it could be, if you have symptoms that put you into a LOCA procedure, then one of the followup actions could be, turn on the igniters. We have not gotten that far yet.

COMMISSIONER GILINSKY: Are there any instruments to detect hydrogen?

MR. ROSS: There are two monitors.

MR. RUBENSTEIN: One in the upper compartment, one in the lower compartment. They are double sensers.

COMMISSIONER GILINSKY: They are in now?

MR. RUBENSTEIN: Yes.

MR. ROSS: Okay. Other than that this upgrade program would take one or two years, we do not have a specific time in which these features would be provided. If we reach agreement on the program as a whole, I would suspect that improvements like this would go in at some scheduled outage, like the first refueling, but again, we have not negotiated agreement with them on that.

Next slide.

(Slide.)

MR. ROSS: Now, there are subsequent matters in Phase III of the long-term program that more or less parallel the rulemaking effort that is mentioned in the action plan for degraded cores. A little more on this on the next slide, to illustrate what TVA has in mind.

Next slide, please.

(Slide.)

MR. ROSS: They have a task force that is looking into alternatives other than distributed igniters such as halon suppressants. The nature of the rulemaking will probably require looking into the filter vented containment and other aspects of degraded core, perhaps core retention devices.

There are other ways to inert the containment, like were discussed for Zion and Indian Point, like exhausting a gas turbine or something like that. This is part of a two-year program.

Okay, that is the TVA or licensee effort on mitigative measures. Let's go to the next slide now.

(Slide.)

MR. ROSS: The question on igniters can be divided into two parts, safety and efficiency. We will go into the efficiency, that is, to what extent would the igniters result in a containment pressure that would not be able to contain it. Some computer methods developed in context of the off-shore power systems.

Plants which involve the ice condenser have produced a computer code known as CLASIX, which is regarded by the developers as still being under development. It is not verified yet. However, the code was applied to the Sequoyah case with the proposed distributed igniters, with the results that we will see in the next few slides.

Let's go to the next slide now.

(Slide.)

MR. ROSS: There are two codes that feed CLASIX. The regular containment code for ice condensers is called LOTIC, L-O-T-I-C, which would provide the containment conditions, pressure and temperature and moisture conditions up until the point you started getting hydrogen, and for the application down here, you would also need the computer code MARCH, which is an NRC code, or developed under NRC sponsorship by Batelle Columbus, that is used to get the exit conditions from the reactor, hydrogen and other mass and energy.

CLASIX then takes the ice condenser and divides it up into compartments where you can calculate the local gas mixtures, and as user input you can decide when to start burning hydrogen, when to stop burning it. The heated gas would be transported then if it is in the lower compartment through the ice if there is any ice, where you would melt the ice and go to the other compartment.

If you have flow through the ice condenser from the lower to the upper, and there is hydrogen in the lower compartment, you will transport it to the upper. Each compartment has its own individual set point as to when to stop and start ignition.

Okay, next slide.

(Slide.)

MR. ROSS: The other codes that I mentioned, the MARCH and the LOTIC code, the MARCH code uses the sequence S2D, which means a small break LOCA with no ECC injection. This would allow the core to drain down, boil off, and then after about an hour heat up and start interacting with the water vapor and producing hydrogen.

The base case in CLASIX assumed 10 percent, but as I said before, that is user input.

All right, let's go to the next slide.

(Slide.)

MR. ROSS: The other initial conditions up to the point where hydrogen is produced from LOTIC were covered by Point Number 1, which would give you the volumes, temperatures, pressures, and so on. The burn parameters are variable, and we show some cases where other than 10 percent for the onset ignition is covered. The air return fans -- it can vary.

COMMISSIONER GILINSKY: Can you tell me where the fans are? Where are they located?

MR. ROSS: We could go back to one of the slides. Just a minute.

(Whereupon, a discussion was held off the record.)

MR. ROSS: Charles Tinkler with the Containment Systems Branch can describe it. We don't have a vu-graph right now.

MR. TINKLER: The fans are located in separate rooms in the lower region of the containment, roughly in the same section that the ice condenser is in, although they are located beneath the ice condenser in the annular compartment in the lower region.

COMMISSIONER GILINSKY: They are going up past the ice condenser?

MR. TINKLER: They discharge into the active lower containment volume. The fans draw suction from various points in the containment, including the upper compartment and discharge into the active lower compartment volume, which then flows into the ice condenser.

COMMISSIONER HENDRIE: But the general flow path, as I recall it, is that you discharge out of the fans into the lower compartment. The excess pressure then drives the principal stream up through the ice condenser, banks into the upper compartment.

MR. TINKLER: That is correct.

COMMISSIONER HENDRIE: And then you have a few much smaller dead-ended regions. Are those all set up fo recirculation? I just don't --

MR. TINKLER: Part of the hydrogen skimmer system which serves to turn over the atmosphere in those dead-ended regions and feeds it to fans -- they essentially --

COMMISSIONER HENDRIE: So that the dead-ended volumes also have a circulation that goes around that?

MR. TINKLER: Yes.

MR. ROSS: Okay. Let's look at some numerical results on the next slide.

(Slide.)

MR. ROSS: These will all be either pressures or temperatures or ice masses remaining for what will be referred to as the base case, and the base case parameters are printed in rather small print at the bottom. We have two fans and one spray. All the base case will represent an onset of burn at 10 percent, and a burn down to zero.

Each burn burns the hydrogen completely. The abscissa is time in seconds, and at the origin you see zero. That is the onset of hydrogen production. This starts when MARCH got the core up hot enough to produce hydrogen, which was almost an hour previous.

So, if you added 3,480 seconds to each time on the abscissa, then that would be real time following the break.

This is the lower compartment temperature, so the ordinate is in degrees Fahrenheit, and the scale is to 3,000. When you finally get enough hydrogen, 10 percent in the lower compartment, you get a burn and you see a spike temperature up to about 2,000.

In this base case, there were nine separate burns. Each burn involved 100 pounds of hydrogen in the lower compartment. There are several curves, once again, for the base case. Let's look at the next slide.

(Slide.)

MR. ROSS: There is one burn for this base case in the ice condenser itself, and that is shown by this peak here.

Next slide.

(Slide.)

MR. ROSS: Reverse it.

(Slide.)

MR. ROSS: This is the pressure that accompanied the base case, the pre-hydrogen pressure -- the ordinate now is pounds per square inch absolute, and the time scale on the abscissa is the same. The pressure has been rising as predicted by the LOTIC code, due to the fact that you have a small break, and then the hydrogen burn gives a delta of 46 pounds, depending on which burn -- burn gases going through the ice and melting some ice.

Hydrogen to a certain concentration is also migrating in the upper compartment. If during this predicted accident sequence you got the 10 percent at the upper compartment, it would burn there also.

Next slide.

(Slide.)

COMMISSIONER GILINSKY: Are these burns all taking place in the lower compartment?

MR. ROSS: Yes. Well, if you look at the upper compartment temperature, and if you got a spike there, that would represent an upper compartment burn, and there are some cases in the parameters that have been run so far where you do get upper compartment burns.

In this base case, the hydrogen concenteration in the upper compartment exceeds eight but not ten, so the model that was put into it, it did not burn. If you believe that it burned at eight, it would have burned. So, there is a lot about the code that is user input. The physics of when it should burn are certainly not put in. It is these parameters that would flow either from the TVA tests or the Lawrence Livermore tests or both.

COMMISSIONER GILINSKY: Let me understand. If you have the fans running presumably you have the same concentration.

MR. ROSS: No, it is time dependent. The flow rate of the fans is 40,000 cubic feet per minute. The upper compartment volume is around 700,000 cubic feet. So it just takes time. It is burning faster than it can move out.

COMMISSIONER GILINSKY: Before you get it --

MR. ROSS: Right, but for that this probably would not be worth anything. This shows the pressure spikes due to the flow from the lower compartment to the upper compartment. I think the first spike there which is tallest is the fact that it burned in the ice condenser itself.

Next slide.

(Slide.)

MR. ROSS: This is the residual ice mass remaining. The calculation was terminated on all these at about 80 percent metal-water reaction, because at that point I think you would have proceeded to a core melt situation anyway.

Now let's look at the next slide, which is a table.

(Slide.)

MR. ROSS: We have been looking at Line 1 base case, again, where you started burn at 10 percent and burned to completion. In Case 2, the parameter was -- for onset of ignition was lowered to 8 percent, and you got more burn, and notice the upper compartment temperature went to 260, because you did get a burn in the upper compartment.

We do not have any detailed slides here on anything other than the base case. Case 3 with the one fan, the results are not much different than the base case which had two fans. A limited amount of ice. You notice that the peak pressure did go up to 41 psia.

The pressure suppression would be then for the upper containment spray.

COMMISSIONER GILINSKY: Let me just ask you something. If you have 10 percent hydrogen burning in a closed vessel, I guess I expected higher temperatures -- pressures. Is the thing that keeps you from that --

MR. ROSS: The venting.

COMMISSIONER GILINSKY: The venting. I see. Okay.

MR. ROSS: And then the increased temperature in the upper compartment, like for Case 4 especially, would be absorbed to a degree by the spray water, which is about 6,000 gallons a minute, I believe. Then no fans at all would be the case where you did not -- you see the peak temperature going up in the upper compartment. You would not be getting the beneficial effect of preferential burning.

The lowest pressure predicted was 27 psig, and adding in 15, the yield pressure, as you recall, is about 42 psia. So, with the no ice situation, that is right on the borderline or a little bit below.

Now, the precaution that we have to observe on all of this is, these are very preliminary results. We have not reviewed the code at all. This is material that had been furnished to us. The licensee was very careful to point out they have not verified it either. There is a lot of work to be done on this code.

Next slide.

(Slide.)

MR. ROSS: Looking at what we have done at NRR, there have been two efforts, the experimental effort at Livermore and the analysis work done at Battelle-Columbus.

Next slide.

(Slide.)

MR. ROSS: We are sponsoring a small-scale test at Livermore on the igniters that are proposed to be used at TVA to try to determine the onset and completion of the burn of hydrogen-air-steam mixtures. We have about a ten cubic feet vessel that is being instrumented with pressure transducers and gas analyzers and igniters furnished by TVA are being mounted on a trailer out in California at the Livermore test site.

Construction is under way now. Testing should start in about a month, and should be finished by the middle or end of October.

Next slide.

(Slide.)

MR. ROSS: A schematic of the arrangement is a cylindrical test vessel shown on the left with various sample ports, and means of furnishing hydrogen and air, and then the steam generator to add the steam.

Okay, next slide.

(Slide.)

MR. ROSS: On the analysis side, we have had a limited number of runs done with the MARCH code itself. Now, MARCH, in addition to doing a core calculation, has relative to CLASIX a relatively simple containment model. It does have an upper and lower compartment. It has ice, but it has some limitations also.

For example, it does not model the heat removal by the containment spray as long as it has ice, so there are some features about it that if we were going to use it exclusively for this purpose, it would need improvement. For the limited purpose of comparing it with CLASIX, we have had some runs. Let's go to the next slide.

(Slide.)

MR. ROSS: We used roughly the same hydrogen source term as was used in CLASIX. In fact, it was furnished by that. Move the slide up just a little bit, and you will see the time in seconds is the abscissa, and pounds in hydrogen released is the ordinate. This is two-fourths or three-fourths of the total core metal-water reaction.

Okay, next slide.

(Slide.)

MR. ROSS: Some of the results -- and the righthand entry containment peak pressure has two numbers, actual and adiabatic, and the adiabatic is the number if you had no heat removal by the ice or sprays, whichever happened to be working at the time.

The actual column actually runs lower than the CLASIX numbers. This shows the principal sensitivity study was the onset of ignition, and you see here eight, ten, and twelve, the extent to which you burn to completion. You see Case 5 it burned only down to 4 percent, and the burn time, and the peak pressures, the actual peak pressures, 20 or 30 pounds, roughly analogous to the Westinghouse stuff.

The same admonishment applies to MARCH. It has not been developed for this detailed purpose, and would require more development if it were to be used for that purpose. We have not yet sponsored or worked out an arrangement where the code would be modified, and I am not sure whether we will or not, there being competing priorities.

Next slide.

(Slide.)

MR. ROSS: Okay, we discussed then the features that are being proposed by TVA to mitigate large amounts of hydrogen both in rates and amounts. We have discussed some of the analyses that have been done, the confirmatory work by the staff. Since the final decision on the Sequoyah operating license above 5 percent is near, if not today --

since not today, it seems like there are several options available to the NRC.

The plant currently is at 5 percent or lower, and one option until igniters are installed and found to be both safe and efficient, the license could just be kept at 5 percent. On the other hand, Option B, shown here, and which we find acceptable, the NRC could authorize operation up to 100 percent, up until the igniters got in and put the igniters in at some suitable time.

In between Options B and C are also -- they are graded between A and B. We could -- the NRC could permit operation up to some power, such as 50 percent, until the igniters were operational. Or it could go ahead and authorize 100 percent for some limited period of time, with some kind of license condition to say, you must have had either igniters or some equivalent mitigative measure operational by then.

So, we are throwing these out for discussion. The staff report said we did recommend Option B.

This concludes our direct presentation.

COMMISSIONER GILINSKY: What is the recommendation now, the 50 percent? We took this up, a similar question, when we were talking about --

MR. CASE: Let me try to explain, Mr. Gilinsky. Fifty percent is not directly related to safety considerations, although one can argue there is a benefit in operating at 50 percent versus 100 percent, because it does provide more time for operator actions in the case of things going wrong.

The basic reason for our belief that one ought to place a 50 percent limit is the prudency of the situation. TVA has proposed some relatively new features for this plant. They have recently at least completed an initial evaluation and got it in to us today, I guess. We are in the midst of our evaluation, and given that situation, it seems prudent to us to limit the power to 50 percent, while that evaluation is ongoing.

Moreover, that does provide a vehicle for converting TVA's plans for continuing evaluation into an enforceable licensing commitment, and it does it in a way that it encourages them to work hard on this subject, and provides an incentive for them to work with us in coming up to a final evaluation of these igniters as distinguished from Option C, which would be more or less of a stick approach to the question: if you don't do the job, you will suffer a horrible penalty.

We think the incentive approach of Option B is a preferable approach.

COMMISSIONER HENDRIE: Let's see if I can phrase it for myself, and then you can tell me if I have a reasonable interpretation of the view.

Sequoyah is getting -- I guess they have about completed, or are getting close to completing the test work which they have to do at the 5 percent permitted operation -- operating level. We all recognize that their ongoing efforts are of substantial magnitude in connection with the subjects of accidents more severe than the design basis, hydrogen in particular.

We have before us a proposed advance notice for rulemaking on the degraded core matter, and we are also, I trust, if the staff proceeds as it plans, we will pretty quickly have a proposed interim rule to provide some interim measures in that regard, and we all recognize that the -- that Sequoyah is an ice condenser containment. It falls somewhere in the middle between the quite small volume containments and the big dry containments which appear to be considerably less sensitive to these things.

Now, it appears to me that TVA has taken a fairly aggressive and forthcoming sort of view on this. Rather than standing back and saying, well, tell us what you want us to do, why, they have slammed ahead and studied the problem, and looked at things that seemed to them reasonable.

They have proposed and are, I guess, moving forward to implement this igniter system on the basis that for at least a fair range of core damage accidents in which some hydrogen would be evolved, perhaps up to TMI levels, and that for which a full core melt and all that great line of catastrophe would not follow, that for this fairly broad range of intermediate class accident beyond the design basis, it appears that if you are able to burn such hydrogen as has evolved -- as it is emitted from the primary system and sort of burn it in chunks, and have time between burns for the containment heat removal operation to act, that there would be substantial mitigative benefits from such a system.

MR. CASE: TVA's view and our view, although neither of us have completed an evaluation --

COMMISSIONER HENDRIE: You are moving ahead. I think that is a good thing for them to do, to be thinking and acting on, but we find ourselves now, or you find yourselves not having been able to collect as much information as you would like to complete your sort of -- I don't know whether to call it Phase I or come to a satisfactory level of understanding, and understand some of the details of the proposition

The question now is, well, okay, should Sequoyah sort of stay where it is in its start-up sequence until we get this straightened out in a couple of months or understand it better in a couple of months, or is there some reasonable intermediate progress that could be allowed here that would be compatible with keeping future options open, compatible with safety requirements, and so on.

I judge what you are saying is that it would be reasonable to allow them to continue the power escalation and testing up to, you say, 50 percent.

MR. CASE: And if there were brief short-period tests that they wanted to undertake above 50 percent for a good reason, we would consider those on an individual case basis.

COMMISSIONER HENDRIE: Yes. Presumably if they were of short duration and if they had appreciably the fision product burden and so on -- but hopefully, as I read it, you are -- your situation is more one of needing a couple of more months to receive and digest information on the igniter system and its benefits to hydrogen control, to allow some of these test results to come through, and we have always been in a situation like that -- in a situation like that, we have always been reluctant to stamp anything final.

I guess I read you as saying, well, you know, some progression along the power escalation, that would be quite safe, and you are not prepared to sign off on this proposition. That is sort of the basis.

MR. CASE: In general, our safety position on this machine is expressed in the report, that given the improvements made since TMI, it is our view that for ice condensers in general and for Sequoyah in particular, our current view that those improvements have reduced the likelihood of a TMI type hydrogen release to such an extent that we can allow them continued operation or starting of operation, and let it continue pending completion of the rulemaking proceeding.

And this position that we are now taking --

COMMISSIONER GILINSKY: I don't want to tie you up in sort of regulatory logic, but -- and it is a complicated subject -- but given that position, and I don't think I agree with it, but given your position, you are putting TVA in an awkward situation.

I mean, here they are. They have done more than comply with your requirements. They have been extremely forthcoming, as Joe said, in taking the initiative and studying this problem, and they have been very rigorous about it. Unfortunately, the solution they propose is not one that immediately, clearly might be effective, and therefore they cannot operate at full power.

I suppose if the thing could be proved to either work or not work, they could go back to full power.

MR. CASE: It doesn't, unfortunately, work out that way either. It appears that their schedule for conducting these power escalation tests up to 50 percent --

and then there is a two-week down period, as I remember, Denny, starting in September -- is surely consistent with our schedule of getting new information, absorbing and evaluating that new information.

So, I would hope by the time that they are ready for any sustained operation above 50 percent, we would be in a position to have reviewed it enough to take an affirmative position on their proposal.

COMMISSIONER HENDRIE: In some ways --

MR. CASE: Provided everyone continues to work hard, and this is the incentive that I think is there.

COMMISSIONER HENDRIE: In some ways, Dave Freeman's forward drive down there results in an embarrassment of riches here, and we are struggling hard to get a review handle on it.

COMMISSIONER GILINSKY: At least if you take the position that Ed laid out on whether or not you are going to require further control measures -- Let me ask you, suppose things do not work out as everyone hopes they will. What then? Where does that leave you? Do you then simply go back to the original position, and say it was not required in the first place?

MR. CASE: I would expect by that time the interim rule, whatever it may say, will be in place. Currently, the staff's proposal on that would require studies by ice condenser applicants as TVA is conducting of measures, different kinds of measures to mitigate at least the hypothetical hydrogen problem.

So, they would be in their studies -- they will have been working on those, and perhaps finish by that time. It will be consistent with the interim rule. If the Commission takes a different position on the interim rule, then it is hard for me to say what the situation might be.

COMMISSIONER HENDRIE: I guess the general proposition might be that Sequoyah at that point would be treated as part of -- you know, would be one of several ice condenser designs which would be treated together.

MR. ROSS: I think the --

COMMISSIONER HENDRIE: The mathematicians always have this great game where they would deal with Problem 2 by reducing it to Problem 1, and then say, since they had done Problem 1, why, that is the solution. It is now reduced to Problem 1.

So, in some ways, this is analagous.

(General laughter.)

MR. ROSS: I think the -- there can be a two-part solution. The first part would be the hardest one, I believe, and that would be trying to quantify the benefits, since TMI to demonstrate that there is time to wait while the other portion would be to design, install, and demonstrate the usefulness of the halon system.

We know it is being looked at. It takes time. Work needs to be done. But I think if you concluded that igniters just would not work, then I think that would be the next step.

We had a few pages of discussion on the pros and cons of halon. Due to a press of time, we did not get it into our draft, and if it seems useful in helping the Commission arrive at a decision, we can provide that separately.

COMMISSIONER HENDRIE: I would like to have it separately, just to see what the current thinking is. What I was going to say was, it appears to me that the -- you know, we have talked a little bit about this business of igniting as hydrogen evolves as a preferable circumstance to having a substantial hydrogen buildup in a containment and then some accidental ignition source keys it, as is almost certainly going to happen.

I think it would be very hard to make an argument that a containment with all of the gear in there at the electrical circuitry and so on, that you could have an accident and get flammable hydrogen content in the containment and expect to just ride it on out without an ignition source occurring.

It seems to me it could happen in a given case, but I don't think you could just make that as a general argument for regulatory purposes. It seems to me that the igniter system, either as TVA proposes it, or with more igniters, or different model hot wires, or glow plugs, as the tests may indicate, will turn out to be beneficial in at least a useful range of accident circumstances, in this class of severe core accidents beyond the design basis.

Now, how broad that range -- sort of the range of usefulness, is it the great panacea that cures all the problems? Well, you know, life generally does not turn up great panaceas, but is it that, or is it a fairly limited range?

That remains to be seen, and I expect we will go through the recurring cycles of analysis, each more sophisticated than the last, before we know the final word on that, but I think we ought to have a pretty good hack at it and get our hands pretty well around it in the work that is forthcoming in the next couple of months from the staff, and TVA, and others.

So, it strikes me that the igniter system is going to be a useful addition to the armament, particularly for this intermediate volume, lower design pressure containment system. It is entirely possible that as we think further on it and think about other aspects of degraded core action and so on, that it will not be the only additional piece of armament that one wants to cover -- reasonably cover these possibilities.

I would not for myself think in terms that this is it, and that is going to be all -- what we are going to have to worry about. I think it is possible we might find we want some other measures, but as I look at it, I do not see that the igniters are not going to be useful

So I think it is a step in the right direction, but it certainly does not rule out other measures. We have this classic containment, and the MARK III's have about the same sort of hydrogen problem, about the same volume. The first MARK III will come along, I guess --

MR. ROSS: October, 1981. Grand Gulf.

COMMISSIONER HENDRIE: But presumably we will have an opportunity to look at the proposition before then. I believe that is when they would hope to crank the machine.

MR. ROSS: Yes.

COMMISSIONER HENDRIE: So there was a little more time there. Well --

COMMISSIONER GILINSKY: Let me return to what I was going to say before you started. When we were taking up the case of Indian Point, there was some suggestion that perhaps the reactor ought to run at half power during the period of the hearing or whatever, and these, as I remember, were pretty much dismissed as not really offering very much in the way of increased safety.

MR. CASE: It is hard to quantify the safety benefits, although everybody knows it is in the right direction.

COMMISSIONER GILINSKY: Obviously, if you get to zero --

COMMISSIONER HENDRIE: As I recall, the task force advanced arguments in favor of power at 50 percent, and that there was not a commensurate reduction in risk, and then after all of that, I think you ended up saying, well, in effect, by the time we get through throwing it all in the air and watch it fall down and see how it stacks up, while we guess there might be something roughly proportional. Wasn't that the way you ended up?

MR. BERNERO: Basically what we said was that the risk contribution related to power comes in two pieces, the long-lived activity and the short-lived activity, and the power reduction affects the short-lived but not the long-lived. In this particular instance, at the beginning of core life, all you have to play with are the short-lived activities.

So, first of all the risk at any power level is substantially lower at the beginning of core life, and here it is far more proportional to power level than it is on the average throughout the plant history.

So, what we said in the task force report was that the long-lived activity was less than proportional to the power reduction, the risk reduction associated with long-lived activity, and with the short-lived, it was proportional, so that on balance it was very hard to be quantitative, but it is not a big factor.

Fifty percent power is a factor of two reduction at best, and that is not a very big factor.

COMMISSIONER HENDRIE: In fision products, but it is also a factor -- a substantial factor reduction in the after heat rate, and hence the adiabatic heating rates of undercooled fuel, and hence the whole likelihood that you are going to end up letting go.

MR. BERNERO: A lot more time to figure out what the plant is doing and direct the situation. But at the beginning of core life in a situation like this, you are getting far more benefit per percent of power reduction, but you are already down there at a fairly low power -- low level of risk anyway, because of the small inventory.

COMMISSIONER HENDRIE: If you consider the 50 percent at Sequoyah proposition solely in the context of, it is necessary for safety, I don't quite read it that way. That leads me to some, as you say, logical difficulties.

MR. CASE: The logic by which it was proposed --

COMMISSIONER HENDRIE: I read it more as, you know, we have this proposition made to us, and TVA thinks it is a good one, but they are still working on the analysis and details and staff have not been able to complete that part of it, and it is an open area in the SER and final set of conclusions. Staff needs more time to work on it.

MR. HANRAHAN: No other ice condenser plant is going to be affected, and TVA, as you correctly point out, is forthcoming in going beyond what is required, so it seems appropriate to further stick it to them.

COMMISSIONER HENDRIE: It is a hard safety argument to make from the standpoint of regulatory consistency.

MR. HANRAHAN: But then to use it as a carrot, it seems that they have already come forward saying, you know, they are producing their own carrot. What would you have done if TVA had not come forth with the proposal for the igniters? What would we be proposing in this case?

MR. CASE: That is a hypothetical question.

(General laughter.)

MR. HANRAHAN: You probably would have done the same thing you did with other ice condenser plants.

COMMISSIONER GILINSKY: My own view of this is that there is a problem with this containment, and when we have reasonable assurance that the containment can function and protect the public against a spectrum of accidents we think reasonable, then fine, the thing ought to run. If it cannot, then it ought not to run.

You know, no matter how early in the plant's life or how few fision products there are, we would not let it run without a containment. Well, here we have a containment which cannot cope with accidents of the sort we experienced last year. We are not talking about something that somebody dreamed up, you know, one hypothetical on top of another. It is last year's problem, and whatever credible means I think happening last year qualifies you for credible.

MR. CASE: Well --

MR. ROSS: I need to qualify the results that we have shown here. Due to design differences, the results that were on the slides today in terms of failure pressures, yield pressures, or containment loads such as upper and lower compartment pressures, do not apply to D. C. Cook or MacGuire or any other ice condenser that we are aware of.

These plants are unique, and you cannot generalize.

COMMISSIONER GILINSKY: The precise numbers don't, but the fact that the containments are a factor of two different --

COMMISSIONER HENDRIE: In volume.

COMMISSIONER GILINSKY: In volume, their design pressures --

MR. ROSS: In some instances, the material is 50 percent thicker. In other instances, it is not even a free-standing steel shell. It is reinforced concrete. One plant has a lower compartment --

COMMISSIONER GILINSKY: You are right. We cannot transfer the conclusions.

MR. ROSS: You may still conclude it cannot stand the hydrogen burn.

COMMISSIONER GILINSKY: It calls for analysis.

MR. ROSS: It indicates it should be looked at. The conclusions just don't --

COMMISSIONER GILINSKY: Not necessarily at any rate.

MR. CASE: I want to make one point. I agree with you, if nothing had been done since last year, the transfer of credible --

COMMISSIONER GILINSKY: I understand what you are saying. We have taken a lot of steps. We have given you a lot of instructions. We have proposed a lot of fixes in one way or another, both procedural and hardware, but it comes down to what you regard the lesson is from last year's experience, whether it is that specific things happened which we have now responded to.

I am inclined to draw the lesson that things we did not expect to happen happened, and can we be really confident that comparable things, not necessarily --

MR. CASE: I don't disagree with you. You have a perfectly rational argument, but the more you can put the umbrella on, the bigger the umbrella, the better I feel, and it is just a question, Commissioner Gilinsky, of where your judgment lies and where you draw the line.

COMMISSIONER GILINSKY: It is a question of judgment.

COMMISSIONER HENDRIE: But, Vic, what you said is sort of, you know, the basic way that you come at the question. It does not seem to me to necessarily leave you saying that it would not be a reasonable proposition to allow limited operation for a couple of months. It is clear that we are -- that we do need to do something about the hydrogen proposition. We have it in process, and in a sense -- in a sense Sequoyah arrives at this stage in its progress at an inconvenient time for us, and you know, we are trying to deal with what is a reasonable and prudent way to deal with the application, which is consistent both for the overall safety requirements, the direction we think we are going to end up going there, and with not unnecessarily constraining or penalizing the particular project.

COMMISSIONER GILINSKY: Well, let me --

COMMISSIONER HENDRIE: I don't know that we need to be, you know, getting our feet set in announcing this. It is more an exchange of views with the staff, and we will get back to it in subsequent meetings.

COMMISSIONER GILINSKY: I think there are a couple of features about this problem that make it a little different than some of the other situations that we have faced in which we have made exceptions, and we do allow something to go on for a fairly good time that you would not otherwise.

For one thing, we are not talking here about a fix which we know to be available, and a satisfactory one, but it simply takes a little while to get the hardware in. There are instances of this sort where we have approved it, but we know it is just going to take a certain amount of time, and we say, all right, we know it is a good fix.

MR. CASE: We are more at the frontier here.

COMMISSIONER GILINSKY: Here we are open to a good fix, but we are not sure. I think that is the reason we are holding up, because in fact the actual fix is pretty easy to carry out. That is Number One. Number Two, we are talking about something which is pretty fundamental, the containment.

Take the safety injection system. The other systems are just considered pretty fundamental, and you would not go to Bob Bernero and say, what is the probability of something happening if we unhook the ECCS system for a while. We just don't do things like that, except where we have convinced ourselves by analyzing the system that for one reason or another our extreme tough requirements don't necessarily have to be applied because it is a small reactor or something like that, but we would not unhook one of the basic systems and say, well, you know, it is only for a little while, a month. What is the chance of having a LOCA during that period? That kind of thinking -- I mean, one could do it that way, but over the years, I think we come to regard that as being a little too chancy.

As you say, this is just an exchange. We are looking at the problem in different ways and turning it around. There is not any need to adopt firm positions here, but I think those aspects of it are worth pointing out.

COMMISSIONER HENDRIE: Are there some other things that occur to you at the moment to kick around?

COMMISSIONER GILINSKY: No.

COMMISSIONER HENDRIE: All right. Very interesting. We will look forward to our next session and further discussions.

By the way, you say you got the package from down south today?

MR. ROSS: We were told it is either in the airplane or it is landing. It is the safety analysis. Right.

COMMISSIONER GILINSKY: It is worth repeating what you said. TVA does seem to be approaching this problem pretty vigorously. That is all to the good. In fact, they have taken the initiative on it. I am glad to see that happen.

MR. ROSS: Along that line, they did agree to give us the same data we were looking for from Livermore on a more expedited basis at their own test facility. If they did that, in our opinion it would advance the project a month or two.

COMMISSIONER GILINSKY: Along those lines -- May I ask one more?

COMMISSIONER HENDRIE: By all means.

COMMISSIONER GILINSKY: What are you looking for from the Livermore data in this sense? Are you looking to convince yourself that the igniters will not make things worse, or that they are in fact going to be effective?

MR. ROSS: We are looking overall for safety and efficiency. I think we get the safety thing just from pure theoretical calculations, for example, postulating a stoichiometric fireball, if you would, as big as the distance between the two furthest igniters, and seeing what that does on containment.

I think all the safety aspects can be done that way. The efficiency argument is what you would get from Livermore, and it may be that through sensitivity studies plus whatever data TVA can provide, we don't need to wait for the finish of that experiment. We just have to see how it comes out.

COMMISSIONER HENDRIE: And I think there are some useful things that you would like to have an experimental handle on.

COMMISSIONER GILINSKY: One has to go through that triangular chart and sketch it out again.

COMMISSIONER HENDRIE: Things like, will the glow plugs stand up in a damp atmosphere for a reasonable time? And what the efficiency of ignition is. Is there a gap operating at 1,700, or can you pack down 100 degrees?

MR. RUBENSTEIN: I myself would look for information as an input, say, to a code like MARCH, which would say this is the hydrogen ignition point, and if we reproduce this test many times we would know what kind of an input we want to put into it, and we would get perhaps some burn limits from that, and perhaps even burn times, and the reliability that the plug would work, and it would work at these given percentages of mixtures of hydrogen, air, and steam.

COMMISSIONER HENDRIE: The reason I asked about whether the TVA submissions were in fact in hand today, they are practically in hand. We have scheduled -- There is a meeting scheduled next week on this subject, so you will at least have had a chance to read twice through the TVA stuff, so we may have a little more -- a little more information to discuss.

COMMISSIONER GILINSKY: Yes. Fine.

MR. ROSS: That is right.

COMMISSIONER HENDRIE: As well as continue the more policy oriented part of the discussion.

Okay. I thank you very much.

(Whereupon, at 3:12 p.m., the meeting was adjourned.)

NUCLEAR REGULATORY COMMISSION

This is to certify that the attached proceedings before the

____

in the matter of: BRIEFING ON HYDROGEN CONTROL IN THE SEQUOYAH CONTAINMENT

Date of Proceeding: August 14, 1980

Docket Number: ____________________

Place of Proceeding: Washington, D. C.

were held as herein appears, and that this is the original transcript thereof for the file of the Commission.

David S. Parker

Official Reporter (Typed)

D S Parker

(SIGNATURE OF REPORTER)

H_2 CONTROL MEASURES

FOR

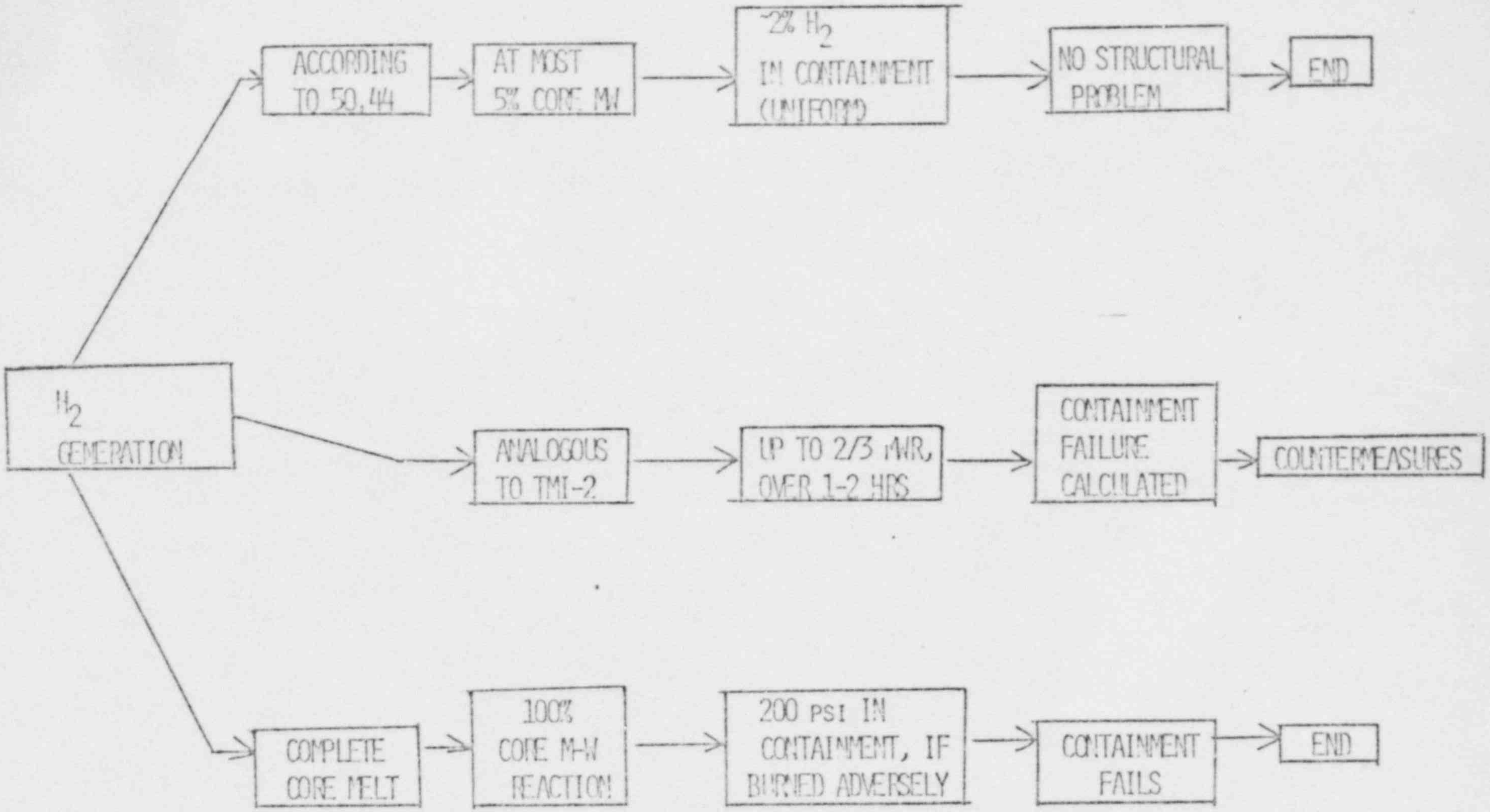
SEQUOYAH NUCLEAR PLANT

COMMISSION BRIEFING

AUGUST 14, 1980

OUTLINE

- H_2 SOURCE TERM
- EFFECTS OF H_2 COMBUSTION ON EXISTING DESIGN
- POSSIBLE REMEDIES AND CONTRAINDICATIONS
    X INTERIM MEASURES
    X LONG-TERM MEASURES
- CONCLUSIONS AND RECOMMENDATIONS


H_2 GENERATION
ACCORDING TO 50.44
AT MOST 5% CORE MW
~2% H_2 IN CONTAINMENT (UNIFORM)
NO STRUCTURAL PROBLEM
END
ANALOGOUS TO TMI-2
UP TO 2/3 MWR, OVER 1-2 HRS
CONTAINMENT FAILURE CALCULATED
COUNTERMEASURES
COMPLETE CORE MELT
100% CORE M-W REACTION
200 PSI IN CONTAINMENT, IF BURNED ADVERSELY
CONTAINMENT FAILS
END

ADIABATIC CONTAINMENT
HYDROGEN COMBUSTION
CALCULATION

INITIAL STATE

VOL = 1.193×10^6 FT^3

T_0 = 77 F

P_0 =16.3 PSIA

MOLES O2 = 615

MOLES N_2 = 2324

MOLES H_2 = 331 = 300KG

ALL HYDROGEN
REACTS WITH OXYGEN
H_2 = 331 MOLES $(1.04 \times 10^5$ BTU/MOLE$)$
$\Delta H = 34.4 \times 10^6$ BTU

FINAL STATE

VOL = 1.193×10^6 BTU

T_f = 2000 F

P_f = NRT/V = 68.6 PSIA

MOLES O_2 = 450

MOLES N_2 = 2324

MOLES H_2O = 331

REACTION PRODUCTS
HEATED BY COMBUSTION
$H_C = \sum C_V, I\ (T_T - T_0)$

CONTAINMENT STRUCTURAL ANALYSES

- TVA
- AMES
- RDA

CONTAINMENT STRUCTURAL ANALYSES

TVA

- NEGLECTED STIFFENERS
- USED ACTUAL STRENGTH INSTEAD OF MINIMUM CODE YIELD STRENGTH OF STEEL
- 33 PSIG YIELD PRESSURE
- 43.5 PSIG ULTIMATE STRENGTH

AMES LABORATORY

- QUASI-STATIC ANALYSIS
- INCLUDED "SMEARED" STIFFENERS
- 36 PSIG YIELD PRESSURE

R&D ASSOCIATES

- ASSUMED STIFFENERS RELATIVELY INEFFECTIVE
- USED MINIMUM CODE YIELD STRENGTH OF STEEL
- 27 PSIG YIELD PRESSURE

RES

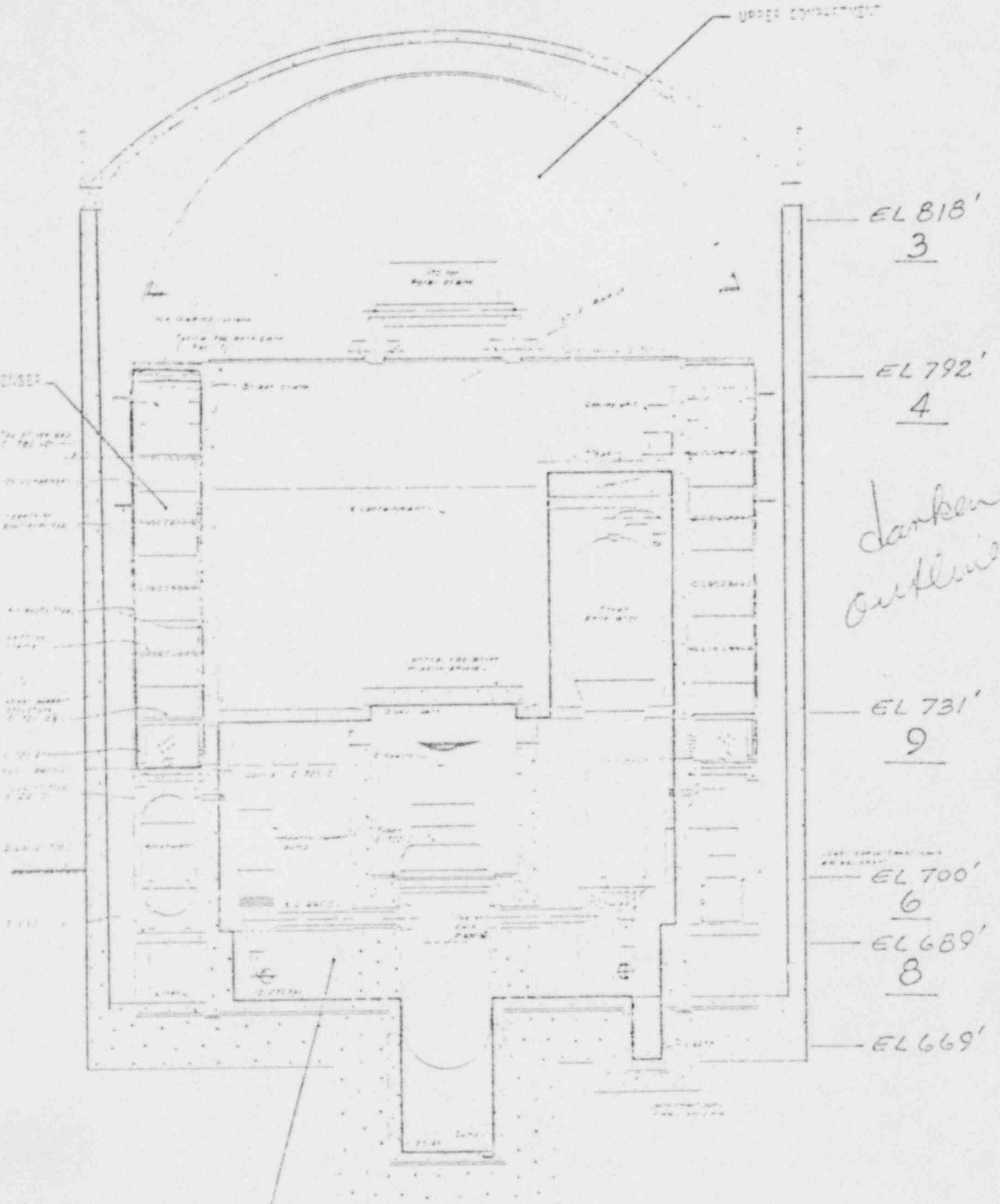
- 34 PSIG YIELD PRESSURE

LICENSEE EFFORTS

SHORT TERM
PROPOSED DISTRIBUTED IGNITION SYSTEM
PHASE I (INTERIM)

- SYSTEM INSTALLATION AND TESTING COMPLETE BY SEPTEMBER 15, 1980
- PRIOR COMMISSION APPROVAL BEFORE SYSTEM IS MADE OPERABLE (TVA SUBMITTAL BY AUGUST 15, 1980)
- SYSTEM DESIGN
    - 30 GLOW PLUGS
        - 18 IN LOWER COMPARTMENT
        - 5 IN LOWER PLENUM OF ICE CONDENSER
        - 4 IN UPPER PLENUM OF ICE CONDENSER
        - 3 IN UPPER COMPARTMENT
    - GMAC 7-G DIESEL ENGINE GLOW PLUG PRESENTLY BEING TESTED
    - UTILIZING BACKUP LIGHTING CIRCUITS
        - SEISMIC DESIGN
        - POWERED FROM EMERGENCY BUSES (EMERGENCY DIESEL GENERATORS)
        - REMOTE MANUAL CONTROL FROM AUXILIARY BUILDING

SEQUOYAH CONTAINMENT



darken outline

DISTRIBUTION OF GLOW PLUGS IN CONTAINMENT

FIGURE

- GLOW PLUG TESTING (STATUS)
  - DETERMINING GLOW PLUG TEMPERATURE AS A FUNCTION OF VOLTAGE (14 VOLTS - ABOUT 1700°F; 12 VOLTS - ABOUT 1
  - DETERMINING DURABILITY OF GLOW PLUG (SPECIMEN HAS CO OPERATE SUCCESSFULLY AFTER 6 DAYS AT 1700°F)
  - DETERMINING RELIABILITY OF GLOW PLUG AS AN IGNITION (ACHIEVED IGNITION IN DRY AIR MIXTURES CONTAINING 12 PERCENT AND 7 VOLUME PRECENT HYDROGEN)
  - DETERMINING THE PERCENT COMPLETION OF HYDROGEN BURNS 100% COMBUSTION OF DRY AIR MIXTURE CONTAINING 12 VOL HYDROGEN)
  - FURTHER TESTING WILL VARY HYDROGEN CONCENTRATION AND STEAM ENVIRONMENT

PHASE II (IMPROVEMENTS)

- IMPROVEMENTS TO BE IMPELMENTED IN PARALLEL WITH TVA'S LONG-TERM DEGRADED CORE TASK FORCE PROGRAM

- IMPROVEMENTS:

  . EACH IGNITOR WILL HAVE INDIVIDUAL CONTROL FROM THE MAIN CONTROL ROOM

  . MORE HYDROGEN AND OXYGEN MONITORS WILL BE INSTALLED TO GUIDE OPERATORS

  . A PLANT COMPUTER TO WARN OF HYDROGEN CONCENTRATIONS REACHING THE DETONATION LIMIT WILL BE PROVIDED.

  . BACKUP DIESEL POWER SUPPLY TO THE SYSTEM WILL CONTINUE TO BE PROVIDED.

  . ENVIRONMENTAL QUALIFICATION OF DISTRIBUTED IGNITION SYSTEM COMPONENTS WILL BE DETERMINED.

  . EFFECTS OF THE HYDROGEN BURN ENVIRONMENT ON COMPONENTS WILL BE ANALYZED.

  . ALTERNATE AND/OR ADDITIONAL IGNITOR LOCATIONS WILL BE SELECTED BASED ON A BETTER UNDERSTANDING OF THE CHARACTERISTICS OF HYDROGEN COMBUSTION

  . INSTALLATION OF HYDRIDE CONVERTERS NEAR THE REACTOR VESSEL VENT, PORV DISCHARGE, AND AIR RETURN FANS WILL BE CONSIDERED.

  . ADDITIONAL CONTAINMENT PENETRATIONS WILL BE CONSIDERED TO FACILITATE AN EXPANDED HYDROGEN MONITORING CAPABILITY.

PHASE III (FINAL)

- FINAL MODIFICATIONS TO BE IMPLEMENTED AT COMPLETION OF TVA'S LONG-TERM DEGRADED CORE TASK FORCE PROGRAM.

- DEGRADED CORE TASK FORCE PROGRAM
  - LONG-TERM (2 YEAR) EFFORT
  - MAJOR TASKS

1. CONTROLLED IGNITION

2. HALON SUPPRESSANTS

3. RISK ASSESSMENT

4. CORE BEHAVIOR, HYDROGEN GENERATION AND TRANSPORT

5. HYDROGEN BURNING AND CONTAINMENT RESPONSES

TVA ANALYSES

. Analytical Effort

- Westinghouse/Offshore Power Systems
- About/year study of critical parameters for various accident scenarios to determine containment response
- Using CLASIX code (under development)

CLASIX CAPABILITIES

1. VENT FROM UPPER COMPARTMENT
2. ICE CONDENSER
3. RECIRCULATION FAN
4. DOORS - LOWER INLET AND INTERMEDIATE
5. INDIVIDUAL REPRESENTATION OF O_2, H_2, N_2 AND H_2O
6. SATURATED AND SUPER-HEATED STEAM
7. SPRAYS
8. H_2, N_2 AND HEAT ADDITIONS
9. BREAK FLOW
10. BURN CONTROL

. PRELIMINARY ANALYTICAL RESULTS

- SELECTED SMALL BREAK LOCA RESULTING IN DEGRADED CORE COOLING (S_2D SEQUENCE OF WASH-1400)

- RATE OF HYDROGEN RELEASE BASED ON MARCH CODE CALCULATION (ONSET OF HYDROGEN RELEASE 3500 SEC AFTER ACCIDENT INITIATION AND ASSUMED TO CONTINUE UNIMPEDED FOR 3000 SEC, RESULTING IN REACTION OF ABOUT 80% OF TOTAL ZIRCONIUM IN CORE)

- HYDROGEN COMBUSTION ASSUMED WHEN 10 VOLUME PERCENT HYDROGEN REACHED

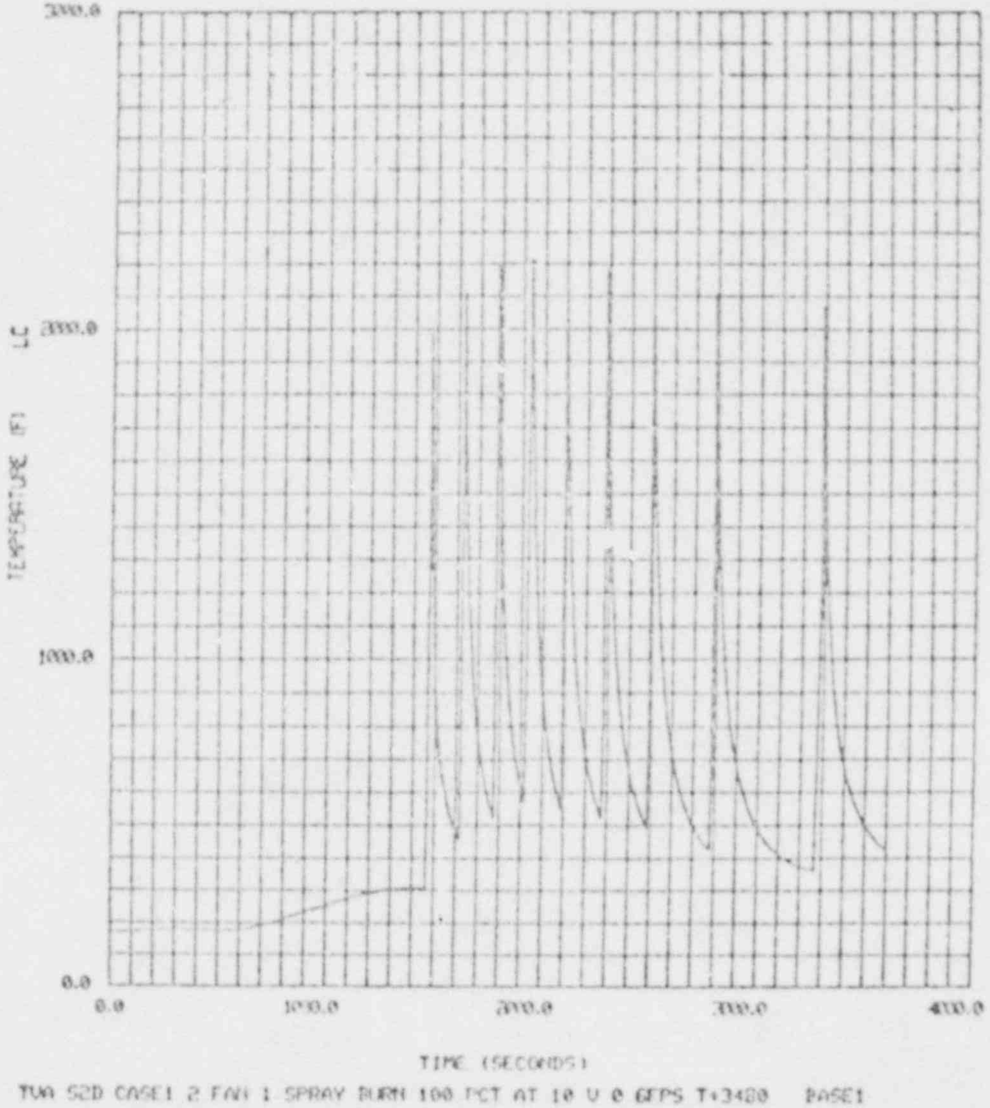
- VARIED ASSUMPTIONS REGARDING AIR RETURN FAN AND UPPER COMPARTMENT SPRAY PERFORMANCE, AND ICE AVAILABILITY.

BASE CASE PARAMETERS

1. INITIAL CONDITIONS:	VOLUMES	
	TEMPERATURES	
	PRESSURES	LOTIC
	ICE MASS	CODE
	ICE HEAT TRANSFER AREA	
2. BURN PARAMETERS:	H_2 FOR IGNITION	10 V/0
	H_2 FOR PROPAGATION	10 V/0
	O_2 FOR IGNITION	5 V/0
3. AIR RETURN FANS:	NUMBER OF FANS	2
	CAPACITY OF EACH FAN	40000 CFM
4. SPRAY SYSTEM:	FLOW RATE	6000 GPM
	TEMPERATURE	125 F
	HEAT TRANSFER COEFFICIENT	20 BTU/HR FT^{2}F
5. ICE CONDENSER DRAIN TEMPERATURE		32 F
6. BREAK RELEASE DATA		MARCH CODE

READY-

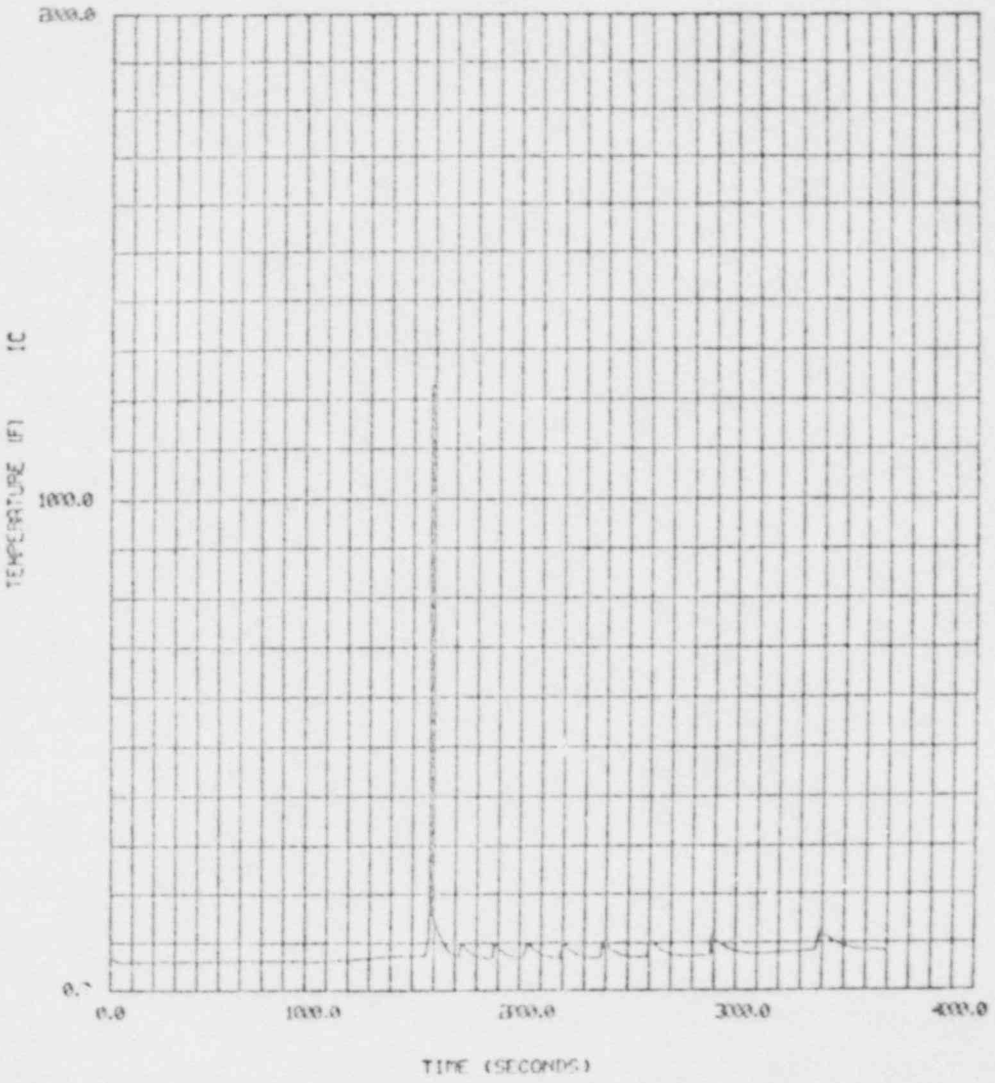
FRAME 01 1



LOWER COMPARTMENT TEMPERATURE

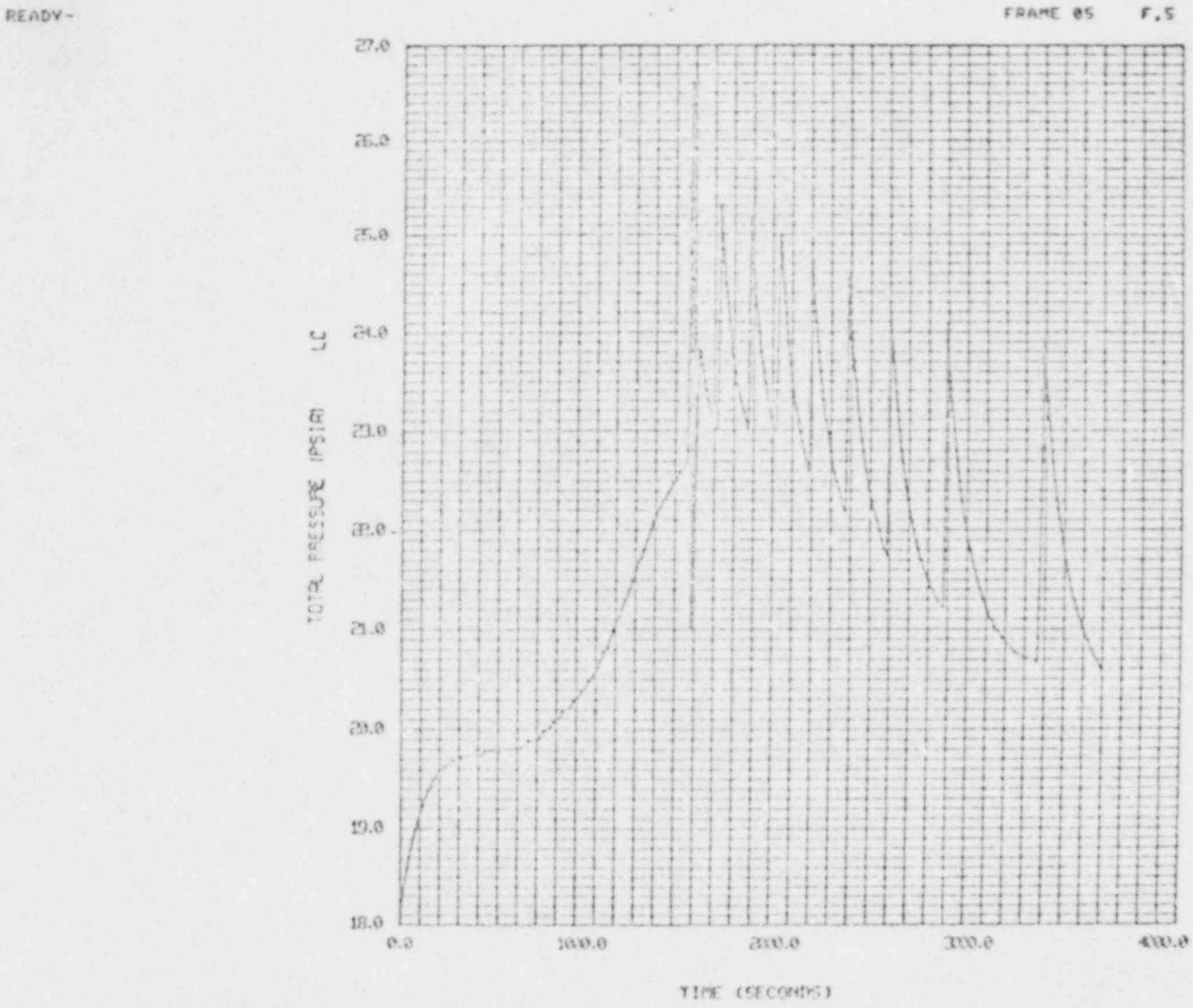
READY-

FRAME 02 1



TVA S2D CASE1 2 FAN 1 SPRAY BURN 100 PCT AT 10 V 0 6FPS T+3480 BASE1

ICE CONDENSER TEMPERATURE

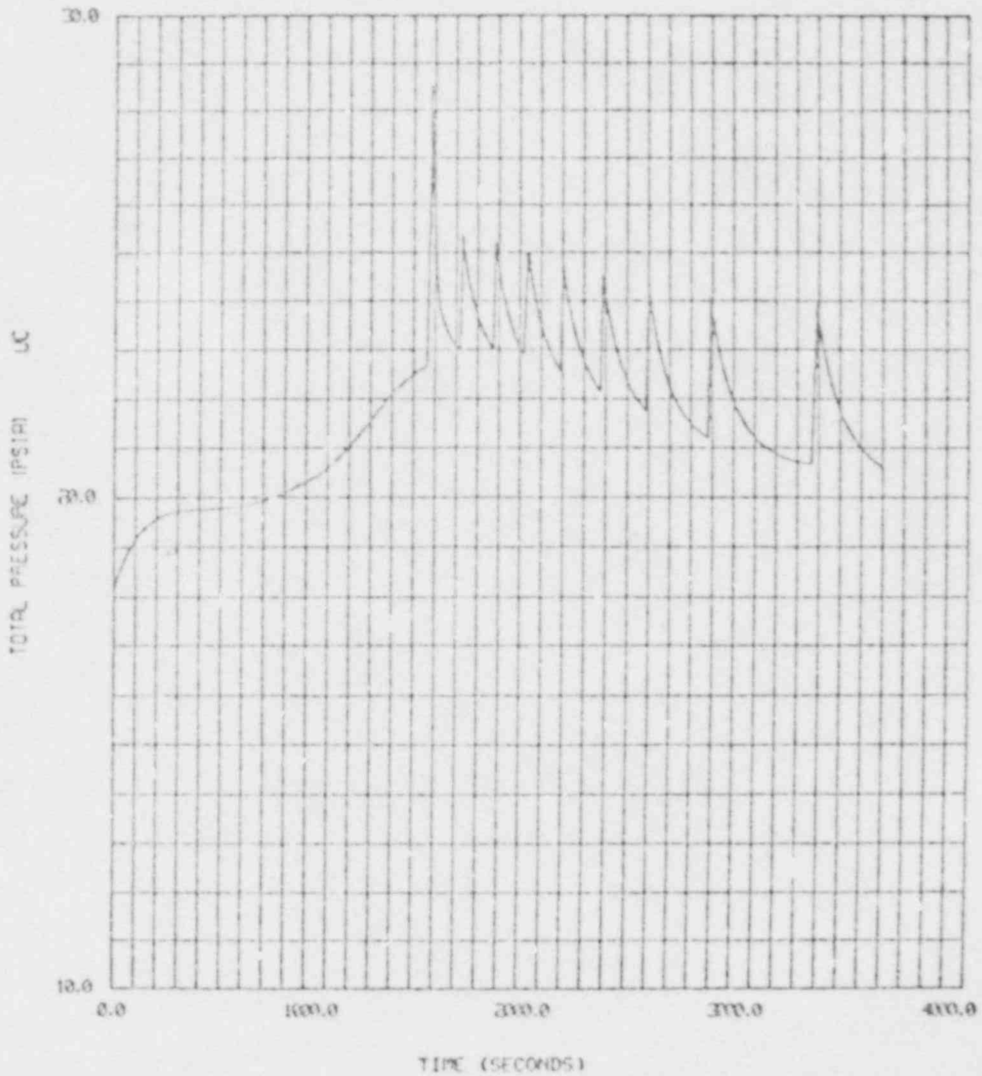


TVA 52D CASE1 2 FAN 1 SPRAY BURN 100 PCT AT 10 V 0 6FPS T+3480   BASE1

LOWER COMPARTMENT PRESSURE

READY-

FRAME 07

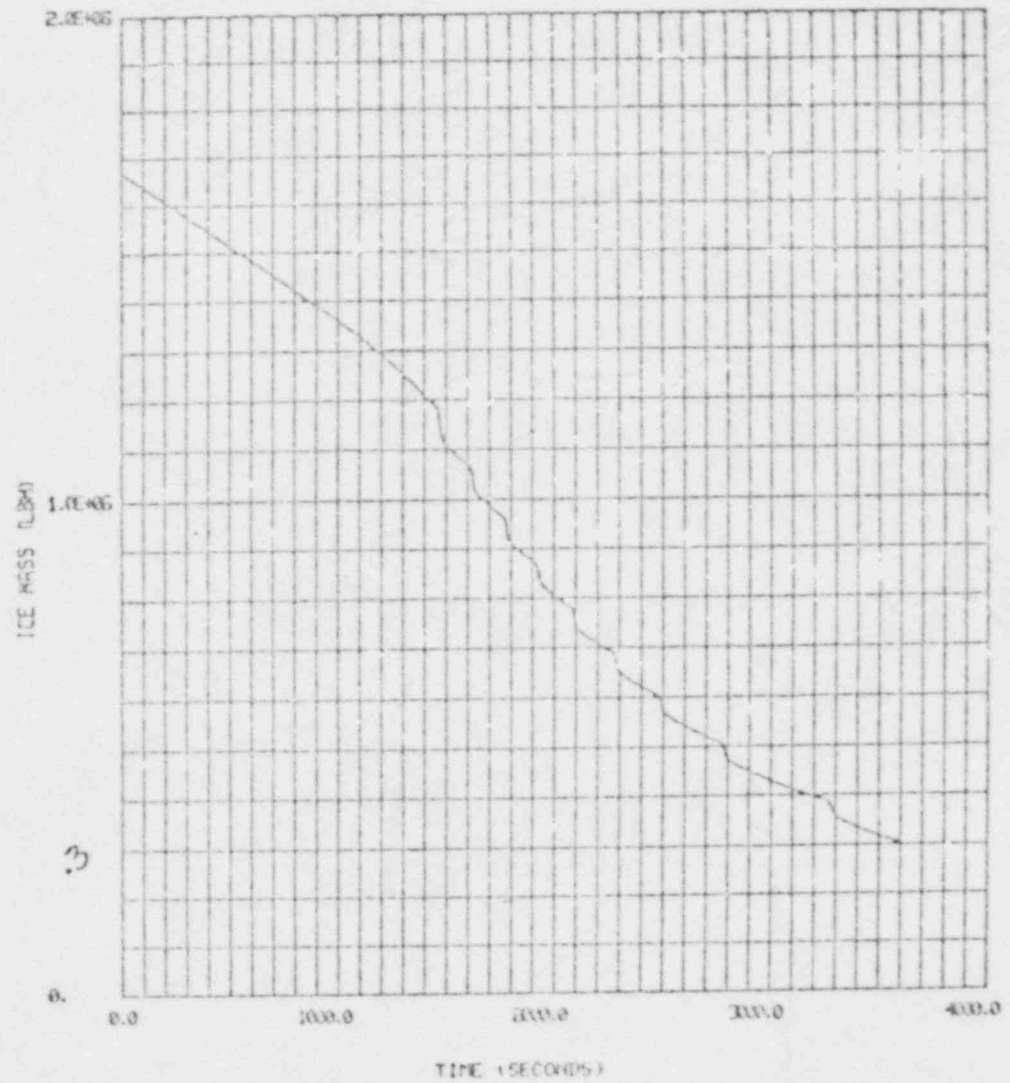


TVA S2D CASE1 2 FAN 1 SPRAY BURN 100 PCT AT 10 V 0 GFPS T+3480 BASE1

UPPER COMPARTMENT PRESSURE

READY-

FRAME 41 F.41



TVA S2D CASE1 2 FAN 1 SPRAY BURN 100 PCT AT 10 V 0 6FPS T+3430 BASE1

ICE MASS

TABLE 1. PRELIMINARY CONTAINMENT ANALYSIS SENSITIVITY STUDIES

	TOTAL H_2 BURNED (LB)	PEAK TEMP. (°F)			PEAK PRESS (PSIA)	
		LOWER COMPARTMENT	ICE BED	UPPER COMP.	LOWER COMP.	UPPER COMP.
1. BASE CASE	900	2200	1200	150	26.5	28.5
2. H_2 IGNITION AND PROPAGATION @ 8%	1050	1200	700	260	28.5	30.5
3. 1 AIR FAN	900	2200	1350	160	26.5	29.5
4. NO ICE*	850	2400	2000	270	41	41
5. NO AIR FANS	1200	2370	2580	1090	46.4	92.4

* ICE EXISTS ONLY FOR THE FIRST TWO OF 7 BURNING CYCLES.

NRR EFFORTS

- LLNL Igniter Tests
- BCL Analyses

LLNL WORK

- OBJECTIVE: EXPERIMENTALLY EVALUATE IGNITER EFFECTIVENESS AND RELIABILITY

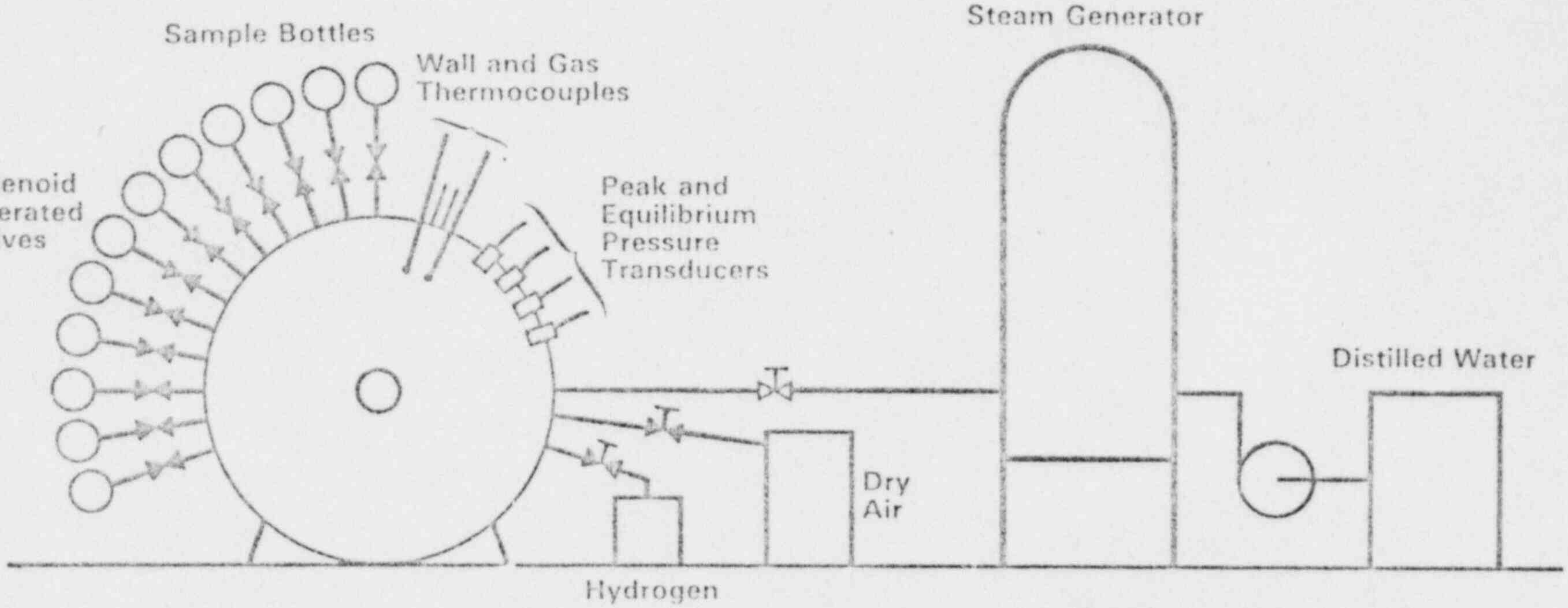
- FACILITY: 700 PSIG PRESSURE VESSEL
  4 FEET DIAMETER X 8 FEET LONG

- INSTRUMENTS: PRESSURE
  TEMPERATURE
  GAS SAMPLING

- SCHEDULE:

  DESIGN & BUILD: JULY - SEPT. 1980
  TESTS : SEPT - OCT., 1980
  REPORT : OCT., 1980

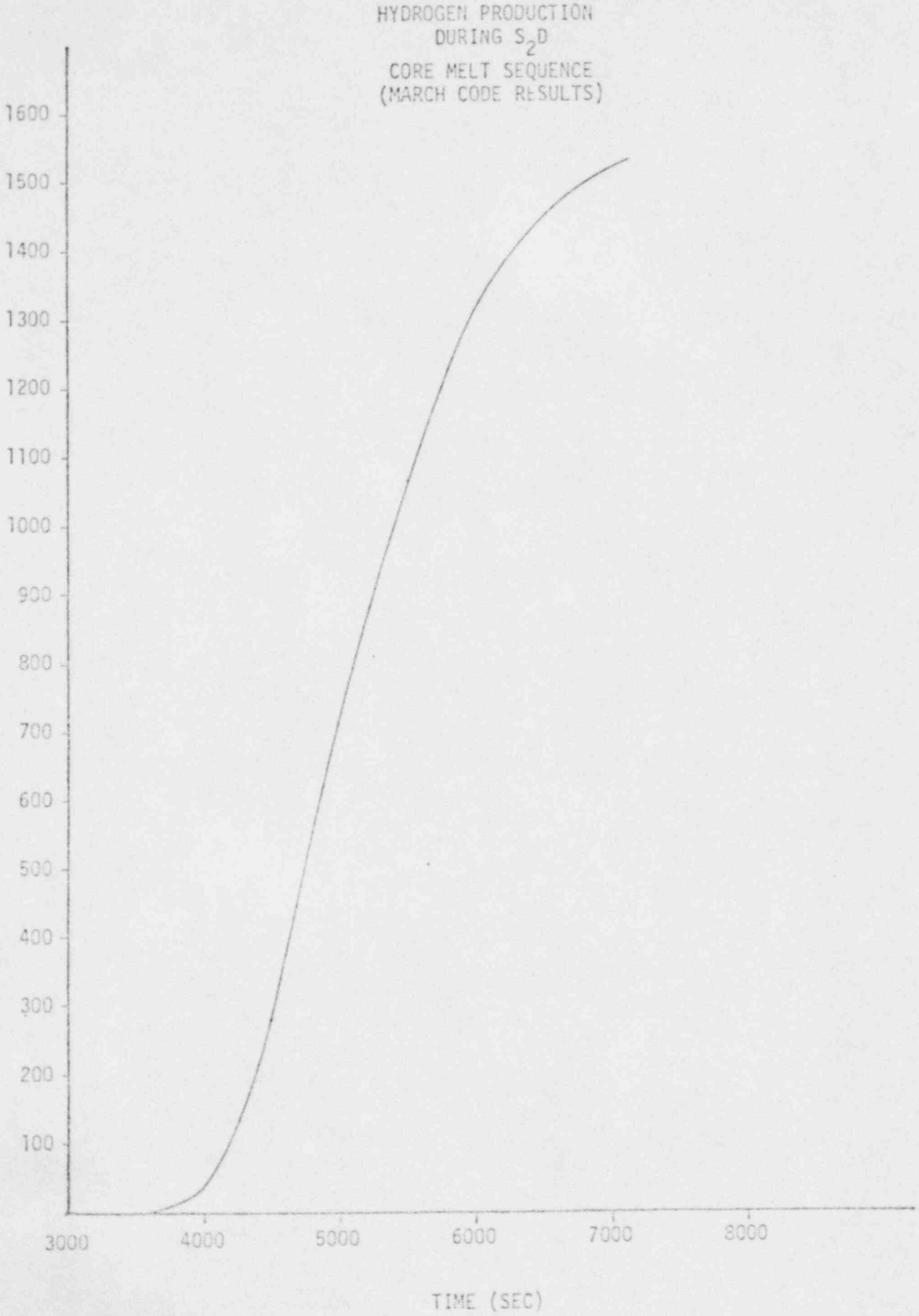
Schematic View of Igniter Test Apparatus



BCL WORK

- OBJECTIVE: EVALUATE EFFICACY OF PROPOSED IGNITER SYSTEM
- ANALYSIS MODEL: MARCH CODE
- FEATURES OF CODE
  - MODELS PRIMARY SYSTEM
  - MODELS CONTAINMENT SYSTEM
    - MULTI-COMPARTMENT
    - TRACKS ATMOSPHERE CONSTITUENTS
    - MODELS HEAT SINKS, ICE BED, FANS, SPRAYS
- SCHEDULE

  PRELIMINARY WORK: DONE
  BALANCE OF WORK: OCTOBER 1980



HYDROGEN PRODUCTION
DURING S_2D
CORE MELT SEQUENCE
(MARCH CODE RESULTS)

TABLE . BATTELLE ANALYSIS OF H_2 BURNING IN SEQUOYAH CONTAINMENT

CASE	H_2 IGNITION SETPOINT (%)	H_2 BURN LIMIT (%)	BURN TIME (SEC)	CONTAINMENT PEAK PRESSURE (PSIA)	
				ACTUAL	ADIABATIC
1	10	0	1	≈ 23	58.
2	10	0	25	≈ 22	58.
3	12	0	1	≈ 24	64.
4	8	0	25	≈ 22	51.
5	8	4	1	≈ 22	36.
6	10	0	1	≈ 31	79.

CASE 6 - ICE BED MELTED BEFORE BURNING OCCURS.

CONCLUSION

- LIKELIHOOD OF A DEGRADED CORE ACCIDENT IS SIGNIFICANTLY REDUCED BY IMPLEMENTATION OF TMI SHORT TERM LESSONS LEARNED
- TVA HAS PROPOSED TO FURTHER IMPROVE SAFETY MARGINS BY USE OF AN INTERIM DISTRIBUTED IGNITION SYSTEM
- DECISION OPTIONS:
  - OPTION A: HOLD AT 5%
  - OPTION B: NOMINAL 50% LIMIT
  - OPTION C: LIMITED 100%
  - OPTION D: UNLIMITED 100%
- STAFF RECOMMENDATION: OPTION B

HYDROGEN CONTROL

for

SEQUOYAH NUCLEAR PLANT, UNITS 1 & 2

August 13, 1980

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HYDROGEN CONTROL

for

SEQUOYAH NUCLEAR PLANT, UNITS 1 & 2

1. INTRODUCTION

1.1 Statement of Problem

In the case of a severely degraded core, the generation and release of substantial amounts of hydrogen to the Sequoyah containment (e.g., from a zirconium-water reaction like that which occurred at TMI-2) could under certain assumptions lead to containment failure. By contrast, a similar event in a conventional, large "dry" containment would probably not lead to containment failure. It is therefore necessary to consider whether scenarios leading to containment failure in ice condenser plants such as the Sequoyah Nuclear Plant are sufficiently likely as to pose undue risk.

1.2 Background

Prior to the TMI-2 accident, Commission regulations regarding hydrogen control (10 CFR Section 50.44); GDC 50 in Appendix A to 10 CFR Part 50) dealt with the hydrogen generated from certain design basis accidents, such as the LOCA. These relatively small amounts of hydrogen generated by a LOCA have been accommodated by the use of small capacity hydrogen recombiners or by delayed purging of the containment.

Following the TMI-2 accident, the staff prepared the "NRC Action Plan Developed as a Result of the TMI-2 Accident," NUREG-0660. Item II.B.7 of the Action Plan states that the staff is preparing interim hydrogen control requirements for small containment structures.

On February 22, 1980, the staff issued SECY-80-107, "Proposed Interim Hydrogen Control Requirements for Small Containments," in response to Item II.B.7 of the Action Plan. In SECY-80-107, the staff concluded that:

> "The 'Short Term Lessons Learned' from the TMI-2 accident have been implemented at all operating reactors and will be implemented at all plants under construction before operating licenses for them are issued. This action makes the likelihood of accidents involving substantial amounts of metal-water reaction smaller than was the case before the TMI-2 accident.
>
> A rulemaking proceeding on design features to mitigate the consequences of degraded core and core melt accidents is under consideration. Pending this rulemaking proceeding, we conclude that: 1) all Mark I containments that are not now inerted and all Mark II containments should be required to be inerted; 2) no interim requirements are required at this time for improvement in hydrogen management capability at nuclear power plants with other types of containment designs; and 3) subject to implementation of item 1, above, continued operation and licensing of nuclear power plants is justified."

A Commission briefing on SECY-80-107 was held on March 19, 1980. Following this briefing, the Commission requested that certain additional information be provided. At its response to this request for additional information, the staff issued SECY-80-107A and SECY-80-107B on April 22, 1980 and June 20, 1980, respectively.

A second briefing of the Commission was held on June 26, 1980. The Commission was advised during this briefing that the staff was preparing an advance notice of rulemaking and a proposed Interim Rule for Commission review and approval. The matters dealing with rulemaking are discussed in Section II, below.

There are a total of 10 licensed nuclear power units with ice condenser containments in the United States. Two of these, D. C. Cook, Units 1 and 2, are licensed for operation at full power. Sequoyah, Unit 1 is licensed to operate up to 5% of full power. The other seven units are under various stages of construction. Construction is scheduled to be complete at the next unit, McGuire, Unit 1, by about October 1980, and at the other six units in 1981 and later.

1.3 Summary

The present status of hydrogen control measures for the Sequoyah Nuclear Plant as of August 13, 1980 is discussed in this section. In summary, the significant new events subsequent to the background discussed above are reported and preliminary assessments are provided.

The staff's view has been that, because of the safety improvements, associated with implementation of the TMI-2 Lessons Learned items, hydrogen control measures beyond those satisfying 10 CFR Section 50.44 (i.e., redundant hydrogen recombiners) are not required for full power licensing of the Sequoyah Plant pending the upcoming rulemaking proceeding. As part of an effort to improve the safety margins at Sequoyah, TVA has proposed the use of an interim distributed ignition system pending completion of its broader studies of alternative systems for hydrogen control.

The ACRS has reviewed the interim system proposed by TVA and has reported its views on the matter (Section 2.5).

In a letter dated July 25, 1980, R&D Associates documented the results of its independent study of the ultimate strength analyses of the Sequoyah containment. We have reviewed and compared this work with similar work done by TVA and by the Ames Laboratory (Section 2.4.2). In a subsequent letter, dated August 4, 1980, R&D Associates reported the results of its analyses on hydrogen production and burning and mitigation by igniters. Our views on this work and on related work by others are reported in Section 2.4.1.4.

The staff has contracted with the Lawrence Livermore National Laboratory (LLNL) for certain experimental studies designed to evaluate the efficacy of the proposed igniter in initiating combustion of various lean mixtures of hydrogen in the presence of varying amounts of steam. We are targetting completion of this work in about three months. The staff has also issued a "Users Request," which is designed to have the NRC's Office of Nuclear Regulatory Research undertake a program of experiments and analyses to obtain information for use in the upcoming rulemaking proceeding. It calls for certain early studies of the ice condenser plants so that any additional safety requirements can be identified and implemented in a timely manner.

TVA has described a three-phase program dealing with hydrogen control and degraded core matters in general. We intend to impose, as a condition of the operating license for Sequoyah, Unit 1, the completion of a substantial study program by TVA.

We believe that there is good likelihood that the distributed igniter system will be established as a worthwhile safety measure. The distributed igniter system will serve to mitigate the consequences of a hydrogen release to the containment under degraded core accident conditions by inducing a series of controlled burns in the lower compartment of the containment to permit the active and passive heat removal mechanisms to dissipate the combustion energy and thereby maintain the pressure response within the containment structural design capability. We will expedite our review, which includes a review of the TVA assessment (to be filed by August 15, 1980) so that a regulatory decision may be made in the fall of 1980.

2. Discussion

2.1 Rulemaking

As part of Item II.B.8 of the NRC Action Plan Developed as a Result of the TMI-2 Accident, NUREG-0660, the NRC will conduct a rulemaking on consideration of degraded or melted cores in safety reviews. The first step in the rulemaking proceeding will be the issuance of an advance notice of rulemaking and an Interim Rule.

2.1.1 Advance Notice of Rulemaking

In SECY-80-357, dated July 29, 1980, the staff seeks Commission approval to publish an advance notice of proposed rulemaking. This advance notice states that the NRC is considering amending its regulations to determine to what extent, if any, commercial nuclear power plants should be designed for a broad range of reactor accidents which involve damage to fuel and release of radioactivity, including design for reactor accidents beyond those considered in the current "design basis accident" approach. In particular, this rulemaking would consider the need for nuclear power plant designs to be evaluated over a range of degraded core cooling events with resulting core damage and the need for design improvements to cope with such events.

2.1.2 Interim Rule

Pending the rulemaking proceeding referred to above, an interim rule is being prepared (and should be to the Commission in August 1980) which contains additional requirements relative to hydrogen control. Specifically, the proposed rule would require that: 1) all Mark I and Mark II containments for BWR plants be operated with an inerted atmosphere inside containment by January 1, 1981; and 2) design analyses be performed for all other plants to evaluate measures that can be taken to mitigate the consequences of large amounts of hydrogen generated within 8 hours after onset of an accident. The design analyses and a proposed design would be filed some six months after the effective date of the rule or by the date of docketing of the application for the operating license, whichever is later.

We expect to request Commission approval for publication of the proposed rule during August 1980, and allow 30 days for public comment.

2.2 Licensee Efforts

2.2.1 Short Term

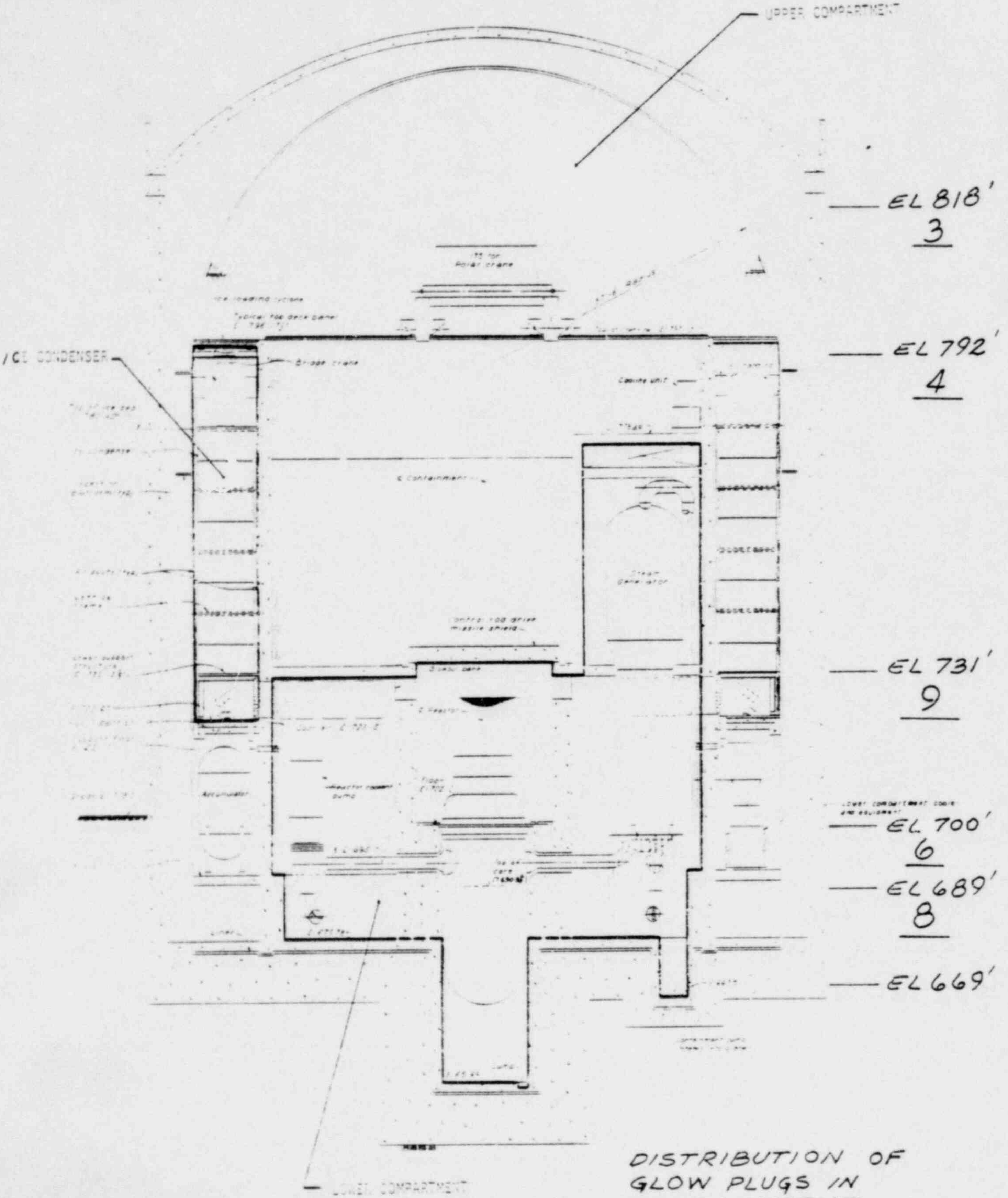
Although TVA considers the existing Sequoyah capability relative to hydrogen control to be adequate pending the rulemaking proceeding, it has taken steps to improve this capability in the near term. Specifically, TVA has proposed to install and implement an interim system of distributed igniters for controlling hydrogen combustion which should limit the effects of large amounts of hydrogen such as that generated during the Three Mile Island accident. On or before August 15, 1980, TVA will submit to the staff for review and approval the safety analysis, system design description and drawings, Final Safety Analysis Report revisions, system test requirements and igniter test results, and proposed revisions to the emergency operating instructions. The distributed ignition system will not be made operable until TVA has received staff approval.

The system will be installed and upgraded in three phases. Phase 1 is an interim effort consisting of system installation and testing, and is expected to be completed by September 15, 1980. The system will use off-the-shelf components, and the igniters will be thermal resistors (GMAC 7-G diesel engine glow plugs are currently being tested). The igniters will be powered from the emergency buses through backup lighting circuits, which are seismically qualified. The emergency diesel generators will also provide power to the backup lighting circuits in the event of a loss of offsite power. The system would be remote manually controlled from the auxiliary building.

Figure 1 is an elevation view of the Sequoyah containment and indicates the number of glow plugs TVA proposes to locate at various elevations in the containment. TVA proposes to provide a total of 30 glow plugs. Eighteen glow plugs will be located in the lower compartment; 8 at the 689.0' elevation, 6 at the 700.0' elevation and 4 at the 731.0' elevation (in the openings to the steam generator compartments). Five glow plugs will be located in the lower plenum of the ice condenser at the 731.0' elevation, and 4 glow plugs will be located in the upper plenum of the ice condenser at the 792.0' elevation. Three glow plugs will be located in the upper compartment at the 818.0' elevation.

TVA is presently testing the GMAC 7-G diesel engine glow plug to determine the appropriate operating conditions, its durability and its reliability as an ignition source in lean hydrogen mixtures. The glow plug temperature as a function of applied voltage is being determined, and TVA has informed us that glow plug temperatures of about 1700°F and 1500°F occur at 14 volts and 12 volts, respectively. TVA also stated that a glow plug specimen has continued to operate successfully after 6 days at 1700°F. At an applied voltage of 14 volts, ignition

SEQUOYAH CONTAINMENT



DISTRIBUTION OF GLOW PLUGS IN CONTAINMENT FIGURE

FIGURE 1

was achieved in hydrogen mixtures of 12 volume percent and 7 volume percent hydrogen. TVA plans to conduct further tests by varying the hydrogen concentration and introducting a steam environment to determine the reliability of the glow plugs as an ignition source and the percent completion of hydrogen burns.

TVA, Westinghouse, and Offshore Power Systems (OPS) have performed a preliminary containment analysis using the CLASIX computer code (currently under development), which indicates that a distributed ignition system would be beneficial in mitigating the potential effects of large amounts of hydrogen. Using an accident sequence similar to the TMI-2 accident (small-break LOCA resulting in degraded core cooling), and assuming partial containment safeguards capability, the analysis indicates that the Sequoyah containment could withstand, based on ultimate strength estimates, the pressure spikes resulting from a series of initiated burns in the containment. The accident sequence assumed a hydrogen release from the reactor coolant system corresponding to about an 80% core metal-water reaction.

The analysis briefly discussed above is discussed in greater detail in Section 2.4.1.1, TVA/OPS Results. The results are preliminary. TVA is working with Westinghouse and OPS to refine and complete the analysis. The status of the staff's evaluation effort and independent analytical effort are discussed in Section 2.4.1.4., Comparison of Results.

2.2.2 Long Term

Phases 2 and 3 of the distributed ignition system installation are long term efforts.

Phase 2 improvements to the distributed ignition system will be implemented in parallel with the rest of TVA's long term (2-year) Degraded Core Task Force Program. Phase 2 will include the following improvements:

- Each igniter will have individual control from the main control room.
- More hydrogen and oxygen monitors will be installed to guide operators.
- A plant computer to warn of hydrogen concentrations reaching the detonation limit will be provided.
- Backup diesel power supply to the system will continue to be provided.
- Environmental qualification of distributed ignition system components will be determined.
- Effects of the hydrogen burn environment on components will be analysed.
- Alternate and/or additional igniter locations will be selected based on a better understanding of the characteristics of hydrogen combustion.
- Installation of hydride converters near the reactor vessel vent, PORV discharge, and air return fans will be considered.

- Additional containment penetrations will be considered to facilitate an expanded hydrogen monitoring capability.

Phase 3 will consist of final modifications to the Phase 2 system and will be implemented upon completion, and based on results, of TVA's long-term program.

TVA has initiated a long-term Degraded Core Task Force Program. The Program's major tasks will involve extensive work in the following areas:

1. Controlled Ignition
2. Halon Suppressants
3. Risk Assessment
4. Core Behavior, Hydrogen Generation and Transport
5. Hydrogen Burning and Containment Responses
6. Containment Integrity
7. Equipment Environmental Qualifications
8. Radiation Dose Code
9. Hydride Converter, Fogging and Other Mitigation Schemes
10. Rulemaking and State of the Art

This effort is to be performed over a two-year period.

The foregoing discussion of TVA's proposed distributed ignition system and companion efforts is based on discussions with TVA and a review of preliminary information concerning their ongoing design, test and analysis activities, and longer term efforts.

Staff conclusions on the overall efficacy of the proposed distributed ignition system in limiting the effects of large amounts of hydrogen resulting from a degraded core accident will be developed following formal submittal by TVA and completion of the staff review of the system design, supporting test results and analyses, and detailed discussions of subsequent phases of TVA's efforts.

2.3 NRC Efforts

2.3.1 NRR Short-Term

2.3.1.1 Igniter Tests at Lawrence Livermore National Laboratory (LLNL)

In order to evaluate the efficacy of the distributed ignition system to be installed by TVA in the Sequoyah plant the staff has obtained technical assistance to gather information through both experimental and analytical efforts.

The staff, through LLNL, will test hydrogen igniters, identical to those to be installed at Sequoyah. An effort will also be made to test the igniters in the configuration or mounting arrangement identical to those proposed by TVA for installation. The experimental test program will determine the efficiency of the TVA igniters by examining their performance under a spectrum of test conditions. The test matrix will serve to gather data on igniter performance in atmospheres with varying hydrogen and steam concentrations since the effect of large steam concentrations on hydrogen combustion in these situations is not well understood.

A schematic of the test assembly is shown in Figure 2. The general procedure will be to start with dry air at ambient conditions inside the test vessel and then add hydrogen until the pre-selected concentration is reached. Steam will then be injected into the vessel at a given temperature. The steam concentration will decrease slowly as a result of condensation on the cooler test vessel wall. As condensation occurs the volume fraction of hydrogen and air will increase slightly until the conditions of interest are achieved. Intermittent or continuous testing of igniters can proceed with appropriate gas sampling continuing up to and just after ignition. By gas sampling we can determine the degree of combustion, i.e., how much of the hydrogen initially present burned after ignition. Instrumentation in the test vessel will also allow for measurement of pressure and temperature conditions.

Another objective of the program at LLNL is to study current hydrogen analyzers utilized in nuclear power plants, including the analyzer type used to measure hydrogen concentrations within the Sequoyah containment. The program at LLNL is expected to be completed within approximately 3 months. Further testing of ignition devices is expected to continue with investigation into the effects of containment spray operation on igniter performance.

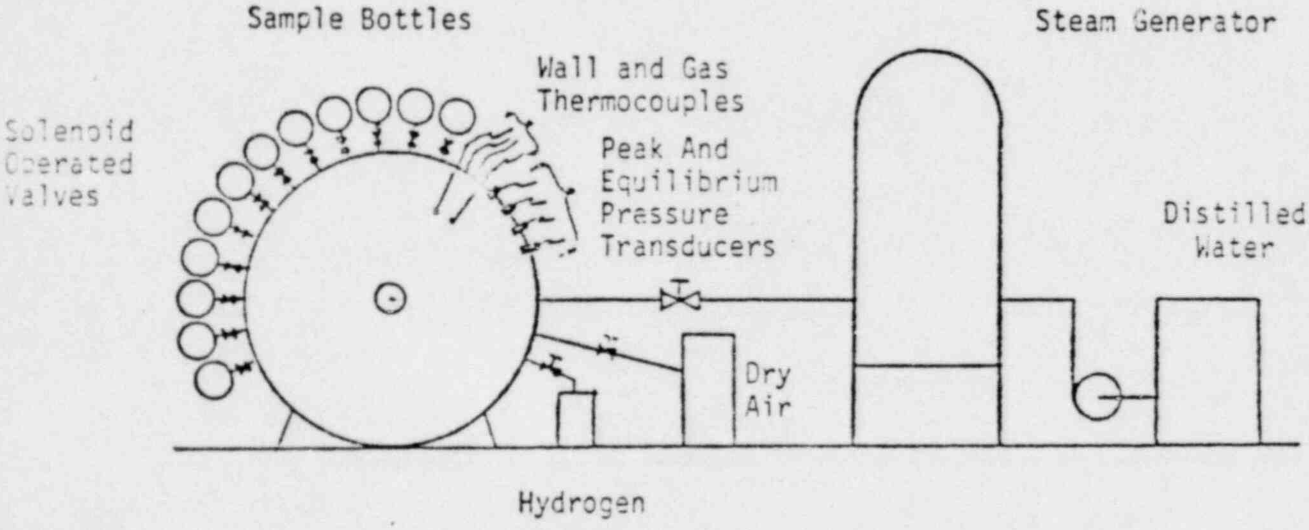


Figure 2. Schematic View of Igniter Test Apparatus

2.3.1.2 Analyses at Battelle-Columbus Laboratory

The staff has also obtained technical assistance from Battelle-Columbus Laboratory (BCL) to study through analysis the effects of igniter performance in the degraded core post-accident environment. The purpose of the analytical effort is to estimate the role and relative worth of igniters in reducing the containment pressure and maintaining containment integrity for accident scenarios where a large amount of core degradation and concomittant hydrogen generation is expected.

Battelle will use the MARCH code to perform the analysis of hydrogen generation and the containment pressure and temperature response. The MARCH code, which was developed by Battelle, has the capability of modeling a multi-volume containment including both active and passive heat removal mechanisms including the ice condenser. Details of preliminary BCL analyses are discussed in Section 2.4.1, Assessment.

2.3.2 NRR Long-Term

As a result of the accident at Three Mile Island, the TMI Action Plan (NUREG-0660), at item II.B.8 calls for a rulemaking proceeding on consideration of degraded or melted cores in safety reviews. To support the staff's participation in the rulemaking we have requested a safety research program that is to provide a basis for evaluating safety systems intended to mitigate the consequences of degraded/melted core accidents for the generic classes of LWR containment designs. The containment types to be studied are the BWR pressure suppression containments, and ice condenser, subatmospheric and dry containments. A significant portion of this progarm will be devoted to assessing various hydrogen control systems for the different containment designs. Among the hydrogen control measures to be studied are: halon systems, gas turbines, inerting, large capacity recombiners, water fog system and distributed ignition systems. The evaluation of hydrogen control techniques will be based on criteria which include large scale implementation feasibility, economics, reliability and consideration of potential adverse impact. As a matter of priority, the staff has identified the ice condenser and BWR Mark III containment designs as those to be first investigated with regard to mitigation systems.

2.3.3 RES Long-Term

RES is developing a research program plan for Severe Accident Phenomenology and Mitigation to support rulemaking proceedings on Degraded Core Cooling, Siting and Emergency Planning, which are called for in the TMI Action Plan (NUREG-0660) at Items II.B.8, II.A.1, and III.A and III.D, respectively. The objective of the research program is to develop the technical bases for Commission decisions during the rulemaking activities. It is the goal to have major aspects of the work completed in 4 years.

As noted above, the RES research program will incorporate the NRR long-term needs.

2.3.4 Relationship to Zion/Indian Point Studies

A study has been undertaken of the containment response associated with the combustion or detonation of hydrogen for the Zion and Indian Point (Z/IP) plants under degraded core or core melt conditions.

The Z/IP effort involves the estimation of the threat to containment from hydrogen combustion or detonations, and the establi[illegible] performance requirements for systems (other than inerting) to mitigate or eliminate the threat. The hydrogen can develop from metal-water reactions (e.g., Zr/H_2O, Cr/H_2O), radiolytic decomposition and reactions of molten core materials with concrete in degraded core/core melt accidents. The investigation has been underway since January 1980, and has comprised three principal areas:

1) Estimate of the amount and possible behavior of hydrogen in applicable accident sequences, including the possibilities and types of non-uniform distributions, the rise and fall time of pressure pulses from the combustion and/or detonation, and how these might add to existing pressure stresses from other sources.

2) Estimate of the response of structures, vessels and vital equipment to the pressure-temperature pulses associated with hydrogen burning/detonations. The in-house effort in this area has been augmented by LASL.

The Z/IP structures studies are not directly applicable to ice condenser plants, except insofar as the same codes and methodologies can be used.

3) Sandia Laboratories has investigated, for RES, the possible problems that the presence of hydrogen might contribute to features of a filtered venting system. Sandia has prepared a compendium on hydrogen burning, detonation and control methodology. The scenarios of accidents leading to the production of hydrogen have also been reviewed.

Some of the results of this program which have applicability to ice condenser plants and other plants include:

1) Codes for the analysis of dynamic loading of containments from hydrogen burning or explosion pressures.

2) A survey and collection of information on combustibility of hydrogen-air-steam mixtures; information on methods of suppression or prevention of hydrogen fires; and ignition information.

3) A summary of the technology for detection of hydrogen.

4) Descriptions of presently used hydrogen recombiners and the problems encountered in their development.

5) Descriptions of other hydrogen control devices and procedures.

As a result of studying accidents more severe than degraded cooling, i.e., accidents involving core melt progression ex-vessel, the Z/IP studies have tended to reiterate previous conclusions on the generation of hydrogen from concrete. Experimental and analytical studies on this interaction of molten core materials with concrete are continuing at Sandia Laboratories.

2.4 Assessment

2.4.1 Containment Loading

2.4.1.1 TVA Results

In order to evaluate the role of igniters in accident mitigation, TVA and the staff have initiated separate programs to analytically and experimentally determine the effectiveness of distributed ignition systems in reducing the threat to containment integrity due to the combustion of hydrogen generated following postulated degraded core accidents.

TVA is currently engaged in an analytical program designed to investigate the consequences of igniter operation in the Sequoyah plant in an accident environment. It is expected that thorough analyses including sensitivity studies on critical parameters for a range of accident scenarios will continue for approximately one year. The analytical work will be performed using the CLASIX computer code which is being developed by Westinghouse/OPS. The CLASIX code is a multi-volume containment code which calculates the containment pressure and temperature response in the separate compartments. CLASIX has the capability to model features unique to an ice condenser plant, including the ice bed, recirculation fans and ice condenser doors, while tracking the distribution of the atmopshere constituents oxygen, nitrogen, hydrogen and steam. Figure 3 shows an example of an ice condenser model for the CLASIX code. The code also has the capability of modeling containment sprays but presently does not include a model for structural heat sinks.

Mass and energy released to the containment atmosphere in the form of steam, hydrogen and nitrogen is input to the code. The burning of hydrogen is calculated in the code with provisions to vary the conditions under which hydrogen is assumed to burn and conditions at which the burn will propagate to other compartments.

As previously stated, TVA is at the beginning of its program to analytically evaluate the effectiveness of their hydrogen ignition system. However, TVA has provided the results of interim calculations performed with the CLASIX code to analyze the response of an ice condenser containment with an operating ignition system. These interim calculations were performed for the accident scenario designated S2D in WASH-1400, which is a small break loss

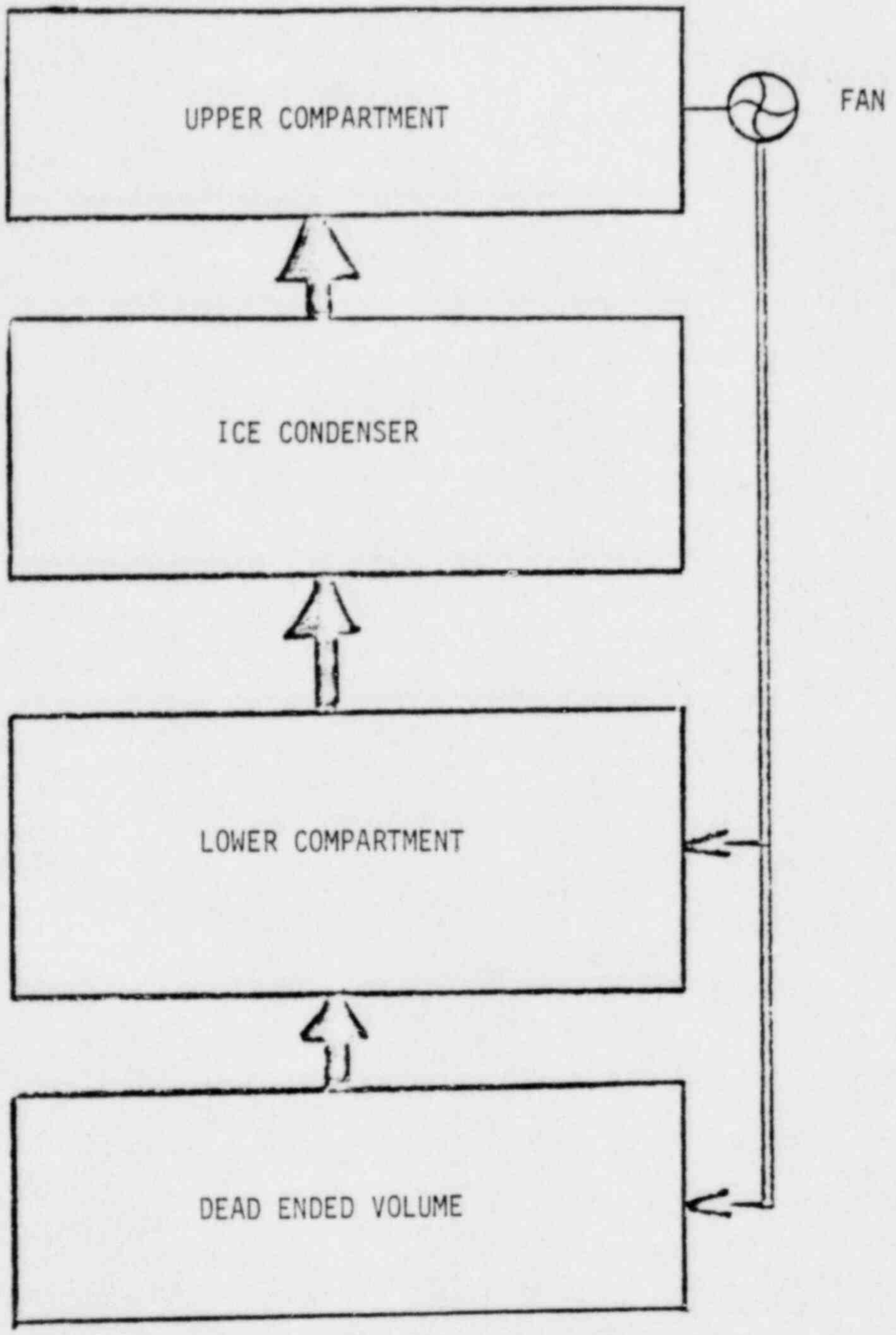


FIGURE 3. CLASIX MODEL OF ICE CONDENSER CONTAINMENT

of coolant accident accompanied by the failure of emergency core cooling injection. The S2D sequence leads to the production of hydrogen from the zirconium-water reaction as a result of the degraded core conditions, i.e., lack of core cooling. The rate of hydrogen production and release to the containment for the interim calculations was based on calculatons by BCL using the MARCH code. The conditions inside the containment prior to the onset of hydrogen generation were determined from LOTIC analyses; LOTIC being the Westinghouse long term ice condenser analysis code previously reviewed and approved by the staff. The CLASIX calculations then begin at the onset of hydrogen production, which occurs at approximately 3500 seconds following onset of the accident. Table 1, which presents the parameters used in the base case CLASIX analysis, shows that hydrogen ignition was assumed to be initiated at a 10% hydrogen concentration and that burning is assumed to propagate to other compartments with a 10% hydrogen concentration. Hydrogen burning was assumed to occur with a flame speed of 6 ft/sec.

Figure 4 presents the integrated hydrogen release input to CLASIX that was calculated for the S2D transient using the MARCH code. The hydrogen release to containment was terminated, for the containment analysis, after approximately 1550 lbs of hydrogen were released. This mass of hydrogen

BASE CASE PARAMETERS

1. INITIAL CONDITIONS:	VOLUMES	LOTIC CODE
	TEMPERATURES	
	PRESSURES	
	ICE MASS	
	ICE HEAT TRANSFER AREA	
2. BURN PARAMETERS:	H_2 FOR IGNITION	10 V/O
	H_2 FOR PROPAGATION	10 V/O
	O_2 FOR IGNITION	5 V/O
3. AIR RETURN FANS:	NUMBER OF FANS	2
	CAPACITY OF EACH FAN	40000 CFM
4. SPRAY SYSTEM:	FLOW RATE	6000 GPM
	TEMPERATURE	125 F
	HEAT TRANSFER COEFFICIENT	20 BTU/HR FT^2F
5. ICE CONDENSER DRAIN TEMPERATURE		32 F
6. BREAK RELEASE DATA		MARCH CODE

TABLE 1

HYDROGEN PRODUCTION
DURING S_2D
CORE MELT SEQUENCE
(MARCH CODE RESULTS)

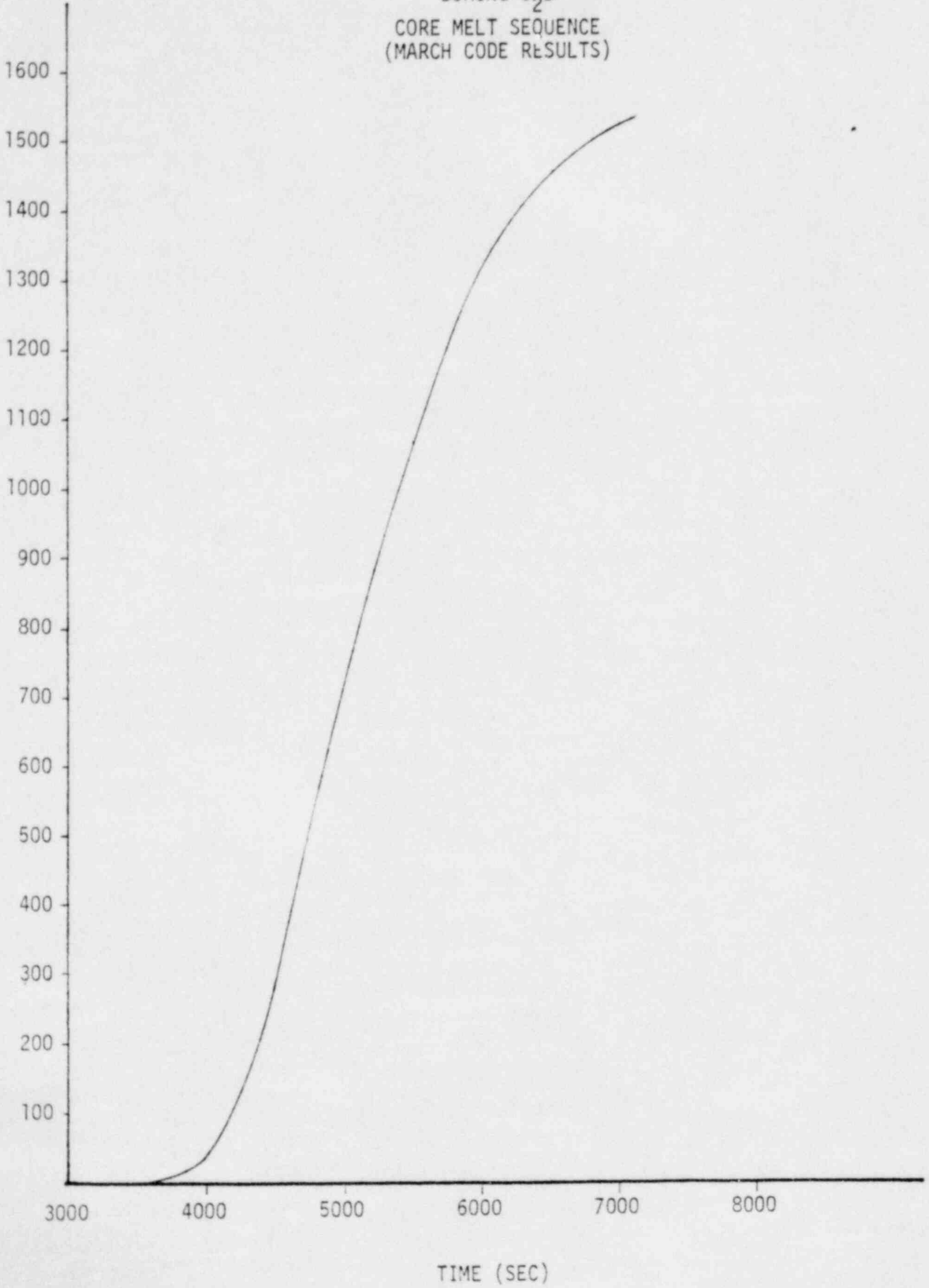


FIGURE 4

corresponds to the reaction of approximately 80% of the total zirconium mass in the core. At this point in the scenario the core is dry, thus there is no steam to produce a further zirconium-steam reaction. Extending the accident scenario to the point of reactor vessel melt through will be the subject of future analyses in conjunction with TMI Action Plan Item II.B.8.

Results of the CLASIX base case analysis are shown in Figures 5 through 10. The results of the base case analysis indicate that the hydrogen will be ignited in a series of nine burns in the lower compartment. One of the burns propagates upward into the ice condenser as can be seen by the temperature transient shown in Figure 6. The total interval over which the series of burns occurs is approximately 3300 seconds. For the first burn a peak pressure of 26.5 psia was calculated in the lower compartment, and 28.5 psia for the ice condenser and upper compartment. The pressure in the containment before the first burn was approximately 22.5 psia. Subsequent burns resulted in successively lower pressure spikes. Peak temperatures of 2200°F, 1200°F and 150°F were calculated in the lower compartment, ice condenser and upper compartment, respectively.

As a result of the action of engineered safety features, such as the ice condenser, air return fans and upper compartment

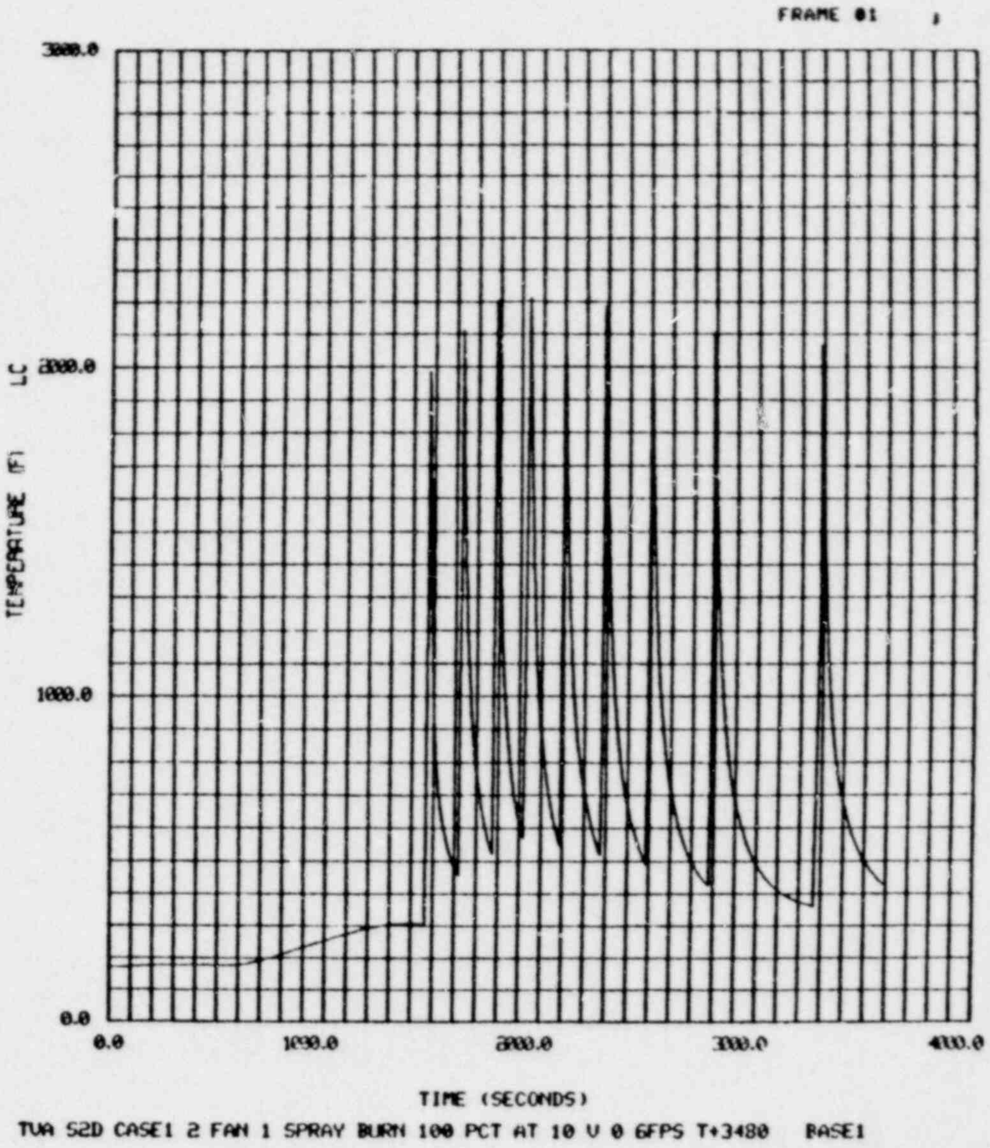


Figure 5. Base Case Lower Compartment Temp. (°F)

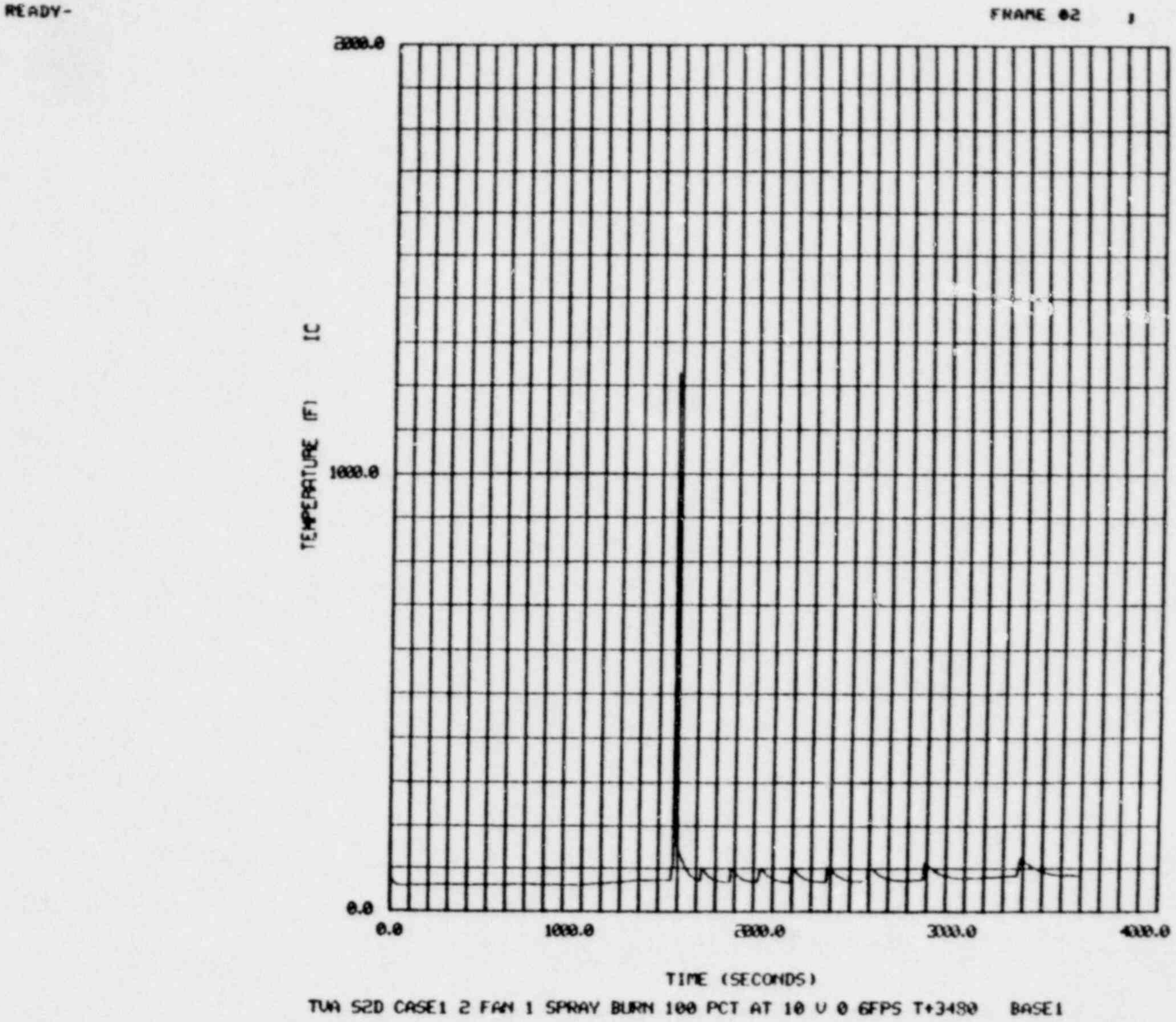


Figure 6. Base Case Ice Condenser Temp. (°F)

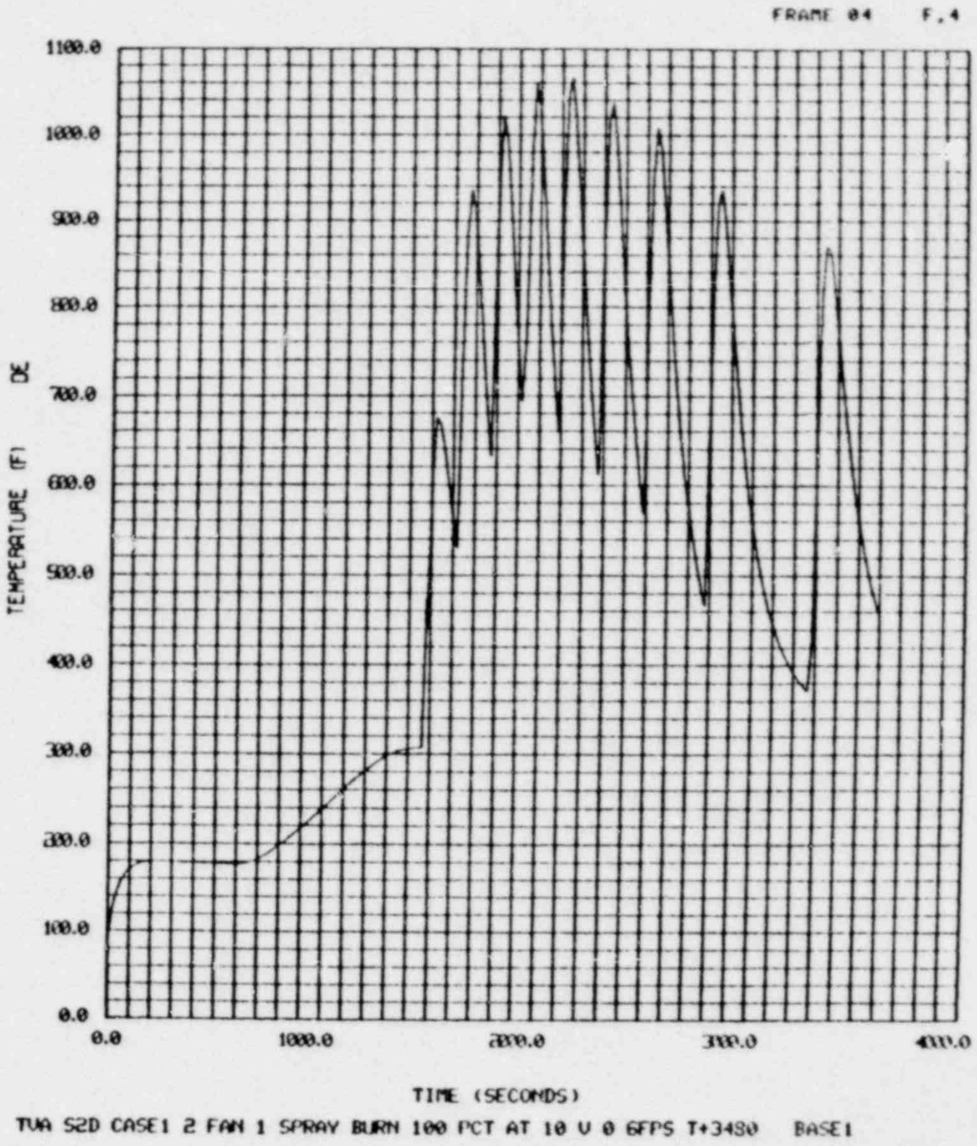


Figure 7. Base Case Dead Ended Volume Temp. (°F)

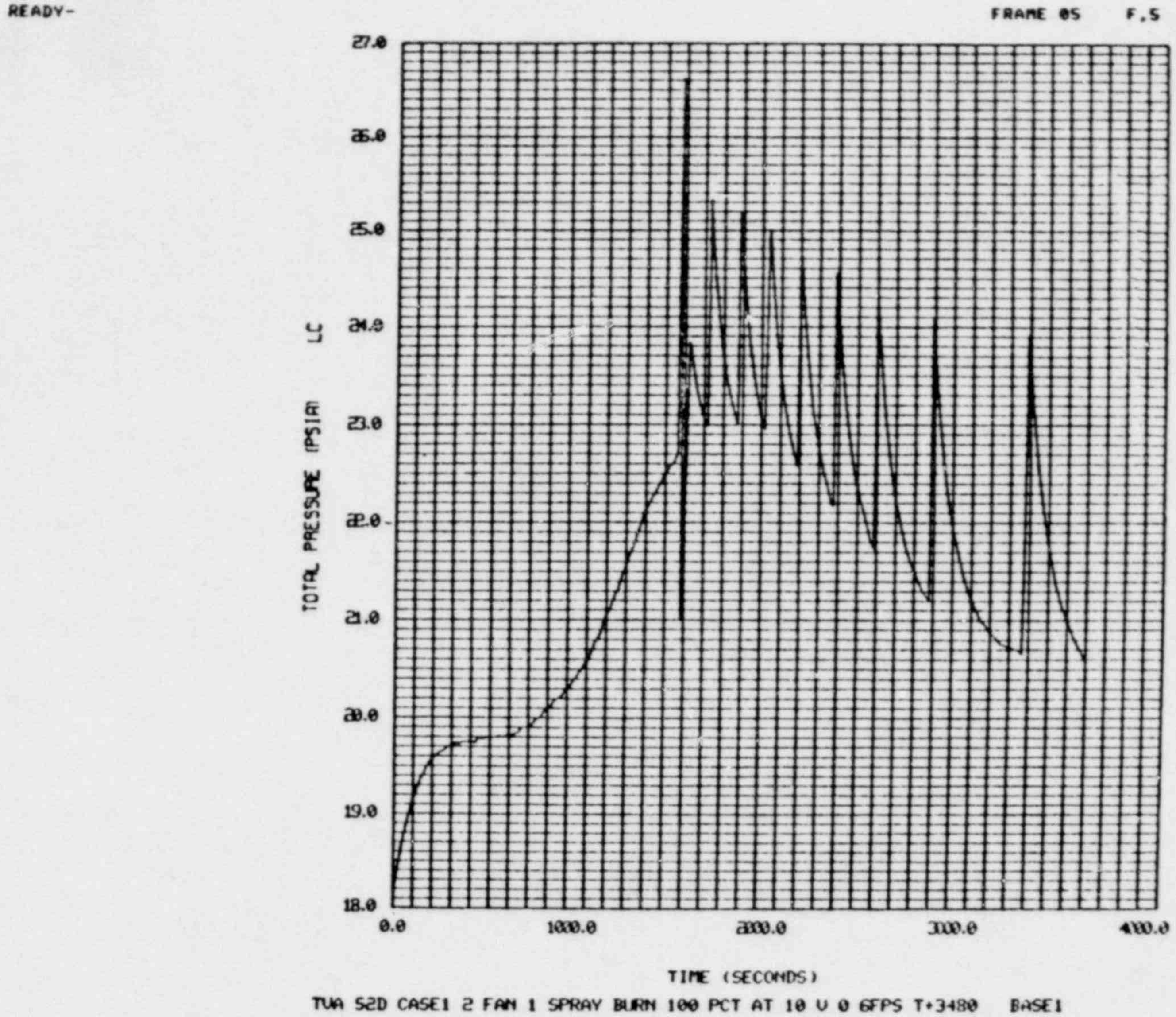


Figure 8. Base Case Lower Compartment Pressure

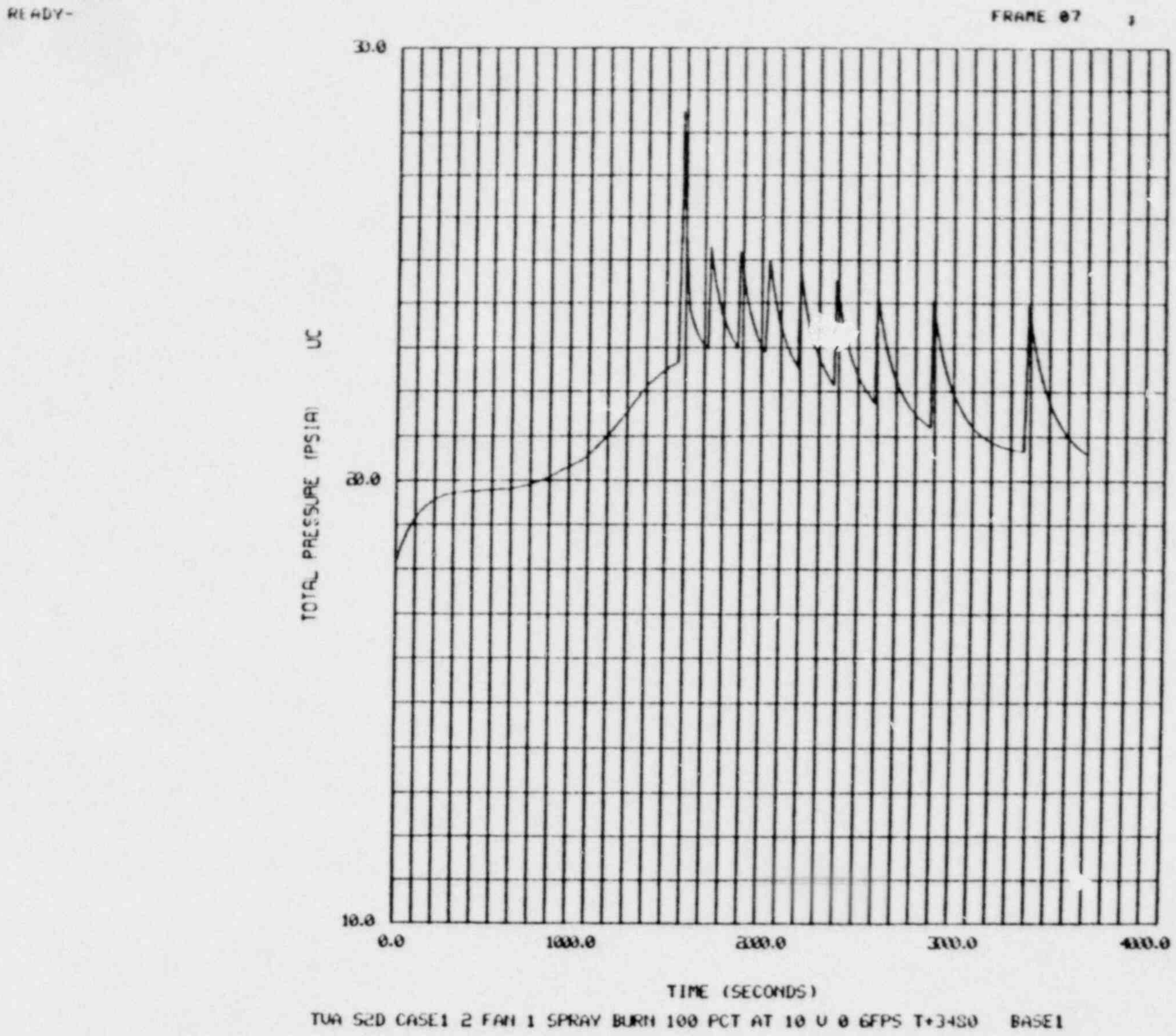


Figure 9. Base Case Upper Compartment Pressure

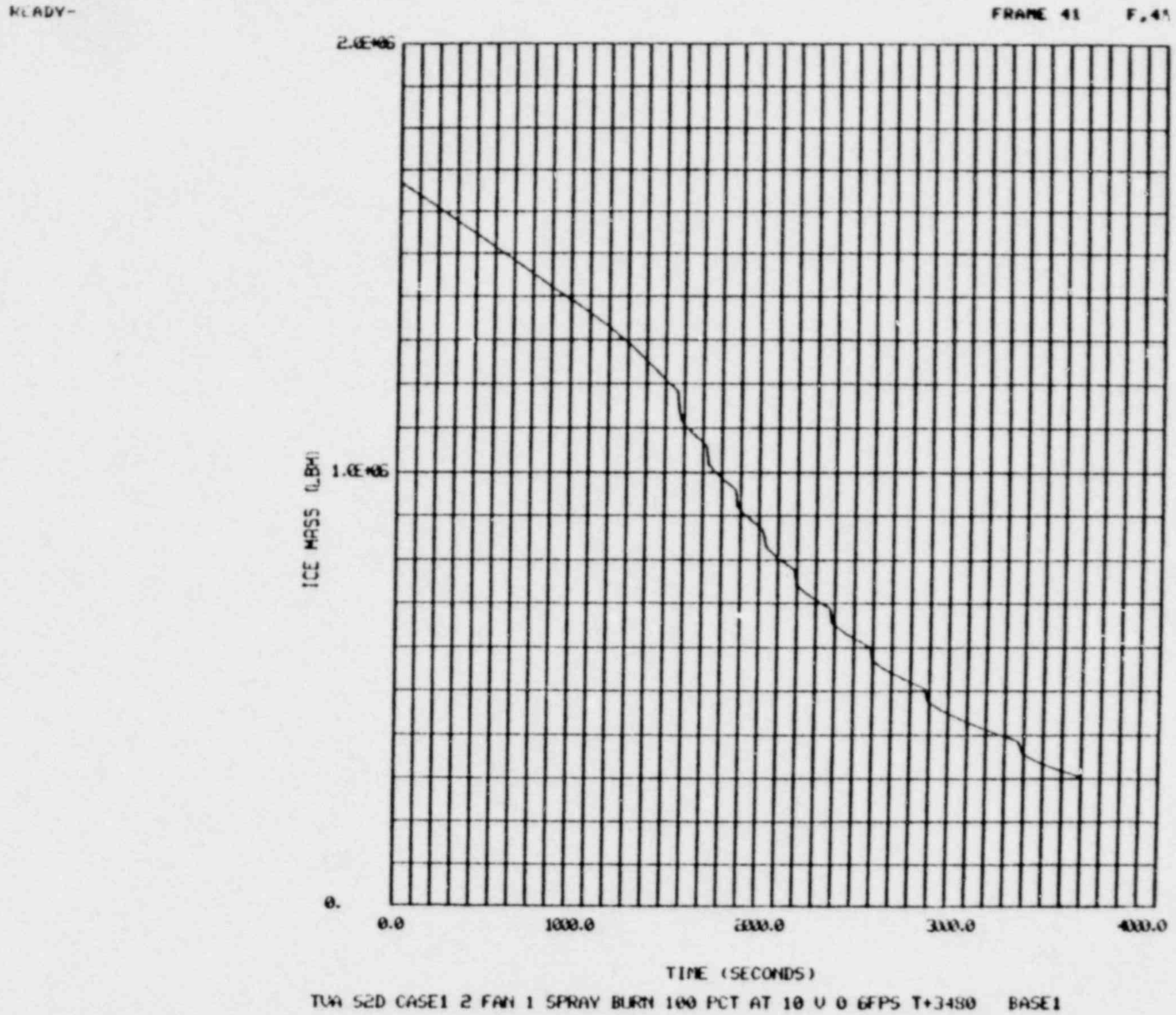


Figure 10. Base Case Ice Mass

spray, the pressure and temperature spikes were rapidly attenuated between burns. The pressure was decreased to its pre-burn value roughly 2 minutes after the burn occurred. After the last ignition of hydrogen, which occurs approximately 6800 seconds after the accident is initiated, there was roughly 300,000 pounds of ice left in the ice condenser section (representing at least $40x10^6$ Btu's in remaining heat removal capacity).

In summary, the results of the TVA base case analysis show only a modest increase in containmment pressure, on the order of 4-6 psi, with the containment remaining well below the estimated failure pressures. The burning criterion used in the analysis caused virtually all of the burning to occur in the lower compartment, thereby gaining the advantage of heat removal by the ice bed. It should also be noted that each burning cycle involved the combustion of only 100 pounds of hydrogen, or roughly $6x10^6$ Btu's of energy addition. By burning at a given concentration in the lower compartment (where one might naturally assume hydrogen concentrations to be higher since this is the area of hydrogen release) there is also the advantage of burning less total hydrogen at a time since the lower compartment volume is only around 1/4 of the total containment volume which allows for expansion of the hot gases to the rest of the containment free volume.

TVA has also performed preliminary sensitivity studies to determine the effects of ignition criteria and safeguards performance on the containment response. Results of several of these studies are shown in Table 2.

The sensitivity analysis performed to date demonstrates that 1) the ignition criterion, at least within the bounds chosen, has little effect on the containment pressure; 2) partial vs full operation of the air return fans makes little difference; 3) ice condenser heat removal is effective in reducing pressure; and 4) without any fan operation to assure mixing, the containment pressures due to burning rise dramatically to the point where containment loses structural integrity. It should be noted that the case which considered only enough ice exists to reduce the pressure spike for two burns (out of seven) is non-mechanistic; i.e., it is not representative of the actual S2D scenario. However, it does importantly demonstrate that even without ice, the containment pressure, with the assumed igniter operation, remains below the estimated failure pressure. This serves to indicate some insensitivity to whatever accident scenario is chosen.

TVA has also provided an estimate of the containment shell temperature rise for two of the cases analyzed, the base case and the case where no ice remains in the ice bed after

TABLE 2 PRELIMINARY CONTAINMENT ANALYSIS SENSITIVITY STUDIES

	Total H_2 Burned (lb)	Peak Temp. (°F)			Peak Press (Psia)	
		Lower Compartment	Ice Bed	Upper Comp.	Lower Comp.	Upper Comp.
1. Base Case	900	2200	1200	150	26.5	28.5
2. H_2 Ignition and Propagation @ 8%	1050	1200	700	260	28.5	30.5
3. 1 Air Fan	900	2200	1350	160	26.5	29.5
4. No Ice*	850	2400	2000	270.	41	41
5. No Air Fans	1200	2370	2580	1090.	46.4	92.4

* Ice exists only for the first two of 7 burning cycles.

the first two burns. The calculation assumed that the atmosphere loses heat to the containment shell by radiation and convection and to the ice condenser when ice exists. Due to the relatively low temperature of the atmosphere in the dead ended compartment, it was assumed that only the water vapor emitted and absorbed radiation. Simple finite difference equations were used to represent the heat balances for the containment shell and atmopshere for a time increment, Δt. The gas and shell temperatures were updated at the end of each time step and the calculation repeated until thermal equilibrium was reached. For the base case analysis the mean temperature of the shell was estimated to increase by approximately 72°F. For the transient with limited initial ice mass the total temperature rise in the containment shell was estimated to be 101°F. An estimate of the temperature distribution through the shell was made using the TAP-A computer program to model transient heat conduction. The temperature difference calculated across the wall for the base case and limited ice mass case was approximately 21°F and 32°F, respectively.

TVA has also provided information regarding the consequences of a detonation occurring in the upper compartment of the containment. For the assumption of a 100% zirconium-water reaction in the core, the upper compartment would have the following composition: hydrogen - 23 v/o, air - 63 v/o, nitrogen - 14 v/o (from the accumulators). This mixture is detonable since the hydrogen concentration is greater than 19 v/o.

A detonation will produce two coupled effects on the containment structure. First the detonation shock wave will deliver an impulse loading to the containment wall. This dynamic loading will quickly decay to a somewhat sustained pressure pulse from the expanding gas that has undergone adiabatic heating. Further heat transfer from the gas to the wall and to internal structures will eventually cause decay of this secondary pressure pulse.

TVA has extrapolated the results of detonation calculations appearing in WASH-1400 (for a dry containment) to the case of an ice condenser containmment, on the basis that the hydrogen concentration is similar and assuming that the nitrogen from the accumulators plays a similar role in the detonation process as the post-accident water vapor present in a dry containment. Following a procedure of WASH-1400, containment failure is predicted to occur if $I\Delta t \geq 0.32\ P_D T$, where I is the time of detonation (sec), P_D is the load that produces the maximum elastic deflection for the structure (psia) and T is the natural period of the ice condenser containment. For the ice condenser containment, $0.32\ P_D T$ is equal to 0.38 psia-sec. Based on the impulse loads from WASH-1400, $I\Delta t$ values more than an order of magnitude lower are obtained.

TVA concludes, therefore, that containment failure due to a detonation shock wave is not expected to occur.

The analysis performed to date by TVA is preliminary in nature. TVA plans to refine the analytical models in the CLASIX code, do other parametric analyses and evaluate other accident sequences, in assessing the effectiveness of a hydrogen ignition system. These additional analyses will be discussed in a future report.

2.4.1.2 NRR/Battelle-Columbus Results

As previously discussed in section 2.3.1, under NRR Short Term Efforts, the staff has obtained technical assistance from BCL to analyze the containment response to the combustion of hydrogen for the small loss of coolant accident scenarios (S2D). The calculations were performed using the MARCH code with a 2-volume model of the Sequoyah containment. The MARCH code model consisted of a lower and upper compartment, with the ice bed modeled as a junction and not as a separate volume due to code constraints. Code features include models for ice bed heat removal, structural heat sinks, return air fans and containment sprays. The sprays in the ice condenser model, however, are presently assumed, due to code constraints, to have heat removal capacity only after the ice is completely melted.

The results of analyses performed by Battelle using the MARCH code are summarized in Table 3. The calculations are preliminary and do not represent final confirmatory analyses of hydrogen igniter performance. All of the results presented were from analyses based on the S2D transient, the same accident sequence as that assumed in the TVA analysis. The containment peak pressure values shown in Table 3 are the pressures calculated due to hydrogen burning up until the time reactor vessel head failure occurs. Results beyond this time are the purview of studies into core melt accident transients and are not relevant to degraded core accident analysis. The actual containment peak pressure value given is that pressure calculated assuming heat removal mechanisms (e.g., ice bed, sprays) function to reduce the energy addition and subsequent pressure rise. The adiabatic pressure given for each case is the pressure calculated to exist assuming no heat removal occurs during the hydrogen burn. By comparing the values for each case one can identify the relative effectiveness of the heat sinks, knowing that the initial containment pressure prior to burning was approximately 20 psia.

As can be seen from the table, the pressure rise following a hydrogen burn is approximately 3 psi when ice remains in the containment. As noted in Table 3, case 6 was performed using the non-mechanistic assumption that the ice

Table 3. BATTELLE ANALYSIS OF H_2 BURNING IN SEQUOYAH CONTAINMENT

Case	H_2 Ignition Setpoint (%)	H_2 Burn limit (%)	Burn Time (sec)	Containment Peak Pressure (Psia)	
				Actual	Adiabatic
1	10	0	1	≃ 23	58.
2	10	0	25	≃ 22	58.
3	12	0	1	≃ 24	64.
4	8	0	25	≃ 22	51.
5	8	4	1	≃ 22	36.
6	10	0	1	≃ 31	79.

Case 6 - Ice Bed Melted Before Burning Occurs.

bed was melted before the onset of hydrogen burning. For this case the containment peak pressure was seen to increase to 31 psia, demonstrating that the upper compartment sprays are also effective in removing the combustion energy addition.

The shape of the pressure transient calculated using MARCH was similar to that calculated by TVA using CLASIX in that hydrogen combustion was calculated to occur in the lower compartment in a series of burns. Following each burn and concomitant pressure spike, the containment pressure was rapidly reduced until the next burn was calculated to occur.

Although the analyses performed at Battelle are preliminary, they provide further support that given certain conditions igniters will function to limit the containment pressure increase due to hydrogen combustion such that the containment structural integrity will be maintained. What remains to be investigated by further analysis is how wide a range of accident conditions the igniter system will serve to mitigate.

2.4.1.3 R&D Associates Results

In addition to the analyses provided by TVA and BCL, we have received a letter report (dated August 4, 1980) prepared by R&D Associates on hydrogen combustion in the Sequoyah containment. The R&D Associates report is included as Attachment 1.

The R&D Associates report addresses two concerns (stated below) that were part of their overall assessment of the ultimate strength analysis of the Sequoyah containment. The two concerns are:

1. How would the analyses and results be altered if the stresses are caused by ignition/detonation of 300-600 Kg of hydrogen distributed uniformly and nonuniformly in the containment.

2. To what extent can distributed ignition sources mitigate the effects of hydrogen?

In their discussion, R&D Associates contends that (a) the complete adiabatic combustion of 300 Kg (660 pounds) of hydrogen uniformly mixed in the containment would result in containment failure; (b) a non-uniform distribution of the hydrogen could lead to detonable mixtures which would also result in containment failure; and (c) the use of igniters constitute an uncertain means of pressure control when considering the uncertainties in the rate of hydrogen generation and the rate and extent of mixing in the containment.

TVA has responded to the R&D Associates report. TVA agrees with the analysis of the adiabatic burning of 300 Kg (660 pounds) of hydrogen, and points out that they have previously reported that an ice condenser containment can accommodate the adiabatic burning of approximately 450 pounds of hydrogen.

TVA further states that calculational techniques have progressed beyond the overly conservative assumption of adiabatic burning and that more mechanistic analyses are being performed. For example, the CLASIX code accounts for the rate of hydrogen release from the reactor coolant system, the transport of constituents (hydrogen, oxygen, nitrogen, steam) throughout the containment, the effects of heat removal mechanisms and the performance of a distributed ignition system, to arrive at a more realistic assessment of the containment response.

TVA's developmental program includes igniter tests and containment analysis to overcome technical difficulties and determine the efficacy of the proposed distributed ignition system as a viable means for hydrogen control. Furthermore, TVA has studied, and is actively studying, alternative hydrogen mitigation schemes, including continuous inerting of the ice condenser containment and the injection of halon as a post-accident inerting agent.

TVA has also analyzed the consequences of detonation loads on the containment structure. A 100 percent zirconium-water reaction was assumed which gives a hydrogen concentration of about 25 percent by volume. Based on the results of their analysis, TVA concluded that failure of the containment due to a detonation shock wave is not expected to occur. However, TVA states that the resulting relatively long term pressure due to the oxidation of a large amount of hydrogen would exceed the ultimate capability of the containment. This same conclusion would also obtain from a calculation of the adiabatic burning of 600 Kg of uniformly mixed (18 v/o) hydrogen.

TVA however did conclude that the containment can withstand, within the ultimate capability of the containment, both the detonation load and the long term pressure from the adiabatic burning of 18 volume percent hydrogen distributed uniformly in the lower compartment.

2.4.1.4 Comparison of Results

In evaluating the results of the various analyses, the point to remember is that the calculations performed to date are preliminary in nature and do not represent the final analytical assessment of hydrogen ignition systems.

The TVA results using CLASIX are based on an unverified, unreviewed code, which is still under development. This calculational technique, in the staff's opinion does hold considerable promise for estimating the containment transient reponse due to hydrogen combustion since it already contains many basic features necessary to perform the calculation. Furthermore, the results from CLASIX tends to be confirmed by the results from the MARCH code.

The MARCH code is also largely unverified but does provide the capability to estimate the transient response due to hydrogen combustion within containment. The MARCH code, which has not been formally released and documented, does not appear to have the capability of the CLASIX code with regard to containment calculations. This is understandable since containment calculations are only one aspect of this code, which also models the reactor coolant system. Nevertheless, the code represents a substantial improvement over hand calculations which conservatively assume the burning of hydrogen and containment pressurization to be an instantaneous adiabatic process.

With regard to the R&D Associates report included as Attachment 1, our comments are presented below.

Part (a) of the report indicates that containment failure is likely if 300 kg of hydrogen were assumed to burn instantaneously (or adiabatically) inside the containment. This corresponds to approximately a 35% (based on Zr mass of 43,000 pounds) of core-cladding reaction.

The assumed burning of 600 Kg with twice the energy addition to containment is also shown to result in containment failure.

The staff generally concurs with these conclusions, considering the basis of the calculations, and cites that similar conclusions were reached in the staff's Commission paper, SECY-80-107 (February 22, 1980). Specifically, the staff concluded that calculations based on the instantaneous, adiabatic burning of hydrogen would demonstrate that an ice condenser could only tolerate a cladding reaction of 25%.

At this time the staff feels that the simplified analysis contained in the R&D Associates report does not lend itself to assessment of the mitigation potential of TVA's distributed ignition system. Although there are areas where information is lacking, the staff and TVA are pursuing these concerns both experimentally and analytically.

Part (b) of the report is technically correct but it may be overly conservative to evaluate the effects of such large pockets of concentrated hydrogen without examining the likelihood and timing of their formation.

The postulated 300 Kg of hydrogen (118,000 cu/ft at standard conditions) represents a pocket of 247,000 cu/ft when diluted with air to its detonation limit. This represents half of the volume of the lower compartment. It is difficult to conceive how such a large volume could form without contacting some of the igniters to be distributed in this region of the containment.

The mixing of air in the lower compartment can be expected to take place on a time scale governed by recirculation fan capacity, which provides for a change of air in the lower compartment every five minutes. Hydrogen evolved on a time scale longer than this can be expected to be reasonably well mixed by the time it leaves the lower compartment.

In the illustrations given in the R&D Associates report, the rate of introduction of the hydrogen (1% reaction per minute) leads to concentrations in the lower compartment below 10% at equilibrium. It takes over ten minutes to approach equilibrium and with effective igniters present, ignition would be likely before a 10% concentration was reached. The hydrogen concentration in the lower compartment would then revert to a lower level and the buildup would start again, resulting in a series of small burns.

The fact that the hydrogen would be free of oxygen at its point of introduction and then become diluted with oxygen as it is distributed throughout the lower compartment suggests that relatively small masses of hydrogen may be ignited near the upper flammability composition limit if constant sources of ignition are present. These ignitions would take place before there is much buildup of hydrogen throughout the lower compartment. When the staff takes these additional aspects of heterogeneity into consideration, we feel that igniters are a promising hydrogen control feature.

2.4.2 Structural Response

Three independent analyses of the Sequoyah containment were performed by the licesnee (TVA), Ames Laboratory and R&D Associates to determine the containment capacity to withstand a postulated hydrogen burn/detonation. All three analyses were based on use of the elementary thin shell theory with variations in assumptions to account for the stiffeners and use of material strength data.

The TVA analysis neglected the presence of the stiffeners and adopted the actual strength (lowest tested strength) of the steel material instead of the minimum code specified yield strength. TVA concluded that the vessel capacities at yield and ultimate strength of the material were 33 psig and 43.5 psig, respectively. The TVA study also concluded that based on the 43.5 psig ultimate strength, it could withstand the consequences of a postulated hydrogen combustion equivalent to 25% metal-water reaction. This analysis is simple and conservative in not accounting for the strength contribution of stiffeners. However. use of the actual mill-test strength data rather than the code specified minimum gives a greater containment structural capacity.

At the request of NRC staff, Ames Laboratory conducted a preliminary quasi-static analysis of the ultimate strength of the Sequoyah containment. The analysis concluded that gross yielding of the shell, including stiffeners, would occur at a static pressure of 36 psig. The total ring and stringer stiffener areas were smeared to form an equilvaent shell for stress calculations. In effect, this amounts to assuming that the rings and stringers are equally effective as the shell membrane at the yield load. An ultimate burst analysis was also performed, however, the result of such an analysis is not considered appropriate because of the uncertainty about the limiting ductility of the shell.

Ames Laboratory also concluded a preliminary analysis with simplifying assumptions of the ultimate dynamic strength of the Sequoyah containment subject to a postulated hydrogen detonation in a lower compartment. Since the loading due to such a localized detonation is not axisymmetric, circumferential bending is assumed to occur and the behavior of the stiffened shell will most probably be dominated by the rings adjacent to the compartment. A typical ring is analyzed with material and geometric nonlinearities included. The dynamic loads are idealized as (1) an initial impulse which approximates the detonation phase and (2) a venting dynamic pressure which decays linearly from a maximum to zero in 0.030 seconds. The ANSYS computer code was used to obtain onlinear transient solutions. By conservatively assuming that the ductility capacity of the vessel (maximum strain divided by yield strain) is two, the maximum value of the venting pressure is found as 31 psig.

Ames Laboratory's quasi-static analysis gives a capacity value similar to that of TVA (36 psig versus 33 psig). Because of its use of the smearing assumption, the 36 psig value is more optimistic than the 27 psig obtained in the R&D Associates' analysis discussed below. The ultimate dynamic strength analysis referred to above is based on several unconfirmed assumptions. The result of such an analysis (i.e., 31 psig) is best viewed as a reasonable estimate of the likely containment capacity due to a localized hydrogen detonation.

After reviewing the Ames Laboratory's quasi-static analysis of the Sequoyah containment and performing its own analyses, R&D Associates concluded in its report that gross yielding of the shell would occur at about 27 psig. The rationale employed by R&D Associates was that the stringers are only partially effective and the rings are totally ineffective in resisting internal pressure in the linearly elastic range. Locally high bending stresses were calculated to exist near the rings and stringers but were not considered to affect the vessel capacity for one-time loading. In essence, therefore, the 27 psig (based on Von Mises Failure criterion) represents the theoretical strength of an unstiffened 690 inch radius by 1/2 inch thickness cylinder of infinite length.

Of the three analyses, the work performed by R&D Associates gives the most conservative result because code specified minimum material yield value were used and only partial effectiveness of the stringer stiffeners was assumed. Simplified individual panel analyses were also performed by R&D Associates but were not considered to be meaningful with respect to the evaluation of overall containment capacity. A refined finite element analysis modeling the entire structure is presesntly underway as a part of the ongoing Ames Laboratory effort.

With regard to potential gross vessel leakage at stresses above the design stress and up to yield stress, while no experimental data are available at this time to provide a basis for precluding such leakage, it is our considered opinion that as long as stresses are kept below or at the yield range, the above mentioned gross leakage should not occur up to the lower-bound vessel capacity (i.e., in the range of the 27, 33 and 36 psig) estimated by the three independent analyses.

Another simplified Sequoyah containment analysis was performed by the staff of the Office of Nuclear Regulatory Research. The study predicted a capacity of 34 psig at gross yield of the vessel. Since the study is also based on a set of unconfirmed assumptions, it does not significantly add credence to the overall capacity estimates provided by the three previously discussed analyses. Having reviewed the R&D Associates' analysis, TVA concurred with the results of the analysis except for the use of material minimum yield strength. TVA also noted that the flat plate analysis and testing programs proposed by R&D Associates might not be useful. This is consistent with our view on the same subject discussed above.

In summary, the Sequoyah containment has been calculated to have a lower-bound internal pressure capacity ranging from 27 psig to 36 psig, compared to its design pressure of 10.8 psig (equivalent safety factors of 2.5 to 3.3). For the case of localized hydrogen detonation considered, a 31 psig vessel capacity was estimated based on several unconfirmed assumptions(an equivalent safety factor of 2.8). The vessel was qualified by actual test to 13.5 psig (1.25 design pressure).

2.4.3 Role of Distributed Ignition System

TVA proposes to install a distributed ignition system in the Sequoyah containment for additional hyrogen control, in advance of any rulemaking decision on degraded core accidents. The system will consist of glow-type igniters distributed throughout the upper and lower compartments of the containment. They will be activated (and remain activated in the event of a LOCA). It is TVA's intention that the system will serve to in-initiate controlled burning of lean hydrogen mixtures in the containment.

It is also considered desirable to initiate combustion in the lower compartment since the affected containment volume is only a small fraction of the total containment volume and the concommitant energy release from a hydrogen burn may be more readily accommodated by heat removal in the ice bed and by the containment spray. As discused above, TVA will test the igniters to determine their behavior and effectiveness in post-accident environments, and analyze the containment response to quanity benefits and identify any risks associated with the installation of a distributed ignition system.

TVA has also committed to evaluate the effectiveness of the hydrogen monitoring system, and expand the system to provide information on the concentration of hydrogen throughout the containment for the accident duration. As discussed previously in Section 2.2.2, TVA has committed to study alternative hydrogen control systems as part of their overall longer term effort.

2.4.4 Additional Views

We have received additional views from Charles N. Kelber, Assistant Director, Advanced Reactor Safety Research (DRSR) (Section 2.4.4.1), and Robert M. Bernero, Chief, Probabilistic Analysis Staff (RES)(Section 2.4.4.2). The viewpoints of these individuals are quoted below.

2.4.4.1 Consideration of Hydrogen Igniters at Sequoyah

"In the context of considering accidents involving only partial degradation of the core, as at TMI-2, with intermittent operation of safety systems, it is my view that the deployment of hydrogen igniters should be carefully reviewed by a containment systems analysis to make sure that their use will be effective and that there will be no negative effect on safety. The chief considerations are that the burning be controllable with sufficxient accuracy to assure that undesirable flame propagation, e.g., downward propagation, does not occur, and that the atmosphere be well enough mixed that unstable burns, such as turbulent deflagration, that can lead to high overpressures, are highly unlikely. In addition, the strategy of operation of the system should assure that heat removal sources such as the Ice and the Containment Sprays are active, effectrive, and available at the time of burning.

"As I see it, the requirements are that the operator know the concentration of hydrogen is below 9%, that burning should not, however, strt until the concentration is somewhat above 4%, that if the intention is to burn in the lower compartment, means be provided to assure good mixing in that compartment, and that appropriate interlocks be provided to assure heat removal.

"Such a containment systems analysis should also compare the utility of alternative control methods, such as Halon injection, or a water fog generated by modify8ing a spray header to produce very find droplets (of the order of a few to ten microns in diameter) which will then remain suspended in the lower and upper compartments and effectively quench a hdyrogen fire.

"In the wider context of core melt accidents, such as may be required by a degraded core cooling rulemaking, consideration may have to be given to means of presure relief, most likely via a filtered venting system. While it may be premature at this time to enter into such considerations in any detail, the igniter system, or its equivalent, should be such as not to preclude or adversely affect the proper functioning of such a system if it is decided in the future to employ one."

2.4.4.2 Overall Risks and Hydrogen Control in the Sequoyah Plant

"The Sequoyah Plant has undergone a unique form of analysis in parallel with the OL review. Sequoyah was one of four plants selected for probabilistic risk analysis (PRA) in the Reactor Safety Study Methodology Applications Program (RSSMAP). The Sequoyah Plant was the first of the four to be analyzed and a draft report on this analysis was prepared in late 1978. Work on the other three plants shows areas where the Sequoyah work might be refined but the other work did not develop any knowledge that would invalidate the Sequoyah RSSMAP results. Reports on all four of the RSSMAP studies are not in final preparation for publication in September 1980.

" A comparison of the overall risk of the Sequoyah design was presented to the Commission in SECY-90-283, dated June 12, 1980, as part of the Indian Point Tsk Force report. Figure 7 from SECY-80-283, attached, presents the early fatality risk profiles for several designs including Sequoyah if one compares them all at the same site (Indian Point). That analysis, based on the Reactor Safety Study (WASH-1400) and RSSMAP shows the overall risk of the Sequoyah design to be about the same as the Surry PWR design.

"The Sequoyah RSSMAP study identified interfacing systems LOCA and emergency cooling and containment recirculation failure scenarios as the dominant risk sequences. Steps have already been taken by the owner to suppress these dominant accident sequences by reducing the probability of the occurrence. An analysis of the RSSMAP results which was discussed in Enclosure, SECY-80-107B dated June 20, 1980, showed that a risk reduction of about a facator of four could be achieved by inerting the continment. This would esliminate the rapid combustion of hydrogen as a substantial contribution to containment failure from overpressure in the dominant accident sequences. It appears that approximately the same level of risk reduction could be achieved if measures were taken to assure combustion of hydrogen as it was released to the containment. Slow combustion of the hydrogen would provide more time for available heat sinks to absorbe the heat of combustion. Removal of the hydrogen and oxygen by combustion would reduce their partial pressures somewhat cancelling the effect of the heat of combustion in raising containment pressure. There is nothing in the RSSMAP analysis to suggest that controlled ignition of the hydrogen in containment could substantially increase risk in the Sequoyah design, although a specific analysis would be needed to assess the matter. This presumes, of course, that the installation and control of igniters does not somehow compromise the operation of some other safety system."

2.4.4.3 Preliminary Assessment of the Use of Igniters as a Method of Hydrogen Control in the Sequoyah Nuclear Plant

The staff has had certain members of the Brookhaven National Laboratory (BNL) working for several months on assessments of hydrogen control measures for the Zion and Indian Point plants. To benefit from expertise developed in conjunction with that work, we requested their review of the proposed use of igniters at the Sequoyah Nuclear Plant.

Because of the short duration of the BNL review, they were not able to arrive at our definitive conclusions. Their future involvement in this effort is expected to be more useful. A copy of the BNL report, dated August 8, 1980 is provided in Attachment 2.

2.5 ACRS Views

The ACRS has considered the general question of the need for improved hydrogen management capability at nuclear power plants and the specific question regarding acceptability of the interim distributed ignition system proposed by TVA.

In its "Report on TMI-2 Lessons Learned Task Force Final Report," dated December 13, 197, the ACRS stated that:

> "The ACRS suppots this recommendation. However, the Committee believes tht the recommendation should be augmented to require concurrent design studies by each licensee of possible hydrogen control and filtered venting systems which have the potential for mitigation of accidents involving large scale core damage or core melting, including an estimate of the cost, the possible schedule, and the potential for reduction in risk.
>
> The ACRS agrees with the recommendation made by the Lessons Learned Task Force in NUREG-0578 that the Mark I and Mark II BWR containments should be inerted while further studies are made of other possible containment modifications in accordance with the general recommendations in this category. The ACRS also recommends that special attention be given to making a timely decision on possible interim measures for ice-condenser containments."

The ACRS also considered the interim distributed ignition system proposed by TVA during the July 1980 meeting. The ACRS concluded that "Though the work accomplished to date is limited in scope, these studies are definitely responsive to the Committee's recommendations on these points." The Committee further stated in its letter of July 15, 1980, that in its opinion, "...their present incomplete status need not delay the issuance of a full power operating license."

3. CONCLUSION

The NRR conclusions relative to hydrogen control measures for the Sequoyah Nuclear Plant are detailed below.

The implementation of the short term Lessons Learned items at the Sequoyah Nuclear Plant and other operating nuclear plants has significantly reduced the likelihood of a degraded core accident which results in large releases of hydrogen.

TVA has proposed to further improve safety margins relative to hydrogen control by designing and installing an interim distributed ignition system. We believe the proposed system has the potential for improving the hydrogen control capability in ice condenser plants and plan an accelerated review of the proposed system. We expect to complete our review of the system by November 1980.

In view of the potential for safety improvements associated with the proposed distributed ignition system, there are several options available at this time. These options and the option recommended by NRR are detailed below.

Option A: Hold at 5%

Under Option A, TVA would be restricted to its present 5% power limit until such time as the NRC review and approval of the distributed ignition system (or other mitigative measures, should the igniters prove to be unacceptable).

Option B: Nominal 50% Limit

The maximum power level of the reactor should be limited to 50% of full power until questions concerning the net safety benefit of the distributed ignition system proposed by TVA are resolved to the satisfaction of the NRC.

If the licensee requests authorization for short periods of power operation above 50% to meet testing requirements or for other reasons, such requests would be considered on an individual case basis.

Option C: Limited 100%

Under this option, TVA would be authorized (in terms of H_2 control) to proceed to 100% power, with a license condition that, if the NRC has not concluded by 1/1/81 (date is exemplar) that distributed igniters are sufficient (or that some alternative is), then the full-power operation would cease.

Option D: Unlimited 100%

Under Option D, 100% power would be authorized without a time limit.

Of these four options, we recommend Option B. In our opinion, short-term operation at 50% power poses no undue risk and has a considerable benefit to TVA in checking our various phases of its steam cycle. TVA plans a two-week outage after the initial 50% test. We expect to have completed the major portion of our review of TVA's safety analysis by that time. The only remaining aspect would be completion of the confirmatory ignition studies at LLNL. At present, we believe that a complete safety evaluation by the staff will not be available until November 1980. This allows one month to evaluate the LLNL work. Thus, under Option B, Sequoyah could possibly operate about two to three months at 50% power, without a final staff position on additional H_2 control systems. We believe that there is reasonable assurance of no undue risk for this mode of operation, on the basis that:

1. application of remedial measures since TMI-2 have lessened the likelihood of a degraded core;
2. long-term operations above 50% power would not be considered until we had reached a firm conclusion whether the distributed ignition system had a high likelihood of NRC approval; and,
3. any limited operations above 50% power would be authorized on a very limited time basis.

R & D ASSOCIATES
Post Office Box 9695
Marina del Rey,
California 90291

4 August 1980

Nuclear Regulatory Commission
1717 H Street, N.W.
Washington, D. C. 20555

Attention: Commissioner Victor Gilinsky

Dear Victor:

Enclosed is the second part of our report on ice condenser plant containment response to hydrogen production and burning and mitigation by igniters. If you have any questions or comments, please call. We expect to see you and John Austin on Friday.

Best regards,

Harmon

Harmon W. Hubbard

HWH/dl

Enclosure: "Hydrogen Problems in Sequoyah Containment,"
August 1980.

ATTACHMENT 1

HYDROGEN PROBLEMS IN SEQUOYAH CONTAINMENT

INTRODUCTION

This letter report completes the RDA response to a request from the Nuclear Regulatory Commission to critique the ultimate strength analysis of the Sequoyah containment. This second report deals with the last two tasks of the work statement.

1. How would the analyses and results be altered if the stresses are caused by ignition/detonation of 300-600 Kg of hydrogen distributed uniformly and nonuniformly in the containment?
2. To what extent can distributed ignition sources mitigate the effects of hydrogen?

A preliminary discussion of these topics was attended by Commissioner Gilinsky and Dr. John Austin at RDA on 18 July 1980.

RESULTS

1. a) 300 kg of H_2 gas mixed uniformly with the air and steam (if less than 40 percent steam) in the Sequoyah containment volume following an accident would be completely combustible if ignited (see Figure 1). This complete combustion could occur so rapidly as to exceed the capacity of the available heat removal processes, and could produce a pressure as high as 5.5 atmospheres, thus rupturing the containment (see Table 2). The combustion of 600 kg of H_2 would of course have more severe consequences.

   b) A nonuniform distribution of 300 kg of H_2 present in the containment would consist of parcels of gas richer in H_2 than the uniform distribution. If these separated parcels formed while the blowers were operating, they would probably be mixed, combustible and perhaps detonable. If they were all detonable and all ignited, the damage to the containment would be worse than that due to ignition of a uniform mixture. If the gas parcels were not detonable, the pressure upon combustion would probably be at least as high as the uniform distribution. Under some circumstances, it would be possible to collect pockets of gas too rich in H_2 to burn. As the outer edges of such pockets mix with air, partially combustible mixtures would form. The results of igniting such a distribution would clearly depend on the sizes of the parcels and the timing.

It should be noted that harmless mixtures of H_2, air and steam may become highly combustible or detonable as steam is condensed out (see Appendix B). Thus one mechanism employed for removing heat from the containment also removes the combustion inhibitor from the containment.

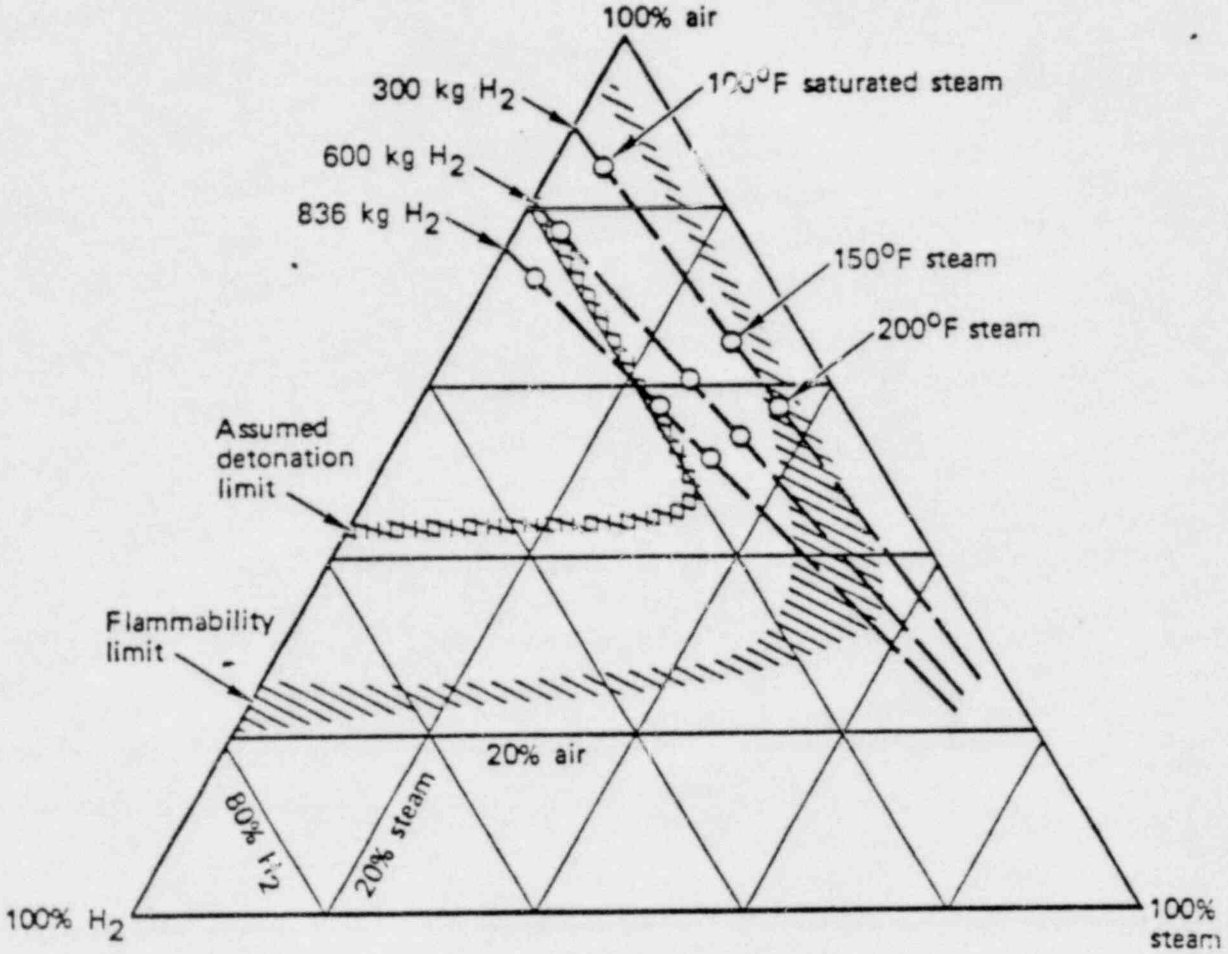
2. If the rate of hydrogen formation is sufficiently low, and the mixing of H_2 is complete and rapid so that all the gas in the containment gradually increases in H_2 concentration, then the presence of enough igniters could prevent overpressurizing the containment. This would be accomplished by releasing the heat of combustion at low concentrations over a long enough period of time to be handled by the heat removal equipment. However, if the Zr reaction rate is high relative to heat removal processes, then igniters might only delay containment failure. Table 3 shows that a 1 percent per minute Zr reaction rate, accompanied by the burning of hydrogen at its rate of formation, would match the steady-state heat removal capacity of the RHR equipment.

If the H_2 is not thoroughly mixed, then there is a possibility of igniting a detonable pocket of gas with an igniter. If left to its natural end, such an H_2-rich pocket could disperse below the detonation limit (∿20 percent H_2) when its ignition would cause less of a problem.

Since the possible rates of generation of H_2 following an accident and the rate, place, and degree of mixing with air are highly uncertain, the use of igniters can only be an uncertain means of pressure control. Improper use might be detrimental rather than helpful. On the other hand, if it is assumed that there are many unavoidable ignition sources in the containment, it is certainly true that control of the time and place of ignition is preferable to chance. In this sense the use of igniters seems beneficial.

COMMENT

It is our opinion that the uncertainties in H_2 generation and mixing are so dependent on hardware details and scenarios that they are unlikely to be greatly reduced by further work. For this reason we believe it may be a better use of resources to explore thoroughly the feasibility of using an inert atmosphere in the containment, so as to avoid the hydrogen burning problem.



Limits of flammability and detonation based on Shapiro and Moffette WAPD-SC-545, as reproduced in WASH 1400.

Figure 1. Uniform mixtures in the Sequoyah containment vessel.

TABLE 1. INPUT DATA FOR SEQUOYAH PLANT

1.	Free volume of containment vessel(a)	3.2×10^4 m^3
	Weight of contained air at 27°C, 1 atm.	3.7×10^4 kg
	Gram moles of air	1.3×10^6
	Gram moles of oxygen	2.7×10^5
2.	Weight of zirconium in core(b)	1.9×10^4 kg
	Gram moles of zirconium	2.1×10^5
3.	Yield of 100% Zirconium-water reaction	
	Weight of hydrogen	836 kg
	Gram moles of hydrogen	4.2×10^5
	Heat of reaction(c), $Zr + H_2O$	1.1×10^{11} joules
	Heat of H_2 burn(d) (to form liquid H_2O)	1.2×10^{11} joules
	Total heat of reaction + burn	2.3×10^{11} joules

4. Molar quantities and partial air pressure of saturated steam in containment

At 100°F (38°C) vapor = 8.1×10^4 moles = 0.06 atm.
150°F (66°C) = 5.9×10^5 moles = 0.25 atm.
200°F (93°C) = 8.4×10^5 moles = 0.78 atm.

NOTES:

(a) Sequoyah Nuclear Plant, Preliminary Safety Analysis Report (PSAR), Table 5.2-1 gives the total containment active volume as 1,142,000 ft^3, comprised of 730,000 in the upper compartment, 125,000 in the ice compartment, and 287,000 in the lower compartment.

(b) Sequoyah PSAR, Tabel 1.3-1, gives the clad weight as 41,993 lb.

(c) G. W. Keilholtz, ORNL-NSIC-120, Annotated Bibliography of Hydrogen Considerations in Light-Water Power Reactors, Feb. 1976, Table 1, Heat of Reaction = 122 to 137 kcal/mole Zr.

(d) Lewis and Von Elbe, p. 685, 68.3 kcal/mole H_2O.

TABLE 2

	H_2 Quantity		
	300 kg	600 kg	836 kg
1. Percent Zr Reaction	36%	72%	100%
2. Moles H_2	$1.5x10^5$	3.10^5	$4.2x10^5$
3. Partial Pressure @ 300°k (atmospheres)	0.12	0.23	0.32
4. Molar Ratio $\frac{H_2}{Air}$, Uniform Distribution	0.11	0.23	0.32
5. Detonatable (D) or Combustible (C)[a] Mixture, no steam present	C	D	D
6. H_2 Concentration Multiplier Required relative to uniform mixture[a]			
a) to reach detonation regime	2.0	1.0	1.0
b) to reach stoichiometric ratio of 0.42:1 for H_2:air	3.8	1.8	1.3
7. Steam Vapor Pressure Required:[b]			
a) to prevent detonation of uniform mixture	0	0.1 atm	0.4 atm
b) to prevent combustion of uniform mixture	0.9 atm	2.0 atm	2.3 atm
8. Energy Release in 100% Combustion, Joules (liquid water product)	$4.3x10^{10}$	$8.6x10^{10}$	$1.2x10^{11}$
9. Final Absolute Pressure in Adiabatic Combustion (Initial Air Partial Pressure 1 atm, Initial Temperature 300°k)[c]			
a) No steam, 100% combustion	5.5 atm	10.0	13.3 atm
b) No steam, 50% combustion	3.3	5.8	7.3
c) Steam @ 190°F, 50% combustion	4.1	6.5	8.3

NOTES:

(a) Approximate, based on regimes outlined in Figure 1.

(b) Approximate, based on regimes outlined in Figure 1, plus molar concentrations of saturated steam as a function of pressure.

(c) Assuming products of combustion behave as ideal gases, and assuming a constant-volume reaction.

TABLE 3. HEATING AND COOLING RATES IN SEQUOYAH CONTAINMENT

Time when Fission Product Heat (Cumulative) Equals Total Heat of Reaction	3000 sec
Rate of Heating at the 1% per min Zr Reaction Rate	
Zr Reaction	18.0 MW
H_2 Burning	20.0
Total	38.0 MW
Rate of Fission Product Heating at 2 hours (when ice has been melted in DBA)	27 MW
Steady-state Cooling Capacity of the 2 RHR Heat Exchangers[a]	67 MW
Net Margin of Cooling Capacity (Beyond Chemical Reactions @ 1%/min and Fission Product Heating)	2 MW

NOTES:

(a) Sequoyah PSAR, Table 6.3-2 cites 2 heat exchangers, each having a capacity of 1.15 x 10^8 BTU/h at specified conditions.

APPENDIX A

LITERATURE SEARCH ON EXTENT OF HYDROGEN BURNING AND FLAMMABILITY LIMITS FOR MIXTURES OF H_2, AIR, AND STEAM

In considering the effects of 300 kg to 600 kg H_2 in the Sequoyah containment vessel, questions of lean mixture flammability limits and the extent of combustion are important. The 1976 literature survey by Keilholtz (1) provided citations for most of the sources used in this brief study, and provided much of the available data on flammability and extent of combustion.

EXTENT OF COMBUSTION

Keilholtz states that combustion of 100 percent of the hydrogen will not occur until the hydrogen comprises about 10 vol percent of the H_2-air mixture. A partial combustion data point of 50 percent combustion is quoted for a 5.6 vol percent H_2 mixture in air. This point is attributed to Shapiro and Moffette (2), a reference that we were unable to obtain in the available time. However, Furno, et al. (8) indicate about 90 percent combustion for an initial mixture of 8.5 percent H_2 as compared with 5-10 percent combustion for mixtures of 6.9-7.4 percent H_2. If 300 kg H_2 were uniformly distributed throughout the active volume of the Sequoyah Unit 1 containment vessel, it would constitute a 10 vol percent mixture with air (neglecting steam), and hence could burn completely.

FLAMMABILITY LIMIT

The lean mixture threshold of flammability is given by Keilholtz as 4.1 vol percent H_2 in air but at this concentration, Egerton (3) as well as Keilholtz point out that the flame front is not coherent, and flame propagation is upward only.

Downward propagation begins with a hydrogen concentration of about 9 vol percent (1), (3). Drell and Belles (4) state that a 9 percent mixture will burn completely (a point to be compared with the Keilholtz 10 percent mixture for 100 percent combustion). Even the lean mixture non-coherent flames are postulated to burn a mixture that is richer than the original mixture, because the high diffusion rate of H_2 permits access of additional H_2 to the flame (4). The diffusion rate of H_2 is also important to the dispersal of segregated pockets of hydrogen, and will be discussed later.

STEAM DILUTION

The effects of dilution by steam are potentially important. Drell and Belles (4) state that inert diluents have scarcely any effect on the lean-mixture limit of flammability, where 300-600 kg of H_2 in Sequoyah would be, if uniformly distributed. They claim water vapor has effects similar to CO_2, and they show data of Coward and Jones (5) (which we were unable to obtain) such that only after more than half the mixture is CO_2 does the fraction of H_2 required for flammability begin to increase. These findings are consistent with the ternary mixture chart of Shapiro and Moffette for H_2, air, and steam, wherein the lean mixture flammability limit is at a nearly constant H_2 fraction as the steam content increases from zero to about 50 vol percent.

DETONATION

Shapiro and Moffette indicate a triangular shaped detonation regime in their ternary mixture chart, a regime bounded approximately by a 19 vol percent H_2 line at the lean mixture boundary and a 45 vol percent air line at the rich mixture boundary. Although the original reference was not available to us, it appears that the authors constructed the detonation regime by extrapolating from data on dry mixtures of H_2 and air. We note that Drell and Belles show the range of detonability of H_2 in air from 18.3 vol percent to 50 vol percent H_2. We could find no information on the effects of inert diluents on the detonability of hydrogen-air mixtures, and we note the caption on the Shapiro-Moffette ternary mixture chart: "Assumed Detonation Limits." We conclude that the effects of steam on detonability of H_2-air mixtures are essentially unknown. The nearest information we could find was cited by Keilholtz, and this pertains to detonations in Knallgas-team mixtures (6). Knallgas is a stoichiometric mixture of H_2 and O_2. In reference (6), experiments indicated that a minimum of about 65 vol percent Knallgas in saturated steam at 100°C was required for detonation. This would correspond to about 44 percent H_2.

The occurrence of detonation is also influenced by the size and configuration of the vessel, and the nature of the walls (4,7), which further complicates efforts to predict detonation precisely.

REFERENCES

1. G. W. Keilholtz, "Annotated Bibliography of Hydrogen Considerations in Light-Water Power Reactors, ORNL-NSIC-120, Feb. 1976.

2. Z. M. Shapiro and T. R. Moffette, "Hydrogen Flammability Data and Application to PWR Loss-of-Coolant Accident," WAPD-SC-545, 1957.

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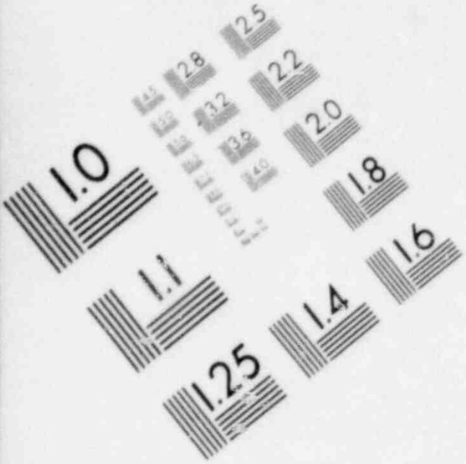
4. I. L. Drell and F. E. Belles, "Survey of Hydrogen Combustion Properties," National Advisory Committee on Aeronautics Report 1383, 1958.

5. H. F. Coward and G. W. Jones, "Limits of Flammability of Gases and Vapors," U. S. Bureau of Mines, Bulletin 503, 1952.

6. J. A. Luker and E. C. Hobaica, "Effect of the Initial Mixture Density on the Formation of Detonation in Knallgas Saturated with Water Vapor," Journal of Chemical and Engineering Data, 6, 2 April 1961, pp. 253-256.

7. L. B. Adler, E. C. Hobaica, and J. A. Luker, "The Effect of External Factors on the Formation of Detonation in Saturated Knallgas-Steam Mixtures," Combustion and Flame, 3, 481, 1959.

8. A. L. Furno, E. B. Cook, J. M. Kuchta, and D. S. Burgess, "Some Observations on Near-Limit Flames," Thirteenth Symposium (International) on Combustion, 1971.



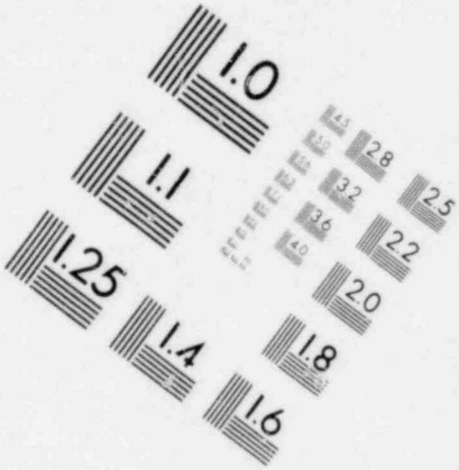
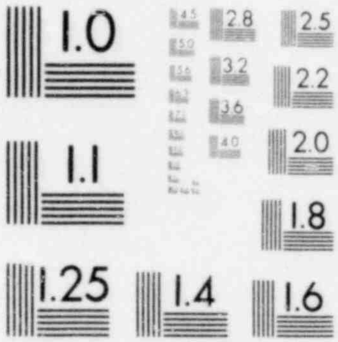
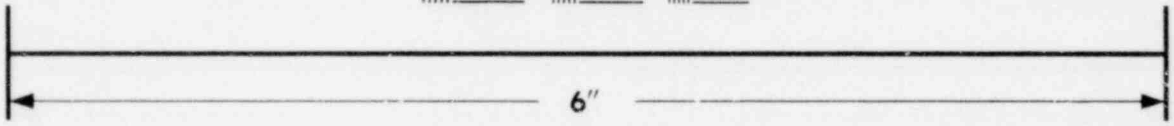
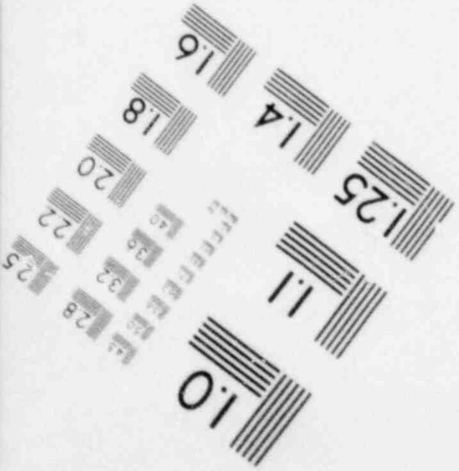
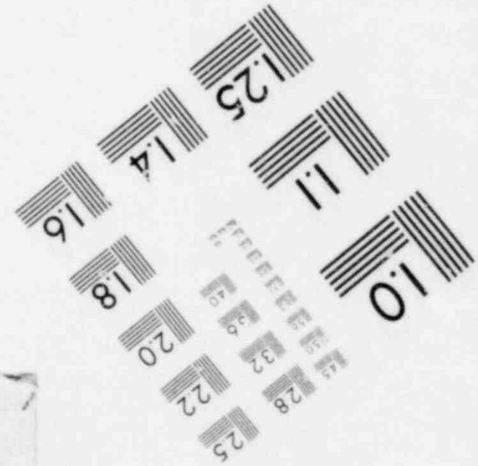


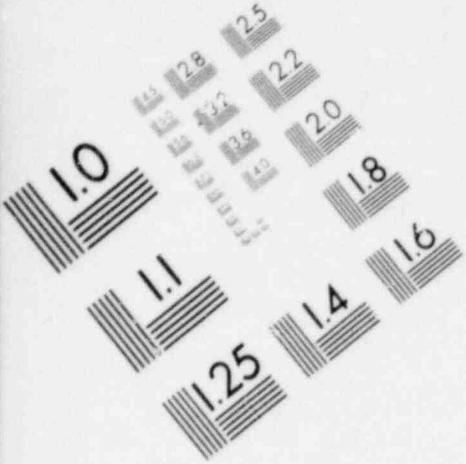
IMAGE EVALUATION TEST TARGET (MT-3)











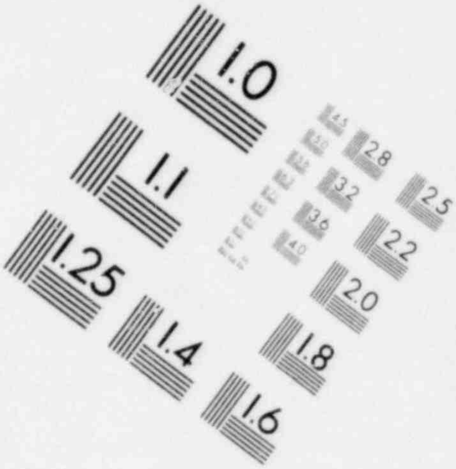
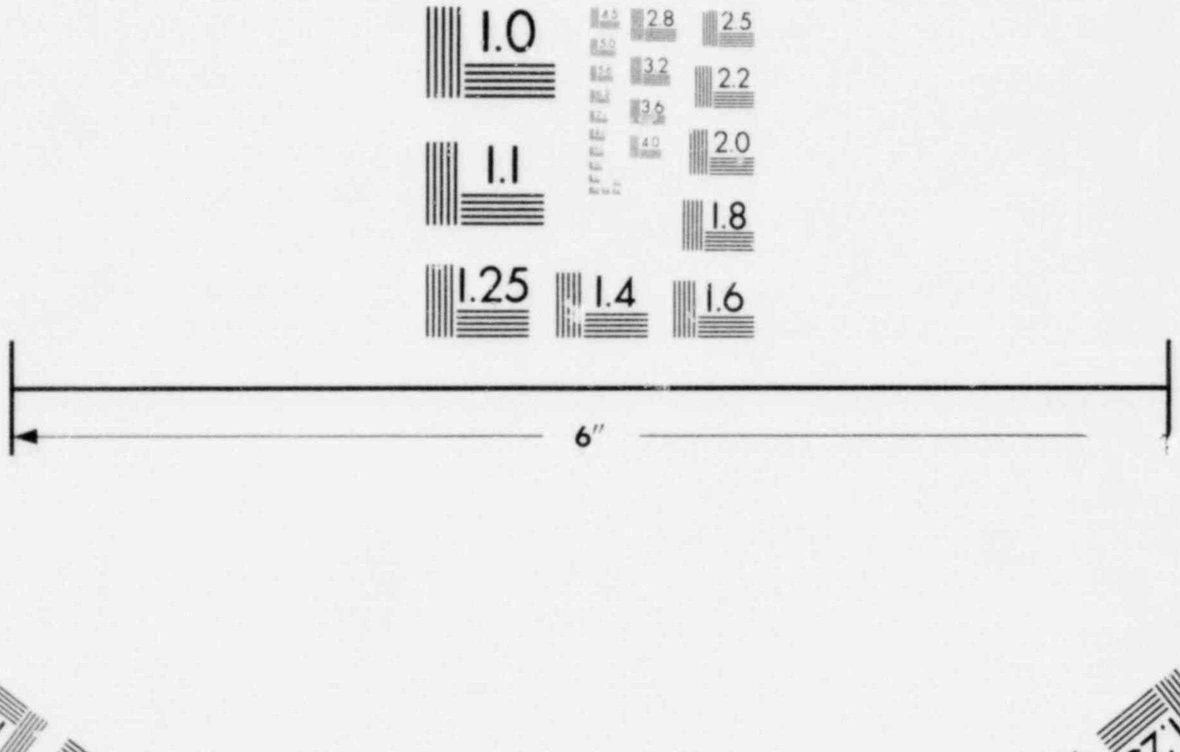
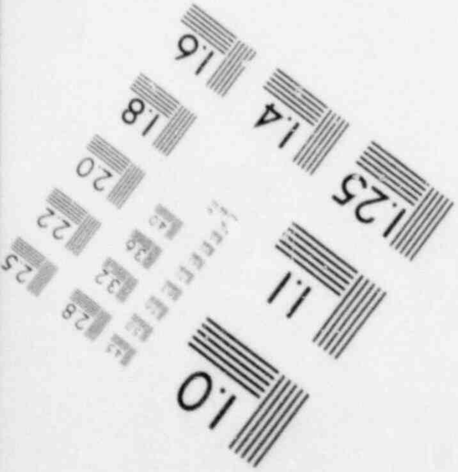
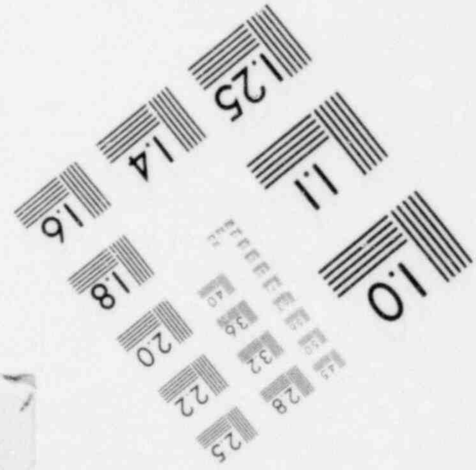


IMAGE EVALUATION TEST TARGET (MT-3)







APPENDIX B

HYDROGEN-AIR MIXING BY FAN

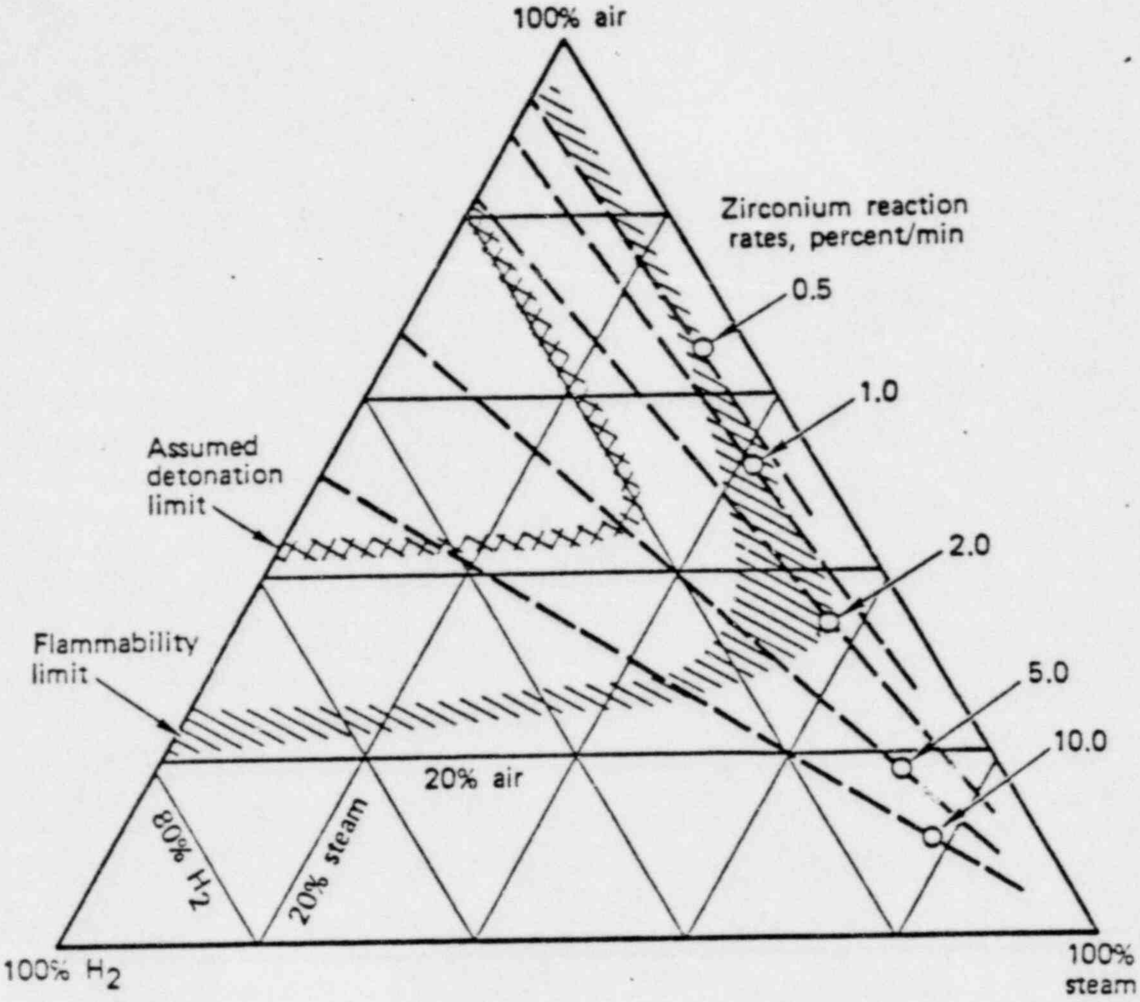
Air recirculation fans are provided in the Sequoyah containment for returning air to the lower compartment after a postulated blowdown. Two such fans are provided, each having a rated capacity of about 40,000 cfm. The purpose of the fan-induced recirculation is to convey steam produced by residual heating to the ice condenser, if the emergency core cooling system should fail (failure of the ECCS is also a situation that could permit a zirconium-water reaction and hydrogen generation). The design basis for the recirculation system is an air flow rate of 40,000 cfm, corresponding to the operation of one fan. Some parameters related to mixing and burning of hydrogen in an air flow of 40,000 cfm have been calculated, and are presented in Table 4.

The air velocities in the ice condenser and upper plenum are low. Nevertheless, the flow would be turbulent in the upper plenum of the ice compartment, so the flow entering the upper compartment should be well mixed. If hydrogen were being generated by a 1% per minute reaction of zirconium (as an example), the rate of hydrogen flow would be about 10% of the air flow, giving a mixture containing about 9% H_2. This would be combustible, according to the literature cited elsewhere in this report.

A reference calculation is illustrated in Figure 2, where mixtures of 40,000 cfm air and the hydrogen yields of various rates of zirconium reaction are plotted on the ternary mixture chart. Each reaction rate corresponds to a straight-line locus, with steam rate determining the position on any line. The one point plotted on each line is for a steam rate that corresponds to the heat release rate of the Zr-H_2O reaction and the latent heat of vaporization of water. It can be seen in Figure 2 that the yield of $Zr-H_2O$ reaction rates in excess of 2% per minute can produce detonable mixtures with 40,000 cfm of air if the steam content is sufficiently low. Rates of several percent per minute were calculated for some accident scenarios in WASH 1400.

Table 4. Air Circulation Parameters

Design Data From Sequoyah PSAR	
Number of Blowers	2
Capacity of Each Blower	40,000 cfm
Ice Condenser: Flow Area (net)	1,326 ft^2
Height	48 ft
Annular Thickness	11 ft
Effective Circumferential Length	267 ft
Lower Compartment Active Volume	2.87×10^5 ft^3
Total Containment Active Volume	1.24×10^6 ft^3
Derived Parameters, for One Blower Operating	
Air Velocity: a) In Ice Bed	30 ft/min
b) In Upper Plenum of Ice Compartment	14 ft/min
Air Reynolds Number in Upper Plenum (kinematic viscosity of air @ 50°C = 1.15×10^{-2} ft^2/min)	2.6×10^4
Air Residence Time in: Ice Compartment	1.6 min
: Lower Compartment	7.2 min
: Total Active Volume of Containment	31 min



Limits of flammability and detonation based on Shapiro and Moffette WAPD-SC-545, as reproduced in WASH 1400.

Figure 2. Locus of state points for mixtures of 40,000 cfm air with the hydrogen yield of various Zr reaction rates.

BROOKHAVEN NATIONAL LABORATORY

ASSOCIATED UNIVERSITIES, INC.

Department of Nuclear Energy

Upton, New York
(516)345-2629

August 8, 1980

Mr. Denwood F. Ross, Director
Division of Systems Integration
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Denny:

As per your request, the BNL "hydrogen team" has performed a preliminary assessment of the use of igniters (glow plugs) as a method of hydrogen control in the Sequoyah Nuclear Plant. This assessment is based on our present understanding of the igniter scheme proposed by TVA. This understanding, in turn, is based only on conversations held with NRC personnel during the past week.

It is our understanding that TVA proposes to use approximately thirty glow plugs which will be distributed uniformly around the containment building (upper and lower compartments) and that they will be used to mitigate the consequences of a hydrogen release to containment which derives from a degraded core accident (but not necessarily a full core meltdown). TVA will initially include one or two hydrogen detectors as part of this scheme, but the specific locations of both the detectors and the igniters are unknown to us. They will rely on the return air fans, which are intended for design basis accident accommodations, between the upper compartment and the lower compartment to ensure a distributed mixture of hydrogen, air, and steam. Their intended strategy is to burn hydrogen in the lower compartment with the aid of the glow plugs and to remove heat and reduce pressure with the available containment heat sinks. It is our understanding that TVA has performed an analysis which supports this scheme for a selected accident scenario (small pipe break with failure of emergency coolant injection) and that they have used their newly developed code CLAS-IX to compute inter-compartment flows and pressure and temperature histories in both compartments.

Although it is difficult for us to develop a firm position on the use of igniters as proposed by TVA without the benefit of a fuller description of their overall plan, we can say, based largely on our own studies of possible hydrogen control approaches for Zion and Indian Point, that the exclusive use of igniters as a means of controlling hydrogen for a wide spectrum of accident scenarios (insofar as hydrogen release as a function of time, space, and accident environment is concerned) may not be prudent. As far as the use of glow plugs or any similar form of igniters in Sequoyah is concerned, we have several concerns and reservations, as is noted below.

1. With regard to the use of igniters in the lower compartments, it may be possible that some igniters will be in the noncombustible regime, while other igniters may be in the deflagratable or detonable regime. Activation of igniters may thus initiate combustion phenomena (explosions/detonations) which entail larger pressure rises than expected on the basis of stoichiometries which exist in the neighborhood of the few diagnostic probes.

2. The potential for focusing effects related to detonations in geometrically converging regions in the containment building should be assessed.

3. It would be important to know the combustion-associated pressure and temperature histories of the lower compartment. These prescribe the flow rates through the ice chest. In turn, this determines heat loss to ice and flow rates and modes of melted ice. Further, the amount of uncondensed combustion products reaching the upper chamber is also so determined. Finally, this determines the pressure rise of concern.

4. With regard to hydrogen ignition in the lower compartment vs the upper compartment, it is not clear to us that lower compartment ignition and hydrogen consumption will always be obtained without concern for upper compartment ignition. If upper compartment ignition does occur, can the resulting pressure and temperature be tolerated?

5. Several concerns arise in connection with the ice chest performance in the presence of hydrogen combustion.

   (a) For a given scenario it would be important to know how much ice is lost to steam and how much ice then remains to cool the combustion products that are generated in the lower compartment.

   (b) Is the ice chest susceptible to combustion-generated effects which can challenge its structural integrity?

   (c) We have a particular concern for the ice chest's foam insulation and its surrounding cover. We have not been able to identify (from the Sequoyah FSAR) the material compositions of the foam and cover, but it may be that these materials are flammable. There appears to be on the order of twenty tons of foam surrounding the ice chests. Combustion of this material could engender serious pressure and temperature conditions within the containment structure. It is apparent that an ignition of hydrogen could serve as an initiator of the foam cumbustion. It is important to identify the compositions of the foam cover in order to assess their roles in relation to the course of events during a degraded core accident in the ice condenser plant.

6. In order to perform a detailed evaluation of the igniters, it would be important to know the precise design function(s) of the igniters. Their ability to "perform" can only be measured against their intended design function(s).

7. With regard to NRR-sponsored experiments at Livermore Laboratory, it would be important to have a more precise and complete characterization of the conditions of the experiments in order to judge whether useful, pertinent and complete ignition information will be obtained for a range of expected accident conditions. In particular, it will be important to know whether or not flow effects and possible droplet quenching will be accounted for.

8. The secondary purpose (stated in the Sequoyah FSAR) of the Air Return Fan System is to limit hydrogen concentration in potentially stagnant regions in the lower compartment by ensuring a flow of air from these regions. Without onsite electrical power, a flow of air from these stagnant regions could not be ensured. We are concerned that a local detonation or explosion could cause a failure of the non-return valves which normally isolate the air return paths between the lower compartments. A failure of these valves would produce a direct path between the compartments which bypasses the ice chest.

I hope that this inforamtion will be useful to you. If you have any questions on the foregoing, please do not hesitate to contact me.

Warm regards,

/s/ Bob

Robert A. Bari, Group Leader
Safety Evaluation Group

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