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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

In the matter of:

Docket No.

PEER REVIEW MEETING

BMI-2104 REPORT (DRAFT)
RADIONUCLIDE RELEASE UNDER LWR
SPECIFIC ACCIDENT CONDITIONS

VOLUME II: A BWR ANALYSIS

Location: Washington, D. C.

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TAYLOE ASSOCIATES

Court Reporters
1625 I Street, N.W. Suite 1004
Washington, D.C. 20006
(202) 293-3950

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1 UNITED STATES OF AMERICA
2 NUCLEAR REGULATORY COMMISSION

3 BMI-2104 REPORT (DRAFT)
4 RADIONUCLIDE RELEASE UNDER LWR
5 SPECIFIC ACCIDENT CONDITIONS

6 VOLUME II: A BWR ANALYSIS

7 Room 1046
8 1717 H Street, N.W.
9 Washington, D. C.

10 Tuesday, 24 May 1983

11 The Peer Review Meeting commenced at
12 8:30 a.m., pursuant to notice, Mr. Melvin Silberberg,
13 Peer Review Chairman, presiding.

14 COMMITTEE MEMBERS PRESENT:

15 M. Silberberg, Chairman

16 M. Jankowski

17 R. Bernero

18 D. Cooper

19 R. Vogel

20 D. Roe

21 W. Castleman

22 W. Kastenber

23 A. Reynolds

24 R. Ritzman

25 L. Zumwalt

C. Johnson

COMMITTEE MEMBERS PRESENT: Continued

D. Walker

MM:jl 1:1

P R O C E E D I N G S

MR. BERNERO: Ladies and gentlemen, I would like to get started please.

Good morning. My name is Bob Bernero.

About two weeks after the last meeting of this august group, I was appointed to direct the Accident Source Term Program Program Office, so that's why I'm here.

I hope to be seeing more of you now. As you undoubtedly know already, the NRC and its contractors is embarked on a perilous path, trying to look at the physical chemistry of core melt and fission product transport in order to predict in a much more realistic way what actually can get out in a nuclear reactor core melt accident. In order to have both a technically sound and a usable estimate of such source terms, we do need -- in fact, absolutely have to have -- peer review, sound peer review to test the scientific basis on which these predictions would be made.

You demonstrated in the first review of the PWR, when all the long knives came out, that this is a functioning peer review. I read those comments from the last cycle. And I said you know when a peer review is working, when the people who read the comments turn red in the ears. And I am pleased to say that the process is working. I hope that our recycle through the contractor of your comments is reasonable, proper, and satisfactory. And I look forward to the further

1 comments you provide.

2 Now I'll turn the meeting over to Dr. Silberberg,
3 who will chair it for the balance of the two days.

4 MR. SILBERBERG: Thank you, Bob.

5 As you can tell, a lot has happened since we last
6 met. I know there was a period of silence, where you didn't
7 hear from us, and that was because everyone was going back to
8 their respective cubbyholes and drawing boards, trying to
9 bring together and bring to bear the comments -- our response
10 to your comments from the first meeting.

11 By way of introduction, before bringing you up to
12 date, where we have been in the last four months, what I would
13 like to do is just note a few regrets from people who were
14 not able to be here today.

15 First, from the United Kingdom, Mr. Abby and
16 Mr. Potter were not able to be here today.

17 Mr. Thorguson, from Canada.

18 Bob Hilyer, from the United States.

19 And Saul Levey sends his regrets -- personal
20 problem, he was not able to be here.

21 But nevertheless, as ever, he was productive and he
22 sent in his comments ahead of time. And he asks that they be
23 read into the minutes, and we will do that sometime -- probably
24 tomorrow.

25 Carl Johnson was nice enough to tell me that he was

1 going to be an hour late, so we can expect Carl here pretty
2 soon.

3 In the meantime, we have with us our colleagues from
4 overseas.

5 We have Mr. Petrangeli, who was here at the first
6 meeting, from ENEA, Italy.

7 I don't see Mr. DeMunk yet, from the Netherlands
8 Licensing Authority. I assume he will arrive shortly.

9 And Dr. Soda, from GERI, from Japan.

10 Now, there will be, throughout the course of today,
11 a variety of backup materials that will be provided that
12 Battelle's staff has been working on diligently that we will
13 be passing out in the due course of the meeting today, things
14 like a separate appendix on a description of the TRAP melt
15 code.

16 I must say, in addition to Battelle, Oak Ridge Labs
17 have put together and brought with them, I hope, their report
18 on the tellurium chemistry and the basis for how tellurium is
19 being treated in this report.

20 And we will also provide a summary of peer review
21 comments that I will say a little bit more about before
22 Jim Giesecki makes his presentation.

23 (Slide.)

24 As Bob Bernero noted, we have taken your comments
25 quite seriously and digested them. And within the first month

1 after our -- after the meeting, there were a number of things
2 that became quite evident to us as a result of your feedback,
3 as well as our own impression from the first review.

4 I've listed here four items -- there were many more
5 -- and I want to assure you that they have been correlated
6 and summarized. But there were four comments in particular
7 that actually had an impact on how ASTPO did its planning and
8 how we revised our approach to the program that has unfolded
9 since the last meeting.

10 For example, many of the commenters -- there was
11 a consensus that said the data base for the supporting -- the
12 data base which supports the codes and that might be used for
13 code validation is not visible in the work that we presented
14 and that this needs to have its own emphasis.

15 Second comment had to do with the fact that this
16 work has large uncertainties to it and in it, obviously, at
17 this stage. And some parameters are more sensitive than
18 others.

19 And so a need for an uncertainty and sensitivity
20 analysis was presented, Along with some of the other support-
21 ing activities, we have now added these as supporting
22 activities to the Staff work, as well as to the contractor
23 work.

24 Also, as you recall, there was much debate on the
25 question of just what the containment loads are and the

1 challenge to the containment in terms of containment response,
2 particularly with respect to the early failure mode question.

3 And you will see later that we have addressed this
4 in a supporting activity.

5 Finally, the question of new technology in dealing
6 with reactor cooling system upper plenum, in terms of thermal
7 hydraulics modeling, was clearly an area that was noted by
8 consensus of the reviewers, in terms of working with -- start-
9 ing with the MERGE code, which Battelle and everyone else
10 admits is a first start to the problem. And we have had to
11 address that in our supporting activities.

12 Now, putting this altogether, basically we now have
13 four elements to what we call the reassessment of the technical
14 bases for source terms.

15 (Slide.)

16 Element One is a preparation of a summary report on
17 the data base for validating codes to predict releases for the
18 codes that we used in the Battelle reports. This will be
19 put together by various NRC contractors making contributions
20 to it, and the Oak Ridge National Laboratory has the lead and
21 will publish the report as an Oak Ridge document, with due
22 credits to all of the contributors.

23 Element Two is basically the same element. It's the
24 Battelle analyses for what has now been enlarged to five
25 plants. And I'll discuss that when I go into the scope in a

1 little more detail.

2 We have now identified Element Three, as Bob Bernero
3 noted, as a very separate and distinct activity that is
4 deserving of a status all by itself, namely the thorough peer
5 review of the scientific basis for the work -- first, what we
6 call the technical experts' peer review, which is what is
7 going on now and what we had in January and will continue,
8 and then a broad-based review by an independent scientific
9 organization.

10 And we have been working on this for some time, and
11 we expect, shortly, to receive a proposal from the American
12 Physical Society, to hopefully participate and conduct this
13 review.

14 Finally, Element Four, which always existed, but now
15 is a lot clearer in our minds, is basically the element which
16 picks up all of the supporting staff activities that you will
17 see in a moment that evolve from the first peer review, as
18 well as a way of pulling together all of the contractor
19 products, together with the Staff-supporting activities lead-
20 ing to an appraisal of the significance of the reassessed
21 source terms, when we are all done.

22 I will say a little something about schedule before
23 I close, so you can see how they all fit together.

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1 MR. SILBERBERG: The scope for Element 2 has been
2 enlarged to include now the Zion large high-pressure
3 containment PWR right here today. We now refer to the
4 Battelle reports as the BNI-2104 series, and they are
5 Battelle Reports Volumes 1 through 5, 1 through 4. And
6 they, if you will, stand alone. And for that reason, we
7 refer to the contractor designation and not to a NUREG
8 designation.

9 (Slide)

10 Element 4 has expanded as a result of the peer
11 comments. Starting with an appraisal of the products from
12 Elements 1 and 2, we are now adding in parallel studies
13 that will largely done by the staff with some support from
14 NRC contractors on the state of the art of the loads which
15 one -- if you will, best-estimate loads -- which one might
16 expect to be needed in order to determine the response of
17 containment for, if you will, steam spikes first, hydrogen
18 burns, and other items that are challenged.

19 Containment response in terms of early
20 containment failure. If there is anything we learned from
21 the Surry study -- and really, it shouldn't have been a
22 surprise -- was that early containment failure is really
23 the thing that really challenges risk based on the current
24 technology available now, whereas in late containment
25 failure we have a lot of other retention mechanisms in the

1 containment that are acting to reduce source term.

2 The uncertainty and sensitivity analysis, we
3 have been reviewing with several laboratories,
4 possibilities for how this might be conducted. And early in
5 June we will make a decision as to how we will organize
6 this and what the scope will be.

7 If you will, this is a rather challenging task,
8 and since we want to get the first study done in 6 months,
9 it will, of course, be limited in many respects, but
10 hopefully will form the basis for an ongoing follow-on on
11 uncertainty and sensitivity analysis that will be more
12 comprehensive, that we can ultimately use at the end of the
13 program to pull these things together. So you will hear
14 more about this in due course.

15 This element also picks up what we call the
16 review and appraisal of work going on outside of this
17 program, if you will, in the industry; namely, the IDCOR
18 study and the ANS source term study. This will be reviewed
19 by NRC contractors as well as the staff and will allow us
20 to make a comparison of what -- now others have calculated
21 similar events and similar sequences. And we will, of
22 course, factor those results into our appraisal.

23 Finally, we have decided to ask the Los Alamos
24 people to use TRAC initially to explore and improve the
25 analysis of the upper plenum in the reactor coolant system

1 in the vessel to, if you will, support or extend the MERGE
2 analysis. And this is now underway.

3 In Element 4, we will, of course, appraise the
4 comments from the peer review, first this group and then
5 finally the independent group that will do the appraisal.

6 Now, when we are all done in this time frame, we
7 will have what we call NUREG-0956, the real NUREG-0956,
8 which will be the sequel to 0772, and will, in effect, be a
9 reassessment of where we stand at this point in time, if
10 you will, at the end of this year and into the spring.

11 We will not release the draft of 0956 for
12 comment until after all of the peer reviews are done. And
13 you will see this on my next slide.

14 (Slide)

15 We should have the code validation report
16 complete by August and reviewed. The five plant reports,
17 still draft but issued as draft, complete in September of
18 '83. The peer review, last peer review, which will be the
19 one that I referred to, the independent peer review. The
20 broad-based peer review, will be we hope around May of '84
21 and would then lead us to 0956, publication of draft for
22 comment and then -- I mean broad public comment. Then
23 December '84 would be a final report.

24 Now, what is the schedule for the peer reviews
25 of this group.

1 (Slide)

2 Let me give you some of these dates and what
3 our current plans are so that hopefully you can make your
4 plans for the summer accordingly.

5 We are here today. We hope that in early July,
6 maybe second week in July, what we would do is complete the
7 Peach Bottom analysis and review and Grand Gulf and bring
8 on Sequoyah, Sequoyah review.

9 Now, we recognize at this meeting today -- and
10 we beg your indulgence -- that we did not have all the
11 materials available to you on both Peach Bottom and Grand
12 Gulf.

13 But we feel that with the materials that you
14 have, plus the oral presentations and the handouts, that
15 there are enough new issues -- some old ones, too -- but
16 there are enough new issues in dealing with the BWR designs
17 that the next 2 days will be well spent and will be an
18 excellent, if you will, precursor to the July meeting,
19 which would then allow us to bring into final focus the
20 Peach Bottom and Grand Gulf plan and Sequoyah. If possible,
21 we would add an extra day to the meeting if we need to.

22 Hopefully, around the middle of August, second
23 week of August, we would review the Surry plant, revised to
24 bring into account additional analyses that Battelle is
25 currently planning and currently working on that Jim

1 Gieseke will report on as the next speaker.

2 We will have the Zion plant reviewed in August,
3 and it's not clear at this time how many of the sequences
4 we will go into in Zion. It could very well be that we may
5 just pick out one or two that would allow one to get a
6 reasonable comparison with a Surry-type plant. And that is
7 still to be evaluated. It's really a function of time and
8 resources.

9 Then finally, we would ask this group to review
10 the code validation report from Element 1. Hopefully, you
11 would have the code validation report to review sometime in
12 early July or mid-July.

13 Now, because we have brought on two additional
14 areas of work which in themselves require we think separate
15 consideration, we have two possible additional meetings
16 that we will schedule. One, of course, would be dealing
17 with containment loads and response, and we think this
18 would be the appropriate meeting for specialists that deal
19 in these particular problems. So I suspect we may narrow
20 down the review here possibly.

21 Then on the uncertainty analysis, since that is
22 so important and has such impact on judging the results of
23 the entire program, I believe we will have an extra meeting
24 on that, but it's not clear what the composition of that
25 review will be.

1 That's really all I had to say. If there are
2 some cogent comments or what have you, I would be happy to
3 answer them now for clarification.

4 Doug Cooper.

5 MR. COOPER: Do we still have under consideration
6 the simulation of the TMI incident and the comparison
7 between what was predicted and what was found?

8 MR. SILBERBERG: Yes. That's sort of an ongoing
9 activity in the office, and Walt Pasadack of our staff is
10 following that as well as Mike Jankowski.

11 We have some ongoing work at several of the
12 laboratories that have been looking at this problem. At
13 some point, I am not sure when, but at some point it will
14 find its way into the program, maybe as part of Element 1
15 or maybe as part of Element 4.

16 But we think that the TMI-2 accident and its
17 value here and its relationship and its role here will have
18 to be placed in perspective. So you can expect that that
19 will be done, and we will certainly invite your comments on
20 it.

21 But we also, in dealing with TMI-2, part of the
22 problem is it is not quite the same sequence as the
23 sequences we're talking about here, so it needs to be
24 looked at very carefully and dealt with in its own special
25 way. But nevertheless, that is certainly a useful thing to

1 do.

2 MR. KASTENBERG: Could you tell us a little bit
3 about why you chose Zion as the fifth plant instead of
4 something like the MARK-II containment?

5 MR. SILBERBERG: Certainly. We could have also
6 additionally chosen MARK-II.

7 MR. CASTELMAN: What made you choose Zion-2?

8 MR. SILBERBERG: Zion represents kind of another
9 class of high-pressure containments, really different than,
10 let's say, the Surry class or the Oconee class. And also,
11 it allows us another comparison with a companion study
12 that's going on in IDCOR, which has included Zion-2. So it
13 kind of gives us -- it spreads the high-pressure
14 containments, and it also allows us to communicate with the
15 IDCOR results. Those, I think, are the main points.

16 As far as the MARK-II, what we will try to do in
17 Element 4 of the staff appraisal of risk and regulatory
18 significance, we will try to place the MARK-II in
19 perspective relative to the results we have on MARK-I and
20 MARK-III, and to the extent that we find perhaps that it's
21 worth an extra calculation or two, we may indeed have to do
22 that.

23 MR. BERNERO: I think it's worth adding, the
24 licensing staff is deeply involved in the review of the
25 Limerick PRA, which is a MARK-II containment. And we have

1 communication with them, and some of this program's
2 calculations may be generated to assist them, but the
3 MARK-II focus you will find there in that review rather
4 than here in these five plants, just due to the limited
5 resources.

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TAYLOR ASSOCIATES
1625 I Street, N.W. - Suite 1004
Washington, D.C. 20006
(202) 293-3950

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12,

1 MR. SILBERBERG: I would now like to introduce
2 Dr. Jim Gieseke from Battelle, who will tell you about what
3 Battelle -- how Battelle is addressing and has addressed
4 the January Peer Review Comments; and in concert with Jim's
5 presentation, later on we will be passing around a summary
6 of the comments that we received from various reviewers and
7 observers from the January meeting.

8 A rather concise summary has been put together
9 by Chris Ryder over here in back of me from our staff, and
10 sometime throughout the two days if you have any comments
11 on how we have interpreted your comment or how we summarized
12 it, or abridged it or what have you or you think some clarifi-
13 cation is needed, please make a note of it on your copy,
14 and sometime during the meeting if you can see Chris Ryder,
15 why he will be happy to take your notes and make appropriate
16 corrections. Chris is over here. Jim Gieseke.

17 MR. GIESEKE: Thank you, Mel. I'm happy to be
18 back in spite of what you might think.

19 (Laughter.)

20 We rather enjoyed all the discussions the last
21 time; we certainly thought we'd enjoy doing it again.

22 (Laughter.)

23 (Slide.)

24 There are really three topics today. This is the
25 first of three that have to do with this. BMI 2104, Volume 1,
is the topic of our last discussion, the Surry plant and

1 its calculations. We want talk first about what we are doing
2 in response to the review comments, but before we get into
3 that too deeply, just to restate the situation and make it
4 clear where we are going with all of this--

5 (Slide.)

6 --I would like to read for you the objectives of
7 the study, which are to develop updated from release plant
8 fission product source terms for five types of nuclear
9 power plants and for accident sequences giving a range of
10 conditions.

11 I think that's important: to realize that we're
12 looking for ranges of conditions to see the effects of, as you
13 will note down here, the effects of different conditions and
14 different assumptions. The estimated source terms that we
15 derive are to be based on analyses of fission product released
16 from the fuel, transport and deposition of those fission pro-
17 ducts using improved computational tools in a consistent step-
18 by-step manner.

19 Our second objective is to determine the effects
20 on fission product release associated with the differences
21 in input which are associated with differences in plant design
22 and accident sequences primarily. We've also done some sen-
23 sitivity calculations as we've gone along, just to see some
24 major impacts of different consumptions.

25 And the last objective, then, which is a result, is

1 to provide in-plant time and location-dependent distributions
2 of fission product baths.

3 (Slide.)

4 Now to give you an overview, I'm not sure at this
5 time whether this Zion will be a separate report from the
6 Surry Revisited. But to go through Volume I--is the Surry
7 plant-- not "slurry plant." You don't know how many slides I
8 corrected that on, I must have missed one--

9 (Laughter.)

10 -- which we talked about before, which was done
11 using the MARCH 1.1 code.

12 Volume II is a Mark I, BWR, Peachbottom plant.
13 One of the topics of discussion today--sequence is AE, TC and
14 TW.

15 Volume III of this is Mark III design, BWR,
16 Grand Gulf is the selected plant. We're looking at sequences
17 TC, TQUV, TPI. This is also to be discussed later, calcu-
18 lations that we have to date.

19 The next volume is Sequoyah ice condenser contain-
20 ment. We're not entirely fixed on these, but we think we'll
21 probably--it looks like we'll be using the S2H, S2D, TMLB,
22 TML sequences.

23 Then we come to Surry Revisited, which is revisited
24 in the sense that we'll be using MARCH 2 code rather than
25 MARCH 1.1 code.

1 You'll hear about the major differences that have
2 to do with, of course, slumping, the same sequences as before
3 for Surry, and finish up with Zion's.

4 We now mention the sequences -- and I totally defin-
5 ed on that -- to clear up a little bit the differences -- well,
6 before I go on and talk now about we have done with regard to
7 the Surry plant, I do want to acknowledge input that we have
8 been receiving.

9 (Slide.)

10 Westinghouse has provided us with information on
11 the upper plenum design; Stone & Webster on the containment
12 geometry and the compartmentalization.

13 EPRI -- Dick Vogel has chased down information on
14 the concrete composition for us.

15 And Sandia, of course, as you are aware, provided us
16 with release from the core concrete interaction.

17 And Oak Ridge has provided input in terms of release
18 from the fuel.

19 MR. JANKOWSKI: What about B&N?

20 MR. GIESEKE: On the Battelle, Northwest has pro-
21 vided this information, the spark code for the boilers. But
22 we'll acknowledge them when we get to the boilers.

23 (Slide.)

24 We had a number of peer review comments. As Mel
25 mentioned, these are being handed out. This is a summary that

1 Mel alluded to by Chris Ryder that will be provided to you.
2 But the general topics in there, I'd like, for your informa-
3 tion, to quickly run through have to do with -- the comments
4 were categorized under the topics of accident sequence and
5 system behavior, fission product release from fuel, thermal
6 hydraulics chemistry, primary system transport deposition and
7 reentrainment, transport deposition and reentrainment in
8 containment, code validity sensitivity, and also report
9 structure and organization report in general.

10 These topics and the comments we have read and
11 considered. And the result of these considerations have led
12 to some modifications or additional calculations that we're
13 doing from the Surry analyses.

14 (Slide.)

15 I have tried to use this slide to show you where
16 the material is going to appear.

17 Volume 1, which is the first Surry analysis, using
18 the MARCH 1.1, is probably going to be published in a matter
19 of a few weeks, pretty much as is, with some modifications
20 noted on here or some considerations. And these will be
21 discussed today in these additional calculations or modifica-
22 tions.

23 There are other issues that we are addressing,
24 and we will run through these just to clarify what we are
25 doing to the Surry analysis as a result of our last peer

1 review meeting.

2 First of all, we will be using MARCH 2 code for all
3 the sequences. That will not appear in Volume 1, but it is a
4 basis for a volume which I identified on the previous slide
5 as being Volume 5.

6 As far as the upper plenum geometry in the MERGE
7 calculations, we obtained information, as I mentioned, from
8 Westinghouse -- as I mentioned -- with some details. We'll
9 be going through and using a better definition of the upper
10 plenum geometry.

11 Improved release rates from fuel -- this is basical-
12 ly the work done by Oak Ridge in considering two types of
13 release, one being the control rod -- release of control rod
14 materials, and the second item being tellurium release. And
15 I think you may hear some of that today or tomorrow, of what
16 they have done.

17 The fourth item is an issue that came up as a
18 question: What is the effect of the inventory distribution
19 in the core?

20 We had assumed that it was a flat profile. We
21 thought it might be good to do a little bit of sensitivity
22 analysis. We had done a little bit on this to see what the
23 difference might be on release rates.

24 We brought up the issue of decay heatining of
25 deposits as possibly having an impact on subsequent deposition

1 of the fission products in the primary system. We have some
2 calculations, preliminary sorts of calculations that we can
3 talk about today. And that issue will be addressed also in
4 Volume 5.

5 There were comments dealing with the nodalization
6 of the primary system. And when we redo it, we will look at
7 the nodalization, expecting that we use a finer nodalization.

8 There was a question that we had in our minds about
9 the Surry geometry of the containment. This all has to do
10 with the core concrete release. I think we may have used the
11 wrong diameter a little bit. We don't know what the impact
12 of that is -- wrong diameter of the cavity. But we correct
13 that, and we get melt temperatures for MARCH now, and we would
14 look at the possible impact of water in the cavity on core
15 concrete release.

16 Another item is the effect of water condensation on-
17 to the wall and what that does to deposition in the con-
18 tainment -- or as referred to, as diffusiophoresis. We've
19 done some calculations we'll report today to show the impact
20 of that -- plus, that will be -- it's been added to the NAUA
21 code, so that will be automatically be included in the next
22 volume.

23 (Slide.)

24 We keep going down our list. I think there was
25 some question about flow rates that we used before -- spray

1 removal efficiency in our calculations for the containment,
2 removal from the containment. We've gone back, checked those.
3 We have some calculations to show today, and we'll be using
4 the same sort of procedure for the next issue.

5 We looked, just very briefly, at sensitivity to
6 drop size. That will be mentioned today in a talk.

7 We mentioned, when we had our last review meeting,
8 that we had not included the deposition from the flow back
9 through the primary system, after melt-through -- the reactor
10 vessel. We had not taken into consideration any deposition,
11 and that will be included when we redo it.

12 The questions of compartmentalized containment is
13 to be evaluated, and we expect to use a better compartmentali-
14 zation in the calculations.

15 Now that we have obtained information -- better
16 information, definition of the containment geometry -- and
17 we had not prepared this appendix before, and we are handing
18 out an appendix today for you to look at. It will go in
19 Volume 1. There was a place for it in Volume 1. It just
20 wasn't completed before. So, that will be included in
21 Volume 1 and referred to by appearing in Volume 1.

22 Then, there was some analyses that were done on
23 pressure spike sensitivity, or hot-drop model sensitivity that
24 we will discuss briefly today, relating to the containment
25 failure analysis. This is not a part of either of these, but

1 is input to NRC's containment failure analyses task that was
2 mentioned. We thought it would warrant a brief go-through on
3 that, because it was a major question that came up in the
4 peer review meeting in January.

5 (Slide.)

6 Okay. So, I have now a list of the topics we will
7 be covering in this part, the additional results with the
8 additional calculations that go into Volume 1.

9 (Slide.)

10 TRAP melt 2 description, as I mentioned, will be
11 available and handed out.

12 Pressure spike sensitivity, relating to containment
13 failure, is a topic.

14 Transport and deposition in the containment, with
15 diffusiophoresis. And there's questions regarding spray.

16 One more item I forgot to put on here, which is the
17 effect of decay heating, and we won't forget it just because
18 it's not on the list, but we will talk about that.

19 So, these are the items, and we'll take them in
20 order, starting with the TRAP melt description, which is just
21 a handout.

22 So, we'll go through -- Pete Czybulskis will talk
23 about containment, questions relating to pressure spikes.

24 Ken Lee will talk about transport and deposition in
25 the containment, as revised. And Rich Denning will talk about

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1 decay heat on the primary surfaces and the effect on deposi-
2 tion.

3 So, with that, we'll move on to those talks on some
4 of those topics, starting with Peter Czybulskis.

5 MR. VOGEL: Mel, I've been assuming we'll get copies
6 of the slides?

7 MR. SILBERBERG: Yes, we'll cycle them through after
8 each speaker.

9 MR. GIESEKE: Do you want to have the viewgraphs
10 in one big pile or individuals for each of the issues?

11 MR. SILBERBERG: One --

12 MR. WALKER: Are you going to do any more on the
13 secondary structures?

14 MR. SILBERBERG: For the auxiliary building?

15 MR. GIESEKE: You're talking about the auxiliary
16 building?

17 MR. WALKER: Yes.

18 MR. GIESEKE: We're getting all the geometry infor-
19 mation and checking that out as we go back through.

20 MR. CZYBULSKIS: Good morning.

21 As a result of the discussions at the last peer
22 review meeting, there are a number of questions raised about
23 the pressure spikes that led to the potential early containment
24 failure in Surry.

25 Just let me make a point of clarification. I

1 believe, in the draft of BMI 2104, we made no statement about
2 the likelihood of containment, early containment failure. I
3 think all the release calculations were predicated on the fact
4 that the containment's failure does take place. It said nothing
5 about the probability, and I think there is some misunderstanding
6 as to what the intent of it was, Whether the probability
7 is low or high is still an open question and one that will
8 be addressed further.

9 What I will describe to you today is a series of
10 sensitivity studies that we have performed since the last peer
11 review meeting to try to get some insight on how the peak
12 pressure associated with an early pressure spike might vary as
13 a function of modeling and input assumptions.

14 I might also note that these calculations were done
15 with MARCH 2; as opposed to MARCH 1, which was used in the
16 other study. There were rather substantial revisions in the
17 input in the physical description of the plant in these studies
18 from the one we used earlier.

19 In particular, we had the benefit of some detailed
20 discussions with Westinghouse on what the internals of the
21 reactor look like. There are still some outstanding questions,
22 and I'm expecting some further input from Westinghouse as to,
23 in particular, the lower support structures. But these calculations
24 were done with the best information we had available.
25 So, let me talk about these.

1 (Slide.)

2 The objective of these studies was to investigate
3 the containment pressure loading as a function of modeling and
4 input assumptions, very simply.

5 (Slide.)

6 The way we went about this exercise is illustrated
7 here.

8 As I said, we calculated the series of MARCH 2
9 cases, varying the heat transfer assumptions and the heat
10 transfer models that we are utilizing included what I call
11 particulate heat transfer, which is basically a very simple
12 quencher - model that assumes, for a given particle size, as long as
13 the water is in the cavity, the particles will find the
14 water, until you either run out of water or until the particles
15 are quenched.

16 That's a point of departure, basically very similar
17 to what we have been doing for MARCH 1.1 for some period of
18 time.

19 We did this for a series of particle sizes.

20 The next set of calculations was particulate heat
21 transfer, up to the point that the core debris form a debris
22 bed. And the time for forming a debris bed was determined on
23 the basis of levitation calculation. Basically, the more rapid
24 the heat transfer, the more steam you generate, the harder it
25 is for the bed to form.

1 Again, these were done as a function of several
2 particle sizes.

3 The third set of calculations were, again, initiated
4 with the particulate heat transfer. But instead of using the
5 levitation calculation, we just assumed that the debris would
6 form as soon as the particles solidified.

7 Then, there was a series of calculations done in
8 which I varied a number of assumptions about the in-vessel
9 behavior, about how the vessel fails, to see what difference
10 it makes on the predicted contrainment response.

end 3

MM:jl 4:1

1 (Slide.)

2 Just to provide some perspective, let me point out
3 the base case here. This was Surry TLMB prime, using the
4 assumptions on the code as it is. This is kind of the
5 reference time scale, with steam generator dryout 68 minutes,
6 core uncovering at 99, start of melt at 120, start of core
7 slump 149.

8 I might point out here I use what I call a gradual
9 core slump model, as opposed to letting the core slump all at
10 once. Though it turns out that for these calculations once
11 the core slumping starts, it proceeds very rapidly to com-
12 pletion. Of course, as I said, the core started the slump
13 at 149 minutes and collapsed at 151 minutes. Bottom head
14 failed about a minute later, so most of the calculations that
15 I will be talking about take place following head failure and
16 treat the debris failure in the cavity.

17 (Slide.)

18 Let me throw up a review, pressure and curves.

19 Just a few examples, and then I will summarize what
20 is seen.

21 This is a typical pressure-time history. This
22 happens to be for debris particle size of one inch. And this
23 is for the particulate points model. The core uncovers in
24 this area, then melts. The head falls at this point, and
25 this is where you get the interaction in the bottom head.

1 In this particular case, the peak pressure is about 80 psi.
2 That's for one-inch particle size.

3 MR. REYNOLDS: I have a question. Is this for
4 water coming down on top of the debris from the accumulators?

5 MR. CZYBULSKIS: This is the water coming down on
6 top of the debris due to the accumulated discharge at the time
7 of head failure.

8 (Slide.)

9 Same sequence, same modeling assumptions, just a
10 smaller particle size. You get essentially the same behavior,
11 but instead of 78 or 79 psi, I think this one goes up to 84.

12 (Slide.)

13 And if we go to the other extreme and take a very
14 small particle size -- and there's nothing scientific about
15 the particle size choice -- I start out with a 2/10ths-inch
16 diameter particle, went up a factor of 5, to 1 inch, and down
17 a factor of 5 the other way.

18 We go to a very small particle size. You get a
19 higher pressure spread. This is for the quench model.

20 MR. REYNOLDS: What are the other contributions,
21 besides steam and hydrogen? The total seems to be higher than
22 the sum of the two.

23 MR. CZYBULSKIS: That's air in the containment.

24 MR. CASTLEMAN: What governs the amount of hydrogen
25 there? Is it governed by the surface area?

1 MR. CZYBULSKIS: Let me come back to the hydrogen
2 for a moment since you asked the question.

3 MR. SILBERBERG: Excuse me. I would like the
4 speakers to identify themselves -- name and affiliation,
5 please.

6 MR. CZYBULSKIS: This is --

7 (Slide.)

8 -- the hydrogen, quantity of hydrogen in the
9 containment, in one of the particulate cases.

10 Basically, what we see is a very rapid increase in
11 hydrogen, essentially at the time of head failure. Essential-
12 ly all of this hydrogen comes from the metal water reaction
13 during the in-vessel phase, and there's relatively little
14 hydrogen produced during this quenching phase, because the
15 debris is at temperature for so short a time it doesn't have
16 time to react. So, you get a rapid release of hydrogen when
17 the vessel fails, very little additional hydrogen until you
18 get into the concrete. And then you see the hydrogen come up.

19 I'm trying to keep this short. Let me depart from
20 the figures and just give you a summary of a number of the
21 cases that we ran.

22 (Slide.)

23 I apologize -- this is a very busy slide. Let me
24 just try to point out some of the things on here.

25 The first three cases that I showed you, the

1 particulate quench for a one-inch particle, we had a peak
2 pressure of 76. For a 2/10ths-inch particle, we had 84. And
3 for a .04-inch particle, we had a pressure of 94 psi at this
4 particular assumption. This is for the simple quenching model.

5 If we now go to the levitation model -- which are
6 the next two cases -- and in this case, instead of the parti-
7 cle quenching completely down as far as it can go, it forms
8 a debris bed when the steam generation rate drops, so you
9 don't get quite as much quenching as you do in the first case.
10 And instead of a 76 psi, we had 74. Instead of 84 psi, we
11 had an 82 psi. It doesn't make an awful lot of difference
12 whether you use a quenching or the levitation model.

13 Now, if we go to a series of calculations where we
14 ignore the levitation assumptions and just switch to the
15 debris bed on solidification, you get some interesting results.
16 That's not necessarily more true than anything else. If you
17 take the small particle and switch to debris bed on particle
18 size, you get 76 psi; but a very interesting thing happens
19 here, that debris bed is not very coolable and you get -- for
20 that particulate size, you get this kind of pressure-time
21 history.

22 (Slide.)

23 Instead of the real rapid spike, you can see some
24 slope on this curve. The reason you see the slope on that
25 curve is this.

1 (Slide.)

2 You get a tremendous amount of hydrogen generation
3 if you have an uncoolable debris bed, recollect the base
4 cases down, and here you have twice the hydrogen.

5 If you try to hold the debris bed and it doesn't
6 quench, basically you get rapid hydrogen generation.

7 (Slide.)

8 MR. GINSBERG: Ted Ginsberg, from Brookhaven.

9 Is it true, in all these cases, the interaction is
10 water-limited? In other words, you're dealing only with
11 accumulator water, and you basically evaporate all the water?

12 MR. CZYBULSKIS: Right. In this particular case,
13 there's a finite amount of water available to interact with
14 the debris; that's correct.

15 Going back to some of these cases, let me just
16 point out one case, the lowest pressure case that we predicted
17 was basically one where we tried to form a debris bed on
18 solidification. The debris bed didn't quench. So, I said if
19 it quenches, let's not do the debris bed calculation. Let's
20 go straight to the concrete attack, and this is the one that
21 leads to the lowest pressure, far and away, because basically
22 it didn't evaporate very much water, quenched the debris a
23 little bit, formed the bed, and then went on to the concrete
24 attack.

25 Then, I went through a series of calculations where

1 where I tried to look at what difference to the in-bed
2 assumptions make and what happens later on.

3 I look at the tensile strength of the bottom head
4 as it might affect the timing of the failure, saw very little
5 effect on the containment pressure. I looked at the amount
6 of structure that came down with the debris bed and basically
7 multiplied the core support structure by a factor of two,
8 saw minimal effect.

9 I changed the core-slumping assumptions as, again,
10 there wasn't much of an effect; changed the effect of core-
11 melting temperature, instead of using 4130 nominal inches, I
12 used the UO_2 melting point -- again, minimal effect; changed
13 the core meltdown model, and it seemed to decrease the
14 pressure a little bit.

15 And the last case shown on this slide is -- I tried
16 to combine a number of things that I thought might contribute
17 to increasing the amount of energy that's contained in the
18 core debris and therefore might increase the containment peak
19 pressure. And lo and behold, for the same particle size, of
20 .2, I went up to 86 psi from the 82 I had with the reference
21 case.

22 So, basically, what we are seeing in this set of
23 calculations is a relative insensitivity of the peak contain-
24 ment pressure to the modeling assumptions. And what it comes
25 down to is as long as you have a finite amount of core debris

1 interacting with a finite amount of water -- which is the point
2 that Ted made a moment ago -- and you mix them together, the
3 precise assumptions of how you mix them together are not all
4 that important. You tend to transfer the energy, generate the
5 steam and get more or less the same pressure response.

6 Now, what this means, in terms of containment
7 failure, I think that's something that the Task Force will
8 address. It's an ongoing activity.

9 In terms of the things though, the 82 psi is not a
10 very strong challenge for the containment. But just to put
11 things in some kind of perspective, I would also like to
12 present some results for a different containment design at
13 Surry.

14 (Slide.)

15 Surry is a calculation -- it's actually on a B&W
16 containment, or B&W reactor in a containment that is almost
17 the same volume as Surry is. And there's some key differences
18 here. If I do the March 1.1 calculation in this design, I get
19 110 psi pressure. If I do the more or less identical calcula-
20 tion with March 2, I get about the same answer.

21 Then, if I make some assumptions about the debris
22 beds, if I don't let the steel react, I get a lower pressure;
23 if I let the steel react in one of these forced-debris bed
24 situations, I get a higher pressure. And it's largely due to
25 additional hydrogen generation.

1 If I don't let the corium react, of course I get the
2 lowest pressure around.

3 So, I will stop at that point and entertain any
4 questions there are.

5 MR. COOPER: Ted Cooper, Harvard.

6 What was the primary difference between the two
7 containments that you studied there?

8 MR. CZYBULSKIS: I guess I gave you the comparison
9 and didn't really give you the contrast. I'm glad you asked
10 the question.

11 The key reasons for the difference in the peak
12 containment pressure -- there are two or three. One, you
13 will recall, is that Surry is subatmospheric containment, so
14 it starts out at 10 psi, absolute, as opposed to 15. So,
15 there's 5 psi. And if you take that difference and raise the
16 temperature, it's bigger than that.

17 The second difference that's fairly important to
18 the peak pressure that you reach is the water inventory in
19 the primary system.

20 It turns out that Surry has a relatively small water
21 inventory. The water inventory affects the containment
22 pressure at the time of the head failure. Obviously, the
23 higher the pressure at the time of head failure, the higher
24 the maximum. So, there is that difference between the Surry
25 calculation and the B&W reactor.

1 The third difference -- and that was the point that
2 Ted Ginsberg made during my presentation -- in the case of
3 the B&W design, you are not limited to the accumulator water.
4 There's additional water available from overflow in the sump.

5 MR. COOPER: Would that suggest, then, we might be
6 able to mitigate certain kinds of sequences by getting rid
7 of some of the primary water, rather than trying to put as
8 much in there as possible?

9 MR. CZYBULSKIS: I wouldn't jump to that conclusion.

10 MR. KASTENBERG: Bill Kastenberg, from UCLA. The
11 hydrogen acts as an uncondensable in all of these calcula-
12 tions; right?

13 MR. CZYBULSKIS: That is correct.

14 MR. KASTENBERG: So, explain why, in a case where
15 you had all that hydrogen generation, it tended to spread the
16 peak pressure, rather than just raising the peak. Why did it
17 spread it out over time?

18 MR. CZYBULSKIS: It's a question of how fast you
19 are reacting. In the case of the simple quenching model,
20 everything that happens happens very rapidly. In the case of
21 the debris-bed model, which is the one that led to the rapid
22 hydrogen production, how fast you generate the steam is limit-
23 ed by the debris-bed heat flux, and you require the steam to
24 have the reaction with the water. And that's the debris bed
25 -- lower heat flux tends to spread the process out in time.

MM:jl 4:10

1 So you see some of that slope that you do not in a simple
2 quenching.

3 Incidentally, the point you made about hydrogen
4 acting strictly as a noncondensable, in all of these cases
5 your steam inerted, so I did not talk about possible effects.

6 Any other questions?

7 (No response.)

8 MR. CXYBULSKIS: Thank you.

end t.4 9 MR. SILBERBERG: Thanks, Pete.

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7.5
revised/
Pat

1 MR. LEE: My name is Ken Lee from Battelle
2 Columbus. This morning we are going to talk about
3 modification or improvement of the model for removing also
4 particle by spraying, especially in the case of S2D, as we
5 did the last time.

6 I am going to talk about the possible
7 modification of this model. And one of the questions which
8 came up last time was the effect of water droplet size on
9 removal weight. So we are going to address that.

10 (Slide)

11 As you can see, we have been using this model
12 for modeling the aerosol behavior in the containment. The
13 reason we do not -- we do not have any water spraying
14 mechanism in the core. So what we did was to incorporate
15 this simple first order aerosol removal rate. Where you
16 have the aerosol concentration with decay in this fashion
17 where N is the number of spray drop concentration and this
18 is the velocity of the water drop. Small g is the settling
19 velocity of aerosol particles.

20 Because of the hydrodynamic interaction between
21 the aerosol particle and water drop, there is a collision
22 called fission. And at that time we have the two
23 mechanisms. The first is inertial impaction effect, and the
24 second being the intersection mechanism. And of course,
25 Stokes number in the inertial impaction. It is written like

1 this (indicating).

2 One of the problems we found at that time was
3 really this measured impaction effect is not all that
4 great, simply because particle size we are dealing with is
5 on the order of 1 micron. Water droplet size ranges
6 anywhere between 500 -- 400 to 1,000 microns.

7 It turns out that this comes from the model
8 which incorporates the Stokes flow, but the water droplet
9 size in our case is large. The assumption of the Stokes
10 flow probably is not accurate, because of this increasing
11 Reynolds number effect.

12 Bonded layer around the water drop might be a
13 little bit thinner than what we thought it would be, which
14 means particles could penetrate a little bit farther toward
15 the water drop.

16 (Slide)

17 This is terminal settling velocity as a
18 function of particle size. This is the predicted terminal
19 velocity using the Stokes flow model. And you can see if
20 you go up to higher -- the quality of this slide is not all
21 that great. This is 1,000 micron right here, and you have
22 100 micron. Previously, we were talking about the size
23 range of the water drop, this range. And obviously, if you
24 draw a straight line, obviously there is a deviation
25 between the predicted terminal velocity and the actual

1 terminal settling velocity, which means the Stokes flow
2 model applies.

3 So I think what I am going to do is to employ an
4 inertial impaction mechanism, which is based on laminar or
5 potential terminal flow regime or maybe we can go up to a
6 potential flow model so that we can properly incorporate
7 this inertial impaction effect in this.

8 (Slide)

9 what I have here is collision efficiency as a
10 function of proper size. In this calculation, what I have
11 is only intersection effect. And the first thing you notice
12 is that collision efficiency is real small simply because
13 the size ratio by errors of particle to the water drop is
14 small, but nevertheless in this collision efficiency
15 increases rather rapidly as the droplet size decreases. So
16 in this case, it's in inverse proportion to the scale of
17 water droplet diameter.

18 Now that chart is just the collision efficiency.
19 But with a fixed amount of water available, if you have a
20 small droplet size, then you are creating more surface
21 area, which means that your removal rate will probably
22 increase.

23 So at this point we realize that the effect of
24 droplet size is rather dramatic. The last time, I think we
25 used a droplet diameter of 1,000 micron, and some of you

1 didn't agree with that 1,000 micron. So I think the next
2 time around, we are going to -- well, first of all, we are
3 going to improve the model, and then we are going to
4 incorporate this couple of droplet size, water droplet
5 size, and see what kind of effect that will have on the
6 overall concentration decay in the case of S2D.

7 (Slide)

8 Another question which came up at that time was
9 whether the model was capable of accommodating the
10 existence of a two water flow rate, one being injection
11 spray rate and then about 5 minutes later there will be
12 recirculating pump operating. And then both of them will go
13 on until containment fails in the case of diameter.

14 Otherwise, that injection pump will turn on at the time of
15 20 minutes, will continue operating until water runs out.

16 In our new model we have to incorporate these
17 two separate flow rates, so now we can handle this in
18 containment injection pump flow rate of about 3,200 gallons
19 a minute. And subsequent recirculation pump flow rate of
20 3,500 gallons per minute.

21 (Slide)

22 So we are reexamining this collision mechanisms
23 we have in the spraying model, and we are going to use this
24 correct terminal settling velocity especially for large
25 droplets. We are considering to incorporate another

1 collection mechanism for small particles. I don't think the
2 effect of this will be dramatic, but for small particles
3 Brownian diffusion might contribute to the collection
4 mechanisms of these aerosol particles by spraying droplets.

5 And of course, this is, as I said, two separate
6 spraying flow rate.

7 Again, we do not have any removal mechanism due
8 to diffusion freezes. And that question came up.

9 (Slide)

10 So we went back and made some calculations with
11 diffusiophoresis mechanism and another one without
12 diffusiophoresis as a removal mechanism. This case happens
13 to be an AB delta. I don't know whether you remember all
14 this or not, but this is D2 metal release, and after that
15 this is the aerosol particle release during the
16 vaporization release.

17 It turned out that diffusiophoresis is not all
18 that important. There are a couple of reasons why they turn
19 out not to be important. First of all, I think the water
20 surface area is not too large compared to the containment
21 volume, and then thermal hydraulic conditions are such that
22 the wall temperature might be cooler than gas temperatures.
23 But as time goes on, the wall particularly picks up the gas
24 temperatures, so that you really don't have a substantial
25 temperature difference between the containment atmosphere

1 and the wall.

2 Really, that's all I have to say today.

3 MR. SILBERBERG: Ken, I have a question. When you
4 say the wall surface area is limited, do you include the
5 surface area provided by other internal structures within
6 the containment?

7 MR. LEE: Last time what we did was we used a
8 single volume, but I don't think we included all of the
9 available surface area.

10 MR. SILBERBERG: If you did, do you think it
11 would still make a difference?

12 MR. LEE: According to this result, I still don't
13 think it will make a lot of difference. But I have to
14 mention that this mechanism is now in this, so next time
15 around it will be -- all the calculations will include this
16 mechanism.

17 MR. CASTLEMAN: Will Castleman, Penn State. I
18 have a question about the collision deficiency. Are you
19 saying you think the expression is correct that the main
20 problem has to do with the Stokes settling velocity, or are
21 you questioning the overall relationship for the collision
22 efficiency?

23 MR. LEE: The expression we had is the one we had
24 the last time. But I think we are going to adopt a new one
25 which will be more realistic, because the water droplet

1 size is so big that this expression, which is based on the
2 Stokes flow model, won't be any good. So we're going to
3 have a new expression with that, and I think that will
4 increase the collision efficiency.

5 MR. CASTLEMAN: The new expression will be the
6 diffusion of the extreme temperatures around the droplet?

7 MR. LEE: I think right now we're looking for a
8 simple expression, which can get into -- we're not going to
9 start from scratch. I think if we can come up with an
10 analytic solution similar to this -- I know there is one
11 expression which is good for the potential flow regime. But
12 if we can find an expression which can cover between this
13 one and the potential flow regime, I think that's what
14 we're going to have.

15 MR. COOPER: Doug Cooper, Harvard.

16 From the scrubber literature, the Walton-Wilcock
17 data that has been correlated within impaction parameters
18 where over an impaction parameter plus a constant squared,
19 that's probably good toward the potential flow of the
20 high-velocity regime.

21 One of the things that's going to increase your
22 velocity and should be taken into account is the pressure
23 of the sprays. If you have even 1 psig on the spray, I
24 think you are going to get a few meters per second initial
25 velocity of the drops. And because they have a substantial

1 mass, they have a substantial characteristic time or
2 stopping distance. So that initial velocity could carry
3 through a substantial portion of the containment.

4 MR. LEE: Right. I am aware of that possibility
5 also. I think at one time we just assumed the droplet on
6 the terminal setting lies there. Again. I guess it just
7 depends on what kind of droplet size we are going to use.

8 Another thing I might add, like you mentioned,
9 this expression is such that you have got to have a Stokes
10 number larger than 1.214 essentially, and that's kind of
11 hard to have. That might be true for the case of, again,
12 Stokes flow. But I think if you go to this potential flow
13 regime, you really don't have to have a Stokes number --

14 MR. COOPER: That's right. There's no critical
15 Stokes number really in the other one.

16 The other thing I am concerned about is the
17 diffusiophoresis, which I mentioned in the memo to Mel. But
18 as you pointed out, it's not so much a collection by the
19 droplets, because often that's offset by the
20 thermophoresis. But this business of flow to the walls I
21 think needs yet some more study.

22 In the scrubber literature it's been found, for
23 example, if you condense roughly a quarter of the vapor, if
24 the gas is roughly a quarter water vapor and you condense
25 pretty much all of that on the walls, you take out about a

1 quarter of the aerosol concentration.

2 MR. LEE: Exactly.

3 MR. COOPER: I just believe in the physical
4 situation that there's going to be an awful lot of water
5 vapor produced.

6 The calculation I ran through for the Surry
7 situation suggested 5,000 pounds would give you almost a
8 containment volume's worth of water vapor, and that should
9 be condensing on the walls, running down the side of the
10 walls, being heated up again. I think that's going to give
11 a lot of collection. And I was surprised by the results of
12 the first calculation. It may be we're not getting enough
13 heat conduction out of the containment.

14 MR. LEE: Right. I think what happens is before
15 the core melting starts, you get a lot of condensation in
16 the containment. But we don't have an efficient product at
17 that point. Actually, that was one thing we found.

18 The second thing we thought we had -- we
19 consider this condensation of water steam into particles,
20 and you have to compete with -- I mean this
21 diffusio-phoresis has got to compete with that condensation
22 of the water vapors and particulates. But again, this
23 model does not calculate the water vapor concentration in
24 the vicinity of the wall. We just take the condensation
25 rate which is calculated by the thermal hydraulic cause.

1 So that's what we have found so far.

2 But I agree with you.

3 MR. COOPER: The final point I wanted to make is
4 that at the beginning of a leak we should get adiabatic
5 expansion in this chamber, and that should lead to real
6 supersaturation and perhaps enhanced particle growth and,
7 therefore, enhanced particle deposition.

8 MR. LEE: Right.

9 MR. WILLIAMS: David Williams, Sandia.

10 The comments I sent in on the S2D analysis are
11 on the whole thing. I noted I had a great deal of
12 difficulty reconciling the expression being used there for
13 spray efficiency with the results that were coded for S2D
14 delta or S2D sequence both for gamma and delta.

15 MR. LEE: S2D gamma and delta. Okay.

16 MR. WILLIAMS: In particular, the suspended
17 aerosol concentrations in the S2D delta sequence that were
18 quoted in one of the figures indicated a particle residence
19 kind of no more than a few seconds, whereas as you noted in
20 that expression for the impaction efficiency, that term is
21 extremely small for particles of the order of a few microns
22 -- no, the interception term is extremely small; the
23 impaction term doesn't come in at all for Stokes diameters
24 less than 1.214.

25 And yet the actual results quoted seem to imply

1 a large collection efficiency. Have you looked into that at
2 all?

3 MR. LEE: Right. Can you identify yourself once
4 again?

5 MR. WILLIAMS: David Williams, Sandia.

6 MR. LEE: Right. I think I read your comment, and
7 you are precisely right. I think this expression is, like I
8 said, is not correct. One thing, because of the flow model
9 I just talked about, and the second one, as you pointed
10 out, this began if Stokes number becomes less -- well, I
11 guess you're talking about two takes, and it really should
12 have been suppressed for the regime where the Stokes number
13 is less than 1.214. So that was a mistake.

14 I think I read your comment, and you were
15 precisely right.

16 MR. WILLIAMS: Thank you. That clarifies my
17 concern.

18 MR. RITZMAN: Bob Ritzman from SAI.

19 Did I understand you, Ken, to say when you redo
20 this again you are going to use a spray droplet size
21 distribution?

22 MR. LEE: No.

23 MR. RITZMAN: You're not going to use a
24 1,000-micron spray drop size?

25 MR. LEE: I think we're probably going to use 400

1 or 500. But I think I will have to ask your opinion or the
2 opinion from -- I think the last time we used 1,000 micron,
3 there was a lot of objection to the size of the water
4 droplet. But we are not going to model a size dispersion
5 of a water drop. I don't think it's really worth it. It's
6 just a matter of which number you pick. Probably surface is
7 a million diameter water droplet.

8 MR. COOPER: Typically, the sort of mean diameter
9 surface volume ratio.

10 MR. ROE: Donald Roe, Roe & Associates.

11 Could you describe how you are handling the
12 condensation and heat transfer at the wall?

13 MR. LEE: No, I didn't describe that.

14 MR. ROE: Would you describe briefly how it's
15 done, what level of modeling is included?

16 MR. LEE: We just take the condensation rate
17 provided by the thermal hydraulic code and use that rate to
18 calculate the removal rate.

19 MR. ROE: How is that condensation rate
20 determined? What's in the thermal hydraulic modeling?

21 Rich, maybe you could answer that.

22 MR. DENNING: We use the MARCH code, and that has
23 empirical heat transfer correlations of the type, the
24 Togomi type of correlations.

25 MR. ROE: Were you considering wall heat

1 capacity?

2 MR. DENNING: Yes. We are modeling the thickness
3 of the walls and heat transfer into the walls.

4 MR. SILBERBERG: Thanks, Ken.
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TAYLOE ASSOCIATES
1625 I Street, N.W. - Suite 1004
Washington, D.C. 20006
(202) 293-3950

1 MR. DENNING: I am Rich Denning, and I am going
2 to be discussing a small study that we did to look at the
3 effects of decay heat that is deposited on the surfaces of
4 the reactor coolant system and its effect on temperatures.

5 (Slide)

6 As you will recall, the MERGE analyses that look
7 at the reactor coolant system temperatures as a function of
8 time are done quite independently from the TRAP analyses,
9 and the flows and temperatures that are predicted by MERGE
10 are then input into TRAP.

11 TRAP predicts deposition of fission products on
12 the reactor coolant surfaces associated with those fission
13 products as decay heat. But the effect of that decay heat
14 is not then cycled back into the MERGE analysis to
15 determine what the effect is on the temperatures and the
16 flows.

17 We are definitely not interested in coupling the
18 MARCH, MERGE, and TRAP analyses, but we recognize that in
19 order to do this problem right, that maybe eventually what
20 is required. So what we wanted to do is to look and see
21 what is the effect by going through a single iteration of
22 MERGE and TRAP analyses.

23 And I think that there are basically two issues
24 that are of concern here. The first one is how important is
25 the feedback of the decay heat from the fission products

1 during the time period of our TRAP analysis on changing the
2 thermal hydraulic conditions within the reactor coolant
3 system.

4 Then there is a very closely related question
5 but a very important one that says, what happens in the
6 long term if we put fission products on surfaces during the
7 period when we have flow in the reactor coolant system?
8 What we do is basically we just forget about them then.

9 But there really is a question, what happens to
10 them in the long term? After we move on to the other phases
11 of the accident, is it possible that these fission products
12 will cause surfaces to continue to heat? Is it possible
13 fission products will be reevolved? Is it possible we could
14 set up strong convection patterns within the vessel that
15 bring air into the vessel, change the chemical form of the
16 fission product?

17 So basically, these are the two issues that we
18 are trying to address. The approach is to adapt MERGE so we
19 can include fission product decay heat source term in
20 calculating the structure temperatures, and then to perform
21 one set of iterations, MERGE run, TRAP run, take the
22 fission products from the TRAP run, put those back into
23 MERGE and run again and see if we see a significant
24 difference between the temperatures of the two MERGE runs,
25 do we see a significant difference in the deposition in the

1 two TRAP runs?

2 (Slide)

3 The accident sequence for which we did this was
4 the S2D epsilon case, or the S2D case. It doesn't matter
5 what the containment failure mode is here. I just wanted to
6 review for you what the flow path is in this sequence.

7 we have assumed a small break in the cold leg, a
8 flow path that goes from the core into the upper plenum
9 region down a hot leg through the steam generator. That's
10 important. The steam generator not only is massive, but in
11 this particular case could very well have active cooling.
12 So the fission product decay heat that goes into here could
13 be carried away quite easily and then out to the
14 containment.

15 (Slide)

16 In order to do this, we did a series of ORIGEN
17 calculations for three burnups corresponding to three
18 different core regions: 11,000, 22,000, and 33,000
19 megawatt-days per metric ton.

20 Then we looked at different times after
21 shutdown. We actually added the three core regions back
22 together again. We didn't look locally to see what the
23 effects were.

24 And we grouped by major groups the noble gases:
25 an iodine group, cesium group, tellurium group, and then

1 everything else thrown into a balance. This group is really
2 represented by aerosol.

3 And we looked at the fraction of the decay heat
4 that is associated with the full core inventory of each of
5 these at these different shutdown times. And then this
6 table is put into the MERGE code. And then we looked. We
7 did a MERGE analysis, a TRAP analysis. And we looked to see
8 how many fission products did we have deposited in the
9 upper plenum.

10 (Slide)

11 I am going to focus here on the upper plenum.
12 The three major regions for deposition here could be the
13 upper plenum, the hot leg, and steam generator. But I am
14 really going to focus here in looking at the upper plenum.

15 This shows noble gases are actually resident in
16 the region and not on the structures. This is the TRAP
17 analysis, fraction of core inventory. You will notice the
18 iodine which was transported in the form of cesium iodide
19 initially started to deposit on surfaces, but then as the
20 surfaces heated up, was driven back off.

21 The cesium which was primarily deposited as
22 cesium hydroxide, some of it deposited as aerosol, the
23 tellurium, and then the balance.

24 Now, if you took this figure and the last figure
25 and multiplied the fractions of core inventory times the

1 neats, what you would see is at the end of this time period
2 most of the heat is coming from the tellurium and the
3 aerosol, a little bit more from the tellurium than from the
4 aerosols.

5 The tellurium, incidentally, you will see that
6 this behavior for the BWRs that we will get into later
7 today may change substantially. We probably won't see as
8 much tellurium deposited in the primary system.

9 But in this case, most of the heat in the
10 structures at this time at the end of the period is coming
11 from the tellurium, almost as much as is coming from the
12 bulk of the aerosols.

13 (Slide)

14 The representation for the upper plenum, if you
15 recall, for the Surry PWR in its first volume draft, we did
16 not have good representation of data for the upper plenum
17 structures. We subsequently have that. But this study was
18 done before we had that.

19 The case that we have used is what we have
20 called the hot upper plenum case, which minimized, was at
21 the lower bound of what we thought the surface area and
22 structure mass in the upper plenum was.

23 So the effect that we see here may be
24 overemphasized over reality, although I don't think
25 greatly. The maximum it could be would be a factor of 4.

1 But there might be some overemphasis of this effect.

2 This is the temperatures that we see in the
3 upper plenum without the fission product decay heat and
4 with the fission product decay heat. And at the end here,
5 where we are slumping into the lower plenum, we have a
6 difference of about 400 degrees Fahrenheit, which is not
7 insignificant. And the rate of heating of the structures is
8 fairly significant here due to fission products.

9 (Slide)

10 The effect of that on the fission products is
11 shown in the final slide. Recall that this particular --
12 other than the tellurium, there was not a great deal of
13 retention in this particular case. There is virtually no
14 effect on the aerosol deposition, which is a major
15 contributor to the heat source.

16 There was enhanced deposition of the
17 higher-volatility materials on the aerosol particles. That
18 is, instead of depositing on the surfaces, they deposited
19 on the particles.

20 And we saw some change in the location of the
21 deposition, and we also saw a change in the deposition
22 mechanisms. Much more of the deposition was happening
23 associated with the aerosol deposition rather than the
24 direct vapor deposition.

25 As far as the total primary system behavior, we

1 saw some significant -- well, quite significant on the
2 cesium iodide effect on the retention. We saw only about
3 half as much retention.

4 But in that particular case, we had very little
5 retention anyway. So I am not sure how meaningful that
6 particular amount is. A small effect on the tellurium.
7 Small effect on the cesium hydroxide.

8 Our conclusions from this are that this could be
9 a significant effect. We do not plan to adapt our models
10 for the analyses that we are performing for the last three
11 cases. That would be a major undertaking.

12 We do, however, think that it does raise,
13 continue to raise, significant questions about the
14 long-term behavior of fission products that are deposited
15 in the reactor cooling system. I think this would be a
16 major consideration in the sensitivity studies that are
17 going to be initiated this summer.

18 I will be glad to answer any questions.

19 MR. WALKER: Dee Walker from Westinghouse.

20 On those numbers, you had about 60 percent of
21 the tellurium on the surfaces and 2 percent of the
22 aerosols. What if you got 3 or 4 percent of core decay heat
23 on the surfaces?

24 MR. DENNING: Right. 2 percent of each of those.

25 MR. WALKER: Not very much, actually.

1 MR. DENNING: Not very much, actually, but enough
2 to have a fairly significant effect on the heating of the
3 structures. And also, recognizing the uncertainties in our
4 depositions are significant, if we were to get into a
5 regime -- and for example, this afternoon you will see a
6 case where we get some fairly significant deposition of
7 iodine on the upper plenum structures -- we could get into
8 regimes that involve quite a bit more heating than that.

9 MR. COOPER: Your description made me think of
10 something. When you get the vapors onto the particles, then
11 you deposit particle plus vapor on the wall.

12 Does the code keep track of the fact that it
13 still has material that is potentially in vapor form if it
14 gets heated again, or does it take it now and connect it to
15 the particles in a way that won't come up?

16 MR. DENNING: It will allow it, if it condensed
17 on the particles, it will allow it to vaporize off the
18 particles.

19 MR. COOPER: Good.

20 MR. VOGEL: Vogel, EPRI.

21 The relative importance of the fission product
22 heating depends upon what you have assumed with regard to
23 convective heat transfer from the core to the upper plenum.
24 I assume, since at the moment that is sort of an open
25 question, that you probably didn't assume very much. Is

1 that incorrect or what?

2 MR. DENNING: Let me answer the question. I am
3 not sure that I completely understood it. I think there is
4 a major issue that regards how much natural convection
5 exists in the upper plenum, particularly in the period
6 after we melt through the lower head of the vessel. And in
7 the long term, the thermal hydraulic condition in the
8 vessel is going to be an extremely difficult problem to
9 resolve: What is really happening in the vessel in the long
10 term, how much convective cooling is there of surfaces?

11 In the shorter term, what we assume -- what we
12 did was we had flows driven from volume to volume by the
13 generation rate of material. Within the upper plenum the
14 heat transfer structures due to natural convection was
15 based upon natural convection correlations based upon
16 Grashof number types of considerations.

17 MR. WALKER: One more. In the TMLB' sequence, the
18 small-break sequences, you have a fairly short time between
19 the introduction of material on the lower head and the
20 vessel melt-through.

21 I guess my question is: Is that a result of the
22 code, is it something you really believe, or in Surry is it
23 a result of not having much water down because of the
24 atypicality of the lower-end region because of the steam
25 sweep section subsequent to core slump?

1 MR. DENNING: With regard to the pressurized
2 cases, like TMLB', I think there is little uncertainty that
3 shortly after the core falls into the lower plenum, you
4 will fail the lower head because of the internal pressure
5 and the strength.

6 You really don't have the melt through the lower
7 head. All you have to do is really heat it up. So I think
8 there is very little uncertainty in those particular cases.

9 There is more uncertainty in the unpressurized
10 cases as to just what the duration will be, and you will
11 see this afternoon or this morning when we talk about BWRs
12 quite a different predictive behavior than for those
13 particular sequences and quite an effect on the types of
14 the periods of release, the processes that are going on
15 while the core is in the lower plenum region.

16 MR. WALKER: You know, it just seems to me it's
17 difficult to convince yourself you will have a coherent
18 enough slump that you will drop a whole bunch of material
19 down there and drop through the bottom head in a hurry. It
20 seems to me you will drip material down there and have a
21 fairly significant steam sweep before you get through that
22 head if there is any water at all down there. Maybe that's
23 just an impression.

24 MR. DENNING: Your questions are certainly good
25 ones about do you really dump the material down in the

1 lower plenum quickly or does it more gradually slump into
2 the lower plenum.

3 In the reanalysis we are going to do, we are
4 going to be looking much more at gradual slumping type of
5 models and the effect of that.

6 In addition, you will see that in the MERGE
7 analyses and TRAP analyses we have done for the BWR, we
8 have considered this period of lower plenum behavior much
9 better than we did in the Surry analyses. We go back to the
10 Surry analyses; we will be looking more at what happens
11 when we are producing this rapid generation rate of steam
12 at the end of this period in vessel.

13 Pete, did you have something you wanted to add
14 to that?

15 MR. CZYBULSKIS: Peter Czybulskis, Battelle.

16 I just wanted to amplify your comments that, in
17 fact, in most of the things that we are doing today, we are
18 shying away from the coherent slump down in the lower
19 plenum all at once.

20 In particular, for example, the Surry
21 calculations that I discussed, even though they were
22 addressing what happens in the after-vessel head failure,
23 we use what I call the gradual slump model. We have taken
24 into account the holdup of the debris on the support
25 structures and then the stuff falling into the head

1 subsequently.

2 It just turns out there isn't an awful lot of
3 delay in terms of the attachment of the head, as Rick
4 pointed out correctly, in the case like 'TMLB' where you
5 operate at 2200 or 2300 psi. It just doesn't take very long
6 to heat the head to a point where there's very little
7 structure.

8 MR. REYNOLDS: Reynolds, GBA.

9 Why are you considering more and more the
10 gradual slump as opposed to all of it coming out at once?
11 Is there any experimental data or any evidence to move in
12 that direction?

13 MR. DENNING: That's a matter of interpretation.
14 There are people that read into the behavior of out-of-pile
15 experiments at KFK that you do have that kind of slumping,
16 more of that kind of slumping behavior rather than more
17 coherent drop.

18 I think that intuitively we tend to believe that
19 the gradual slumping behavior is more realistic than the
20 sudden dropping. But you raise an excellent question about
21 the state of validation and understanding of these.

22 And a point that I would like to make as often
23 as I can today is the sensitivity of the results we get to
24 modeling assumptions in the core region and the primary
25 system thermal hydraulics. Although you will see reported

1 today single values for fission product releases, you
2 should recognize those values could be changed dramatically
3 by just such things as the slumping behavior.

4 We will show you an example this afternoon, not
5 intentional sensitivity study but basically the same
6 sequence that we have done with Peach Bottom and Grand
7 Gulf, where we get very large differences in primary system
8 deposition just due to a fairly minor change in the
9 treatment of the modeling of the core slumping.

10 MR. WALKER: Rich, in this particular case, it is
11 important too because it's a question of whether the
12 fission products are in the vessel available for release or
13 whether they've been transported down the system and vented
14 out somewhere as a result of transport in the TMLB question
15 case.

16 MR. DENNING: Yes, that's right.

17 MR. RITZMAN: Ritzman, SAI.

18 I want to try to get this picture straight of
19 fission product heating and reevolution and transferring to
20 particles. In a location if a surface heats up from the
21 deposit fission particle, reevolves and somehow it
22 partitions more favorably to aerosol particles, is that
23 downstream where the aerosol is cooled, or does it occur in
24 the same cell?

25 MR. DENNING: I think it's downstream, but I

1 would like to let Mike see if he could answer that because
2 he has looked at the TRAP results more than I have.

3 Do you want to attempt to answer that?

4 Also, we have to be careful not to
5 overgeneralize this particular result to all cases.

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TAYLOR ASSOCIATES
1625 I Street, N.W. - Suite 1004
Washington, D.C. 20006
(202) 293-3950

1 MR. KULHMAN: Mike Kuhlman from Battelle.

2 what we see in this analysis, Bob, is something
3 that is similar to what we have seen previously, which is a
4 vapor deposit on the first structures that it sees when
5 these begin to heat up previously due only to the hot steam
6 coming from the core region. Now we have this additional
7 heat which is coming from the decay heat of the fission
8 products themselves.

9 You wind up preinvolving them into the gas
10 change, which at some point in these analyses it's actually
11 being cooler than the surfaces than are the particles being
12 treated. Throughout, the analysis is being at the
13 temperature of the gas stream. We are incurring some
14 problems there because there is no fission product heating
15 on the particles themselves, allowing them to reach the gas
16 temperature.

17 what you are seeing is mainly transport
18 downstream. I think the figures Rich gave in terms of
19 reduced deposition or retention efficiencies were only for
20 the upper plenum.

21 MR. GIESEKE: That was for the entire plenum?

22 MR. KULHMAN: For the entire plenum system. That
23 would imply then there are more of the vapors being
24 transported with the particles which are less subject to
25 deposition than the steam generator. Had the material then

1 transported downstream with the vapor, it certainly would
2 have been plated out very efficiently in the steam
3 generators in the system, but it wasn't able to because of
4 the slumping particle.

5 MR. RITZMAN: The decay split there, the gamma
6 portion of decay heating is more penetrating than the beta
7 energy. How do you partition the beta and gamma
8 contributions in this analysis, or did you not?

9 MR. DENNING: We put the decay heat in the
10 structure. We are not modeling the depth of the structure
11 -- actually, we don't have to model, we don't have to do
12 analysis. The structures here are thin enough so that it
13 doesn't matter. We put the decay heat, whether it is beta
14 or gamma, into the structures.

15 MR. COOPER: Cooper, Harvard.

16 Just a quick comment. The heat transfer to and
17 from the particles in the gas stream is so rapid, I don't
18 think you will find the decay heating raises them above the
19 gas temperature.

20 MR. SILBERBERG: Thank you, Rich.

21 We will declare a 15-minute break.

22 (Brief recess.)

23 MR. SILBERBERG: Thank you.

24 I would just like to add to the comment that Jim
25 Gieseke made, and would like to acknowledge officially for

1 the record that in the ensuing 3 or 4 months, the
2 cooperation that we requested from the industry at the last
3 meeting regarding input of information to support our work
4 was very well received by a number of groups.

5 And we would like to express our appreciation
6 for the support we got from Westinghouse, General Electric,
7 particularly for the BWR reports, obviously, and from Stone
8 & Webster.

9 And with that, back to Jim Gieseke, who will now
10 discuss the Peach Bottom analysis.

11 (Slide)

12 MR. GIESEKE: To move on to the next topic, which
13 is, as I referred to it earlier, Volume 2 of BMI-2104,
14 which deals with the MARK-I design, Peach Bottom reactor in
15 particular.

16 And I reiterate the acknowledgments, since there
17 has been additional input to us on this topic, particularly
18 the help we've gotten from General Electric in providing us
19 with all sorts of information that we need, and also PNL,
20 who have done the development of the SPARK code which we
21 are using for aerosol removal in suppression pools.

22 (Slide)

23 Just to quickly go through -- I don't know if
24 you can see this very well or not -- the whole procedure
25 that we are following in this is very similar to the

1 procedure that we followed previously for the Surry
2 reactor, where we begin with the selection of the plants
3 and then the accident sequences, specify the geometry and
4 the accident sequence phenomenon, and then go through the
5 thermal hydraulics analysis with the MARCH code for both
6 the fuel neatup, which comes over -- information is used
7 over this way, and in the primary system and containment
8 thermal hydraulic information, which reads in the other two
9 directions, followed by MERGE calculations for the reactor
10 coolant system in this case, which then is followed by the
11 transport and the reactor coolant system of the TRAPMELT
12 code.

13 Information from MARCH used for release from the
14 fuel in the CORSOR code also gives us the initial
15 temperature of the melt for the core-concrete interaction
16 model, the release from the core-concrete interaction as
17 does the information from the CORSOR code which tells us
18 that is still there when it arrives at the concrete.

19 This then is combined in a series here, and this
20 will have to be described individually for the sequences.
21 It's not a straight-through shot in all the cases. There is
22 a lot of complications involved in handling the codes.
23 Sometimes you run an hour code for a while, then you stop
24 it and start it, a SPARK code, then you pick up the
25 calculations later. That will be explained.

1 That is the final calculation which all this
2 leads towards, which is then released to the environment.

3 (Slide)

4 Just to briefly give you a list of the topics we
5 will be discussing. In case you are wondering what I am
6 doing, this is an introduction.

7 (Laughter)

8 Following that, we will be hearing from Rich
9 Denning on the sequence descriptions and thermal
10 hydraulics. Mike Kuhlman will tell us about the reactor
11 coolant system transfer as well as release from the pool,
12 then transport in containment and attenuation in
13 suppression pools, Ken Lee. And I will try to summarize it
14 a little bit following those.

15 With that, we will go on to Rich Denning.

16 (Slide)

17 MR. DENNING: I am Rich Denning, and I will be
18 describing the accident sequences, what happens in these
19 accident sequences, and the thermal hydraulics,
20 particularly the primary system thermal hydraulics.

21 The design that we will be talking about is a
22 MARK-I design. And for this particular design we have
23 selected Peach Bottom 2 as a representative reactor. And
24 the reason is obvious. That's the reactor that was analyzed
25 in WASH-1400. So, for historical reasons, we wanted to

1 analyze that reactor. In addition, we have quite a bit of
2 information on that particular reactor.

3 I guess I should also say I would like to thank
4 Steve Hodge for all the help from Oak Ridge that he
5 provided to us in describing the reactor from his
6 experience with Browns Ferry.

7 The sequences that we selected to analyze here
8 were basically the risk-dominant sequences. We used the
9 same philosophy that we described before for the Surry
10 plant. That is, we were looking at severe accident
11 sequences, particularly one that had the greatest effect on
12 the risk.

13 We wanted to cover a spectrum of behavior, and
14 that's why we have selected the AE sequence, a large LOCA
15 sequence of failure for the CC system. In WASH-1400 the TC
16 and TW sequences were overwhelmingly the dominant accident
17 sequences, not only from their consequences but also their
18 predicted comparabilities in WASH-1400.

19 NRC has a program called ACEP, accident sequence
20 evaluation program, which is reevaluating the probabilities
21 of accident sequences from the 1,300 PRAs that are out in
22 the world today.

23 The results of that are quite consistent. The TC
24 and TW are still very important accident sequences. TQOV
25 also an important accident sequence. You will see we

1 analyzed that for the Grand Gulf.

2 The AE isn't really an important accident
3 sequence from a PRA viewpoint, but our other objective was
4 really to look at a spectrum of conditions in the primary
5 system and the containment. So that's why we picked this
6 particular sequence. And I will be describing what those
7 are if those initials don't mean anything to you.

8 (Slide)

9 The code that we're using here is the MARCH 2
10 code. MARCH 2 is still under development. The version that
11 we have used here, essentially this version, has been
12 available to the national laboratories since approximately
13 January, and they are undergoing peer review comments on
14 it.

15 We really had a number of participants in coming
16 up with the MARCH 2 code. It really is broader than the
17 laboratories that are indicated here.

18 There were a number of objectives for developing
19 MARCH 2 rather than the MARCH 1.1 code. Those objectives
20 primarily related to since MARCH 1.1 had been released, the
21 number of laboratories such as Brookhaven, Sandia, Oak
22 Ridge which had been developing their own models for
23 studies that they had been performing with the MARCH code.

24 So there were a number of new models, improved
25 models that were available in various forms and various

1 versions of MARCH spread out around these laboratories.

2 So one of the reasons was to upgrade the models
3 in the code, to put in these models that people had been
4 working on for a few years.

5 There are problems in the transportability of
6 MARCH 1.1, partoly related to the code structure, partly
7 related to the language. It's very CDC-oriented, some of it
8 even the Battelle computer oriented. Some of the changes in
9 MARCH 2 do relate to code structure language. It's written
10 in FORTRAN 77, although the version we've been using here
11 is a FORTRAN 4 version. And there are some corrections also
12 in MARCH 1.1 that have been included in the MARCH 2 code.

13 I am going to quickly identify some of the
14 improved models that are in MARCH 2 over MARCH 1.1. This is
15 by no means comprehensive. Under each of these there is
16 quite a story to tell.

17 One of the most important changes is in the
18 representation of the decay heat. In the MARCH 1.1, the
19 component of decay heat coming from the heavy elements is
20 not included. That is included in MARCH 2. So typically,
21 you see higher decay heat, somewhat shorter times for
22 heating up the core, this type of thing in MARCH 2.

23 Water and steam properties, quite frequently in
24 MARCH 1.1 there were single values that were used for water
25 and steam properties independent of the particular regime

1 you are in. There have been a number of changes for
2 improvements there.

3 Heat transfer correlations in the core, they
4 have been upgraded significantly. Some of these make fairly
5 significant results in the results; some make very little
6 results. But most of these changes do improve the
7 credibility of the code.

8 In the area of debris coolant interactions,
9 there are a number of changes, and I will only identify a
10 few of these, including a debris beds to represent the
11 heating of the debris bed -- I am sorry -- the cooling or
12 heat transfers from the debris bed have been incorporated.
13 These are actually Brookhaven models that have been
14 incorporated in the code.

15 These things can make some significant
16 differences in the behavior. And you saw some sensitivity
17 studies where Pete showed the effect of some of these
18 options.

19 The zircalloy steam reaction modeling has been
20 upgraded. There is steel-steam reaction that is now allowed
21 in some regions, such as in the reactor cavity, and this
22 can have quite a contribution to the amount of hydrogen
23 that's produced. There have been significant changes in the
24 hydrogen burning models. Many of the HECTOR models have now
25 been incorporated into the MARCH code.

1 There are some improvements in the way that we
2 have used MARCH that aren't necessarily new models or new
3 options in MARCH 2 but which are things which have evolved
4 and are easier with the MARCH 2 code, such as the more
5 gradual slumping that Pete Czybulskis talked about before.

6 In these PWR analyses, we have used what we call
7 a gradual slumping model. That is, when the fuel gets to a
8 fairly low amount of melting, we allow it to start to slump
9 and provide its heat to the water in the lower plenum area
10 and then later eventually will get to a period where we
11 will then slump the rest of it into the lower plenum.

12 And you will see that's going to have a
13 significant effect when I show you the results of the
14 temperatures in the reactor coolant system.

15 I would like to point out one thing to make
16 clear that's not included. One of the models that we are
17 currently putting into MARCH 2 is a SHROUD model. If you
18 are familiar with the BWR design, there is a can around
19 each assembly, a zircalloy can around each assembly.

20 Oak Ridge has developed a SHROUD model for MARCH
21 which treats that can separately from the cladding. We are
22 currently incorporating that into the MARCH 2.0 code, but
23 it was not incorporated in the version we used to run these
24 analyses. So the zircalloy that's associated with the can
25 is assumed to be at the same temperature as the zircalloy

1 that's associated with the cladding.

2 That is probably not a terrible approximation,
3 but it certainly is one that we will be looking at later in
4 sensitivity studies to see what that effect is. Oak Ridge
5 has actually done some sensitivity studies with our model
6 to see what that effect is, too.

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TAYLOR ASSOCIATES
1625 I Street, N.W. - Suite 1004
Washington, D.C. 20006
(202) 293-3950

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1 The BARK I design is significantly smaller than
2 the PWR containment that we talked about at the last meeting.
3 This region that I'm tracing out here represents the contain-
4 ment--not this outer building here, but this is the primary
5 containment, is a steel shell. This is a steel containment. It's
6 a free-standing steel shell. This is the drywell region
7 here. This is the wetwell region here, where the suppression
8 pool is there is a vapor space here. The volume here in the
9 drywell region is 159,000 cubic feet. The vapor space in the
10 wetwell is 119,000 cubic feet. That compares with approxi-
11 mately two million cubic feet for the large-size PWR--so a
12 much smaller containment design. And this, of course, will
13 affect residence times and things like that.

14 The purpose, of course, for this kind of configur-
15 ation is if one gets a pipe break accident, then the steam
16 is relieved through vents into the suppression pool, and as
17 you will see in the transient type of sequences we'll be
18 looking at, the relief is through spargers into the suppression
19 pool.

20 Now let me talk a little bit about the failure
21 of this containment. In WASH-1400, there were analyses done
22 that indicated that the failure pressure, the ultimate failure
23 pressure for this containment, might be in the range of
24 250 psia, but there were some approximations in those
25 analyses. In the treatment of this containment in WASH-1400,

1 a failure pressure of 175 psia plus or minus 25 psia was
2 assumed. That's 175 psia. It was also assumed as a result
3 of the analyses that the failure location would be right here
4 in the wetwell. Now, that had a lot of implications for the
5 accident sequences.

6 First of all, recognizing a failure location in
7 this region, it was felt that we could not assume that the
8 failure occurred there, that the water would stay in the
9 torus, so the dominant accident sequences in WASH-1400 or
10 the major consequence accident sequences are ones in which
11 containment failure occurs before core meltdown begins.

12 As I explain the TC and TW sequences, you'll see
13 why that happens, and in which--that the containment has
14 failed before the core is melted down, and where the water
15 here is basically assumed to have left this location, and
16 that the blow-down from the primary system into the suppression
17 pool area doesn't really go for water, so the relief is basi-
18 cally in this room here.

19 I'll talk a little bit more about the failure
20 modes for this building, the reactor building, later, but
21 let me say in WASH-1400, it was felt that there were two
22 kinds of failure. One is--there is a quadrant of this region
23 down here that has a ceiling that goes directly to a floor
24 that goes to the outside, and it was assumed that one-fourth
25 of the time corresponding to that quadrant, the failure in

1 this building would occur in that quadrant, and you would
2 have fission products released into this vapor region, and
3 then directly to the outside, and these are called the
4 "gamma prime failure mode sequences." They are the large
5 consequence accident sequences in WASH-1400. Let me repeat
6 again: it is assumed in these sequences containment failure
7 had preceeded core meltdown, the release from the primary
8 system goes directly into this region here, and then directly
9 to the outside without the potential for deposition.

10 The other failure mode that was assumed in WASH-
11 1400 was -- this is for this reactor building out here now--
12 that you had a blow-out occurring in blow-out panels in this
13 region of the reactor building, and there was transport that
14 occurred from this room either up through connected volumes
15 and then out or up an annular region, that is, between this
16 free-standing steel shell and this concrete wall that is
17 behind there, and the analyses that were actually done are
18 really for this pathway here--that is, up this annulism and
19 out the building, and those are called the "gamma failure
20 modes," and have somewhat less consequences than the gamma
21 prime, but still quite large.

22 The amount of retention within the annulus is
23 significant, but less than an order of magnitude effect.

24 Okay. Now, subsequent to WASH-1400, the NRC had
25 a study done in Ames, Iowa, to look at the failure levels

1 for steel containments. One of the steel containments they
2 looked at was a MARK I design. The predicted failure pressure
3 was 123 psia, significantly less than 175 psia in WASH-1400,
4 and the location of failure was felt to be in this place
5 right here-- this arrow goes a little too far -- right at that
6 point right there, in a drywell region. That, of course, is
7 going to have significant implications. It means that the
8 water will not be displaced down here. We assume the water
9 is not displaced as a result of containment failure.

10 Any releases that occur from the reactor coolant
11 system into the drywell are going to be able to go out of
12 that failure without going into the suppression pool in some
13 of these sequences. This will be clear as we go through some
14 of the sequences.

15 This reactor building here is really divided into
16 two regions, the lower region, below a refuelling floor, and
17 an upper region. The lower region has a three psi guage de-
18 sign pressure to be able to withstand a tornado. The upper
19 region is just a steel shell, a metal-siding type building
20 that has very little strength. There are also blow-out
21 panels in this region. There are blow-out panels from this
22 region into that region, and there are blow-out panels from
23 here into the environment. You will see as we get into the
24 analysis of these sequences that the integrity of this
25 building can be very important, and the things that happen

1 in this building can be important with regards to mitigating
2 the consequences of the accident sequences.

3 I will discuss one sequence in which we have looked
4 at the effect of retention within this building. In the
5 other sequences, we have assumed that the failure is such
6 that we would either blow down from here into the--this
7 cavity room, and out into the environment. We would have
8 passed up into here and failed this part of the system, or
9 that the failure of the primary containment is sufficiently
10 violent that it leads to failure of the secondary containment
11 reactor building.

12 There is one sequence, however, TC, in which we
13 look at the effect of this reactor building on additional
14 retention.

15 MR. KASTENBERG: Rich, does the change of your
16 idea of where the containment fails change the relative
17 risk dominance of the sequences?

18 MR. DENNING: No, it doesn't change. These
19 sequences are so dominant from a probability standpoint as
20 well as a consequence standpoint that it doesn't really
21 affect that, but you will see it will have a significant
22 effect on the release patterns, what periods of the accident
23 are important from a release standpoint.

24 We have taken this pathway here for the study.
25 We don't really feel the question has been really resolved

1 adequately as to whether the failure is here, there, or
2 possibly some other place, and it might even be a probablistic
3 consideration, could very well be something that differs
4 between different designs.

5 But we have for the purposes of this study con-
6 sidered the drywell failure.

7 MR. KASTENBERG: That was the next question.
8 In the material we were sent, I guess it confirms that is the
9 only one you've looked at.

10 MR. DENNING: That's the only one we looked at.

11 MR. KASTENBERG: My next question was going to
12 be, why didn't you look at both that failure and the wetwell
13 failure.

14 MR. DENNING: It was only a matter of time. That's
15 the type of thing that certainly could be a recommendation
16 that could come out of this meeting, but basically we want
17 to see the results of that.

18 MR. KASTENBERG: All right. I recommend it.

19 (Slide.)

20 MR. DENNING: All right.

21 I've already pointed out the things on this next
22 view graph. That is, for the study that we have here we are
23 going to look at 132 psia, and failure in the drywell.

24 (Slide.)

25 Now I would like to describe the AE sequence, a

1 large LOCA with failure of the ECC system. This is a se-
2 quence that happens very rapidly. The beginning of core
3 melt is at 12 minutes. Now this is very important. In the AE
4 sequence as we have analyzed it with MARCH II, we predict a
5 containment failure that is 132 psia is reached before we
6 have melted through the bottom of the reactor vessel.

7 So the failure of containment occurs during the
8 core meltdown period. I'll show you the implications of
9 this as far as flows and that type of thing, then reactor
10 vessel failure occurring quite a bit later at approximately
11 two hours, and the only failure mode of the containment we
12 really considered here is the gamma prime -- that is, direct
13 release to the environment.

14 We haven't considered the gamma, although the
15 gamma failure mode is certainly a possibility for this se-
16 quence, just as it is for the TC sequence for which we've
17 analyzed.

18 (Slide.)

19 MR. SIGAL: Can you elaborate why the contain-
20 ment fails at 34 minutes?

21 MR. DENNING: The reason the containment fails
22 at that time is a result of hydrogen generation, the amount
23 of hydrogen we predict has been produced due to zirconium
24 water reaction is sufficient at that time to lead to con-
25 tainment failure.

1 MR. SIGAL: Subsequent question -- is it because
2 you include the shroud zirc alloy with the clad zirc alloy?

3 MR. DENNING: That certainly is a contributor
4 to that, Raj. If there were no shroud reaction, then cer-
5 tainly you wouldn't have failure at that time. However, we
6 do expect to have significant shroud reaction. Pete, do
7 you want to comment on that?

8 MR. CZYBULSKIS: Rich, I'm not sure that you're
9 totally correct that the shrouds dominate that effect. There
10 is a tremendous amount of zirconium in that core, whether
11 you look at the cladding alone or whether you combine them
12 with the shrouds.

13 At the time of containment failure, I don't have
14 the exact numbers at my fingertips, but I believe you react
15 on an order of the third of the available clad. I'm not sure
16 that including the shrouds is particularly important, but it
17 is a point of concern.

18 MR. WORMAN: Stone and Webster. Relative to the
19 hydrogen, I wanted to clarify a point. My reading of the
20 document was this: that a hydrogen burn or explosion, but
21 rather an overpressurization due to the hydrogen existence
22 in the containment--these are inerted containments with hy-
23 drogen in the first place. Now, you inert them in addition
24 with steam. You are not treating the hydrogen explosion;
25 you're treating an overpressure of hydrogen.

1 MR. DENNING: Exactly. It's not a hydrogen burn
2 in this MARK I sequence. It's a matter of the non-condensed
3 full gases being pushed into the wetwell vapor space
4 and really overpressurizing due to the noncondensables.

5 MR. WORMAN: I might add it would be good if the
6 analyses to support of that assumption include in the report,
7 just state in the text that's how this happened. People from
8 Missouri would like to see that.

9 MR. DENNING: This is the flow path within the core.
10 Basically what we have is a core region, a dome steam separa-
11 tors. I've only shown two of the steam separators here. And
12 in this large LOCA sequence, we've had a failure in a re-
13 circulation loop, and so on its way out into the drywell,
14 the pathway is through the steam separators down an annular
15 region and out into the drywell.

16 The representation that is used in MARCH and in
17 TRAP looks like this:

18 (Slide.)

19 The regions that are modelled are small top guide
20 region shroud head, pipes and separators, the lower outer
21 annulus, and then exiting out into the containment. The
22 really important region here is the separators.

23 (Slide.)

24 The kinds of temperatures that are predicted with
25 the MERGE code subsequent to the MARCH analyses -- these show

1 gas temperatures, the structure temperatures are fairly
2 similar, and that's really what I'd like to show you.

3 (Slide.)

4 The important things I would like to point out --
5 this is the separator temperature. It's going up into the
6 region of approximately 2000 degrees Fahrenheit, and staying
7 in the region of greater than 1500 degrees Fahrenheit. And
8 this region is very important from cesium iodide deposition
9 as you'll see. It's because these temperatures stay pretty
10 high in this region here for the steam separator in this
11 case -- Dr. Ritzman?

12 MR. RITZMAN: What is time zero on this plot?
13 Is that the beginning of core melt?

14 MR. DENNING: Beginning of core melting.

15 MR. RITZMAN: I'd like to make a comment now for
16 the record -- that that be put on all view graphs or all
17 figures because it's very confusing what zero time means.

18 MR. SILBERBERG: Thank you.

19 MR. DENNING: Okay.

20 Now the things I would like to point out are the
21 turnover here. This is partly as a result of the slumping
22 and partly as a result of just steam coming out of the lower
23 head. But what we see is a turnover in these plots with the
24 temperatures -- where the higher steam flow rate as the core
25 is falling into the lower plenum and producing more steam --

1 it's turning over the temperatures in the rest of the system.

2 You'll see some cases particularly this afternoon
3 where the peak temperatures are really clipped off, leading
4 to more retention than we have in this particular case.

5 All the cases that you will see this morning, the steam
6 separator temperatures are going to stay up in this region
7 of 1500 to 2000 degrees F. And that's going to have a very
8 important impact on the retention of cesium iodide.

9 (Slide.)

10 During the period prior to primary containment
11 failure, the flow path is from the drywell into the suppres-
12 sion pool. Anything that doesn't get scrubbed out in the
13 suppression pool is really getting stored up in this region
14 right here.

15 (Slide.)

16 After containment failure, the material that was
17 stored up in here, the first thing that happens, remember,
18 containment failure rate, is going to happen right here.

19 It happens while we're still melting down in the
20 core region. After containment failure, we blow down this
21 region back into the drywell, and then out, and then through
22 some pathway to the environment. In this particular case we
23 have only considered --

24 MR. VOGEL: Where is grade on this? It looks like
25 the break on the left hand side might be below grade.

1 MR. DENNING: This, for example, is, I think,
2 unrealistic. That I'm pretty sure is below grade. Yes.
3 Actually the pathway is kind of like those for that parti-
4 cular flow pattern.

5 MR. COOPER: Rich, when you blow down back into
6 the drywell, are you now bringing all or much of the water
7 from the wetwell into the dry containment, or at least some
8 of it? When you look at it, it looks like a siphon or some-
9 thing that would bring it back into the drywell.

10 MR. DENNING: I don't believe that effect is
11 credible. It certainly isn't one that we have taken into
12 account.

13 See, there's a vacuum breaker here that opens.

14 MR. COOPER: So you have a check valve.

15 MR. DENNING: I see, I'm sorry. I see exactly
16 what you're saying. There's a vacuum breaker here that
17 allows the flow to go from here back to here, and that
18 is where the break--

19 MR. COOPER: So you won't get the liquid from
20 the wet suppression well into the drywell when you get the
21 pressure difference?

22 End tape. MR. DENNING: No.

23

24

25

MM:jl 9:1

1 MR. WORKMAN: Could you address the large horizontal
2 arrow going through the large 8-foot concrete section of the drywell?

3 MR. DENNING: This is to represent -- there are a
4 number of paths through here into different regions. And
5 there is a potential for flow paths into here and up through
6 here.

7 In the case, for example, where we considered the
8 containment -- I'm sorry, the reactor building remaining in-
9 tact, the gamma sequence, it would have been a pathway some-
10 thing like this. There are a number of penetrations that go
11 through here, with openings from this area into rooms there.

12 But basically, what I was really trying to show is
13 there are a number of possibilities here and quite a bit of
14 uncertainty as to just exactly what flow path there is here.

15 But we should recognize, for the gamma prime
16 sequence, we're assuming that we have something that's a
17 somewhat direct pathway like that.

18 (Slide.)

19 Now, I'm going to move on to the TC sequence. This
20 is a transient, with failure to scram.

21 In this sequence, basically you have a transient
22 accident, the rods don't go in, nor does liquid control go
23 into shut down the reactor. You are dumping a large fraction
24 of the decay heat into the suppression pool. The heat-removal
25 capability for the suppression pool can't keep up with it.

1 You overheat that water, raise the pressure in the containment
2 up to the point where it fails, and you fail the containment
3 before you've started the meltdown.

4 At this point, then, you cavitate pumps that are
5 providing water back into keep the core cool. You then start
6 to heat up, begin core melt at about 1-1/2 hours. And in our
7 analyses, we predict pressure vessel failure occurring about
8 217 minutes. We've considered a gamma prime and a gamma
9 containment failure mode for this particular sequence.

10 MR. REYNOLDS: What might start the transients?
11 What are the things -- are you sensitive --

12 MR. DENNING: It has to be a transient that would, I
13 believe, cause isolation of the steam line. There are a
14 variety of transients that can lead to various conditions.
15 I'm not sure exactly what the points are essential to get into
16 a TT sequence that gives you trouble, but it's that type of
17 thing. There are a large type of transients that can start
18 the sequence.

19 MR. REYNOLDS: What you did you assumed for this
20 particular calculation. Does it matter?

21 MR. DENNING: It doesn't matter.

22 MR. KASTENBERG: Just to go back for a second, you
23 only looked at the gamma failure mode for the sequence, if I
24 recall, from the material we were given?

25 MR. DENNING: You will see results of the gamma

1 prime and a gamma sequence.

2 Now, in reality, there are a number of gamma
3 sequences -- that is, behavior in the reactor building. And
4 as I talk about some of these uncertainties, I'll identify
5 some of those.

6 The flow path here is from the core to the steam
7 separators, through the steam dryers, and out the steam line.
8 There's a bypass pathway around the steam dryers once the
9 water level has dropped below a certain level. And that's
10 represented by about 15 percent.

11 So, there is some flow that is bypassing -- that
12 the important deposition areas within the system are the
13 steam separators and the steam dryers.

14 (Slide.)

15 This shows the type of representation for the
16 MERGE and TRAP analyses -- the top guide area, shroud areas,
17 pipes and separators.

18 This is the bypass area to the steam line, steam
19 dryers, and upper outer annulus, then connecting through a
20 relief line and down to the suppression pool. The suppression
21 pool, of course, is not modeled in TRAP, it's modeled by the
22 SPARC code.

23 (Slide.)

24 The types of temperatures that we obtained in the
25 TC sequence are fairly similar to the AE. We see the turnover

1 behavior. We see the separators and the steam dryers being
2 at temperatures in this range, 1500 to 2000 F. And that
3 turned out to be very important as far as the cesium iodide
4 deposition is concerned.

5 (Slide.)

6 The flow pathway from the vessel during the period
7 before you have melted through the lower head of the vessel
8 is through a steam line and relief line, into the suppression
9 pool.

10 Remember, the containment has failed in this case.
11 And back then, from this vapor space to the dry well, to the
12 failure -- and in the gamma prime sequence, to the environment
13 -- in the gamma sequence, into this volume here. And then,
14 this particular area here has a standby gas treatment system
15 of significant capacity that can take flow from their reactor
16 building and this upper area of the reactor building, draws
17 from both of those equally, takes them through trains and
18 filters and out through to the environment.

19 In the TC gamma sequence for TC, we found the
20 capacity of the standby gas treatment system to be less than
21 the rate of steaming from here, so that we have a significant
22 amount of material escaping out through the walls of the
23 building, even though the standby gas treatment system was
24 operating during the time period of release.

25 Additionally -- and this is getting a little bit

1 ahead of the story -- there's a fairly limited capacity of
2 the HEPA filters associated with that train to retain the
3 aerosols generated here and the material that went through the
4 standby gas system. There was some filtering, but that did
5 not have a major effect onto the environment.

6 MR. RAJ SEHGAL: I guess the steaming rate is propor-
7 tionate to the power that you assume during this transient. I
8 think you assume about 30 percent power? 30 or 40 percent?
9 Which is very high -- TC.

10 MR. DENNING: Let me make a comment. Then, I think
11 Pete should probably also address this.

12 Although we have a power level of 30 percent at the
13 beginning of core uncover, as the core uncovers, that's
14 reduced in modeling that's done within the MARCH code, so
15 that it does not stay at 30 percent power during this period
16 of core uncover.

17 Pete, do you remember the details of that enough
18 to give some idea as to what that looks like?

19 MR. CZYBULSKIS: We use the 30 percent equilibrium
20 power level while the core is fully covered. I believe, from
21 everything I've read and discussed with my friends in GE,
22 that is an appropriate power level to use for this particular
23 transient.

24 As the core begins to uncover, we reduce the power
25 to the point of when the core is nearly dry. It is down to

1 decay heat. And from then on in, we're down -- back to decay
2 heat as a function of time.

3 MR. RAJ SEHGAL: I believe the best estimate values
4 are lower than 30 percent, even when the core height is full.

5 MR. CZYBULSKIS: I wonder if our General Electric
6 friends would care to comment --

7 MR. DENNING: Excuse me just a second, Pete. Let
8 me comment, for the recorder here, Raj Sehgal, again, was
9 commenting and saying he felt that the best estimates for this
10 equilibrium power level were less than 30 percent. I believe
11 that the 30 percent is a good number for this particular
12 sequence.

13 In the Peach Bottom reactor, you'll notice, for
14 Grand Gulf, we do use a different value than the 30 percent.
15 The principal effect here, I think, Raj, would be with regard
16 to the timing of containment failure. It would be later in
17 time. That would have a little bit of effect on the decay
18 heat levels. But I don't think that that's the thing that's
19 driving the steaming rate that is affecting the outleakage of
20 the reactor building, as opposed to what's going up the stand-
21 by -- through the standby gas treatment system.

22 In addition, we don't see the standby gas treatment
23 system as providing significant filtering. What it's really
24 doing is providing you with an elevated release rather than
25 a ground-level or slightly elevated release.

1 Now, what I think the biggest uncertainty associated
2 with this gamma failure sequence is -- is in what happens to
3 the fire protection system in the reactor building. In this
4 region of the reactor building, there is a fire protection
5 system that will be activated on a combination of -- basically
6 a smoke detector or an ionization. And with the aerosol
7 release, we'll get that -- and with high temperature. And
8 we'll get that. And this is something that our friends from
9 Oak Ridge have analyzed, is that it's possible that once we
10 failed this building that we will have a sprinkler system
11 operating in here, and that could have a tremendous effect on
12 the retention of fission products.

13 We haven't actually analyzed that sequence. However,
14 it introduces other uncertainties, and that is you have a
15 great deal of hydrogen that is being generated by this system.
16 When we're in the dry well here, we are inerted. When we dump
17 into the reactor building, basically what happens in the TC
18 sequence and the TW sequence, we blow steam into this building
19 and exhaust it of its air, but we also, during this melting
20 period, put a lot of hydrogen in there.

21 If the sprinkler system does come on, what will
22 happen is the air will be brought back in and you will defin-
23 itely have a highly flammable condition; and with the kind of
24 integrity, the strength of this, it's not going to survive the
25 hydrogen burn.

1 So, I think in that case, where you have the sprink-
2 lers operating, you'll have some period of sprinkler operation,
3 some period of effectiveness, a hydrogen explosion that then
4 is very large in comparison with the strength of this building
5 to be able to withstand it, and then a great deal of uncer-
6 tainty as to what happens after that.

7 Now, the particular sequence we have analyzed is
8 not that sequence. The one we analyzed is a case where we
9 failed this building, we have allowed the blowdown panels
10 from this area to blow down into this area. We've considered
11 the standby gas treatment system as sucking out 25,000 cubic
12 feet per minute through a combination of these two.

13 And when there's a difference between the amount of
14 steam coming in and that 25,000 cfm, we've allowed that to
15 leak outside the building and take with it fission products.
16 That's the gamma sequence we analyzed here, you'll see,
17 because of the combination of fairly large outleakage and be-
18 cause the filters are not that effective, that the retention
19 in the reactor building is not particularly large.

20 I'm going to skip the discussion of the TW sequence,
21 other than to make a few -- just a few comments, because of
22 the time.

23 MR. WALKER: These are transient sequences, and
24 you're talking about availability of the power protection
25 system, also availability of the standby gas treatment system.

1 What is your situation with respect to power
2 availability, fire stations?

3 MR. DENNING: Obviously, that would depend very
4 much on the transient that you had going into the sequence.
5 I'm not sure -- I would imagine -- I'm not sure I can answer
6 that.

7 Peter, do you know the answer to that?

8 MR. CZYBULSKIS: There are a variety of transients,
9 a number of which do not involve loss of outside power. In
10 those cases, you have your standby gas treatment system
11 available. In the transients that do involve the loss of out-
12 side power, I believe the standby gas treatment system is on
13 emergency power. So, from that point of view, I think it
14 would be available, except for those sequences where you
15 completely lose power.

16 MR. WALKER: This is not like the TLMB --

17 MR. DENNING: No.

18 MR. CZYBULSKIS: Not necessarily.

19 MR. DENNING: What I wasn't sure about is what the
20 implications were of loss of off-site power to the sprinkler
21 system, whether pumps are required for that.

22 MR. HODGE: There are electric, motor-driven pumps
23 -- come off the diesel generators at the plant. There's also
24 a diesel-driven fire pump, independent diesel.

25 MR. DENNING: I will quickly make a couple of

1 comments about TW. It looks a great deal like TC, except
2 that it's very much extended in time. In this particular
3 case, we have the transient that is accompanied by loss of
4 decay heat removal from the pool. We have the core, however,
5 down at decay heat levels, dumping its decay heat power into
6 the pool, slowing raising its temperature until we get to the
7 point where the containment pressure has reached the failure
8 level, at 1800 minutes.

9 Then, we see cavitation after containment failure,
10 cavitation of the pumps, so that we lose makeup to the
11 reactor vessel.

12 (Slide.)

13 Look at these time periods, very long periods of
14 time before we can begin to start the core melt -- very long
15 time before we get to reactor vessel failure.

16 The only failure mode we've looked at in
17 this case is the gamma prime failure mode. The temperatures
18 in this case are fairly similar to those in TC, except
19 extended very much in time.

20 (Slide.)

21 Finally, let me make my plea again to point out how
22 important some of the modeling assumptions in the thermal
23 hydraulic area and containment response area are as far as
24 driving deficient particle transport. Some of these, as we
25 see them, are, of course, time of containment failure, such

MM:jl

9:10

1 as in that AE sequence. If we're overestimating the amount of
2 hydrogen production or underestimating the failure levels of
3 the containment, that could have a significant effect on the
4 fission product release to the environment.

5 Location of containment failure -- you'll see more,
6 as we get into results, how important that is; whether the
7 containment failure occurs in the dry well or the wet well,
8 for example, could have a significant effect.

9 The reactor coolant system thermal hydraulics are
10 subject to significant uncertainty, this turning over the
11 temperatures -- if it happens earlier than what is shown for
12 these Peach Bottom sequences, it could lead to more retention.
13 If it occurs later, we could very well be underestimating --
14 overestimating the retention.

15 Then, again, the response of the reactor building,
16 what happens to the reactor building after primary contain-
17 ment failure? Can it withstand the pressure loads that occur
18 as a result of blowdown of the primary containment failure?
19 What happens to hydrogen in the reactor building? Is there
20 a potential for hydrogen explosion? What happens to the
21 sprinkler system in the reactor building? What are the path-
22 ways for release in the reactor building.

23 That completes the things that I have to say at this
24 point.

25 Raj.

MM:jl
9:11

1 MR. RAJ SEHGAL: One question about temperatures.
2 How come the temperatures in these scenarios are much higher
3 than those in the PWR scenarios?

4 MR. DENNING: The question from Raj Sehgal is how
5 come our temperatures are higher than they were in the PWR
6 scenarios.

7 The reason is primarily related to the length of
8 time of the accident sequences. We have a fairly long period
9 of time when we are dumping heat. It's not because the
10 core outlet temperatures are higher. Actually, our core
11 outlet temperatures are lower. But the total period of time
12 that we're dumping heat into the upper regions is longer,
13 and that is why we get higher temperatures than we got at the
14 PWR analysis.

15 MR. RAJ SEHGAL: Is that true in AECs, also; you're
16 melting very fast?

17 MR. DENNING: Yes. That's a fairly fast meltdown,
18 but that is really the same reason in that one, too, in
19 comparison to the PWR sequences.

20 MR. VOGEL: With regard to MARCH 2, are we tracking
21 where the water is yet?

22 MR. DENNING: In the BWR?

23 MR. VOGEL: In BWR or PWR.

24 MR. DENNING: I wasn't sure what you meant. We've
25 always tracked where the water is, but I wasn't sure exactly

1 what you meant.

2 In the BWR controls, controls occur largely on
3 water levels within the reactor coolant system. And we do --

4 MR. VOGEL: I mean, during the course of the
5 accident, where the water is, it doesn't seem to be ever
6 called out in the reports.

7 MR. DENNING: I'm not sure. Give me an example of
8 what type of thing you're thinking of.

9 MR. VOGEL: Where the water is during the course
10 of the accident.

11 MR. CZYBULSKIS: Which particular water, the primary
12 system? Containment?

13 MR. VOGEL: When they get mixed up -- I don't care
14 -- the total water is what I'm after.

15 MR. DENNING: What you're saying is you would like
16 to see how much water is on the floor, how much water is in
17 the --

18 MR. VOGEL: Yes, how much is back in the reactor
19 vessel.

20 MR. DENNING: Certainly, all of that is tracked and
21 could be provided.

22 MR. VOGEL: I think that would be almost as import-
23 ant as the fission product location.

24 MR. DENNING: Also, for your information, the energy
25 balances are printed out as a function of time in MARCH 2, to

1 to aid the user in knowing where various energies are going.

2 MR. VOGEL: Now, let me ask a related question.

3 During the time in which the hydrogen is generated, is the

4 bottom of the reactor vessel filled with water?

end 9

1 MR. DENNING: Yes. For the in-core period, yes,
2 you are right. There is water in that region.

3 MR. VOGEL: Is most of the hydrogen generated
4 during that period?

5 MR. DENNING: It depends upon the accident
6 sequence.

7 MR. VOGEL: In, for example, TC?

8 MR. DENNING: I think the answer is no, although
9 an important amount of hydrogen is generated.

10 MR. CZYBULSKIS: Obviously, the timing of the
11 hydrogen generation varies. In the case of TC or TW, you'll
12 get significant hydrogen generation as the water level
13 drops and the core proceeds to heat up and melt.

14 You will get additional hydrogen generation
15 after the core slumping begins. In the case of the AE
16 sequence, you will get very level hydrogen generation up to
17 the point before slumping because the core has been
18 uncovered and there is very little steam in there.

19 When the core starts to slump into the bottom
20 head, you will get large amounts of steam generated which
21 flow out past the core and lead to significant amounts of
22 oxidation, hydrogen generation.

23 MR. VOGEL: One of the things that was puzzling
24 us as we read some of these sequences was unless you call
25 upon the water in the bottom of the reactor vessel, there

1 isn't enough steam available by a large amount to react
2 with the zirconium to give the hydrogen which is predicted.

3 MR. CZYBULSKIS: That is very correct.

4 MR. VOGEL: This means you are boiling out water
5 from the bottom of the reactor vessel.

6 MR. DENNING: Right.

7 MR. VOGEL: I have one further comment, since I
8 have got the microphone. And it's more of a general
9 comment. We are seeing a lot of -- the results of a lot of
10 codes and so on. It seems to me for this global peer review
11 to be helpful, we need to have some preceding specialist
12 peer review with perhaps reports to this committee.

13 For example, a problem of when the containment
14 fails and so on is an extremely significant one and also
15 one for the specialists. As I look around at the
16 composition of the peer review group, I don't -- maybe I do
17 somebody a disservice, but I don't really see experts in
18 that particular area.

19 And this we have also the problem of having six
20 or seven codes back to back here. It's not the fault of
21 Battelle, I am sure, but we really don't know what's in the
22 codes yet in many of them. And we really need an earlier
23 ongoing peer review of each one of these codes as to the
24 physical principles modeled, the coding, whether the codes
25 are properly interfaced and so on, for us to really be able

1 to do something meaningful.

2 MR. COOPER: A couple of small points. It might
3 be worth checking the carbon bed for aerosol filtration
4 also, whether or not it's going to get clogged.

5 The other thing is when the HEPA filters fail,
6 you'll have a greatly reduced resistance; therefore, you
7 should get according to the fan curves in back a
8 substantial increase in airflow through them.

9 MR. PETRANGELI: Petrangeli from Italy.

10 I would ask if you considered during the TC
11 sequence the possible activation of standby
12 gases in a liquid control systems --

13 MR. DENNING: The liquid control system?

14 MR. PETRANGELI: Yes.

15 MR. DENNING: We assumed that that system has
16 failed to get into that sequence. So we didn't consider
17 the effect of it.

18 MR. PETRANGELI: The second question is, if you
19 consider the same system and those of the control rod
20 cooling water for the other sequences, like the AE
21 sequence, not a shutdown means but a means for adding
22 cooling water, I believe the difference is not so much
23 because the flow rates are not very high but there is
24 evidence that operators will tend to use the system in case
25 of core cooling problems; as an example, the Browns Ferry

1 accident, the accident with what operators tried to do with
2 the sources of water.

3 MR. DENNING: Yes, we certainly recognize this. I
4 don't dare let Steve Hodge get the microphone from Oak
5 Ridge or he'd spend the rest of the day talking about SASS
6 analyses on that.

7 It was not our intent to look at the
8 probabilities of sequences of this type, but to look at the
9 consequences of these sequences once we got into the failed
10 condition.

11 MR. REYNOLDS: In your listing of key
12 uncertainties, I wondered if the gradual slump in MARCH
13 versus a sudden slumping of the core is a key uncertainty.
14 Does it matter very much to any of these sequences whether
15 you have a gradual or very sudden slump?

16 MR. DENNING: Yes, it does matter whether we have
17 a gradual or very sudden slump. It affects the timing of
18 containment failure in the AE sequence, and it affects the
19 turnover of the temperatures in the system in the other
20 sequences.

21 And it's a broader question than just that, the
22 gradual slumping versus the coherent slump. But there's a
23 whole spectrum of different conditions that are possible
24 for slumping behavior that would affect the thermal
25 hydraulic conditions in the reactor coolant system. And

1 apparently, cesium iodide would be -- retention would be
2 very sensitive to that.

3 MR. KASTENBERG: Just an editorial comment. If I
4 recall, nowhere in the manuscript that we received did you
5 mention that the reactor initially is inerted nitrogen.
6 Somewhere you might mention it. And if it has no effect on
7 anything you have done, you should state it.

8 MR. DENNING: That certainly is an oversight.

9 MR. KASTENBERG: Just editorially. It's not
10 there.

11 MR. KULHMAN: I am Mike Kuhlman from Battelle. I
12 will be talking about the primary system retention and
13 deposition of the Peach Bottom sequences which we have
14 looked at.

15 (Slide)

16 The three sequences are, of course, the AE, TC,
17 and TW. I want to talk first a little bit about the RCS
18 thermal hydraulic characteristics as they affect retention
19 of materials in the primary system; talk briefly about the
20 release from core for these three sequences; and finally,
21 about what the retention factors are for the primary system
22 and what the characteristics of the release to the
23 containment and to the suppression pool are for each of the
24 sequences and what -- there is currently a lot of interest
25 in what the particle size is which is emitted from the

1 primary system.

2 The things which are important in the thermal
3 hydraulic characteristics are, of course, the temperature
4 and flowrates because these determine the driving force for
5 condensation, for example, for the volatile species. The
6 flowrates determine your residence times in the primary
7 system, which is -- and the constant flowrate also
8 determines the concentration of the materials in the
9 flowing gas streams.

10 (Slide)

11 In general, the Peach Bottom analyses from MARCH
12 were similar to what we saw in the Surry analyses. By that,
13 I don't mean the actual magnitudes of the temperatures were
14 the same. They weren't. This means similar thermal
15 response. We saw the typical, as Rich was showing in his
16 codes, temperature volumes would heat up, surface
17 temperature would heat up and cool back down.

18 You'd have deposition on the surfaces during the
19 early portion of the accident, subsequent reevolution of
20 this material from some of the surfaces as they heated up
21 and it moved downstream, so it wouldn't be able to be
22 recaptured by the same surfaces which have previously
23 emitted them. In that sense, they were similar to what we
24 saw for Surry.

25 The gas flowrates we see in these sequences --

1 and I will present a few rough curves of what these
2 flowrates look like because they are very important -- are
3 similar in magnitude to what we saw in Surry. But the
4 timing is different. And this has very significant
5 implications on the primary system behavior and in terms of
6 retention of these different species.

7 And finally, I would like to point out, since we
8 are using different coremelting model, it does lead to a
9 different thermal history for the core. By that I mean the
10 temperature profile of the core as a function of time is
11 different from before.

12 This leads to difference in the calculated
13 release rate from core and also leads to differences in the
14 flowrates through the primary system. So we will see how
15 these things affect the calculations of the TRAPMELT code.

16 (Slide)

17 The timing of various events of interest in the
18 primary system for AE, the large break very quickly
19 initiated melt, the vessel dryout is the time in which the
20 water has essentially been all boiled out of the primary
21 system or actually out of the lower head of the pressure
22 vessel.

23 And the vessel failure times are indicated here.
24 what I wanted to point out is for each of these three
25 sequences, we have what I would call a flushing out of the

1 entire primary system which precedes this dryout. This is
2 the flush which is due to the dribbling of material from
3 the core into the lower head, enhanced rate of steam
4 generation.

5 And as you will see in the next couple of
6 slides, there's a very much enhanced steam flowrate which
7 brings about sweeping out of all the material in the
8 primary system into the containment, gives it a very
9 limited residence time in the primary system.

10 Another thing to note here is the duration
11 between vessel dryout which is essentially the end of
12 significant flows in the primary system and the time of
13 vessel failure. Here we've got a period of approximately 80
14 minutes in which the molten core is just sitting in the
15 bottom of the reactor vessel, continuing to emit.

16 It cools out during the slumping process, then
17 heats back up and begins reemitting material. The materials
18 it's emitting, of course, are the low-volatility species,
19 the aerosol-forming species, because by the time you reach
20 this, you have already essentially exhausted your cesium
21 and iodine and what you're going to get from the tellurium
22 inventory.

23 (Slide)

24 I show a couple of flowrate calculations. These
25 come from the MARCH analyses for AE and TC sequences. This

1 is flowrate in pounds of steam per second from the core. So
2 you start off with in the neighborhood of 10 pounds per
3 second for the TC sequence. During the slumping process
4 you're up well over a couple of hundred pounds per second
5 for a period of about -- in the neighborhood of several
6 hundreds of seconds to a thousand seconds.

7 Then after that process is finished and you
8 reach the vessel dryout time, you then have a very minimal
9 flowrate which is due only to gas expansion.

10 For the AE, you even have a more exaggerated
11 case with a very low flow, then a very sharp spike of flow
12 which lasts for about 600-some-odd seconds.

13 So what you have during this period is a very
14 efficient sweeping out of the primary system contents of
15 anything that was suspended in the system up to that time.

16 (Slide)

17 Taking, in a sense, the inverse of these
18 flowrate curves, we have residence times here for the AE
19 sequence. As you recall, the spike in the previous curve
20 was down in this neighborhood of time, 1,500 to 2,000
21 seconds.

22 You have reasonable sorts of residence times for
23 aerosol retention and cesium iodine retention here, some
24 fluctuations in the flowrate. And here's your increasing
25 flowrate due to the core continuing a slump on a

1 node-by-node basis till finally down a very high flowrate,
2 very short residence times; finally, the vessel dryout. And
3 you have, for all intents, a residence time which lasts up
4 to the point of vessel failure. This is for the AE
5 sequence.

6 (Slide)

7 TC is a similar shape curve. You can see again
8 you're in the many hundreds to thousands of seconds
9 initially during the low flowrate. Slumping occurs. Short
10 residence time. In the TC we see a small flow following
11 this major slumping. Then you get down to a stagnant
12 primary system.

13 (Slide)

14 If we look at the CORSOR release rates, these
15 are predictions based on the 077 to release rate
16 coefficients, with one notable exception: the tellurium
17 release rates are now being calculated taking advantage of
18 the information provided by Oak Ridge and which relies on
19 the extent of zirconium oxidation at each node in the core.

20 The unoxidized zirconium is a strong getter, if
21 you will, for the tellurium and results in a much reduced
22 tellurium release rate until any particular node of the
23 core is oxidized beyond 90 percent oxidation zirconium, at
24 which point the rate of release is enhanced by about a
25 factor of 40.

1 For the AE sequence, the release rates -- all my
2 times here are in zeros measured from time of coremelting.
3 That's the only timescale that matters here at the primary
4 system.

5 You can see the essential exhaustion of the
6 cesium inventory and the iodine inventory relatively early.
7 Tellurium is emitted at very low rates relative to what we
8 calculated for Surry.

9 The aerosol release rate, once we get started
10 here after about 800-900 seconds, is not exhibiting
11 enormous fluctuations. This period is the period of very
12 minimum retention time in the primary system, which I
13 showed you on the previous graph. So you have hundreds of
14 grams per second being emitted by the core.

15 You will see at the end of this talk that this
16 material reaches its exodus from the primary system very
17 near its primary particle size due to the extremely short
18 residence time. There is no way to effectively retain this
19 material.

20 Down here from this point on we have material
21 which is emitted into essentially a stagnant primary
22 system, which gives you a fairly long retention time, good
23 possibilities for coagulation of growth and gravitational
24 removal of the material in the primary system.

25 (Slide)

1 MR. CASTLEMAN: This is a very minor point, but I
2 assume you mean total iodine here?

3 MR. KULHMAN: Yes. Just an iodine release.

4 MR. HAZEN: Mike Hazen, Stone & Webster.

5 I would like to ask a question about the release
6 rates. Are those release rates constant in time step to
7 time step?

8 MR. KULHMAN: What we're doing is taking CORSOR
9 code predictions which are based on, I believe, for AE, I
10 believe we had quarter or half-minute time steps in MARCH.
11 At each time step the core release rate for each node is
12 each of the 240 nodes is calculating. This is done
13 throughout the course of the accident.

14 We then examined the cumulative release from the
15 core and break it down into 20 regions of essentially
16 constant -- which are treated as having a constant release
17 rate over the period. We integrate these rates to check it
18 against what the CORSOR code predictions are at the end of
19 each of these time intervals to make sure we are within
20 about a percent.

21 (Slide)

22 Let me just show you briefly for the other
23 sequence of interest, the TC. Once again we have very
24 significant aerosol generation during that very low
25 residence time period. Then, interestingly enough, the

1 aerosol generation drops and then begins to come up once
2 again just prior to vessel failure.

3 Again, as you can see, the cesium and iodine
4 inventories are about exhausted prior to this very high
5 flowrate regime.

6 (Slide)

7 TW really has nothing very new to say. By way of
8 information, what is emitted from the core is of interest.
9 These are the fractions which are emitted prior to vessel
10 dryout, and I will show you in a second the key species
11 emitted prior to vessel failure.

12 The only point I wanted to make here is that you
13 are really, as you can see, emitting 80 percent, roughly,
14 of your more volatile species prior to vessel dryout, and
15 you have essentially your complete initial inventory of the
16 other materials still available for release.

17 (Slide)

18 What these figures are are for cesium. These are
19 masses in kilograms of the species which are released by
20 the time of vessel dryout, released from the core, not from
21 the primary system necessarily, and prior to vessel
22 failure, dryout and failure times. The releases of dryout
23 and vessel failure time are indicated here.

24 Just to give you an indication of relative
25 importance of the material which is released during that

1 stagnant phase of the sequences, here we have more than
2 half of the aerosol material is generated and pumped into a
3 stagnant primary system, whereas for the TW and TC cases we
4 have a much reduced importance of that period of the
5 accident.

6 Again, the more volatile species are already out
7 of the system by the time of vessel dryout.

8 (Slide)

9 As we have seen with the Surry analyses, once
10 again the aerosol composition is dominated far and away by
11 the ten. Fission products are on an expanded scale by a
12 factor of 10, so it says no more than 3 percent of the
13 aerosol initially is made up of the moly and about 2
14 percent barium. And these fractions are actually lower
15 during the course of the accident sequence. Again, just to
16 point out the importance of the non-fission product
17 inventory for the aerosols.

18 (Slide)

19 Beginning to look at the TRAPMELT predictions of
20 what is retained in the primary system for the AE sequence.
21 By way of reminder, the key areas for retention are the
22 core region for the aerosols only, the steam separators and
23 the lower annulus region on the way to the jet pump intake.

24 The total columns represent what has been
25 released from the core as a function of time. The total

1 retained is the mass of that material which is retained
2 somewhere in the primary system.

3 This time represents the vessel dryout time
4 approximately. You can see nothing new has taken place with
5 the vapor species. Yet the aerosol retention really begins
6 to take off as you begin to age that contained aerosol. You
7 will see that perhaps more dramatically when it is
8 expressed in terms of a retention factor for the primary
9 system.

10 (Slide)

11 This is just a --

12 MR. CASTLEMAN: Castleman, Penn State.

13 On that previous viewgraph, you had one column
14 of numbers going up and down. Are they not cumulative
15 numbers? That's cesium hydroxide, I am a little confused. I
16 was thinking of the cesium hydroxide retained. I guess you
17 see the same thing in several columns going up and down.

18 (Slide)

19 MR. KULHMAN: I should have pointed that out.
20 This says that the time 570 seconds after melt we've
21 returned 33.5 kilograms of the cesium hydroxide. We have
22 emitted 81.7. The emitted columns are, of course,
23 cumulative. The retained is a function of time. This
24 material is free to reevaporate.

25 MR. CASTLEMAN: So you are accounting for

1 reevaporation.

2 MR. KULHMAN: Right. Should this material be
3 located in the steam separators, which for the AE sequence,
4 you get only up to about 1,000 degrees F., I believe. If
5 they get above that, then you can see the reevolution of
6 the cesium hydroxide taking place.

7 For the cesium iodide as well, you see the
8 material is retained more effectively initially and the
9 masses present on the surface actually decreases with time
10 for a bit. The aerosol you will never see that, because we
11 have no resuspension mechanisms acting on the aerosol.

12 (Slide)

13 These are the same numbers but expressed
14 differently for the AE sequence. Again, this is time of
15 vessel dryout, so this is the essentially stagnant period
16 of the accident.

17 If you look at the retention factor, which I
18 should define as being the total mass retained in the
19 primary system divided by the total mass which has been
20 released from the core at that time, so it's not really a
21 true efficiency, but it has a similar flavor.

22 The retention factor for aerosol is not really
23 changing greatly through this period, but after vessel
24 dryout you see the trend from 30 percent retention up to 70
25 percent retention which is experienced just prior to vessel

1 failure. And most of this obviously is taking place in the
2 core region, since the material emitted into the stagnant
3 system doesn't reach any other control volumes in the
4 primary system.

5 For the cesium iodide, cesium hydroxide, it
6 turns out the lower annulus is where this material
7 ultimately resides -- ultimately meaning at the time of
8 vessel failure. A lot of this material was deposited
9 previously in the steam separators, reevolved as they
10 heated up, and then subsequently deposited in the lower
11 annulus.

12 In terms of a bottom line figure, these 18 and
13 19 percent retentions for cesium and iodine and 14 percent
14 retention for tellurium and 70 for the aerosol,
15 characterize the primary system behavior for the AE
16 sequence.

17 Again, with respect to the tellurium, we should
18 keep in mind that only about a third of the tellurium
19 inventory is released in the core.

20 MR. KELLY: Jim Kelly from the University of
21 Virginia.

22 I notice that the numbers in this table are
23 significantly different from the numbers in the handout. Do
24 you discuss the changes in the model that were responsible
25 for --

1 MR. KULHMAN: No changes in the model. Changes in
2 the input to the model. What you have was performed with
3 two different sets of input. One was, there was a different
4 emission rate of materials used in those analyses. And
5 secondly, we used a different thermal hydraulic input data
6 for the set of information.

7 MR. GIESEKE: I forgot to mention in the
8 introduction that we have gone back to some of these and
9 checked over the assumptions and the numbers and have
10 revised some of the figures that appear in Chapter 7,
11 primarily.

12 We have sent out in the mail revised Chapter 6.
13 And you probably have that. Plus, I believe, a little bit
14 of Chapter 7 also.

15 We have available today, or will have, a new
16 Chapter 7, totally new Chapter 7. It includes the numbers
17 that are being presented, as well as -- well, it's the
18 total story on Chapter 7 that we have to date. And that
19 will be handed out.

20

21

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23

24

25

TAYLOR ASSOCIATES
1625 I Street, N.W. - Suite 1004
Washington, D.C. 20006
(202) 293-3950

1 MR. SHERRY: Rick Sherry, NUS.

2 Mike, in comparing the tellurium retention factors
3 to the cesium iodide and cesium hyhydroxide, tellurium reten-
4 tion is lower for these sequences. This wasn't the case for
5 the Surry analysis, where, in general, the tellurium reten-
6 tion factors were much higher than the cesium or iodine.

7 Can you comment on the reason for this?

8 MR. KUHLMAN: I think I can.

9 This data is all fairly fresh and needs some
10 digestion. Yet, a couple of differences from the Surry
11 analysis.

12 First of all, Surry, we were releasing tellurium
13 at the rate which we had published in 0772, which is a
14 considerably higher rate than the rate of release for these
15 accidents, which take into account, in a rudimentary fashion
16 at least, the inhibition of tellurium release due to the
17 zirconium clad. But we are releasing tellurium at a much
18 lower rate now.

19 We're also releasing it really relative to the
20 cesium, cesium and iodine. Tellurium is coming out of the
21 core later in the sequence. And there's not as much tellurium
22 coming out, also. Of course, it's the first order process.

23 So, as the tellurium, the rate of it being driven
24 to the surface is dependent on the concentration at any time.
25 This tellurium release is occurring more, I believe, during

1 that low low residence time period of the accident, near the
2 high flow rate, Since the core is hotter at that time, more
3 of the tellurium release is occurring at that 1500 to 2000
4 window, where you have very low residence time. So, that
5 material, then, is less subject to the chem absorption even
6 that it would be had it been released concurrently with
7 cesium and iodine.

8 I think it's all a question of timing. Again,
9 when this material is released at the worst possible time for
10 it to be released, which is as the core is hot, as some of
11 the material is slumping from the core to give you the high
12 flow rate.

13 MR. VOGEL: I think, just from the way you phrased
14 your reaction to the tellurium question just now, leads one
15 to suspect here you are really believing in this tellurium
16 behavior.

17 And before we let tellurium behavior get embedded
18 too thoroughly in the lore of reactor safety, it might be a
19 good idea to recall that, first, we haven't seen the Oak Ridge
20 data, but I think -- I'm familiar with most of the experiments,
21 and a lot of the experiments on tellurium are on a very small
22 scale. I think there's going to be several more chapter and
23 verses on the tellurium story before we really come to a firm
24 agreement on that point.

25 MR. SILBERBERG: Yes. The tellurium story is by

1 no means final. We certainly don't want to give that
2 impression. But what the Battelle people are doing are work-
3 ing right up to the razor edge, if you will, of the state of
4 the technology as we know it today. Unfortunately, that's
5 where we are. We are trying to make, if you will -- make use
6 of that state of the art.

7 Now, we have a tellurium report that we will have
8 available later today, this afternoon. And you are all
9 commended to read it tonight.

10 And if there are questions, Bob Wishner from
11 Oak Ridge has graciously consented to answer such questions
12 at this stage. And of course this will be an evolving story
13 on tellurium.

14 MR. VOGEL: Yes. The reason for my comment, some-
15 times the separation between the fact and hypothesis in a
16 complicated analysis like this gets lost.

17 I was a little worried that hypothesis was drifting
18 over into fact here.

19 MR. CASTLEMAN: I would just like to second the
20 point that Dick Vogel is making, because I noticed on page 56
21 in the document that it was stated that the tellurium release
22 is not well quantified. But then, you go, later, to page 632,
23 and it makes it sound like this whole problem is solved and
24 it is quantified, and I think it's a little misleading.

25 MR. SILBERBERG: See what happens when you get a

1 little data. It goes a long way.

2 (Laughter.)

3 MR. JOHNSON: Johnson, Oregon.

4 Mike, could you clarify the way you handled the
5 cesium hydroxide there? When you talk about its reevaporation
6 or reevolution, is this the cesium hydroxide?

7 MR. KUHLMAN: Yes, it's a good point.

8 MR. JOHNSON: Why would you think it stayed cesium
9 hydroxide? In that form, it's one of the more reactive --

10 MR. KUHLMAN: We have incorporated into the TRAP
11 analyses a chem absorption phenomenon as well as to the
12 condensation for cesium hydroxide.

13 MR. JOHNSON: It's a little more than chem absorp-
14 tion. It's a formation of new compounds in the system.

15 MR. KUHLMAN: Once the new chem absorption is remov-
16 ed from possibly ever reevolving, so there's two mechanisms
17 operating on cesium hydroxide, it can react with the surface
18 and be permanently bonded there. You'll see some examples of
19 that in some of the other sequences. Also, there's another
20 portion of it which is allowed to condense and reevaporate.
21 How realistic that can be, I don't know.

22 If it is condensing, I agree the odds are good that
23 the condensed material is going to react with the surface
24 when it condenses with cesium hydroxide.

25 MR. JOHNSON: Absolutely.

1 MR. SILBERBERG: Are you saying you don't allow for
2 cesium hydroxide interaction with the surface now?

3 MR. KUHLMAN: We have two modes of cesium hydroxide
4 interaction with the surface. One is chem absorption, which
5 is irreversible. One is condensation, which is subject to
6 subsequent reevaporation.

7 MR. JOHNSON: You have to be careful what surface
8 you are condensing on.

9 MR. CASTLEMAN: Maybe this is jumping ahead a little
10 bit of what you are intending to cover, but I noticed, in a
11 few of these points raised by cesium iodide and cesium hydrox-
12 ide on page 720, Table 7.8, where you give a final distribu-
13 tion of the species, both cesium iodide and cesium hydroxide
14 released to the environment are almost the same fraction, .19
15 versus .20, which also surprised me a little bit in view of
16 the chemical difference and the fact that cesium hydroxide
17 presumably -- chem absorbs, and cesium iodide doesn't.

18 Is there a reason for that? Is that because what
19 gets released is more associated with the aerosol? Or is it
20 just insensitivity to these mechanisms and chemical differ-
21 ences?

22 MR. KUHLMAN: I was surprised at that myself. I
23 think that was for the AE sequence. For the TC, you see a
24 vast difference in the retention of the two.

25 MR. CASTLEMAN: Why is that? I'm not sufficiently

1 MR. KUHLMAN: I haven't had the time to look at all
2 the data and track all this material through the primary
3 system. There are a lot that are not immediately apparent
4 aspects to this data as to what is really taking place, and
5 I frankly can't answer that question.

6 MR. JOHNSON: Aren't the time relationships almost
7 the same here, the thermal hydraulic characteristics?

8 MR. KUHLMAN: Yes. We're talking about just one
9 sequence; the cesium and iodine releases from the core are
10 simultaneous essentially. So, you would expect them to
11 experience the same conditions as they flow through the
12 primary systems; yes.

13 Maybe I'm missing the point.

14 MR. JOHNSON: I'm just going back to Castleman's
15 point.

16 MR. KUHLMAN: That makes the TC hard to explain.

17 MR. JOHNSON: Well, maybe that's a starting point.

18 MR. ROE: I had a question on presentation. I look
19 at a table like this. I like to try to add up numbers to
20 get to one, or unity. I have a hard time interpreting this.

21 A question, then, might I suggest, depending on
22 the answer to the question: Would it be useful to have a
23 table presented in terms of fraction of initial inventory
24 presentation of these different nuclides? In that, you can
25 then keep track of the distribution, in a fractional sense,

1 of each species throughout all nodal volumes of the system,
2 in fact, and what also reaches their environment.

3 I don't see too much of that in here, and I was
4 wondering why not. Or do you have a different philosophy
5 that you're trying to follow?

6 MR. KUHLMAN: Trying to keep our page charges down.
7 Tables are sort of helpful for a lot of things when you're
8 dealing with four species, five volumes, and 20 times and
9 five states for each species, they become pretty cumbersome.
10 So, we have hammered around a lot of ideas just within our
11 group to try to explain to somebody else in the group who is
12 not familiar with these what we are doing.

13 We, obviously, haven't come up with the ideal solu-
14 tion to this yet. But we do present it in this fashion here
15 to give a retention factor for what is emitted from the core
16 into the primary system, because that is, to me, the only
17 number here which has some physical meaning to me.

18 If I have to multiply this, in turn, by the fraction
19 released from the core, you're not quite there yet, and perhaps
20 you would ultimately like to see an efficiency out of what the
21 lower annulus actually saw, how much did it retain, because
22 that turns out to be really an important parameter, because if
23 the upstream conditions change, your lower annulus would be
24 seeing more material, it would be capturing more material.

25 It's a dilemma. I don't know of any better way,

11:8

1 other than throwing in tables and several different types of
2 units, which is what we've tried to do at this point, where
3 we have the masses retained and masses released as a function
4 of time -- retention factors. And at the end, we have a
5 summary table, so far, that has the retention mechanisms.

6 If we went to microfiche, maybe we could incorpor-
7 ate all of these at once.

8 If you have any suggestions for a table format you
9 would like to see, I'd be interested in seeing it.

10 MR. REYNOLDS: Are some of the low retention factors
11 that you have for cesium iodide and cesium hydroxide due to
12 the rapid evolution of steam or the rapid flow of steam? And
13 is that due to the slumping model that you are using?

14 MR. KUHLMAN: In part.

15 MR. REYNOLDS: How would it change if you had
16 dumped all of the fuel down coherently?

17 MR. KUHLMAN: We will see, within the comparison
18 between these numbers and Grand Gulf, some of the sensitivity
19 to that mode of core slumping. Maybe we ought to wait until
20 we get to the Grand Gulf and discuss this point then. I
21 think it's a good point.

22 MR. REYNOLDS: Does this indicate that this
23 represents an advantage of the slumping -- I'm sorry, this
24 represents a disadvantage of the gradual slumping because
25 your retention is low. There likely would be great

11:9

1 disadvantages of coherence slumping. This would be an
2 advantage of coherence slumping.

3 MR. KUHLMAN: Yes, it would.

4 But another thing that coherence slumping brings
5 about is an enhanced aerosol emission rate when the core
6 reaches higher temperatures as we keep a core, which would,
7 in this model, allow the slump -- on an individual node basis,
8 if you keep altogether until 75 percent, for example, has
9 reached the molten point, your temperatures will increase, and
10 aerosol generation rate will increase as well, which will, in
11 turn, drive up your aerosol retention factors.

12 (Slide.)

13 For the AE, if you look at the mass retained of
14 cesium iodide and cesium hydroxide in the steam separators,
15 which are the Volume 2 and the lower annulus, which is
16 Volume 3, it has the shape you would suspect from looking at
17 the table, tabulated values, where the material retained in 2
18 reaches the peak and then rapidly reevolves that material,
19 which is then captured downstream in the lower annulus region.

20 So, that was just a profile of what the retention,
21 as a function of time, looks like.

22 (Slide.)

23 Translating that into what the injection into the
24 containment or the dry well looks like, this is the cesium
25 iodide curve here; cesium hydroxide here. And the aerosol is

1 the dashed curve. So, you can see we're pumping in roughly
2 250, 300 kilograms of aerosol into the dry well during the
3 course of the accident. And this all occurs during that
4 flushing phase of the sequence.

5 One other thing I wanted to point out is that,
6 remember, there is that stagnant period, which is indicated
7 here by no emissions into the dry well. This would be follow-
8 ed, then, with a spike at the end as the pressure vessel
9 fails and the material which is still suspended there is,
10 then, injected into the dry well.

11 (Slide.)

12 TC -- we don't really need to examine this except,
13 again, here's the vessel dryout times, everything subsequent
14 to this is into the stagnant period of the accident.

15 Once again, the volatile species emission has
16 already stopped by that time.

17 (Slide.)

18 In terms of the retention factor for TC, you have
19 here 11 percent of the cesium iodide; somewhat higher per-
20 centage for the cesium hydroxide.

21 Tellurium here reaches 80 percent retention. And
22 this, again, I think is due more to the timing. This is a
23 much longer sequence than your AE was. You have a very short
24 period prior -- at the flushing period. Here you have a much
25 longer period, with the core melting -- lower retention factor



1 for the aerosol, partly due to the fact that the emission
2 rate of aerosol is lower during this stagnant period of this
3 accident.

s2 BU

4 (Slide.)

5 You have a similar --

6 MR. SHERRY: Rick Sherry.

7 Mike, your fission product and aerosol release rates,
8 which you predict through the course of the accident -- do you
9 account for any reductions in the release rates due to changes
10 in the geometry and decreases in the material surface-to-
11 volume ratios?

12 MR. KUHLMAN: No, it's not taken into account at
13 all, Rick. We're using only the March predicted temperature
14 for each node of the core. We do have a flag to indicate
15 whether these nodes are in or out of the core, as a function
16 of time, which could be used if we had some way to estimate
17 the effect of bottom geometry on the emissions for any given
18 node.

19 In the interests of time, I'll get to sort of the
20 bottom line here for these three sequences.

21 (Slide.)

22 There's a couple of things this table could be
23 called, fractional distribution of the species emitted from
24 the core at the time of vessel failure. The four species
25 we're principally concerned with, the vapor is meant to

1 indicate the fraction of the material which has been
2 deposited in the primary system somewhere due to either
3 condensation or chem absorption, 4 and 6 percent for the
4 cesium hydroxide, and 14 for the tellurium. And this
5 would all be due to chem absorption -- aerosol term here --
6 is meant to indicate that portion of the species which has
7 been deposited on surfaces after condensing on aerosol
8 particles, which are then retrained. And here again, similar
9 behavior for the two cesium species and throughout the
10 sequences.

11 Then, the suspended column indicates the fraction
12 of the material emitted from the core, which is still suspended
13 in the primary system that is not retained at the
14 time of vessel failure. And this is that puff release, if
15 you will, which accompanies the vessel failure. And the dash
16 just indicates mechanisms that aren't available.

17 Here, just the aerosol is not deposited as a vapor.

18 The TC indicates strong difference in the method
19 by which the cesium iodide is retained versus the cesium
20 hydroxide. This I did look at in detail. This is almost
21 entirely due to chem absorption of the cesium hydroxide, which
22 is not available, to the cesium iodide.

23 Similarly in the TW case the chem absorption is what resulted
24 from the cesium hydroxide retention from the vapor state.

25 The other obvious figure here is the tellurium chem

1 absorption; for the longer-melt sequences, it's very high
2 in both cases.

3 MR. VOGEL: Mike, I think there's a problem in
4 talking across disciplines.

5 To a chemist, chem absorption is not a very strong
6 interaction, and this is what was bugging Carl -- I think
7 with tellurium -- and particularly, you've got chemical
8 reaction.

9 MR. KUHLMAN: Right. It's not meant to imply that
10 that stuff is available to be re-evolved at all.

11 MR. ZUMWALT: I have a question about the cesium
12 hydroxide. You said part of cesium hydroxide was not con-
13 sidered to be strongly absorbed. Did that enter into this
14 picture?

15 MR. KUHLMAN: It is included in here. I would
16 suppose approximately .01 here would have been available for
17 re-evaporation here, just deposited due to condensation. The
18 rest of this material is irreversably deposited, reactive
19 with the surface.

20 MR. ZUMWALT: Is this due to having different
21 surfaces?

22 MR. KUHLMAN: No, it really isn't. It's due to
23 different rates of the two processes. There's a deposition
24 velocity calculated for the cesium hydroxide. Then, there's
25 also a condensation rate calculated. There's two competing

1 mechanisms for cesium hydroxide retention.

2 MR. RITZMAN: Let me follow that up now. There's
3 not a reaction mechanism between vapor deposit, cesium
4 hydroxide, with the metallic substrate it condenses on; right?
5 There's no solid-state reaction?

6 MR. KUHLMAN: That's right.

7 And I see that as a source of potential problem.

8 MR. RITZMAN: In reality, they probably would?

9 MR. KUHLMAN: Probably would be, yes.

10 MR. WALKER: Let me ask you one question about
11 your numbers.

12 Take the first one, for instance, cesium iodide.
13 Under AE, what it says 4/10ths of it is in the reactor sys-
14 tem, in a depository or suspended -- the rest of the stuff is
15 out in the containment.

16 MR. KUHLMAN: It says 4 percent of it --

17 MR. WALKER: About 40 percent in those three columns
18 -- the other 60 percent is out in the containment?

19 MR. KUHLMAN: That's correct.

20 That's the thing, you can sum to one. If you find
21 what's missing, it's in the containment.

22 (Laughter.)

23 MR. WILLIAMS: David Williams, Sandia.

24 In the Surry analysis, I remember I was quite
25 concerned. As I understand it, in both the MERGE and

1 the TRAP-melt analysis, there is no accounting for exchange
2 of either heat or mass, including radionuclides, between
3 control volumes due to natural circulation. There are some
4 correlations for deposition and heat transfer through natural
5 convection processes, within a control volume, not exchanged
6 within the control volumes. And that since these control
7 volume definitions are somewhat artificial in some cases,
8 they don't correspond to rigorously defined physical boundar-
9 ies that would actually block the actual circulation processes.
10 This could lead to serious error in any sequence with a force
11 flow, where the scheme evolution was low.

12 The same thing would apply, here, to parts of the
13 sequences where we have nearly stagnant conditions.

14 Has anything more been done to address this
15 question, to determine how important it might be?

16 MR. KUHLMAN: This is a good point that you bring
17 up, and it is something to which you would expect the code
18 predictions to be sensitive.

19 If one has misnodalized the primary system, say,
20 you could be very, very sensitive to your error in your
21 representation of the system.

22 The attempt has been made in these, as you pointed
23 out, to treat those volumes, which are well mixed within them-
24 selves, as separate from one another and treat them nearly as
25 successive volumes through which everything passes. And they

1 well-mixed in any given volume. But if that's not the case,
2 you have misformulated the problem, and the degree of errors
3 is going to depend on how far you are from reality and whether
4 anything of significance is occurring.

5 Of course, this is part of what I think the sensi-
6 tivity study aspect of this work should be addressing -- and
7 pretty carefully -- because this whole problem of proper
8 treatment of the flows through the primary system and, indeed,
9 through the containment is something you can only address
10 through, I think, a well-done sensitivity study. And that's
11 not something that we are including in the current work.

12 (Slide.)

13 I only have a couple of more slides which I wanted
14 to present in terms of particle size distribution which exit
15 the primary system.

16 For the TC sequence, as you recall, there are
17 several distinctly different flow regimes and distinctly
18 different retention periods for the accident during the
19 in-vessel melting phase.

20 What is shown here are mass distributions of the
21 aerosol. These are actually not in centimeters. These are
22 micrometers.

23 The two times which are shown here correspond to
24 just prior to the flushing out of the primary system. You
25 have your very large particles. This represents a well-aged

1 aerosol which has had a fairly significant source for an
2 extended period of time. If you can't read this, "the mass
3 median dynamics," which is an aerodynamic diameter, is the
4 2.02 micron signature. You have 2.13. Again, this is just
5 prior to the sweeping out of the primary system.

6 The period during the high-flow regime, the size
7 distribution is represented here, which gives you an aerosol
8 mass median diameter here of .02 microns and a much smaller
9 sigma G, where you are getting closer to what the primary
10 particle size distribution was, where we had started with
11 .05 micron diameter particles. By the time they exit the
12 primary system during this period of the accident, you only
13 have for the sequence, .2 microns.

14 We've seen some cases where the diameter is even
15 smaller during the high-flow regime.

16 (Slide.)

17 To look at these on another basis, look at the time
18 during the core melting. Here you have the aging period, the
19 low-to-moderate flow rates, flushing of the reactor vessel,
20 surges in flow and then, again, the stagnant portion of the
21 accident.

22 These are aerosol mass median diameters. These
23 are presented here for what is going on in the core region,
24 but they are not greatly different from what is actual
25 showing up in the relief line.

1 We have some dots in the Grand Gulf sequence which
2 show what's going on in the core and what's going on in the
3 relief line.

4 What you see primarily is a displacement. So,
5 when this material hits the relief line, you get a large
6 spike. Then, it comes down, tracks underneath this, because
7 a lot of this material is removed prior to getting to the
8 relief line.

9 That's the case for TC. You can see a wide range
10 of aerosol sizes exiting the primary system, as you would
11 expect for an aerosol experiencing such a wide range in
12 retention time for residence time.

13 (Slide.)

14 This is for the AE sequence.

15 Again, the initial low flow sweeping out, and then
16 finally the growth to a fairly constant size up here towards
17 the stagnant period of the accident.

18 I thought these were interesting results of the
19 analysis in terms of what potential mechanisms are going to
20 be acting on these particles as they leave the primary system.

21 That concludes my presentation.

22 MR. SILBERGERG: Thank you, Mike.

23 I think we'll have a few questions.

24 Then, I think we will break at this point for
25 lunch.

1 There is still one other speaker for Peach Bottom.

2 MR. ZUMWALT: I have a question.

3 I'm Zumwalt, from NCSU.

4 On Figure 73, the particle size distribution of
5 aerosols suspended in the dry well, this is probably -- maybe
6 early data. You know the figure I have in mind, it's two
7 parabolic curves.

8 Anyway, I was wondering if the curve was mislabeled,
9 in that the shorter time period is listed as having larger
10 particle size.

11 MR. KUHLMAN: That's what's going on in the dry well,
12 which is taking what comes out of the primary system. I could
13 see where, early on, you could have this larger material being
14 injected into the dry well. I don't know what sequence that
15 is that you're looking at.

16 MR. ZUMWALT: This is AE.

17 MR. KUHLMAN: I would expect if you are, say, less
18 than a thousand seconds since the start of melt that you would
19 have larger sizes. Not until you get out to -- once you get
20 to this high-flow regime, you then get something more closely
21 approximating the primary particle size. So, you can, in
22 fact, have a reversal. It's not due to aging in the dry well.
23 It's due to the changing characteristics of the source to the
24 dry well. I think that's probably what's going on.

25 Isn't that right, Ken?

1 MR. LEE: That's right.

2 MR. COBBLE: James Cobble, San Diego State Univer-
3 sity.

4 I don't want to nitpick at this time what went into
5 preparing the numbers for the data base. There's one general
6 omission -- maybe because there are no numbers in the data
7 base. But one general omission which might affect two or
8 three of the regimes you were talking about for transfer of
9 fission products -- that is, the known interaction at very
10 high temperature steam to form molecules which are essentially
11 hydrated in the gas phase that essentially increases the
12 solubility. You will affect the processes you call weak
13 chem absorption and possibly lead to teulerium and
14 ruthenium transport.

15 Those numbers can be estimated from the data which
16 are available in the solubility of compounds in high tempera-
17 tures.

18 Has anyone made an attempt to see whether those are
19 significant processes? It also depends on the density of the
20 steam, as well as significant temperatures.

21 Has anyone looked at that?

22 MR. KUHLMAN: We've not made any attempt to look
23 at that. I don't know whether the people from Sandia or
24 Oak Ridge have examined that question or not.

25 To my knowledge, that answer would be no.

1 MR. COBBLE: In parlance it's called carryover,
2 maybe a boiler word -- essentially enhance the solubility
3 reaction with high-temperature water molecules. It's well
4 known -- sodium chloride. We now know it for sodium hydroxide.
5 Russians have done work on metallic oxides. So you can make
6 estimations to see what's the type of process. You've got
7 an enormous amount of steam flowing by.

8 For example, your weekly chem-absorbing species --
9 it may be another steam exchange process.

10 MR. SILBERBERG: We will break only one hour for
11 lunch, and I would like to return promptly at 1:35.

12 (Whereupon, at 12:35 p.m., the meeting was recessed,
13 to resume at 1:35 p.m., this same day.)
14
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AFTERNOON SESSION

(1:40 p.m.)

MR. SILBERBERG: Let's call the meeting to order, please.

Ken Lee will make the closing presentation or the next-to-the-last presentation on Peach Bottom as far as containment transport.

(Slide)

MR. LEE: The primary containment is the last barrier for fission product. After fission product leaves the reactor coolant system, the primary containment or the secondary containment is the last barrier the fission product has to pass through before escaping to the environment.

For calculating the transport of fission product in containment system, as we did before, we have been using the NAUA code.

Just to remind you what we have on the board, all the mechanical aerosol deposition mechanisms, gravitational settling, diffusional deposition. And as a particle growth mechanism we have aerosol agglomeration and steam condensation onto particles. And as we talked about this morning, we have diffusiophoresis.

And of course, the source of the material to the containment as well as leakage out of the containment are

1 considered.

2 (Slide)

3 Again this morning --

4 MR. ZUMWALT: I just have a question. I am
5 wondering where one can find more information about the
6 NAUA code. I would like to make a suggestion of having an
7 appendix on it.

8 MR. GIESEKE: There is a description available.
9 Perhaps you could talk to Dick Vogel, who is the U.S.
10 distributor.

11 (Laughter)

12 MR. SILBERBERG: If we can get a waiver from Dick
13 and from the Federal Republic of Germany, which I suspect
14 we could since they are already available --

15 MR. VOGEL: Vic would be easier.

16 MR. SILBERBERG: I guess what we would do, we
17 would just make a distribution to the entire audience here.
18 In fact, that request has been made before, and I think
19 it's probably a good idea.

20 MR. VOGEL: I am a little bit appalled at all
21 this attention. I didn't know, A, I was custodian of the
22 NAUA code.

23 MR. SILBERBERG: I have a witness in the room
24 that says that was the case. He used to work for me.

25 MR. ROE: Let me request this go even farther. We

1 nave, I notice, a writeup on TRAPMELT. I do not have one on
2 MARCH. I think everyone should have descriptions as they
3 exist on the codes that are being used here.

4 MR. SILBERBERG: As you should know, Don, the
5 various codes are in various degrees of documentation
6 level, if you will. That does make it somewhat difficult.
7 But as soon as we can, we will try to get such a set. It
8 will probably start with maybe half the set.

9 And in some cases we are, in effect, kind of
10 having to play catch-up with it. With that, it's not
11 necessarily a justification. What we have to do is to
12 figure out at least for Battelle if we can get 8 days in a
13 week and more than 24 hours in a day. I think we can
14 probably get caught up.

15 MR. VOGEL: I would like to add another thought
16 to this, since this subject has been opened up. And that
17 is, it seems to me in a reactor safety area we have
18 departed a little bit from the traditional method of
19 operation in technical fields. And there seems to be a
20 dearth of journal articles submitted which are then
21 reviewed in the traditional journal sense and then can be
22 used as references as a departure point.

23 And we have, I think, some eight or nine codes.
24 It seems to me every one of those could be a journal
25 article and reviewed. And then after they have gone through

1 such a procedure, we can say, okay, that's that, and use
2 that from there on.

3 MR. SILBERBERG: Obviously, there there was a
4 question of timing. That normal process, in effect, does
5 really go on. But it goes on over a much longer time scale.
6 It's a time scale that is set by itself and you can't, if
7 you will, dictate that time scale. And unfortunately --
8 it's also happened in reactor safety studies in the past.
9 It goes in parallel with and then usually goes beyond and
10 actually comes sort of at the end of the process. And it's
11 something we have to be aware of.

12 But let me note that Element 1, even though
13 obviously it would be nice if it were available today, will
14 be available in the July-August time frame, and Element 1
15 will, along with, if you will, sets of descriptions of the
16 codes. To some extent, a lot of the key phenomena that are
17 in the codes -- that are in the codes, that aren't in the
18 codes -- things like that will be included in this
19 documentation of Element 1. So that that process will be a
20 lot more visible.

21 In fact, if it's worth it, since it's come out
22 now so many times today, if we can maybe tomorrow at this
23 time, we could give an outline of what is going to be of
24 basically the chapters that are going to be in the Element
25 1 document, at least what the basis of it is.

1 So, you know -- in fact, people are working on
2 this right now.

3 MR. BERNERO: I think it's worth adding, too, a
4 code that leaps to mind, the MARCH code, was first
5 documented, if I recall, in 1980 through a publication from
6 NRC NUREG. And there is a very large literature on the
7 MARCH code, the review of the MARCH code.

8 And I just checked with Battelle-Columbus, we do
9 have a draft version, a MARCH 2 users manual. But it's an
10 enormous tome. It's a very big thing. And we wouldn't
11 attempt to flood you with that. That's available for
12 pursuit if anyone wants it. The literature is abundant,
13 task forces' reports, ACRS meetings in this room and things
14 like that.

15 But really, I second Mel's suggestion that the
16 review of what that Element 1 contains, the scope and
17 content of it and on which it was such a fundamental
18 comment from this group, we need your comment on that
19 because it's a necessary part of this.

20 MR. VOGEL: One of the problems is that MARCH is
21 a moving target. We now have MARCH 2.

22 MR. SILBERBERG: That's right.

23 MR. BERNERO: There's a national resolution that
24 we're going to get rid of the numbers after the decimal
25 place. It's going to be MARCH 1, MARCH 2, and I'll shoot

1 the next guy that moves.

2 MR. VOGEL: What about April?

3 (Laughter)

4 MR. SILBERBERG: In fact, I think that what we
5 ought to do, and I think I am going to assign this to the
6 Battelle staff -- I think it's very simple -- is where
7 documentation clearly exists out in the open literature on
8 the codes is the ones that Bob Bernero referred to, we'll
9 make a listing of that available. Where the documentation
10 is not available, we'll try to get these sets together for
11 you before the next meeting.

12 Then that, coupled with the Element 1 document,
13 is about the best package one could have.

14 Again, let's be clear that there is not a
15 complete standardized users manual, as we understand users
16 manuals, for each of these codes. There just isn't. I am
17 not sure there are users manuals for some of the other
18 codes that are being used in some of the companion studies
19 out in the industry yet either. So that's a little bit of a
20 problem.

21 But please bear with us, and we appreciate your
22 concern.

23 I know this wasn't part of your presentation,
24 but now you can go ahead.

25 MR. LEE: This morning I think we talked about

1 flow paths of fission products for both AE and TC. As you
2 know, the flow paths depend a great deal on the actual
3 event, mostly on containment failure time and bottom head
4 failure time. So containment is not as straightforward as
5 was the case for PWRs.

6 (Slide)

7 This is what I call calculation procedure for
8 modeling these transfer fission product in containment for
9 AE sequence. The NAUA code takes the input from the
10 TRAPMELT, and then the fission product goes through the
11 suppression pool. For that we have the SPARC code, which
12 was developed by the Battelle-Northwest Laboratory. And
13 then after that we have a wetwell. For that we use the NAUA
14 code again.

15 And then as the containment fails, the flow path
16 is such that fission product goes into the drywell
17 directly, bypassing the suppression pool. And as you had
18 the bottom head failure, you have additional source from
19 the core-concrete interaction code, which again was
20 developed by Sandia Laboratories.

21 (Slide)

22 This is Peach Bottom AE gamma drywell case. And
23 what we have here is the total mass suspended as a function
24 of time. And as is usual, you take a source as your
25 coremelting start. That starts around 12 minutes. And then

1 at 35 minutes containment fails.

2 So the material leaves the drywell out in the
3 bottom until the bottom head fails, and then you have
4 another source from the core-concrete interaction that
5 starts remaining in the reactor coolant system.

6 That gets into the drywell and then remains
7 suspended until everything leaks out to the environment.

8 (Slide)

9 I think one gentleman had a question this
10 morning about this graph. This is a little bit different
11 than what you had for the same reason explained this
12 morning. But this is the particle size distribution as a
13 function of time. What I have is radius in microns and
14 again gram per cc. And then dependent on the actual time,
15 you could have a large particle about 1 micron radius early
16 on. And then depending on where you are in the reactor
17 coolant system, spend a lot of time explaining the change
18 of particle size shifted to smaller particle size.

19 This particle size doesn't have to necessarily
20 agree with what Mike has, because this is average of what
21 you have in the containment. But the trend is such that it
22 shifted to a smaller particle size.

23 Later on, when the core-concrete interactions
24 start, you take additional source, and the particle size
25 shifts back, depending on the size of the source you take

1 at that time.

2 MR. COOPER: Ken, perhaps we could have this kind
3 of size distribution shown in a cumulative form. It might
4 be more informative in some ways. At this point, that's the
5 differential size distribution. The axis is probably
6 slightly wrong because we don't know that's the
7 concentration. We really want a concentration per size
8 interval. It may be a little easier to work with cumulative
9 distributions, I think, to interpret this kind of draft
10 than fractions.

11 MR. LEE: You mean straightline?

12 MR. COOPER: Yes.

13 MR. LEE: We could do that. I don't know how that
14 can help you better.

15 MR. COOPER: I can't tell from this what the
16 median is, for example, what the standard deviation is. And
17 it's clear that the vertical axis is not quite right in
18 terms of labeling, because it's got to be per something.

19 MR. LEE: You're talking about per radius?

20 MR. COOPER: Right.

21 MR. LEE: Well, I will tell you the area of the
22 code is not in direct proportion to the information that
23 you need. Okay. Size spread, you can pretty much tell by
24 the spread of the curve. But that's a good point.

25 (Slide)

1 Talking about matching mean particle size,
2 that's exactly here. Now, this is average particle radius,
3 but what I have is really geometric mean particle size as a
4 function of time. And again, we see the same trend here,
5 little bit large particle size early on, and then it drops
6 down, and then again shifts to the larger particle size
7 range.

8 MR. COOPER: And this is now on a number basis
9 rather than on a mass basis, number median diameter?

10 MR. LEE: Exactly. Right.

11 MR. GINSBERG: Ginsberg, Brookhaven.

12 On the slide where you show the total airborne
13 concentration or the total mass versus time, a couple of
14 slides back, there is about a 6 order of magnitude in the
15 airborne mass in an extremely short period of time. Is that
16 on the basis of some sort of an equilibrium kind of
17 calculation, or is that on the basis of a rate process?

18 MR. LEE: Which one are you talking about?

19 MR. GINSBERG: That one.
20
21
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1 the core concrete interaction.

2 MR. LEE: Okay. Containment fails at this point,
3 so you have a tremendous flow passing through the drywell.

4 MR. GINSBERG: Go further in time until the
5 vessel fails, down at the bottom. The vessel fails down
6 at that minimum, right?

7 MR. LEE: Right here. That's right.

8 MR. GINSBERG: The vessel fails; from there on
9 you have about a six order of magnitude increase in the
10 airborne mass.

11 MR. LEE: Right.

12 MR. GINSBERG: In a very short period of time.
13 The question is --

14 MR. LEE: You've got alot of material there.
15 You're talking about 4000 kg. of aerosol particle out of
16 the core concrete. At this point I think core concrete
17 interaction is ended.

18 MR. GINSBERG: Is that total release based upon
19 some sort of rate process or is an equilibrium calculation
20 of some kind?

21 MR. LEE: The rate is calculated by this method
22 I mentioned. The rate is in there. It lasts approximately
23 five hours in here.

24 MR. SILBERBERG: It's a rate process driven by
25 the CORCON calculation for the core concrete interaction.

1 MR. VOGEL: What was the composition of the con-
2 crete?

3 MR. LEE: It was limestone, wasn't it?

4 MR. CZYBULSKIS: Limestone, high limestone.

5 MR. VOGEL: May I protest that? We got a sur-
6 prise when we looked at this Surry concrete composition.
7 When VEPCO looked at it for us, it was not high limestone,
8 it was very low amount of carbonate. It was a salacious
9 material, and we think, considering where Peach Bottom is,
10 that this may well be true for Peach Bottom. So I think
11 specifically the composition of the concrete should be
12 checked, since these are calculations specific to a particular
13 reactor.

14 MR. SILBERBERG: I assume that that is something
15 that ought to be easy to get, right?

16 MR. VOGEL: It wasn't easy to get. We had to
17 go to the utility. They had a little struggle.

18 MR. GIESEKE: As far as the Surry calculations are
19 concerned, or were concerned, I think there was--it was mis-
20 leading because I flipped a coin at one point and put lime-
21 stone in the text which I pointed out in one of the meetings
22 was to be taken out and exchanged with basaltic based on
23 what was actually used in the calculations. We never used
24 the limestone concrete in the Surry calculations. I just
25 stuck it into the text because I didn't know what it was at

1 the time I was writing that section.

2 MR. VOGEL: That's very creative.

3 (Laughter.)

4 MR. GIESEKE: And I forgot to take it out until
5 a little bit later after a version had gone out. It was
6 removed from a later issue of the report.

7 MR. VOGEL: Okay. That's good. Then we didn't
8 have the sparging of the CO².

9 MR. GIESEKE: You did not at the Surry. The cal-
10 culations were done with the basaltic concrete.

11 MR. VOGEL: What have we got here?

12 MR. GIESEKE: In this case, all the information
13 we've been given is that it's limestone-rich concrete.

14 MR. VOGEL: Have you seen the real analysis?
15 It's worthwhile checking.

16 MR. GIESEKE: We got that information from two
17 sources, one being ourselves, and one being Dave Powers.

18 MR. VOGEL: I think you yourself should look at
19 the analysis, because we were surprised.

20 MR. SILBERBERG: Dick, I have a suggestion, if
21 you don't mind, since we are now getting contributions from
22 various sectors of the industry. Would the EPRI wish to
23 take it upon themselves to provide clarifying information
24 for the five plants that we are studying relative to concrete
25 as a point of contact? It might save us time.

1 MR. VOGEL: That's an interesting suggestion.

2 (Laughter.)

3 MR. GIESEKE: One is already done.

4 MR. VOGEL: Let's take that under advisement.

5 By no means would we be inclined to take your suggestion
6 lightly. We'll see if we can do it. That's easier -- to
7 ask somebody to do something when you don't know how to do
8 it yourself.

9 (Laughter.)

10 MR. BERNERO: IDCOR is using all the same reference
11 plans, except for Surry, so IDCOR may very well pinned this
12 down.

13 MR. VOGEL: If they have, I don't know it, but we
14 can check.

15 MR. LEE: I don't want to spend too much time on
16 this suppression pool modelling, which was used in this cal-
17 culation.

18 (Slide.)

19 I think sometime this afternoon, or even tomorrow,
20 we are going to have a session devoted to talking about the
21 suppression pool, but nonetheless the mechanisms included
22 in the model, I'll list it here -- condensation of steam, in-
23 ertial deposition diffusion, gravitational settling, and --
24 this is kind of unique -- particle growth due to pressure
25 decrease as the bubble goes up. And that will create the

1 negative deposition. And then, in addition, there's an in-
2 jection impingement mechanism describing the impaction right
3 after the pipe exit core exit, and then the solubility of
4 particles is considered in the models.

5 (Slide.)

6 What you have is a calculated decontamination
7 factor as a function of particle size for different times
8 for the AE sequence. Again the pool depths that are used for
9 this particular sequence is four feet, and bubble diameter,
10 which is found to be very sensitive to the final result, we
11 used .75 cm. and our aspect ratio was assumed to be 1.3.

12 The point I'm trying to make is that the decontami-
13 nation factor is a rather strong function of particle size.
14 In fact, the factor larger than 10^5 -- we just assumed that
15 it's 10^5 . So depending on what kind of particle size you
16 have when you go through the suppression pool, and the decon-
17 tamination factor based on the total mass really determines
18 the size diffusion of the aerosol you have at that point.

19 MR. CASTLEMAN: Could you say just a little about
20 the physics that went into that just so I can appreciate
21 what the calculations are?

22 MR. LEE: I think I would rather leave it to --

23 MR. SILBERBERG: That will be discussed, actually,
24 after the next presentation.

25 MR. LEE: But this particle size dependence is

1 clearly due to the inertial impaction mechanism. Again,
2 the same reason we talked about this morning, the Stokes
3 number plays an important role here. And then, depending
4 on the condition, steam condensation plays an important
5 role here. That's another reason why this bubble size is
6 important. And then pool depths -- the deeper pool you have,
7 I think you expect that decontamination factor will increase.

8 But I would point out that this factor is defined
9 to be a concentration of going in divided by a concentration
10 of leaving the pool, is that right? I'm always confused with
11 this. So, this is like we're talking about three percent re-
12 lease and this is like more than 99% -- like 10^5 we're talking
13 about 99.999% retention of collection.

14 MR. KASTENBERG: Before you leave that, I have a
15 question. This sequence is AE gamma or AE gamma prime?

16 MR. LEE: AE gamma prime.

17 MR. KASTENBERG: So those other figures were
18 mislabeled when you said AE gamma?

19 MR. LEE: We just have one AE sequence: that's all
20 AE gamma prime.

21 MR. KASTENBERG: After vessel failure, you don't
22 get scrubbing of the pool, right?

23 MR. LEE: That's right.

24 MR. KASTENBERG: So--

25 MR. LEE: This is before the containment fails.

1 The containment fails at 35 minutes.

2 MR. KASTENBERG: If you took an overall decontamina-
3 tion factor--

4 MR. LEE: You cannot read it from here because
5 this is the factor -- the function of particle size -- but
6 DF based on the mass, you have to multiply this with the
7 size distribution you have. Now, overall decontamination
8 factor you have to integrate over the mass as a function of
9 time.

10 MR. KASTENBERG: Do you have any idea what that
11 would be?

12 MR. LEE: Overall, I think we have about 30 DF --
13 a DF of about 30. So we're talking about 3% of the material
14 going into the pool escape the pool. Now we will have a
15 little bit of low DF for TC sequence.

16 MR. KASTENBERG: But wait. After the vessel fails,
17 you don't get any scrubbing, right? The release goes to
18 the drywell?

19 MR. LEE: Right.

20 MR. KASTENBERG: And then out?

21 MR. LEE: Right. I'm just talking about this for
22 time.

23 MR. KASTENBERG: I understand. But past this time
24 would this be significant?

25 MR. LEE: I'm not talking about -- it's not going

1 to be significant for this sequence, because we receive
2 alot of material at the containment failures.

3 MR. DENNING: I'd like to clarify something.
4 You kept saying "after vessel failure." It's actually after
5 containment failure which occurs before vessel failure that
6 you no longer have scrubbing. It's pressure pull.

7 MR. KASTENBERG: As impressive as these numbers
8 are, when you look at the overall risk, it's not going to
9 have an impact.

10 MR. SILBERBERG: For AE.

11 MR. KASTENBERG: For AE.

12 MR. LEE: You're right.

13 MR. CASTLEMAN: Despite the fact that
14 you don't want to go into the physics now, could I just ask
15 one question? You have a bubble diameter there of three-
16 quarters of a cm. Supposing that were half the size, or
17 twice as big, how much might that affect these numbers?
18 I don't have a feeling whether the three-quarters of a cm. --

19 MR. LEE: We probably have a sensitivity analysis
20 result. Do you have anything like that?

21 Debra -- do you have any?

22 MS. HAWKINS: I've got some results of the bubble
23 size.

24 MR. LEE: It's rather dramatic. Also, the ratio --

25 MR. COOPER: Just to suggest that the model that

1 you have might be compared against the models that are
2 traditional, the scrubber literature, and also against
3 some scrubber results. I'm a little surprised at the high
4 collection efficiency for one-micron particles and half-
5 micron particles in this case.

6 MR. SILBERBERG: Higher for one than a half?

7 MR. COOPER: What surprises me is that they're
8 so large at all.

9 MR. LEE: I have had alot of problems because
10 my DFs are so low.

11 (Laughter.)

12 MR. COOPER: You have solved them in that case.

13 MR. VOGEL: Perhaps Dr. Cooper isn't aware that
14 EPRI has an on-going program on scrubbing of aerosols in
15 Battelle, Columbus, and we are in the process right now of
16 scrubbing cesium ioside aerosols. And hopefully these will
17 be available for use.

18 MR. LEE: This is just an example of calculated
19 total solid particulate material at various locations --

20 (Slide.)

21 --at different times. And I think to understand
22 better, I think we just listed some of the important events
23 in here. Again, melt starting time is 12 minutes. Then you
24 start getting this material. And right before containment
25 fails, you've got so much suspended in drywell, and about

1 the same amount of material deposited in drywell again that
2 alot of the material has gone to the suppression pool and
3 captured, and very little escapes into -- suppression pool
4 to reach the wetwell. And, as the containment fails, the
5 flow path changes. Normal particles go through two suppression
6 pools, so the amount of material captured in the pool remains
7 constant. And then, I guess head failure time is here. You
8 have a really low source coming out of the primary system for
9 the same reason Mike Kuhlman talked about this morning.

10 And then, as your head fails, you start getting
11 this material from the core concrete interaction as well as
12 from the reactor coolant system.

13 And right here, I think that's a rather long time,
14 at the end of accident I have about 20 hours in there. The
15 material ends up being located either in the drywell or
16 in the pool. The wetwell -- I guess you really don't have
17 anything left in the wetwell -- and then escape to the environ-
18 ment.

19 And as you pointed out correctly, the final re-
20 lease amount does not really depend on the efficiency of the
21 suppression pool in this -- for this sequence.

22

23

24

25

1 (Slide)

2 Let me go through one more thing. Okay. This is
3 for different species here. Again, 18 percent of the cesium
4 iodide at the end of an accident remains in the reactor
5 coolant system, and a significant amount of material is
6 captured in the pool, and 14 percent end up in the drywell,
7 mostly by gravitational settling, and then about 21 percent
8 goes out to the environment.

9 MR. REYNOLDS: What pool is that?

10 MR. LEE: Suppression pool.

11 MR. REYNOLDS: Okay.

12 MR. LEE: And we've got a pretty much similar
13 number for cesium hydroxide. In case of tellurium because
14 of source timing, we have a different number. A lot of the
15 tellurium gets released in the drywell at the time of
16 core-concrete interaction, and also as Mike Kuhlman again
17 mentioned in the morning, even after the tellurium system,
18 tellurium gets released later, so tellurium doesn't have a
19 chance to go through the suppression pool.

20 So as a result, you have a rather high release
21 fraction. And if you direct your attention to the
22 blackboard there, in the case of cesium iodide, I guess it
23 started with one here, 99 percent goes through the reactor
24 coolant system. Out of 99 percent, 18 percent stays there,
25 which is the same number you have in the viewgraph.

1 Out of that, I guess the remainder goes into the
2 drywell, and the 47 percent has a chance to go through the
3 suppression pool. 40 out of 81 goes to the suppression
4 pool, and the remainder goes directly to the drywell, and
5 then it pretty much goes to zero. Then you come out with
6 .21.

7 So that is the flow path or the way of the
8 cesium iodide. And you get a similar figure in the case of
9 cesium hydroxide and tellurium.

10 MR. VOGEL: Let me make sure I understand what
11 you've done on the tellurium. Are you assuming CO2 sparges
12 through this melt from the limestone?

13 MR. LEE: I cannot answer that question.

14 MR. GIESEKE: Yes.

15 MR. VOGEL: Okay. That gives you a higher release
16 than if it doesn't sparge through from the limestone.

17 MR. SILBERBERG: Yes.

18 MR. LEE: The core-concrete interaction tellurium
19 gets released at a lower rate because of the cesium
20 hydroxide, cesium and iodine. Another reason is that in the
21 case of tellurium, it goes through this path or through
22 this path, so you really don't have any --

23 MR. GIESEKE: Let me make a point. From what I
24 understand from Dana -- I will try to speak for him, I
25 guess, since he is not here. I will back up a little bit.

1 I have been to the pressure vessel. There are
2 mechanisms, as evidenced by what we learned from Oak Ridge,
3 that will help keep the tellurium tied up with the melt.
4 But apparently, once the tellurium with the rest of the
5 melt material is on the concrete, the sparging process and
6 also the chemistry is such that according to Dana, there is
7 no mechanism that he can see or no chemistry that would
8 hold the tellurium in that melt and the sparging process
9 carries it on through.

10 I am just quoting what he told me.

11 MR. VOGEL: The last time I talked with Dana,
12 that conclusion on the release of tellurium was based on
13 the assumption that it behaved like sulfur. And I recall
14 that there is even selenium between sulfur and tellurium.
15 So I think that's, A, a shakey hypothesis unless it's
16 confirmed by experiment.

17 And secondly, I think that when you've got a
18 rather large mass of molten material, that they effective
19 scale on the release of these volatile materials is very
20 important, and also whether you do or do not have sparging.

21 MR. SILBERBERG: Even if I had a basaltic
22 concrete, I still have sparging, although less than
23 limestone sparging, due to just steam from there. Right?

24 MR. VOGEL: Yes.

25 MR. SILBERBERG: But it would be less.

1 MR. VOGEL: Yes. Am I correct that there is no
2 experimental evidence on the tellurium release from the
3 melt? Does anybody want to contradict me?

4 MR. SILBERBERG: I think that's correct.

5 MR. LEE: We are going to talk about TC gamma
6 prime this time. The flow paths of the fission product is
7 such that they get into the suppression pool first -- do
8 you have any Figure 7.4, page number 7?

9 MR. KASTENBERG: Yes. 724.

10 MR. LEE: Page number 724. Again, that's the way
11 we have been using computer code, the kinds of flow path of
12 the fission product.

13 So the first thing we want to do is to use the
14 SPARC code to calculate the decontamination factor and then
15 model the wetwell. And as the vessel fails, then I think
16 the flow path is directed to the drywell, again bypassing
17 the suppression pool.

18 (Slide)

19 This is the calculated decontamination factor
20 for TC. The same form that you saw before. The pool depth
21 is a little bit larger than we used before. But basically
22 it's the same information.

23 MR. KASTENBERG: How do you use MAUA in a wetwell
24 when there's water in there, when the pool is there?

25 MR. LEE: We just use the space above the pool.

1 MR. KASTENBERG: But can it handle the fact that
2 you have a water surface that's hot?

3 MR. LEE: No, you can't handle that. We're
4 talking about another aerosol deposition mechanism.

5 MR. KASTENBERG: Yes. Just from my understanding
6 of how NAUA works, I wouldn't think you would model that
7 interface correctly.

8 MR. LEE: Specifically, can you think of any
9 specific rather than -- what I did was everything settling
10 on the floor, which is water, I just shoved it into the
11 suppression again. That's one thing I did.

12 If you have any suggestion or any specific
13 mechanism you can think of, I think there might be some
14 important thing we missed.

15 MR. COOPER: Two things we can think of that
16 might be important. One is that if the liquid is
17 evaporating, it will again produce a virtual wind that
18 could oppose any settling tendency.

19 And secondly, that the breaking bubbles will
20 after a while begin to put up some of the materials
21 suspended in the liquid back up into the air. Whether those
22 are significant I am not sure.

23 MR. LEE: Okay. Obviously, we have not considered
24 those possible mechanisms, but we did use the NAUA code for
25 modeling the wetwell.

1 (Slide)

2 Airborne concentration of the particles as a
3 function of time in the wetwell.

4 (Slide)

5 Particle size distribution as a function of
6 time, the same format you saw for the case of AE, but again
7 we're talking about pretty small particles.

8 (Slide)

9 I want to point out at this point that
10 decontamination factor we have for this case is lower than
11 what we have for AE. Again, the overall decontamination
12 factor based on mass, we're talking about decontamination
13 factor of 7, which is rather low, which means about 13
14 percent of the material escapes the suppression pool.

15 And one of the reasons we have such a low
16 decontamination factor is that the particle size dispersion
17 of the incoming aerosol is very small. And at that point
18 you are taking a lot of mass at a rather high rate because
19 of the surge in the flow we talked about this morning.

20 So at some point you have a decontamination
21 factor larger than 100. But that is not really a deciding
22 factor in calculating the overall decontamination factor
23 during the entire period of when the suppression pool
24 operates.

25 MR. VOGEL: How do you model the transport of the

1 aerosol through the pipe to the suppression pool?

2 MR. LEE: What I did is I think before I said we
3 have an impingement zone right after the exit of this gas.
4 We looked at that, and what I did was to calculate the
5 velocity, gas velocity, out of that exit. I added all this
6 opening area, what, 15, 44, in tee quenchers, and the
7 diameter of the hole was .4 inch diameter.

8 So I added all these holes to calculate the
9 injection velocity. and the resulting Stokes number was not
10 large enough to change the calculated factors. Again,
11 particle size was just too small.

12 I don't know whether I answered your question.

13 MR. COOPER: I think the question was how you
14 handle the possibility of deposition in the pipes leading
15 to the pool. And probably the answer is the size
16 distribution is so fine and the residence times so short
17 that the major mechanism might be diffusion, but stuff
18 that's a few tenths' microns is going to get through there
19 very readily.

20 MR. VOGEL: Is that true, that the flowrate is
21 that high?

22 MR. LEE: Right.

23 MR. KULHMAN: During the period of time that Ken
24 is talking about, the residence time on the primary system
25 is well under 10 seconds for these gases to come all the

1 way from the core through the relief lines. We do model
2 diffusive definition in all the pipelines on the way, but
3 even so, there's not much time for that to take place
4 either.

5 Really, in effect, it's going to be an a-major
6 mechanism in the bubbles and any of the pipelines along the
7 way.

8 MR. LEE: Okay. Now we are in the drywell. That's
9 airborne mass as a function of time again, and it depends
10 on the source timing. You have a suspended mass as a
11 function of time. Again, these peaks represent source out
12 of the core-concrete interaction, and this is the cumulated
13 mass leaked out to the environment.

14 (Slide)

15 The same plot except that now we have different
16 species in there. I think one thing I want to point out is
17 again in this tellurium release, you have a rather high
18 release at the time of core-concrete interaction. So as in
19 the case of AE, again you expect that the final tellurium
20 release fraction is not going to be as low as cesium or
21 iodine.

22 (Slide)

23 Mean particle size as a function of time. Again,
24 rather small particles early on, and then maybe larger
25 particles later.

1 (Slide)

2 Okay. This is it. Bottom line. This is the
3 number you have in the morning. The stuff retained in the
4 reactor coolant system, and then 54 percent remains in the
5 pool, a little bit in the drywell, virtually nothing in the
6 wetwell, and 34 percent out to the environment.

7 This tellurium is still 32. If you had this up,
8 it's not going to be 1, which means not all the tellurium
9 was released, especially the stuff which got out of the
10 core-concrete interaction.

11 I talked with Dana Power. We didn't get all the
12 tellurium which was available. So that's the reason why it
13 won't add up.

14 But in the case of AE, everything got released.
15 Some 70 percent, some 60 percent got released. But this is
16 the final result anyway.

17 Now we are going to talk about TC gamma, which
18 means we will give credit to the reactor building, the
19 secondary containment.

20 So what he did was to take this and run this
21 NAUA code once again to model this reactor building.
22
23
24
25

MM:j1 15:1

1 (Slide.)

2 So, this is suspended mass as a function of time
3 and standby gas treatment system is operating at this point.
4 And really, this is some of the mass released outside, plus
5 the mass going through the standby gas treatment system.

6 (Slide.)

7 At this time, we have reactor building here and
8 standby gas treatment system, and then environment. So,
9 instead of point 3, right now we have 20 percent.

10 Now, why is it not zero? Obviously, standby gas
11 treatment system can take only so much, because we're talking
12 about a large flow. And in this calculation, I think we used
13 25,000 cubic feet per minute, going through the system. But
14 because we assumed the HEPA filter in the system fails after
15 collecting 104 kilogram, which we got from Steven Hodge --
16 but, again, we're talking about 4,000 kilogram of material
17 out of the core concrete interaction period, an additional
18 400 kilogram out of the reactor coolant system during the
19 metal release or initial release period. We just cannot handle
20 that kind of a mass.

21 So, the rest of the flow will be directed to the
22 environment. You still have about, in this case, about --
23 you add them up, 13, 14 percent reduction in the final number.
24 But basically we're talking about the same characteristics we
25 saw for TC gamma prime.

1 And I think the next speaker will summarize the
2 whole thing, comparing with the previous result.

3 If you have any questions, I will try to answer.

4 MR. SHERRY: Sherry, NUS.

5 Ken, did you look at the heating of the SGTS filters
6 to that amount of cesium and iodide deposited on them?

7 MR. LEE: No, I have not looked at it.

8 Here was just simple calculation. I think the only
9 thing I did was, like I said, the flow rate -- we have 25,000
10 cubic feet per minute, and then just filled the filter. At
11 the time, the filter collected so much -- in reality, that is
12 not what's going to happen.

13 I think as you collect the material, I think the
14 flow will be restricted, and then collection efficiency, while
15 it's 99,9 percent anyhow, but it's going to be like a
16 transient period. And then you will find it clogged.

17 I don't know. Maybe Steve or Rich -- I don't know
18 whether I answered your question or not. But, no, we have not
19 considered any heating effect.

20 I think this morning we talked about missed mist
21 eliminator. We have never looked at that.

22 MR. WORMAN: Stone & Webster.

23 Can I find that chart very helpful in understanding
24 the cesium iodide data? Would it be possible to add the
25 tellurium to that? I tried to use the table and follow it.

1 MR. LEE: It's rather complicated. I didn't have
2 time to make a viewgraph of that. I think I will do that for
3 different action, for different species.

4 MR. WORMAN: Just for the AE, if you could put the
5 tellurium in parenthesis, it would be very helpful to under-
6 stand.

7 MR. LEE: You could do the same thing for TC, also,
8 which would be a little bit more involved, but I guess you
9 can keep track of which one goes where.

10 What is not in there -- timing is not in there.
11 That is still not complete. But at least you can get an idea,
12 I suppose.

13 MR. CASTLEMAN: During your presentation, you showed
14 us a number of viewgraphs of aerosol radiants versus time.
15 It showed rather dramatic oscillations. Yet, every time you
16 showed us a distribution, it was a nice smooth -- what looked
17 like it would probably end up being a log number distribution.
18 Doesn't it surprise you, with all the settling, agglomeration,
19 and flow exchange from one vessel to another, that these
20 aerosol distribution would show some multiple beats, at
21 least by nodal distribution?

22 MR. LEE: I think there are times where you have
23 multiple or double-modal distribution; you just have so much
24 information with this kind of calculation. But we did see
25 -- just happens to be --

s.2 BU

1 MR. CASTLEMAN: It looked like everyone you showed
2 us was so smooth. You're got these wild oscillations going
3 on.

4 MR. LEE: The mean size we calculated was not based
5 on log numbers. It was computed from the disputized spectrum.

6 MR. COOPER: I understand what you're saying. We
7 ought to have back-mixing or something that would give us
8 two modes -- otypically, the combination of condensation,
9 generation, and sedimentation, depletion, gives you the silt-
10 preserving size distribution. They often look pretty much
11 like what Ken has shown.

12 MR. CASTLEMAN: I've made an awful lot of measure-
13 ments. Usually you see some manifestation when you've got
14 settling and settlement going on. It just surprised me. It
15 looked so smooth.

16 Some people look at it.

17 MR. LEE: Another thing, in this calculation, I
18 think, really, the aerosol mechanisms, like agglomeration,
19 doesn't play an important role, because the residence time,
20 again, is rather short, that the flow turns out to be an
21 important factor. Particles just don't have any time to go
22 through this aerosol agglomeration, as well as deposition
23 mechanism.

24 MR. SILBERBERG: Do you want to pick it up if it's
25 relevant at Grand Gulf?

1 MR. ROE: A very quick question. Is it possible to
2 draw some conclusion here relative to WASH 1400 in terms of
3 this being sort of bottom-line?

4 MR. BERNERO: He's about to, I hope.

5 MR. ROE: Oh, he's going to do it?

6 MR. BERNERO: He does it in here. He's got bottom-
7 line disease.

8 (Laughter.)

9 (Slide.)

10 MR. GIESEKE: Just to refresh your memory, I guess.
11 of the WASH 1400 release, we have then summarized here --
12 we're going to be looking at the two categories that we feel
13 are pertinent, which is the PWR 2 and 3.

14 (Slide.)

15 Comparing those with the calculations that we made
16 for the sequences that fit that sequence description, as you
17 can see, the effect that we noted or Ken noted as he went
18 through the early release from the fuels for the cesium iodide
19 or cesium and iodine categories, where they go through the
20 suppression pool and get scrubbed as compared with the
21 tellurium release, which comes along later from the vaporiza-
22 tion of the core concrete interaction, which has more direct
23 path into the containment, boosting the tellurium above the
24 BWR 2 category for the AE gamma prime case. The TC gamma prime
25 case is a little bit more well-behaved in terms of the timing.

1 It is still below the BWR 2.

2 (Slide.)

3 The other case that was discussed today is the TC
4 gamma case that we just went through, with the building intact
5 at least through the filters up until the time they failed.
6 We were a little bit higher in this particular case and very
7 consistent, as it was, with the TC gamma prime case, much more
8 consistency between the species.

9 MR. KASTENBERG: Could you tell us, in both BWR 2
10 and 3, what are the major things that give you the difference.
11 Obviously, suppression pool is one. The use of an hour code
12 and so on -- which are the most dominant things that give you
13 the difference.

14 MR. GIESEKE: Between the 2 and the 3?

15 MR. KASTENBERG: Between WASH 1400 2 and 3.

16 MR. GIESEKE: We'll have to explain all the
17 differences between those categories fully. I don't know the
18 details.

19 MR. COOPER: I think the question was why did the
20 calculations give different results, what are the primary
21 mechanisms that are giving you more or less emissions at the
22 end of this?

23 MR. GIESEKE: That's what we've been talking about
24 for the last two hours, I think,

25 Going through all the steps again --

1 MR. KASTENBERG: Just in a capsule, what are the
2 most dominant features? In other words, if you wanted to hone
3 some of the calculations, where would you focus? Which ones
4 are not that effective?

5 MR. GIESEKE: What are the most sensitive issues?

6 MR. SILBERBERG: Yes.

7 MR. GIESEKE: As I mentioned, as I put these up, I
8 think the timing is of utmost importance, particularly in the
9 tellurium release, where it either does or does not go through
10 the suppression pool. And also the containment, the primary
11 containment failure timing is important, because at that time
12 you ceased to have the effectiveness of your pool. And so
13 that will shift those numbers up and down.

14 You see the pool -- well, for instance, in here we
15 see, when we go through the pool, we catch essentially all the
16 material that is passing through the pool. But at the point
17 when the containment fails, then you bypass, and that's the
18 crucial issue, because then whatever hasn't gone through the
19 pool basically goes on out much more easily.

20 So, the timing, I think, is very important.

21 MR. SILBERBERG: Maybe somebody else can help, but
22 I think what Bill is asking is, in BWR 2, other than tellurium,
23 basically you're coming out lower for TC gamma prime and AE
24 gamma prime.

25 Okay. What brings you to that point. And in BWR 3,

1 you're coming out higher for the TC gamma. And again, what
2 brings you to that point?

3 MR. GIESEKE: Just the results of the calculations.
4 I wouldn't attach too much -- I wouldn't hang myself because
5 of any of those numbers. They're a little bit up or a little
6 bit down. There are a lot of uncertainties in the calculations
7 and a lot of things that contribute, and those all may go up
8 and down, so I wouldn't attribute any particular significance.

9 MR. DENNING: Can I comment, also?

10 I think that there are a number of very important
11 processes here. You get large uncertainties on the them to
12 get really good -- where are the areas of uncertainty that
13 are potentially major contributors, as well as what are the
14 differences between the WASH 1400 analysis results and the
15 results that we had here. Obviously, one area is in the
16 primary system, We didn't take any credit in WASH 1400. It
17 wasn't the major contributor here, except for the aerosols.

18 Actually, all Jim has really shown is the volatiles.
19 The involatiles, we would see bigger differences from WASH 1400
20 had they been shown, due to the primary system behavior; but
21 there's still significant uncertainty as to what the primary
22 system retention is.

23 Another contributor is the timing in the AE
24 sequence of containment failure. Containment failure has been
25 later, and more of the initial release during core melt to the

1 suppression pool, it would have had a bigger effect. It had
2 a major effect on what went through the pool. If there had
3 been more time for stuff to go through the pool, it would have
4 had a more dramatic effect.

5 If we look at the TC and TW sequences, the
6 suppression pool contribution was important, very important,
7 but the DF there was not really as large as many people would
8 think that it would be. And I think that later we may get
9 some comparison between SUPRA and SPARC, that there could be
10 significantly greater retention and suppression pool in the
11 TC and TW kind of cases than we currently have. We get back
12 to the uncertainties again. We have the question of where does
13 the containment fail, is it in the dry well or wet well?
14 That certainly is a major difference between what we're work-
15 ing on and this.

16 Also, I'd like to say one more thing about the BWR 3
17 and the effect of the reactor building. I think the effect
18 of the reactor building for some sequences will be bigger
19 than we saw with the TC sequence.

20 In addition, there is this possibility of the
21 sprinkler system working for a period of time; but then
22 compounded with the uncertainties of the hydrogen generation
23 and potential for hydrogen explosion, there are an awful lot
24 of areas that have to be examined in more detail than we were
25 able to.

MR. SHERRY: I think I would like to address this question to Rich Denning. One major difference is the higher releases for tellurium between your AE gamma prime analysis in this study and the reactor safety study BWR-2 in this category. Was that the release rates of tellurium? I guess we're about the same for the safety study and for this study in that a large percentage of the tellurium was released during the melt concrete reactions.

Is the difference in the amount of tellurium released to the environment basically due to differences in the time of containment failure between the safety study and the assumed time of containment failure in this study?

MR. CZYBULSKI: Time and location, drywell versus wetwell. The safety study was a wetwell failure, and they got more benefit in the pool.

MR. SHERRY: I thought there wasn't any pool scrubbing in the safety study.

MR. CZYBULSKI: Yes, there was very much so, except for saturated pools. In cold pools there was.

MR. DENNING: In AE that would be true.

MR. REYNOLDS: Why does it matter so much whether the failure is in the wetwell or the drywell? What is it in the geometry in the pathways? In either case, do you go through the pool after the failure? What's the big difference in the geometry?

1 MR. GIESEKE: After the containment failure you
2 don't go through the pool.

3 MR. REYNOLDS: In either case then?

4 MR. GIESEKE: There was some credit given for
5 flow up along the annulus outside the primary containment.
6 Wasn't there in WASH-1400?

7 MR. CZYBULSKI: Excuse me, Jim. With regard to
8 the question, in WASH-1400 we assumed that the failure took
9 place in the wetwell and that the failure took place at 175
10 psi. As a result of those two assumptions, essentially all
11 the melt release and a portion of the release from the
12 core-concrete interaction passed through the pool before
13 the containment failed.

14 MR. REYNOLDS: Was that because of the 175 versus
15 the 132? Or was it because of the geometry?

16 MR. CZYBULSKI: A combination of the two, as it
17 turns out. The lower failure pressure and the different
18 location in the present study results in less of the
19 release passing through the pool.

20 MR. KASTENBERG: Just a follow-on to this
21 question. If you had used all the tools hat you used in
22 WASH-1400 but just changed the failure pressure and made a
23 wetwell failure, how close would you be to what you have
24 got using all of your new tools?

25 MR. CZYBULSKI: I am not sure I exactly followed

1 your question, but let me try to answer.

2 MR. KASTENBERG: I am trying to understand
3 whether the most dominant thing is the fact that you have
4 changed the failure pressure in the location of failure or
5 whether it's all of the physical chemistry we've discussed
6 all day today. That's what I am trying to ascertain, which
7 is more important.

8 MR. CZYBULSKI: It's my impression for the AE
9 sequence, by far and away the most important thing is the
10 location and level of containment failure. That is my
11 personal impression of the results.

12 MR. KASTENBERG: Could you comment on the TC?

13 MR. CZYBULSKI: In case of the TC, as was pointed
14 out earlier, in WASH-1400 we did not take any credit for
15 the suppression pool, and we are taking some credit now,
16 and I believe to a very crude level of approximation.
17 That's really the principal difference.

18 MR. RITZMAN: I want to correct that. In
19 WASH-1400, for accent TC containment remained intact
20 through coremelting when the suppression pool was subcooled
21 and a DF of 100 was used for the pool for the melt release.
22 So that made the melt release relatively low, and that's
23 the reason TC gamma fell in BWR-3 rather than PWR-2 in
24 WASH-1400.

25 MR. DENNING: I am sorry. That is explained in

1 the report, and I didn't want to confuse you by that. But
2 TC gamma prime actually fell in the PWR-3 in WASH-1400, but
3 the BWR-3 is really determined, I think, by the TW gamma.

4 MR. GINSBERG: A comment and a question. A
5 question to the general audience, the other peer reviewers.

6 First, isn't it possible to fail the wetwell in
7 the vapor space and still take credit for scrubbing; or,
8 second, it can fail below the water mark and then you'll
9 lose your water and you don't have any scrubbing. So you
10 have to make one of those two assumptions.

11 Now, listening to all this, what I feel is that
12 the severities of what's happening is governed by when
13 containment fails relative to when the vessel fails. I
14 haven't heard any comments from the other peer reviewers,
15 who I would assume have done similar analyses to see
16 whether they basically agreed with the sequence.

17 I am wondering whether I am in order now to ask
18 for a comment from other reviewers to see whether they
19 agree on the basic -- is there general agreement that the
20 basic sequence and the calculations that led to this
21 sequence are basically valid?

22 MR. SILBERBERG: Anything is in order here.

23 MR. WALKER: You know, I think we're at a point
24 where on the MARK-I we simply haven't done the containment
25 event trees with the splits that have to do with

1 containment failure modes and the flow splits between flow
2 out of the containment and into the pool. Those sorts of
3 things simply haven't been quantified as yet.

4 What I see here is a bunch of calculations
5 without the basic systems work that comes out of a
6 containment event tree having been done yet. I would
7 suggest you ought to do that work. The uncertainty stuff,
8 maybe you ought to do something like the DPD stuff in the
9 PWRs, but that's different than trying to work the basic
10 systems problem with the containment event tree. That just
11 hasn't been done.

12 MR. BURNS: Bob Burns, EDS Nuclear.

13 I can respond to Ted's question on the results
14 we're seeing in the IDCOR program. We see similar types of
15 behavior that are being described here.

16 The major difference we have in our results in
17 the fact that the containment failure times seem to be a
18 little bit later. And as a result, according to the kind
19 of things that Rich Denning was describing, we do get more
20 of the material diverted into the drywell -- I am sorry,
21 from the drywell into the wetwell, also from the vessel
22 into the wetwell where it stays up until the time of
23 containment failure.

24 As a result, we get about 20 percent or so of
25 the type releases you have been presenting here.

1 MR. SILBERBERG: You get one-fifth.

2 MR. BURNS: We get one-fifth of those results,
3 one-fifth lower.

4 In response to your question, Ted, the
5 vaporization release from the drywell in all sequences
6 except TW does go down into the wetwell because TW is the
7 only case we have in IDCOR where the containment failed
8 before melting occurs.

9 MR. SILBERBERG: Thank you very much.

10 MR. COOPER: Although we may find eventually that
11 indeed the timing is crucial, I think there is a lot of
12 value to the iterative improvement process that we're
13 seeing with regard to the models. And one of the things you
14 discover when you do this is when you're close enough to
15 stop -- and typically that happens when you have changed
16 something and it doesn't make much difference.

17 So I think there's a lot of value to it. Those
18 people who do numerical integration there, you keep having
19 the step size and finally it doesn't make a difference and
20 you come away relieved and you can step back a little bit.

21 MR. WALKER: The thing that worries me, we're
22 only iterating on part of the problem.

23 MR. SILBERBERG: Yes, that's true. Point very
24 well taken. Thank you.

25 MR. BERNERO: Excuse me. I wonder if I could

1 raise a point with Bob Burns. I don't know if he's in a
2 position to answer it. Has IDCOR as of this time done any
3 deep containment of entries of the type that Dee was
4 referring to on the MARK-I containment on the MARK-III?

5 MR. BURNS: Deep containment?

6 MR. BERNERO: I think you know what I mean.

7 MR. BURNS: Detailed trees, I take it. I know
8 IDCOR has done some containment event trees. I have not
9 seen them myself, so I don't know about them.

10 MR. BERNERO: Thank you.

11 MR. SILBERBERG: We are going to take a 10-minute
12 break, but it's going to cost us in our time. We're going
13 to close later tonight.

14 (Brief recess.)
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(202) 293-3950

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7.16

1 MR. BERNERO: Let's get started.

2 MR. GIESEKE: I would like to move along and go
3 into the third topic that we have in terms of our analyses
4 to date, which is Volume 3 of BMI-2104.

5 (Slide)

6 But we are talking about MARK-III design BWR; in
7 specific, Grand Gulf. Just to refresh your memory, I had a
8 table of volumes. We are down to this point at the moment.

9 (Slide)

10 This is in the process. This work is still being
11 done. We have looked at the TC and TQOV sequences. We're
12 still working with the TPI. I think if you all picked up
13 copies of material we have, the first part of this Volume 3
14 report available to you, which covers not all of that which
15 we will talk about but which covers the first part of that
16 report, which is pretty much through the thermal hydraulic
17 part, the next part of the report that we're working on
18 would be the release from the fuel and then the transport.
19 So the report goes that far.

20 The discussions today will go beyond that
21 somewhat. We didn't have a chance to get that all written
22 up as yet.

23 (Slide)

24 But we will be talking about some of it, and the
25 topics we will be covering today will be the sequence

1 descriptions and thermal hydraulics. Rich Denning will be
2 doing that. And we will also cover release from fuel,
3 transport in the coolant system. Mike Kulhman will be doing
4 that, covering that topic. And I will try to make perhaps a
5 statement or so at the end, and that will go on.

6 MR. DENNING: I am Rich Denning.

7 (Slide)

8 The Grand Gulf plant is the plant that has been
9 selected to represent the MARK-III. Now, the reason that we
10 picked Grand Gulf was it was used in the reactor safety
11 study methodology applications program, which is a study of
12 four designs that was done following WASH-1400. So we had
13 quite a bit of information on it.

14 There would have been another logical choice,
15 and that would have been the GESSAR plant, which we did not
16 do, and that probably has caused us a little bit of grief.

17 General Electric has provided us a great deal of
18 information on the MARK-III design. In some cases, we have
19 had to adapt that to the Grand Gulf.

20 The analysis that we will show today, we have
21 recently had some additional comments by General Electric
22 on the way they feel the MARCH analyses should be done on
23 some of these. I don't think there are major changes, but
24 there are things that we will have to be giving some
25 consideration to later. But I don't think they have any

1 significant effect on the results that we're going to show
2 you today.

3 The sequences that we will be analyzing are the
4 TC, TPI -- I will explain what TPI is, but in reality it's
5 so similar to TW it really doesn't make much difference
6 which of these we're doing in the TQOV sequences, that
7 these are expected to be risk-dominant sequences.

8 In the boiling water reactors there are so many
9 diverse sources of water to cool the core that the risk
10 studies generally indicate that it's the transient
11 sequences that are risk-dominant sequences and not the
12 pipe-break sequences.

13 (Slide)

14 Grand Gulf is a steel-lined reinforced concrete
15 containment. There are other MARK-III designs that are
16 freestanding steel containments. But Grand Gulf is a
17 reinforced containment. The drywell in this case is here.
18 The wetwell or the suppression pool is now on an annulus
19 around the outside of the plant.

20 There is water inside of a wearwall here that
21 gets depressed in the event of a pipe-break accident that
22 pressurizes the drywell. And then the flow that goes
23 through the vents really goes horizontally through the
24 vents.

25 The outer containment is kind of like the vapor

1 region of the wetwell, but it really is the containment.
2 This is really the containmmnt right here. The primary
3 containment is this region right here. It sees the top of
4 the suppression pool so that anything that goes into the
5 suppression pool will go up into this region here.

6 And of course, there is a steel liner right
7 there that is the vapor barrier or the barrier that
8 prevents fission products from being released to the
9 environment as long as the containment remains intact.

10 The location of failure and the pressure that we
11 are taking into the failure pressure is 72 psia. The
12 location is the junction of the cylindrical wall and the
13 dome that is at this location right there.

14 (Slide)

15 In the case of the MARK-III design, the Grand
16 Gulf design, there is a confinement building around the
17 building, but the standby gas treatment system is much
18 smaller than at Peach Bottom.

19 It was our feeling that in the event of failure
20 of the primary containment, that that confinement building
21 would not offer additional retention. So once the
22 containment fails, we have release to the environment.

23 Incidentally, this is a pretty healthy margin
24 above the design pressure, which is 15 psia. That converts
25 into 3.8 times design.

1 MR. KASTENBERG: Could you show us where the vent
2 pipes are on the down plenum?

3 MR. DENNING: You mean where the vent pipes are,
4 the vent pipes that go -- if this pressurizes, how does the
5 material vent? You see these little horizontal tubes right
6 there? There are three layers of them. There is water in
7 this region right here.

8 I think that actually in the drawing there might
9 be a few dots that look like concrete in there which aren't
10 true. This is a wall right here. This is called the
11 wearwall, and there's a water level in here that under
12 normal pressure conditions would be the same. When this
13 area pressurizes, it pushes the water level down here so
14 that it goes below this horizontal vent, and we relieve
15 that way.

16 Now, as far as the accident sequences that we
17 are studying, this only comes into play after we have
18 melted through the lower head because we are looking at
19 transients.

20 During the transient, while the core is
21 degrading within the vessel, you again have the steam line
22 and a relief line that go directly into sparge rings in the
23 suppression pool.

24 Did that answer the question?

25 MR. WALKER: The 75 psi failure pressure, who did

1 that?

2 MR. DENNING: Actually, I am not sure what the
3 answer to that is. That is a number that we have really
4 gotten from the industry, and particularly from IDCOR.
5 But we don't really have good credentials for that,
6 although they may exist.

7 (Slide)

8 The first sequence is the TC sequence, which we
9 have actually talked about already for the Peach Bottom
10 reactor, if you recall.

11 And this time, the containment failure is at 80
12 minutes. Remember that the system does not scram. In this
13 case, the core power level drops to 16 percent. That heat
14 is dumped into the suppression pool. The suppression pool
15 heats up, and eventually the containment gets to the point
16 at which it fails.

17 We have beginning of core melt at 118 minutes,
18 and core melt is occurring in a failed containment.

19 MR. KELLY: Question. Jim Kelly, University of
20 Virginia.

21 Why is it 16 percent of this reactor and 30
22 percent of the Peach Bottom?

23 MR. DENNING: I would rather let General Electric
24 answer that, if they would be willing to do that.

25 MR. HOLTZCLAW: Kevin Holtzclaw from GE.

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1 The difference is in the equilibrium power level
2 following an ATWS event are different between a MARK-I and
3 a MARK-III design, primarily due to the emergency system
4 that would be providing coolant to the core. So it's a
5 different flowrate, different water level, and consequently
6 different moderation levels. So you have a different power
7 level.

8 MR. DENNING: Okay. Then we have the pressure
9 vessel failure occurring at this time. In each of these
10 cases, we have called the containment failure mode gamma
11 prime, although you will see when you get to TQUV there is
12 a slight difference in the gamma prime.

13 (Slide)

14 The flow pathway within the vessel is exactly
15 the same as modeled for the Peach Bottom reactor. Again,
16 core through the steam separator, some fraction going
17 through the steam dryer, some fraction bypassing the steam
18 dryers. And I won't show you the MERGE and MARCH model -- I
19 am sorry, the MERGE and TRAPMELT model, which is
20 essentially the same as what we use for the Peach Bottom
21 design.

22 Now, the next results, however, are somewhat
23 different than what we obtained for Peach Bottom.

24 (Slide)

25 This is what I alluded to this morning as some

1 sensitivity we see to the core melt modeling and how it can
2 affect the retention-efficient products in the primary
3 system. So I will explain some differences here and
4 remember them when Mike Kulhman gets up to show you the
5 results that he has obtained on primary system deposition.

6 These are the gas temperatures. We haven't
7 labeled these curves. I am sorry they're not labeled in
8 your report.

9 MR. KELLY: May I ask you a question about the
10 previous slide, please?

11 MR. DENNING: The previous slide on the pathways,
12 was that the one?

13 MR. KELLY: Has the containment failed at the
14 time that this flow takes place?

15 MR. DENNING: Yes. The containment already
16 failed.

17 MR. KELLY: Does the suppression pool have any
18 water in it?

19 MR. DENNING: I will get to that part of the flow
20 path in a minute and show you that too. Yes, it does. And
21 that's a good point.

22 For all of the sequences that we've analyzed for
23 the MARK-III, there is water in the suppression pool in the
24 pathway, and there's water in the pathway. Let me go back
25 and let me show you that figure now.

1 (Slide)

2 Here is the containment. Remember, we have
3 transient sequences where, while the core is degrading,
4 your pathway for release is from the steam line through a
5 relief line and into the pool. And the water remains here,
6 and actually there's a significantly greater submergence.
7 That is, the fission products are released much farther
8 below the surface of the pool in the MARK-III design than
9 they are in the MARK-I design.

10 When the core melts through the lower head, it
11 will drop into the reactor cavity. Then we have a pathway
12 into the drywell and now back then again into the
13 suppression pool. So containment failure is here. We assume
14 that when the containment fails, it does not displace this
15 water here.

16 For a number of designs, General Electric has
17 really gone to great extremes to indicate to us anyway, I
18 think quite effectively, that failure will be here as
19 opposed to down there. That's obviously very important to
20 this conclusion that you have water always in the pathway.

21 MR. BERNERO: Excuse me, Rich. If only they would
22 put a vent there.

23 (Laughter)

24 MR. DENNING: Okay. But the point is that the
25 failure of the containment does not displace the water. The

1 release pathways are always into water with water in the
2 pathway.

3 MR. VOGEL: In addition to that, that's below
4 grade, isn't it?

5 MR. DENNING: It's below grade, so you fail here.
6 There's some question as to where the water would run out
7 anyway.

8 (Slide)

9 So those are basically the pathways.

10 Now I would like to get back to the structure
11 temperatures in the TC sequence and show you the difference
12 between the structure temperatures we have calculated and
13 what we calculated for Peach Bottom.

14 Now, the form of it looks basically the same. I
15 am sorry these curves aren't labeled. Actually, you can
16 figure out what they are. But it turns out this is the
17 steam separator here, this temperature right here. And the
18 steam dryers on one of these lower temperatures.

19 But the important thing is that this temperature
20 peak gets turned over much more rapidly in this particular
21 analysis than it did in the Peach Bottom analysis. And the
22 temperatures are brought down to significantly lower
23 temperatures.

24 In the Peach Bottom analysis we saw those
25 temperatures in the neighborhood, evening out here in the

1 neighborhood of 1,500 to 2,000 F. And this difference of
2 500 or so degrees is going to make a fair difference.

3 The difference in the way we have treated the
4 core modeling for the Peach Bottom and Grand Gulf is only
5 in the way we have subdivided the core into radial power
6 regions. In the Peach Bottom analysis we had 10 radial
7 regions across the core with equal volumes. In the Grand
8 Gulf analysis we have broken the regions into nine regions,
9 and they are not of equal volumes. And indeed, the center
10 region, which is the highest or the region that has the
11 highest power level, it's a fairly small region.

12 And apparently, what is happening is it is
13 melting and slumping earlier than the equivalent region
14 within our Peach Bottom analysis, giving this extra cooling
15 of steam, bringing it in earlier and not allowing our
16 temperatures to get as hot as they were and keeping them
17 down cooler. So it's part of this melting/slumping modeling
18 that shows considerable sensitivity to the way we do that
19 melting/slumping model.

20 MR. VOGEL: Rich, with such a sharp peak there,
21 does all of the structure get to that temperature? I would
22 think it would not.

23 MR. DENNING: Yes, this is basically -- I think
24 there is quite a bit of -- the artists have made this peak
25 much sharper than it really is. It doesn't peak like that.

1 I am sure it's much more rounded peak than that. And this
2 is like 10 minutes from here to here, so it's not quite
3 that, not quite as sharp as it appears there.

4 But this representation of the structure, the
5 steam separators, which are pretty massive, represents all
6 of the mass of those structures. So that's an average value
7 for all of the mass of that structure.

8 MR. VOGEL: I would think, in reality then, the
9 surface temperature would be higher and the outside
10 temperature would be lower.

11 MR. DENNING: That depends very much upon the
12 thickness of the structure, of course. The steam separators
13 aren't that thick that their response time is that long. So
14 in that case, it's not true.

15 Certainly, in terms of other structures that we
16 have in here, there could be an effect like that over a
17 10-minute time period. But definitely not for these
18 structures. Their time constant is less than that.

19 MR. SEHGAL: Raj Sehgal.

20 Suppose you contain eroding of Peach Bottom,
21 would you get similar results?

22 MR. DENNING: Same results.

23 MR. SEHGAL: So you would have greater potential
24 of --

25 MR. DENNING: There are some other changes that

1 had to do with the power profiles. This had a flatter power
2 profile than the Peach Bottom. I would suspect if we did
3 the same nodalization, we would have seen similar results
4 for Peach Bottom. I don't think that this is necessarily
5 closer to reality.

6 MR. SEHGAL: This might be longer.

7 MR. RITZMAN: Quickly, you're talking now just
8 about core nodalization, not talking about MARCH 1.1 versus
9 MARCH 2?

10 MR. DENNING: No, just core nodalization.

11 MR. SEHGAL: 500 degrees difference?

12 MR. DENNING: Like 500 degrees, yes.

13 (Slide)

14 I will just say a few things about TPI and then
15 go on to TQUV.

16 The TPI sequence is a transient with a
17 stuck-open relief valve and loss of decay heat removal from
18 the suppression pool. As I mentioned before, it looks a
19 great deal like the TW sequence, and in the long term it
20 looks almost exactly like the TW sequence.

21 We have the core degradation occurring at low
22 pressure. I did forget to mention that. The core
23 degradation really occurs at high pressure in the TC
24 sequence. It occurs essentially at containment
25 back-pressure. Here the -- but what actually happens here

1 is we have a stuck-open relief valve; we are discharging
2 into the sump -- not the sump -- into the suppression pool
3 and heating it up. The decay heat removal for the
4 suppression pool has failed, so eventually after some
5 substantial period of time, we heat that up to the point at
6 which the containment fails.

7 We then lose our makeup water to the reactor
8 vessel, begin core melt. And here is pressure vessel
9 failure. Again, we have analyzed the gamma prime failure
10 mode.

11 The temperatures are quite similar to the ones
12 for the TC sequence, so I won't bother to show you those,
13 and I will move on to TQUV. TQUV is again a transient.

14 MR. WALKER: One question on TPI. When you
15 release the fission products, are you sure the water is not
16 completely gone?

17 MR. DENNING: Yes. Even though you will have
18 flashing of the pool, you don't lose that much inventory of
19 the pool. There's still a lot of water in the pool.

20 (Slide)

21 This transient is, in some respects it's
22 something like TMLB' in that you lose all makeup to the
23 system. The containment failure occurs -- I actually have
24 these reversed as far as what I want in time. We begin
25 core melt at 82 minutes with teh containment intact. We have

1 containment failure occurring at 96 minutes, and I will
2 explain that in a second because it is an important
3 conclusion for this particular accident sequence. That is,
4 it's an overpressure failure, but it's really a hydrogen
5 burn generated overpressure failure.

6 The reason that we get into the circumstances
7 that can lead to hydrogen burning and the failure in this
8 containment have to do with some of the details of the way
9 the sequence proceeds. And let me explain those.

10 In this particular design, we have assumed that
11 there are igniters in the containment. During the period
12 when the core is beginning to uncover and melt, the system
13 is maintained at high pressure. That is, in this particular
14 accident sequence, the guidelines to the operators tell
15 them, before you depressurize the system, check and make
16 sure that your low-pressure ECC systems are operating
17 before you depressurize and put reliance on them.

18 In this particular sequence, they did not
19 operate. So the operator leaves the system at pressure
20 instead of intentionally depressurizing the system. You
21 start to uncover the core, degrade the core, produce
22 hydrogen release, and actually to a large extent bottle it
23 up within the vessel.

24 There are then instructions that say, when the
25 water level gets down to 2 feet, depressurize the system.

1 The logic behind that is it's recognized at that point you
2 are in serious trouble, that in order to buy some more time
3 to get emergency core cooling injection in, it would be a
4 good idea to depressurize the system, force level swell,
5 and recover the core due to the level swell. So the logic
6 behind it is pretty reasonable.

7 As far as the implications to our analysis,
8 however, were the following: When we depressurize the
9 system at the 2-foot water level, we have already produced
10 a significant amount of hydrogen. We dump that hydrogen
11 rapidly into the containment, and the containment pressure
12 then rose up well above the failure pressure of 72 psia.
13 And we failed the containment due to this hydrogen burn.

14 MR. HAZEN: You said you incorporated the fact
15 that Grand Gulf has hydrogen igniters installed. Does the
16 burn occur because the igniters are there and it didn't
17 work?

18 MR. DENNING: I think the fact that the igniters
19 were there would certainly assure that you get a burn. I
20 think with the kind of concentrations you would have,
21 oxygen and hydrogen, that it's quite likely you would get a
22 burn anyway. So I am not sure how important the fact is
23 that the igniters are there, but certainly the igniters
24 would cause a burn to occur.

25 MR. KELLY: Is the containment inerted?

1 MR. DENNING: No. The MARK-III design containment
2 is not inerted.

3 MR. SEHGAL: You assume then that the hydrogen
4 burn pressure is above 72 psi?

5 MR. DENNING: We calculated the pressure to be
6 above 72 psi, yes.

7 MR. SEHGAL: You bring the steam out the same
8 time too, don't you?

9 MR. DENNING: Don't forget, we're going through
10 the cold suppression pool when we do this. The steam is
11 going to get condensed out.

12 MR. PETRANGEL: You assume that the operators
13 decide to make a manual ADA actuation now? Now, this tends
14 to be a little provocative. Why didn't you Assume that the
15 operators decided to actuate one of the vent lines of the
16 containment which are, I am sure, available in these two
17 reactors in Peach Bottom and Grand Gulf?

18 We have in Italy two reactors similar to these
19 two, and we have a small containment vaporized, not the
20 bigger, larger containment which Mr. Bernero was referring
21 to. But you can with time actuate these lines and see the
22 pressure in the containment goes two times the design
23 pressure.

24 MR. DENNING: I believe what we did was
25 consistent with the emergency operating instructions for

1 the operators. I certainly agree there are other things
2 that could happen. I think that what we have done is
3 consistent with the instructions that have been given to
4 the operator.

5 MR. PETRANGEL: So this procedure is shown in the
6 emergency procedures?

7 MR. DENNING: Yes.

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TAYLOE ASSOCIATES
1625 I Street, N.W. - Suite 1004
Washington, D.C. 20006
(202) 293-3950

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19:1

1 (Slide.)

2 Now, in this particular case, we did not see as much
3 effect of this nodalization as we had seen in the others --
4 in the TC and TW. And this is -- and this temperature pro-
5 file is much more similar to what we had releasing in the
6 Peach Bottom. And the amount of retention of cesium iodide
7 is reflected in that.

8 Basically, that concludes the thermal hydraulics
9 part of what I wanted to present.

10 Are there any questions on that?

11 MR. COOPER: I guess I find myself concerned that
12 the choice of where to put the nodes in the analysis can make
13 that large temperature difference -- when the vapor pressures
14 have this exponential dependence on temperature, that could
15 make the choices very important.

16 MR. DENNING. I didn't understand your reference to
17 the vapor pressures.

18 MR. COOPER: Of the vapor pressures of things that
19 are going to be released, typically have an exponential --
20 very strong dependence on temperature. If we get the tempera-
21 ture wrong, we get a very different amount of vapor release.

22 MR. DENNING: Yes.

23 Well, that -- you actually bring up a subject which
24 I think is an important one that we really ought to discuss
25 here with regards to the ability of the MARCH code to

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1 accurately predict -- particularly peak fuel temperatures and
2 time add temperatures; that capability is extremely limited.
3 It relates to the choice of a single melting temperature,
4 and we are stuck with that as far as the MARCH code is
5 concerned -- other than the ability to do sensitivity studies
6 by changing that temperature.

7 Pete, do you want to make some comments.

8 MR. CZYBULSKIS: Just a comment on the sensitivity
9 of the core nodalization, we also are very much concerned
10 that the difference in core nodalization and power distribu-
11 tion seems to make that much difference on the final results.
12 It was somewhat of a surprise to us.

13 However, let me make the following point. In a
14 real core, there is no such thing as a right power distribu-
15 tion. It's a continually changing one with time, or it's
16 changing with reloading and a variety of things that I can
17 go on and on and on.

18 So, it's difficult to come up with anything resemb-
19 ling a right or a unique core nodalization for core power
20 distribution. It's something highly variable, within certain
21 limits, but highly variable.

22 So, I think that's a sensitivity that's inherent.

23 MR. SEHGAL: I would like to dispute that. A lot
24 of schools have treated distribution for the core very
25 effectively within 5 percent, and they've been doing that for

1 years.

2 Every reload, every distribution is measured.

3 MR. DENNING: That's not Czybulskis' point, Raj.
4 I think his point is that this is a variability that occurs
5 during cycles and between cycles.

6 MR. SEHGAL: But load patterns are such that you
7 try to maintain as you distribute.

8 MR. DENNING: But they do vary significantly over
9 cycles.

10 MR. COOPER: It would seem to me that perhps we
11 could, in fact, work with something like temperature frequency
12 distribution, the way we do with particle size distributions,
13 and get something that, indeed, is generally correct.

14 MR. REYNOLDS: Reynolds, Virginia.

15 I would ask a general question.

16 It seems that the transient cases that you are
17 looking at all successfully go through the suppression pool
18 in their blowdown.

19 While you're still on the introductory part of this
20 reactor, are there any cases such as major pipe ruptures where
21 you could fail the dry well, where pressures early could get
22 so high or hydrogen burns or something could happen early
23 to fail the dry well.

24 Is that possible or not?

25 MR. DENNING: Clearly, it's possible. All it takes

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1 is some fairly inventive people to think through the things
2 that you can do that would really bypass that.

3 The whole question really gets down to how likely
4 is it, which really is a difficult, a very difficult question.
5 And I know it is one that, in the GESSAR review, they have
6 tried to seriously -- General Electric, on one side, has
7 tried to seriously look at. And I'm sure the NRC will
8 seriously be looking at that.

9 That, I think, is certainly the key issue regarding
10 this kind of analysis -- I'm sorry, it's a key issue regarding
11 the type of source terms that are credible for a MARCH 3 type
12 of design.

13 There's no question if you can force everything to
14 go through a suppression pool that you are one leg up. It's
15 awfully nice to have that suppression pool in the pathway,
16 and you are raising a key question, which is are there are
17 sequences of reasonable credibility that can bypass that?

18 MR. GINSBERG: Ted Ginsberg, Brookhaven.

19 Sticking with that question for the moment, is it
20 true that the pressure difference, the driving pressure
21 difference to get material to go from the dry well into the
22 suppression pool is just the height of liquid?

23 MR. DENNING: Yes.

24 MR. GINSBERG: So, it would seem the only kind of
25 mechanism would be an exposure mechanism that would

1 destroy --

2 MR. DENNING: Are you saying that would destroy,
3 the dry well?

4 MR. GINSBERG: That would destroy the dry well --

5 MR. ROE: About the only mechanism I can think of
6 is if there's some way that water would be displaced in places
7 that it wouldn't be because of sloshing or something of that
8 type. Is that credible?

9 I notice some other cavities in and around, over
10 the wear wall. Is that a place where water could collect
11 if there was substantial sloshing?

12 MR. DENNING: There had been lots of questions
13 raised, particularly during a blowdown, what would happen to
14 the suppression pool water, will it get splashed up, things
15 like that. There are questions about can you get the sup-
16 pression pool water to come back up into the dry wells for
17 some reason, like condensation, that type of thing.

18 We haven't examined those things in adequate detail
19 to really comment on them.

20 MR. WALKER: Beniero says I've got a conflict of
21 interest.

22 (Laughter.)

23 Anyway, I think on these plants the sequences that
24 are similar with respect to the suppression pool in the con-
25 tainment bypass sequence, just like in the PWRs, where you

1 lose the main pipeline steam isolation valves, I guess I'm sur-
2 prised you didn't do one of those as an example.

3 MR. DENNING: We did give quite a bit of thought to
4 steam isolation reliability. And from the discussions we
5 had with General Electric in Oak Ridge, we are convinced that
6 that was not too likely a pathway for significant release.
7 But once again, it was not a detailed review.

8 But that's why we did not look at that pathway.

9 MR. WALKER: It just seems like those valves ought
10 to have about the same reliability as the suction side valves
11 on the RHR systems, on PWRs, roughly. They're thick valves
12 that failed in the same way.

13 MR. REYNOLDS: Question on the dry well. It seems
14 the hydrogen burn could be faster. Could that be fast enough
15 if you had a major hydrogen burn in there? It's not inerted.
16 Could that be fast enough to give you the pressure before it
17 could be relieved through the suppression pool?

18 MR. DENNING: It's not inerted.

19 But, Pete, you better check me on this. My guess
20 is you're not likely to get combustible compositions within
21 the dry well in the sequences, because you'll blow in the air
22 you start off with. You'll get blown out sometime earlier in
23 an event.

24 MR. CZYBULSKIS: You tend to have more flammable
25 mixtures -- if I can use that expression -- in the wet well

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1 than you do in a dry well for some of the reasons that Rich
2 mentioned -- in particular, in the sequences that we're talk-
3 ing about here, where you are, in fact, dumping much of the
4 hydrogen directly in the pool, and only some of it will get
5 into the dry well. So, the more likely place for a large burn
6 appears to be the main containment, rather than the dry well.

7 Going back -- perhaps just stepping back to the point
8 that you tried to raise earlier, a hydrogen detonation, should
9 it take place, would be the obvious way of failing the dry
10 well.

11 Again, what the likelihood of that kind of thing,
12 that's a question. I suspect it's highly unlikely.

13 MR. PETRANGELI: Does the Grand Gulf plant, the
14 third isolation valve on the steam lines, slow isolation valve
15 which other reactors have -- or there are two isolation valves?

16 MR. DENNING: Yes, two.

17 MR. PETRANGELI: Not a third isolation valve?

18 MR. SEHGAL: They have two, one each side of the
19 containment.

20 MR. PETRANGELI: The one I know -- for example, we
21 have a third valve, which is a third closing valve.

22 MR. DENNING: GE may know the answer to that ques-
23 tion.

24 MR. HOLTZCLOW: Holtzclaw from GE. On the standard
25 plant design, we have three valves in series. So, that was

1 one of the reasons why we believe that a bypass tap right
2 through the main steam line would be would be low probability.
3 I don't recall exactly what the Grand Gulf configuration is,
4 if they have that third valve. But they do have a turbine
5 stock valve along that same line, so you've got a multiplicity
6 in the valve.

7 MR. KUHLMAN: Mike Kuhlman, from Battelle again.

8 I will try to briefly point out the similarities
9 and differences in the Grand Gulf behavior vis-a-vis the
10 Peach Bottom behavior that we talked about this morning.

11 (Slide.)

12 Again, in terms of thermal hydraulic characteris-
13 tics, releases from core, you'll see there are no major
14 differences again. And retention and release from RCS -- it
15 a bit different, as Rich alluded to, in talking about the TC
16 sequences and again presents some information regarding the
17 emitted particle sizes.

18 One of the key differences between the two plant
19 behaviors as far as the sequences go is, you recall, for the
20 AE, TC, and TW, in every case we had a vessel dryout period,
21 the stagnant phase of the accident. Here we have this only
22 for the TC; these two sequences do not have any indication of
23 a vessel dry-out actually occurring. These are times which
24 correspond to a lowered, very low water level in the system,
25 but there's a continuous low level influx of water which

1 provides for a flow throughout the sequence. So, there is
2 not this long stagnant phase of the accident.

3 Another difference is the TQUV does not exhibit the
4 flushing phenomenon that we saw in all of the cases this
5 morning. This TC still has that in it, so there is a large
6 very short duration injection into the containment, as you
7 would expect from a flow curve such as this for the TC.

8 (Slide.)

9 On the TC time scale, you have, at about 3,000
10 seconds -- or actually a little bit before that, you have the
11 initiation of this high flow, beginning, corresponding to the
12 core slumping which takes place.

13 TQUV -- you will note this is not a thousand pounds
14 per second, but it's over here on this axis. You start off
15 with a low flow and come up to a fairly high flow rate and
16 then tail off throughout the accident sequence, which is a
17 bit different than we have seen in the others this morning.

18 (Slide.)

19 The percents of core inventory of the species
20 admitted at the time of vessel dryout, alleged vessel dryout
21 if you will, is, again, similar -- a little bit more in the
22 TPI than for one of the sequences before. But in general,
23 again, you have the highly volatile materials all being
24 released early, relatively early in the sequence, followed by
25 the less volatile materials being emitted, such that at the

1 time of vessel failure, we've emitted all of the cesium
2 inventory --

3 (Slide.)

4 -- the iodine inventory, roughly a quarter of the
5 tellurium here.

6 And if you recall any of the numbers from this
7 morning, this is about a factor of 50 percent higher than
8 any of those this morning -- due to different core heatup
9 history, really -- but these numbers are very much in line
10 with what we saw for the Peach Bottom sequences.

11 (Slide.)

12 The composition of the aerosol is, again, dominated
13 by the non-fission product material and is indistinguishable
14 from what we saw for Peach Bottom.

15 (Slide.)

16 For the Grand Gulf TC sequence, again, these times
17 are measured from the start of core melting. Once again,
18 this is a total which has been emitted up to the given time.
19 This is the amount retained in the primary system at any time.
20 Note that we do have, for example, half the cesium hydroxide
21 being retained in the primary system at the end of the
22 sequence. There's a lot of retention that takes place in
23 here. It's an unfortunate choice of the times at which this
24 table had information listed.

25 In this period is where there is a good deal of the

1 cesium which has been emitted a bit earlier in the accident
2 sequences actually getting to the cooler regions of the
3 primary system and depositing.

4 We see no real enormous increases in the retention
5 factor of the aerosol as a function of time due to the lack
6 of a real stagnant period during the accident, the in-vessel
7 melting portion of the accident.

8 (Slide.)

9 If we look at these same numbers, same data, in
10 terms of retention factors for TC, you see the cesium iodide
11 transport. It initially is held up in the steam separators
12 and is carried on down to the steam dryers as the steam
13 separators heat up. So, you wind up with an overall retention
14 factor of 38 percent for the cesium iodide, and 27 percent of
15 the total is showing up in the steam dryers. This 38 compares
16 with, I believe, 11 percent we had for cesium iodide in the
17 Peach Bottom analysis. Cesium hydroxide, we're retaining half
18 of it -- again, most of this is showing up in the steam dryers,
19 and it has moved during that last flow surge from the steam
20 separator to the steam dryers. And this, again, compares
21 with very little values for the Peach Bottom sequence.

22 Tellurium retention is, again, complete. This is
23 a fraction of what was actually emitted from the core during
24 the in-vessel melting phase, which was about a third, about
25 a quarter of the inventory for the TC.

1 The aerosol retention is fairly similar to the
2 earlier TC sequence. I think we had 69 percent for the Peach
3 Bottom. But again, most of it is showing up in the core just
4 do to gravitational settlement, or removing the larger parti-
5 cles from the distribution.

6 MR. SILBERBERG: Why is the tellurium higher here
7 than in the Peach Bottom?

8 MR. KUHLMAN: The tellurium is higher here. I
9 think it's a question of the residence time in the system.
10 It's all due to chem absorption or chemical reaction with the
11 surface.

12 We initially started putting in data for all of
13 these species for chem absorption and called some of it
14 irreversible chem absorption. But it's due to a longer
15 residence time when the tellurium is admitted.

16 Remember, a lot of the tellurium apparently is
17 emitted during the high-flow regime, for the one Peach Bottom
18 sequence you're thinking of. So, it doesn't have time to hit
19 the surface, if you will

20 MR. HAZEN: Hazen, Stone & Webster.

21 I notice here, for this TC sequence on the MARCH 3,
22 you take credit for scrubbing out some cesium iodine in the
23 steam separators and dryers, same graph TC for the MARCH 1
24 did not, had only annulus space, lower annulus.

25 Why the difference?

1 MR. KUHLMAN: The big difference was temperatures of
2 these structures.

3 Rich was alluding to, in his talk, the different
4 core melting or core nodalization leads to significantly
5 different gas temperatures and therefore different structure
6 temperatures.

7 Even in the MARCH 1, the cell transport of the
8 cesium iodide, what nodal was retained wound up being in the
9 lower annulus, which was downstream of the steam separators.

10 Here we're winding up with the steam dryers being
11 the next downstream volume. They don't reach a high enough
12 temperature to evolve the cesium iodide.

13 The temperatures are on the order of 4- to 500
14 degrees cooler in this case, which is sufficient to give you
15 good -- if you consider 38 percent good -- retention of the
16 cesium iodide and the hydroxide. Part of this, also, is due
17 to the reaction of the cesium hydroxide.

18 MR. SHERRY: Mike, then the conclusion here that the
19 apparent holdup of cesium iodide and cesium hydroxide at
20 Grand Gulf is due really to the assumptions on the core nodal-
21 ization and not really due to any geometrical differences or
22 differences in the calculated behavior which are not attribut-
23 able to the nodalization scheme?

24 MR. KUHLMAN: I would say that's probably true. It
25 certainly is the way it appears in our understanding of what

end 19

1 these results are telling us right now. And that is a signif-
2 ican point.
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1 (Slide)

2 For the TQUV sequence, as you recall, we are
3 again back to the temperatures in the same neighborhood as
4 what we had for the Peach Bottom, which Rich was showing.
5 Here we are down to the cesium iodide, essentially no
6 retention of the cesium iodide in the system.

7 Cesium hydroxide is being retained with about 40
8 percent efficiency. This, you will see in a later slide, is
9 due almost entirely -- I think it is entirely due to
10 chemical reaction, again due to the better contact time for
11 the cesium hydroxide in this sequence.

12 Tellurium being emitted later is occurring in a
13 somewhat higher flow regime for this sequence and is again
14 residence time limited for its deposition.

15 And the aerosol retention is again showing no
16 indications of the benefits you get from a stagnation
17 period.

18 MR. JOHNSON: Mike, at the outset, is there some
19 allocation of cesium and cesium iodide and cesium with
20 cesium hydroxide?

21 MR. KULHMAN: What's done here, we obviously
22 don't think that cesium iodide and cesium hydroxide reside
23 in the core. Take the iodine emission rate predicted that's
24 coming from the core, and the cesium then is allowed to
25 combine with that to exhaust the iodine supply, which is

1 what the results from 0772 indicates should be the case for
2 the temperature and CSI oxygen-hydrogen ratios that we're
3 operating in. All the remaining cesium is then said to be
4 cesium hydroxide.

5 MR. JOHNSON: Here you want to take and retain
6 all the cesium hydroxide. That's what this is saying. You
7 don't retain it as cesium hydroxide. It's at some other
8 compounds. There is in the overall reaction equilibrium
9 chain in a system like this, cesium iodide converting to
10 cesium hydroxide going to the trap.

11 So in reality, that cesium iodide is not lost in
12 the environment. It's still trapped wherever you put the
13 cesium hydroxide, because you are going to run that
14 reaction too.

15 MR. KULHMAN: I am not following the conversion
16 between cesium iodide and cesium hydroxide.

17 MR. JOHNSON: You arbitrarily allocated a certain
18 fraction to each one and not letting the two interact. In
19 real life they will interact. That is in a moist system, as
20 you pull the cesium hydroxide out, it leaves a hole. There
21 is still water around. You are going to start transforming
22 cesium iodide.

23 MR. KULHMAN: You're right, that would occur if
24 you ever removed a sufficient quantity of cesium hydroxide.

25 MR. JOHNSON: You said you removed 90 percent.

1 Isn't that what it says retained?

2 MR. KULHMAN: 90 kilograms is retained, 40
3 percent of the total, total cesium hydroxide which was
4 present.

5 I think realistically -- I am not sure, but I
6 believe you even have to get above 90 percent of the cesium
7 hydroxide removed before you would get any effect on the
8 cesium iodide before the equilibrium would shift
9 significantly.

10 MR. JOHNSON: I would doubt that.

11 MR. KULHMAN: It was looked at in some detail.
12 That's all I can say.

13 MR. COOPER: Since we see rather different
14 behavior for the cesium iodide and the cesium hydroxide, I
15 am curious about what we know about the kinetics of the
16 reactions that form these two. Do we know that there is
17 enough time, for example, for us to move toward the
18 equilibrium that you're postulating before we approach the
19 control surfaces that are picking this up?

20 MR. KULHMAN: That's a good question. That's one
21 that was looked at exhaustively, I think, during the 0772
22 review. I would have to refer you to the appendix to that
23 document, which Sandia has worked since then.

24 The conclusion of Sallach and Ohlrich and
25 Company out there is that for all intents and purposes,

1 these things have reached their equilibrium distribution
2 well before they get to this.

3 MR. SEHGAL: The main thing is the temperatures
4 are very high and the kinetics are very classic.

5 MR. COOPER: It seemed to be kind of a dilute
6 system.

7 MR. SILBERBERG: This subject, you know, is by no
8 means closed. If it needs to be debated further by the
9 chemists, I think it's open for debate.

10 MR. CRESS: Tom Cress, Oak Ridge.

11 Calculate these chemical reaction depositions,
12 cesium hydroxide and tellurium with cesium iodide, do you
13 use a deposition velocity?

14 MR. KULHMAN: That's right.

15 MR. CRESS: Is that a constant regardless of flow
16 and temperature and concentration?

17 MR. KULHMAN: Yes. It appears to be. What we are
18 using from Dana Powers' data, it's the deposition data on
19 oxidized stainless-steel in the steam nitrogen flow. From
20 what they could tell under the concentration regime that we
21 are in -- remember that the cesium in particular is emitted
22 over a fairly short time span of the total melt. And the
23 concentration seem to be irrelevant for this deposition
24 velocity. It was like a factor of 10 difference relative
25 between the cesium hydroxide and tellurium deposition

TAYLOE ASSOCIATES
1625 I Street, N.W. - Suite 1004
Washington, D.C. 20006
(202) 293-3950

1 velocities that we're using.

2 MR. COOPER: The deposition velocity shouldn't
3 depend on the concentration. It should depend, however, on
4 the aerodynamic flow regime that they're in, and that I
5 think would be crucial. It's probably turbulent diffusion
6 matter that molecular diffusion except at a laminar
7 suolayer.

8 MR. KULHMAN: I believe that to be the case. You
9 don't think that is turbulent?

10 MR. GIESEKE: I think it's surface-limiting, not
11 diffusion-limiting.

12 MR. COOPER: You think it's coming into an
13 equilibrium and coming back up?

14 MR. GIESEKE: As best we can tell from the Sandia
15 experiments, the deposition velocities represent a surface
16 reaction rate, in a sense. The tellurium begins to approach
17 the mass transfer coefficients, so you're getting close to
18 diffusion-limiting case. But you're not quite there yet,
19 apparently, and the others fall below that. So it's
20 controlled at surface reaction.

21 MR. COOPER: So it's really reaction rate-limited
22 rather than diffusion transport-limited?

23 MR. GIESEKE: Right.

24 MR. KULHMAN: Okay. Looking at the overall
25 behavior of the primary system for the TQUV.

1 (Slide)

2 As you saw before, there is no retention of the
3 cesium iodide in the sequence. However, we do have 40
4 percent reaction of the cesium hydroxide passing through
5 the system for this TQUV sequence and nearly 70 percent of
6 tellurium is retained, and a typical figure of 65 percent
7 of the aerosol with all of this showing up in the core
8 regime region.

9 With the resulting injection profiles for the
10 injections or ejections from the primary system for the TC
11 sequence --

12 (Slide)

13 -- it winds up, as you recall, there was an
14 initial fairly good flowrate through the system and a very
15 low flowrate for a while, which gave a significant
16 residence time. Then again, the flowrate through the system
17 increases and mass injection into the containment follows
18 the same pattern you would expect, which is not
19 significantly different in terms of magnitudes injected
20 from the sequences this morning for the aerosol at least.

21 (Slide)

22 The TQUV again is very short, sweeping out
23 behavior which we did see in this sequence. And once again,
24 you would have a bit of a spike at the end of this as the
25 pressure vessel fails. Again, this is what is being

1 injected into the pool.

2 So that the distribution in the primary system
3 at the ends of these sequences or at the time of vessel
4 failure, for a TC we have 38 percent of the cesium iodide
5 retained, this being 18 percent retention due only to
6 condensation in the primary system, 19 percent was retained
7 due to the deposition on particles which are subsequently
8 retained.

9 This is the material that would be present in
10 that spike which goes into the pool at the end. Similarly
11 here, TQUV really no condensation due to the higher
12 temperatures again, but chemabsorption or chemical reaction
13 with tellurium, cesium hydroxide already affected. A
14 relatively reasonable residence times for the sequence, and
15 again 64 percent of the aerosol is being retained.

16 The particle size distribution data for these
17 sequences.

18 (Slide)

19 It's somewhat interesting to look at the core.
20 These are mass median diameters for the core in microns.
21 You can see the aging of the material taking place. You
22 have a slower-flowing portion of the accident. This largely
23 hundred pounds per second begins. You get down near the
24 primary particle size and in the core region relief line.
25 Here you have all the detention mechanisms acting to remove

1 the large particles, bring down your mass median diameter.

2 The difference here is the result of the
3 settling out of the large particles. In any event, you
4 reach a fairly stable size here until you begin to get this
5 material blown out of the core in a shorter period than is
6 characteristic for its removal due to gravitational
7 settling.

8 Once this pulse is over with, you are back down
9 to a similar size to what you had before the accident, and
10 this would be coming on down as the flow continued to bring
11 this very fine material in through the relief lines.

12 So the final pulse would be a very fine
13 aerosol-size distribution.

14 (Slide)

15 For the TQOV, remember that was the water mass
16 monotonically decreasing sort of flowrate. We have
17 initially a long residence time to give you the large
18 particles. Then as the flow increased for a while, you
19 actually dump to the smaller sizes. And then the aging
20 begins to take effect again and then bring your mass median
21 diameter on up.

22 Through this region is where the majority of the
23 aerosol generation is taking place. As you can see, you are
24 working with a whole range of mass median diameters to try
25 to calculate your DFs for a suppression pool.

1 This is the current status of where we stand on
2 the Grand Gulf analyses. It's obviously still under way, a
3 little bit behind schedule, but we are continuing to work
4 on further analysis of the results we have from these two
5 sequences and still working on the TPI sequence as far as
6 the primary system goes.

7 Ken has not as yet had an opportunity to do
8 anything with my primary system numbers.

9 That concludes the Grand Gulf exercise.

10 MR. COOPER: I am sorry, Mike, just to pick up a
11 point with Jim.

12 If the deposition velocity is independent of
13 concentration, that doesn't sound as though it's surface
14 reaction rate-limited, though I might be mistaken. If it
15 were reaction rate-limited, we would see the deposition
16 velocity changing with the concentration. So maybe that one
17 needs to be looked at little bit more.

18 MR. SILBERBERG: Okay, let's proceed to the next
19 topic, which I believe is now entering into the realm of
20 suppression pool analysis. I wonder if I could ask the
21 speakers, two speakers on suppression pool, if they could
22 adjust their presentations to a two-thirds' presentation
23 and roughly one-third allowance for questions, if possible?
24
25

MM:j1 21:1

1 In other words, leave about one-third of your
2 allotted time for questions, if possible.

3 MR. VOGEL: I note EPRI is down to discuss the
4 suppression pool.

5 MR. SILBERBERG: No, we have a revised agenda. We
6 removed that.

7 MR. POSTMA: Thank you.

8 However, I will comment.

9 Well, we are down to some things that are perhaps a
10 little bit more fun to deal with, some mechanisms we can all
11 picture a little bit better.

12 (Slide)

13 What I would like to do is describe the technical
14 bases for the SPARC code.

15 My name is Postma. I should say my co-workers,
16 Peter Owczarski and Kevin, should be given a lot of the
17 credit. Pete should really be here, but his wife blessed him
18 with a newborn son just two days ago, and he decided he should
19 be with her.

20 MR. SILBERBERG: Was that on a milestone schedule?

21 M. POSTMA: I think he was a little bit late on
22 that as a matter of fact.

23 As an overview of our work, this SPARC codes was
24 developed as part of a P&L program on the performance of
25 engineering safety features under severe accident conditions.

MM:jl 21:2

1 (Slide)

2 This is work being sponsored by the NRC. We're
3 looking at more than just pools. We're looking at pools, at
4 the containment sprays, at ice beds in the ice condensor
5 plants, at the filters -- you've heard some descriptions of
6 filters today -- and at the containment coolers. And the
7 emphasis is on what happens in severe accident conditions.

8 Particular effort here was a high-priority one. It
9 was a little bit out of our original schedule, but we con-
10 centrated on it so that we could have a tool to be used in
11 this study.

12 I would say, because of our time limitation and
13 because of the state of the art at this time -- this is a
14 preliminary model -- we attempted to make it as realistic as
15 we can --

16 (Slide)

17 -- as we could in the time we had. BUT it's not the
18 final work.

19 We wanted to account for what we thought were major
20 phenomena. First of all, in any kind of air-cleaning system,
21 you know right off the particle size distribution is going to
22 be very important. There is always a particle size which
23 penetrates more than others, and we have to account for that.

24 Pool temperature -- this was one of the important
25 things in the safety study. The saturated pools were said to

1 have a -- it was recognized at that time it was simply a
2 simplification. So, we have to focus on saturated pools ver-
3 sus sub-cooled.

4 Pool depth -- we expect that to be important,
5 because the energy that is dissipated would increase. The
6 bubble residence time would be longer for deeper pools. We
7 have to account for that.

8 Finally, we wanted to account for steam condensation
9 of evaporation. Obviously, if you condense all the gas, the
10 DF would be very high. On the other hand, if you evaporate
11 all the way through a bubble, you can expect a retarding
12 effect.

13 Finally, this tool we developed was to be compatible
14 with the TRAP melt and MARCH codes so we could get decontamina-
15 tion factors for specific sequences.

16 (Slide)

17 As we started this work, we thought how can we go
18 about this. There were a couple of different ways.

19 The first was to say, well, I'm just going to focus
20 on bubbles and do the scrubbing in bubbles. That's one way
21 to approach it.

22 Then, I have comments on the method we did adopt
23 later. The second method is to look at the energy dissipated
24 per unit volume of gas. There are correlations in the scrub-
25 ber literature that approach scrubbing efficiency for

21:4

1 particles in this way.

2 And finally, if we had sufficient data base, if the
3 other modeling approaches worked good, it would be possible
4 to apply experimental data to this question and admit that
5 we are still developing models.

6 (Slide)

7 Let me backwards now and tell you what we thought
8 about these.

9 First of all, the data base is fairly limited on
10 pool structure. We're a little bit limited because we were
11 studying at a slower pace, and we also did some work for the
12 Limerick study. And we were fairly familiar with pool
13 scrubbing.

14 What we can say is there's really no data on
15 saturated pools, so we're very limited to know how to approach
16 saturated pools if you just look at the data.

17 Steam-gas ratio -- we didn't find a consistent study
18 where you could look at the effect of steam-gas ratio and know
19 what its effect would be so you can predict it for the
20 sequences.

21 Particle-size effects -- it's recognized that there
22 is a particle-size effect, but it's very difficult from the
23 literature to identify a clear trend of particle size.

24 Finally, there were very, very few large-scale tests.
25 One large-scale or moderate-scale test was a GE test, and I

1 think that was significant. And it led us to believe that we
2 could approach the bubble-scrubbing approach.

3 So, we concluded that simply applying experimental
4 data would lead us to some problem in justifying whatever DFs
5 we came up with.

6 (Slide)

7 The second thing we looked at was this energy cor-
8 relation. And this we take from Calvert, who, about 10 years
9 ago or so, did a study of various kinds of scrubbers, correlat-
10 ed a cut diameter -- let me tell you about a cut diameter.
11 It's the size at which particles are removed with 50 percent
12 efficiency.

13 What you assume in this method is that all of the
14 bigger particles are removed and all of the smaller particles
15 pass through. That's an approximation for sure, but it
16 works reasonably well for a lot of different kinds of scrub-
17 bers.

18 And we show cut diameter versus pressure drop.
19 This is representative of the energy expended per unit volume
20 of gas. And you see there were various kinds of scrubbers.

21 I mention here a region for the SGS, and that's a
22 submerged gravel scrubber. It's a device which is the type
23 of pool scrubber under development at the Hanford Engineering
24 Development Laboratory. Indeed, it was found -- looked at in
25 terms of energy -- that fit pretty well. And that is a

1 possible approach.

2 And as I mentioned, we would like to retain that as
3 a point of comparison.

4 (Slide)

5 A few comments on this cut diameter versus energy
6 method. It's very, very simple. All you have to know is the
7 pool depth. If you know that, you can get a cut diameter.
8 If you know your particle-size distribution, you simply look
9 at how many particles are larger than that, and that tells
10 you. And it is supported by data obtained for submerged
11 gravel scrubber.

12 I should comment that we attempted to do mechanistic
13 models for the submerged gravel scrubber. We looked at
14 various retention methods in a gravel bed. And no matter
15 how we looked at this, whether it was -- like the Scrubber
16 Handbook approaches this with a partially filled bed, you
17 allow for centrifugal force around the grains. Or if we look-
18 ed at immersed flow, past spheres, or if we looked at flows
19 in the tristese spaces between the particles, we always
20 greatly underpredicted the actual efficiency. So, it made us
21 feel the energy dissipation and the turbulence that develops
22 is not negligible. It dominates with that kind of scrubber.

23 There are some real problems though. This method did
24 not account for steam condensation. It did not account for
25 distances in geometry, did not account for pool temperature,

1 nor did it account for particle growth.

2 And as I mentioned, we will keep that as a point of
3 comparison with the model we have.

4 (Slide)

5 So, we have concluded that we would go to a bubble-
6 scrubbing model, and we started with the standard textbook
7 model in the Fuch's look. And he accounts for sedimentation,
8 inertial deposition, and diffusional deposition. What this
9 neglects is what happens during the bubble formation region.
10 Consider you have a stable bubble, it rises. You follow that
11 bubble and see what happens. As an input, bubble size is a
12 critical input parameter to this model. Bubble circulation is
13 also a critical parameter. If the bubbles do not circulate,
14 then sedimentation is the main mechanism, and it's not a very
15 strong one.

16 But if we do have bubble circulation, if we do
17 know the bubble size, we can model the important mechanisms.
18 Let me describe those mechanisms. Ken Lee already alluded to
19 these; I can mention them just a little more.

20 (Slide)

21 First of all, we have the condensation of steam.
22 And what we assume there is that the fraction of the gas that
23 condenses carries with it its own fraction of aerosol --
24 50 percent of the gas condensed -- we'd say remove 50 percent
25 of the particles, right at the inlet of the pool. Then, we

1 Then, we allow for sedimentation, which is ordinary
2 gravity settling distributed over the cross-section of the
3 bubble.

4 Centrifugal deposition turns out to be a dominant
5 mechanism. The bubbles that rise circulate; the surface moves
6 from the top to the the bottom of the bubble. And because of
7 that you get a centrifugal force. And this centrifugal force
8 causes particles to move radially and be deposited upon the
9 wall.

10 We account for diffusion -- and here we use the
11 penetration theory of mass transfer. You assume that the
12 gas that is close to the bubble whirl moves with it, so it
13 has a certain residence time. You do a transient calculation;
14 you find how much of the gas is depleted by diffusion.

15 Another factor was steam evaporation into rising
16 bubbles. Fuchs points this out. He quotes some experiments
17 of Wieme, some old German work, who claims that if you have
18 bubbling into a saturated boiling pool suddenly the particles
19 aren't trapped anymore. We dug out those references. It
20 turns out they were done in some rather small laboratory
21 scale equipment, about 30 centimeters or so of liquid. But
22 it's something we felt we had to account for.

23 Finally -- not finally, but another factor is the
24 growth of soluble particles. As the bubble goes through the
25 water, it certainly has to be -- if you have soluble materials,

1 they'll pick up water pressure until the vapor pressure is
2 thin, to be equalized. So, we do allow for the growth of
3 soluble material. Cesium hydroxide and cesium iodide are two
4 important materials.

5 Finally, we took a first look at the entrainment of
6 pool liquid which would carry with it some amount of material
7 that had been deposited in the pool.

8 (Slide)

9 MR. CASTLEMAN: Castleman, Penn State.

10 Could I ask a question on this centrifugal deposi-
11 tion. Is that a well-known phenomenon? Or is that something
12 that you have accounted for that is something new?

13 MR. POSTMA: I was going to show you a picture,
14 and I can describe it a little better. I'll discuss it a
15 little bit later.

16 Let me define "decontamination factor" in case
17 some don't know what it is. It's the ratio of this mass
18 entering the pool to the mass leaving. To most of us in air
19 cleaning, we think about penetration, fraction of penetration.
20 That's the reciprocal of the DF. Or if you want to work in
21 fractional efficiencies, you have to find the penetration is
22 1 minus the fractional efficiency.

23 For a single particle size, we assume that the
24 mechanisms operate generally independently -- that is to say
25 the penetration overall is the penetration you would

1 calculate for the product of the penetrations for several
2 removal mechanisms. But, of course, you have to integrate
3 over the particle size distribution to get the total mass
4 that would be removed.

5 (Slide)

6 On this first thing, let me say what we do on
7 deposition due to steam condensation. I think I already
8 mentioned how we handled this. We simply put the gas in.
9 $X_{\text{sub I}}$ is a mole fraction of noncondensibles entering. We
10 assume we have thermal equilibrium, very close to the inlet.
11 We expect that. BUT the GE people -- Fred Moody has done
12 some transient calculations and showed, for reasonably sized
13 bubbles, indeed, it's only, I think, .01 seconds or so he
14 estimates.

15 So, he assumed we had thermal equilibrium in the
16 small stable bubbles very quickly after they entered the pool.

17 So, you can do a mass balance and say, "I have
18 thermal and mass equilibrium." The vapor pressure in the
19 bubble here is the same as the vapor pressure of the water in
20 the pool. So, you can just calculate the mole fractions.
21 You find DF is equal to $X_{\text{sub zero}}$, mole fraction of non-
22 condensibles here versus the inlet.

23 I won't go into the simple matter of defining the
24 pressure here. If you know the vapor pressure, you can calcu-
25 late, due to the weight of water over the density of water,

1 what the pressure is at the point of entry.

2 (Slide)

3 The other problem that is important here -- this
4 shows kind of a horizontal entrance -- if we have this type
5 of inlet, the gas enters and typically forms a big bubble
6 which detaches and breaks up rapidly.

7 Then, we move as a swarm instead of individual
8 bubbles. So, we account for that by recognizing the velocity
9 of the bubble is the velocity with respect to the field
10 around it, whereas the swarm velocity, which determines the
11 transit time, is some larger value.

12 So, residence time is the height from the shattering
13 level on up, divided by the swarm velocity.

14 (Slide)

15 Steam evaporation velocity is important, as I
16 mentioned. It could be important at least, because the
17 only data that exists -- as it has, in effect, on particles --
18 you expect an inward flux for rising bubbles.

19 Think about it for a minute. If you have a warm
20 pool, the bubble enters, it's saturated at the beginning. But
21 as it rises, the pressure decreases. The pressure of water
22 also decreases, so you tend to get a by-bubble. Then, you
23 have mass transfer into the bubble. So, the bubble rises,
24 always has an inward flux.

25 We account for this with the penetration theory of

1 mass transfer and heat transfer. We account for a cooling
2 of the interfacial liquid by evaporation. So, we do a ΔT
3 across the liquid film. Then, we calculate it, a concentra-
4 tion difference of the steam across the gas film. We assume
5 this flux is directed normal to the surface. It turns out the
6 flux increases with height, so we have had to divide our pool
7 into a series of height elements. And I think we used 50
8 height elements to calculate things.

9 (Slide)

10 Here's something I'll just briefly go over. I'm not
11 sure how this was accounted for in the work that has been done
12 by Battelle.

13 It turns out that the magnitude of this evaporating
14 flux depends quite sensitively on the temperature. So, we
15 feel it's important to know what the temperature of the pool
16 is.

17 At first glance, you might say the pool -- a
18 saturated pool is at the normal boiling point. But as we
19 pass noncondensibles through the pool and we've made a
20 calculation here; assuming that the gas is leaving on a
21 saturate, if you do that, you see, you get a fair depression
22 in the pool temperature, at least an equilibrium. This is
23 equivalent to an adiabatic saturation temperature, except we
24 have allowed for some decay heat.

25 So, what we did in SPARC is we allow either an

1 equilibrium temperature by a simple valve balance or user-to-
2 input temperature of the pool based on a more global look at
3 the thing, perhaps from MARCH.

4 (Slide)

5 Particle growth by water sorption -- this is kind
6 of a standard calculation from applied physics. Soluble
7 particles will grow if the relative humidity is greater than
8 a critical value, and this depends on the solubility of the
9 material.

10 Essentially, what you find is, at equilibrium, the
11 vapor pressure in the solution valve is equal to the water
12 vapor pressure in the bubble.

13 Using Fletcher's formula from the physics of rain
14 clouds, we did some example calculations. It shows as a
15 function of the dry particle radius cover, the drop grows.
16 I guess the important thing is humidity of 99 percent. You
17 get a growth factor of roughly 4. So, this calculation is
18 allowed for in SPARC. So, we do allow soluble particles to
19 grow.

20 And I think one of the assumptions that fairly
21 important in SPARC is that we do assign a humidity of
22 99 percent. Really, we wanted to calculate that as a func-
23 tion of height in everything that was going on, but we had
24 some difficulties in getting convergence of the program.
25 That's one of the things we're working on.

1 So, we did kind of back-of-the-envelope calculation
2 for the region near the inlet, and we estimated 99 percent
3 wasn't too bad for the saturation level.

4 (Slide)

5 Bubble shape is an input to the model. First of
6 all, the Fuchs model was based on spheres. You can see the
7 interface moves around and causes centrifugal deposition,
8 gravity settling to the bottom in diffusion. If you have a
9 distorted shape and it turns out bubbles really are distorted,
10 you can get spherical bubbles if you have small bubbles,
11 below about .1 centimeters. As they get bigger than that,
12 they get more and more oblate spheroids. So, we allow that
13 A over B ratio to be an input parameter.

end 21

MM/mm1 T22

1 MR. POSTMA: (Slide)

2 Let me, with this picture, describe the mechanisms.
3 I didn't put down all of the equations that we had. I
4 didn't think we had time for that.

5 Let me show you the centrifugal sedimentation and
6 diffusion. What we said, we have gravity acting downward
7 on the particle giving it a downward velocity. We have
8 this evaporation velocity acting normally to the surface.
9 So we simply resolved those two. It is a deposition are,
10 deposition velocity times an area. It is an integrate over
11 the bottom part of the sphere.

12 Realistically, you would like to look at an
13 individual particle in this boundary layer and simply
14 resolve the forces on it to see how it acts. I don't
15 think they would be very much different. For one thing,
16 this gravitation is a minor factor. It is less than 20
17 percent of the total DF in any case, so we don't think this
18 is an important thing as far as gravity sediment is concerned.
19 If you simply make a material balance on the gas phase in
20 the bubble, you find it decreases with time. It is an
21 exponential type of thing. So the decontamination factor is
22 three halves, it is $D \text{ sub } S$, which the settling velocity,
23 subtract off the steam evaporation velocity, divide by
24 bubble diameter by the timing, which is the time for the
25 swarm.

mm2

1 Let me describe how the others are calculated.
2 for centrifugal force, you simply take a regular $M V$ squared
3 over R , a force on a particle undergoing centrifugal force.
4 You equate that to the Stokes law drag, let that move the par-
5 ticle radially.

6 The real question comes, okay, how do you
7 calculate the velocity? We did two different things. The
8 method that Fuchs uses is to assume potential flow around
9 the sphere, and there the velocity varies with angle. You
10 get a little angle, differential angle. It gives you an
11 incremental area. You simply integrate like you do here,
12 velocity times an area over the whole angle of the part of
13 the bubble.

14 MR. REYNOLDS: I didn't understand that. I
15 thought you were rotating the whole bubble. I thought your
16 centrifugal, the whole bubble was rotating.

17 MR. POSTMA: No. If you imagine the bubble being
18 stationary, fluid flowing down, splits on both sides.

19 MR. REYNOLDS: It is uniform?

20 MR. POSTMA: Goes around like that. When you say
21 is it uniform, I'm not quite sure what you mean.

22 MR. REYNOLDS: It is symmetrical?

23 MR. POSTMA: It is axi-symmetrical. If I put
24 an axis here, it would flow down in all directions.

25 MR. REYNOLDS: Where does the centrifugal force

mm3

1 come in?

2 MR. POSTMA: If you are a little guy, a particle
3 riding along the outside, what you feel is this curvature
4 effect.

5 MR. REYNOLDS: It is right on the edge? It is not
6 on the inside?

7 MR. POSTMA: We assume the interior of the bubble
8 is well mixed. That is another assumption we had to make.
9 That is the one Fuchs makes, the internal part of the bubble
10 is assumed to be well mixed. It has only got a little layer
11 near the edge that we really care about.

12 MR. CASTLEMAN: I thought you were talking about
13 the inside.

14 MR. POSTMA: If you had a discus bubble like two
15 liquids, I think you would have to worry about that. It
16 would be a more complex problem.

17 MR. CASTLEMAN: With the gas in there I couldn't
18 see that was happening.

19 MR. COOPER: This is very similar to the collection
20 of particles in a curved spike. You can do that same kind
21 of analysis either by using as you did, the business of
22 centrifugal force and a drag -- coefficient drag force. Or,
23 you can simply use an impaction parameter. It turns out to be
24 an inertial parameter, it turns out you get the same
25 dimension.

mm4 1 If you do a very quick impaction parameter
2 calculation using the characteristic velocity which has got
3 to be the rise of the bubbles through the liquid, if you
4 use the characteristic time for the particles, which I grant
5 you is somewhat larger because of the hydroscopic growth,
6 if you use in the denominator the diameter of that bubble,
7 you should have very much the right order of magnitude that
8 you will get from this very elaborate calculation.

9 The problem is when I picture those numbers in
10 my mind, that upward moving bubble, the size of the particles
11 being collected and the diameter of the bubble, I get
12 impaction parameters that are terribly small.

13 So that my initial response is to be very surprised
14 if this should, in fact, turn out to be a significant
15 collection mechanism.

16 I have done a few calculations with bubbles going
17 up through liquids. Typically diffusion and sedimentation
18 have dominated, and this kind of mechanism has not been
19 important. I could be wrong. But I call your attention to
20 it, to check.

21 MR. POSTMA: We looked at that very carefully. I
22 would have to say you should go back and really do the
23 integration.

24 If you just look at the Stokes number it turns
25 out bubble size would just be to the first power I think

mm5

1 the denominator. But when you do this calculation, as I
2 recall, you get a D squared down there. So it is a lot
3 more important for the small bubbles, first thing by just
4 looking at that Stokes parameter.

5 MR. COOPER: Whenever one is surprised, one doesn't
6 know whether one is surprised because the truth is
7 surprising, or because a mistake has been made. Yes.

8 (Laughter)

9 MR. POSTMA: I must admit, I was a little surprised
10 too when I first did it, to find that this mechanism
11 totally -- I should say for particles that have inertia,
12 it is common for particles with small size diffusion
13 and this has very little effect.

14 (Slide)

15 Let me hurry along, let me show you some examples
16 of calculations that we have made with this code. There is
17 one more mechanism that Ken alluded to that I haven't even
18 described. That is this impingement, as you enter the pool.
19 I think Battelle Columbus has added that to the SPARC model
20 and accounts for it. It is modeled very much like a cascade
21 impactor where you have a gas jet impinging upon a liquid
22 surface.

23 We didn't put that in. We thought about it, but I
24 felt a little uncertain about the geometry of bubbles
25 entering; whether that could be simply approximated by a

um6

1 plane. Plus I also felt since this inertial thing was
2 so powerful for small particles, that if you would remove
3 them by impaction you would already remove them by the
4 circulation factor, and it probably wouldn't change the
5 result.

6 That could be wrong if you had a very shallow pool.

7 MR. ROE: I am a little confused as to where the
8 particles are, where the bubbles are, and what, in fact, the
9 removal process is. What is being removed? Where are the
10 particles going?

11 MR. POSTMA: Let me go back and show you the
12 picture.

13 MR. ROE: I thought I was following quite well,
14 then I got lost.

15 MR. POSTMA: (Slide)

16 Here is the first assumption, the bulk of the bubble
17 is well mixed. Will you buy that for the moment? Assume
18 that.

19 If I start right at the top you are in the gas flow,
20 okay, and water is flowing down like this because the bubble
21 is rising. Okay. We assume the interface on the gas side
22 is moving at the same velocity at the interface on the liquid
23 side. So the gas is being dragged. So the particle now
24 finds itself in the flow field within the gas, so it is
25 being projected outward. And they hit the wall. And we

mm7 1 assume when they hit the wall they are gone.

2 MR. ROE: You have particles in the gas phase?

3 MR. POSTMA: In the gas phase, that's right.

4 MR. ROE: That's what I was missing. Particles
5 in the gas phase. They find themselves then reaching inter-
6 face of the bubble. Once they hit that because of the
7 centrifugal force, they are now removed to the pool.

8 MR. POSTMA: We assume the surface tension
9 effects cause the particle to be captured in that pool.

10 MR. COBBLE: Where the particles finally end up?
11 At the bottom of the pool or the top?

12 MR. POSTMA: They end up in the liquid phase.
13 This is just one bubble now in a huge pool. Remember
14 there are some other bubbles about. So, the particles hit
15 the surface. We assume they are wet by the liquid, they
16 simply get carried down and they mix in all the liquid.

17 MR. COBBLE: What was the particle size? Are we
18 using uniform particle size?

19 MR. POSTMA: As far as the model we did particle
20 size as a parameter, so we predict for all particle sizes.

21 MR. COBBLE: What I am worried about, there is a
22 whole industry you know, where you float very fine particles
23 to the top by bubbles, not the bottom.

24 MR. POSTMA: I guess I am not worried about where
25 they are, as long as they are in the water at this point.

mm8

1 MR. COBBLE: If they form a foam on the top, then
2 it is kind of a question whether they are in the water or
3 not.

4 MR. COOPER: They are not in the air.

5 MR. POSTMA: Well, I think that is perhaps a good
6 question. I didn't mention it, but our method of accounting
7 for is based on the experiments done, where they actually
8 measure entrainment rates for the pool. We somewhat
9 arbitrarily put a lot of material, like half of the core
10 inventory into the pool and then calculated for that
11 volumetric rate what would that be equivalent to. It turned
12 out to be 10 to the 5th, so we limit our DFs to 10 to the 5th.

13 That is a question I think ought to be studied a
14 little bit more. As a matter of fact, peter Owczarski has
15 ordered some literature searches on that. Particular searches.
16 And that is, do bubbles really circulate like we say they do.

17 We know if we have very small bubbles and you have
18 surface active agents, they rise as solid spheres. That is
19 well known.

20 The question is, for the bubble sizes we are
21 speaking about, is that important? We don't think it is, but
22 we still want to look at that some more.

23 MR. PETRANGELI: It is rather surprising also to
24 me that this mechanism is very important. What I think is
25 that the bubble essentially pulsates in the liquid, and

mm9

1 this movement on the surface should be more important than
2 the entrainment inside the bubble due to the motion or
3 the relative liquid.

4 Did you consider these in some way, this kind of
5 pulsation of bubbles change their shape and things like that,
6 with the size of bubbles you are considering?

7 MR. POSTMA: I certainly agree with your perception.
8 when we look at bubbles in a pool we know they are vibrating.
9 They have a way of moving back and forth because of fluid
10 instabilities.

11 You might think that would be important, maybe not
12 as important. But we haven't found a way to model that. That
13 is what I would have to say, that is part of the energy
14 dissipation we are not accounting for.

15 MR. COOPER: In scrubbing, again, when you have
16 a droplet in a gas rather than a bubble in a liquid, often
17 you find that the thermophoretic forces pretty much offset
18 the diffusiophoretic forces. And I think if you incorporate
19 thermophoresis into these bubbles you are going to find it
20 goes in the opposite direction from that diffusing vapor
21 force. And it again deserves at least to be checked, because
22 we have got some scrubber results that show that even for
23 an evaporating drop the thermophoretic force is greater than
24 the diffusiophoretic force and you are rather than
25 collecting particles because of that, you are not collecting

mm10

1 them. It is going the opposite way.

2 Slim and Hales have pointed this out over a decade
3 ago, and June Stuko at Illinois has demonstrated it.

4 MR. POSTMA: I agree. Thermophoresis we haven't
5 considered. A couple of reasons for that. One, we didn't
6 have time. The other is thermophoresis would mostly occur
7 during the very initial part of the bubble formation.

8 MR. COOPER: It occurs wherever you have the
9 condensation.

10 MR. POSTMA: It turns out for most of the interesting
11 cases you have a lot of evaporation going on right at that
12 time. So it would probably be offset by the large amount
13 of evaporation that takes account of that. But we need to
14 analyze it.

15 MR. COOPER: I am referring to the latent heat.

16 MR. POSTMA: We should add that.

17 (Slide)

18 I think the key thing I want to add here -- here
19 I am showing you the access ratio -- show you the bubble
20 shape is often important here. These curves, you see the
21 elevation is tremendous. The reason is, as you go around
22 that sharp bend on that oblate spheroid, you have much
23 higher centrifugal forces and causes that centrifugal
24 mechanism to be very much more important.

25 I think the most important thing is this model

mm11 1 predicts -- this is no soluble particles of cooled pool,
2 12 feet, 20 degrees Centigrade, and we get a fairly low
3 DF here for this intermediate size range, even if we take
4 this elliptical bubble.

5 MR. VOGEL: Is this 100 percent noncondensable?

6 MR. POSTMA: Yes, it was. It is one of the worst
7 cases you could do.

8 MR. VOGEL: It looks pretty bad.

9 MR. POSTMA: It all depends on your particle size.
10 If you get particles of any decent size you have an elliptical
11 bubble. You see this is still a half micron particle. You
12 are a pretty good one.

13 But, if you are really loaded with particle .1 or
14 .2, this model predicts you are not going to get very high
15 DFs and that is what limited the DFs in some of the cases
16 shown.

17 MR. PETRANGELI: Did you also consider the tendency
18 of the vapor to concentrate also in the middle of the bubble
19 due to the centrifugal effect; or, did you consider the
20 concentration of the particles uniformly within your sphere?
21 Because you have both phenomena if you consider the
22 centrifugal. Because you have an entrainment of gas on the
23 surface, but then you have an internal circulation. You
24 have also a concentration in the middle of the bubble, I
25 think.

mm12

1 MR. POSTMA: You are saying it would be more
2 concentrated in the middle?

3 MR. PETRANGELI: Yes, of course.

4 You have to have some vortex inside the bubble. So,
5 you have centrifugal forces towards the outside, and your
6 centrifugal forces are towards the middle. So your
7 concentration is not uniform in the bubble.

8 MR. POSTMA: We didn't consider that would be the
9 effect.

10 MR. PETRANGELI: You have to be consistent. If you
11 see the bubble stationary and the fluid is moving around it,
12 within the bubble you have movement, you have to have some
13 circulation. And these things occur to send the particles
14 towards the outside, but also towards the inside.

15 So you don't have any uniform concentration any
16 more.

17 MR. POSTMA: That's an interesting point, we
18 haven't considered that. I don't quite know how to calculate
19 that. I guess my own feeling was that as this bubble
20 oscillates going up, with the one effect you mentioned that
21 I would think would cause it to be sturdy inside. We have
22 not accounted for that if there is such a factor.

23 MR. ROE: Is surface tension and wetting at the
24 surface of the bubble an important issue?

25 Do these particles -- do they wet readily?

mml3

1 MR. POSTMA: I think that is a question some have
2 raised. My own experience with scrubbers leads me to
3 believe that for most substances I'm aware of the perfect
4 assumption is a pretty good one. The particles hit the
5 surface, they are captured; they don't just stay on the
6 surface without wetting. It could be there are some cases
7 with unusual materials where that would happen. But, I am
8 not aware of any such data.

9 Do you have a comment on it?

10 MR. ROE: No. You have a strange mix of everything
11 coming out of containment, and who knows what weird things
12 it might be.

13 MR. COOPER: That has been confirmed by experiment
14 quite a few times. They don't have to be hydroscopic or
15 wetted to stick if they are a few microns or smaller, and
16 you have such low velocities here that there is no likelihood
17 any rebound would occur.

18 MR. POSTMA: Let me mention key inputs to our model:

19 (Slide)

20 Particle size, distribution, pool temperature, inlet
21 gas temperature if you use an equilibrium temperature model,
22 the pressure above the pool, the effect of scrubbin, height
23 has to be an input, the average bubble diameter and the
24 information we have so far is based on the GE experiments.

25 Before GE did their experiments, I must say I was

mml4 1 quite uncertain as to how quickly bubbles would break up
2 and what their size would be. But with fairly large
3 experiments that were done by GE, I have been convinced that
4 bubbles break up rather quickly, that they break in fairly
5 small individual sizes. We typically use .5 centimeter. I
6 noticed Battelle result was based on .75. It was an
7 elliptical bubble, probably a good estimate.

8 Steam gas ratio to determine whether you will have
9 initial condensation.

10 And we also allow for viscosity calculation
11 purposes, the makeup of the gas. We consider hydrogen, water,
12 carbon dioxide and carbon monoxide.

13 We keep track of those four and use the standard
14 Wilkin formula for calculating viscosity.

15 We mention a few key improvements we feel in
16 evaluations that ought to be done.

17 (Slide)

18 Whether we need to predict within the code the
19 bubble size distribution so that the user doesn't have to
20 be really smart to know what to pick. There are some data
21 available. We can do some modeling of that.

22 Entrance impingement effect. BCL has already
23 put that in. We also desperately need to compare with other
24 codes and models. EPRI has a model which we would like to
25 do some comparisons with.

mm15

1 I know that is on Jim's agenda.

2 GE has a model and I have talked with them. I
3 think we can make some comparisons with their model.

4 Obviously, we need to compare with experiments.
5 We don't have experiments we can really compare. There is
6 a very substantial program going on in Battelle Columbus
7 under the EPRI support, which is really going to supply
8 some good data. This model might be totally revised based
9 on that experimental data.

10 We need a more realistic model for entrainment that
11 accounts for carryover, and perhaps they have some
12 experiments as Dr. Cobble mentioned, which show other materials
13 tend to accumulate at the interface.

14 Finally, we need to know whether bubbles really
15 circulate the way we assume they do.

16 Very quickly, when you summarize what we have done,
17 we developed the SPARC code in a fairly short time period.

18 (Slide)

19 It has a number of assumptions in it. We think we
20 have accounted for the dominant depletion processes, the
21 predicted DF is very dependent upon the particle size. I
22 think the bottom line I have come to is the prediction of
23 DFs is never going to be any better than the prediction of
24 particle size. Obviously, the overall DF will depend very
25 much on this particle size distribution, and we are continuing

mm16

1 work on it and we hope to improve it to be more realistic.

2 Any other questions?

3 MR. SILBERBERG: Thank you, Arlen.

4 MS. HANKINS: I am Debra Hankins from General
5 Electric. Most of what I was going to cover Arlen already
6 has, so I will try not to be repetitive.

7 (Slide)

8 Basically we got into the pool scrubbing test
9 program because of the fact that in the previous work,
10 saturated pools in particular were given no credit for
11 scrubbing. We felt that was a tremendous conservatism in
12 terms of fission product retention. So, we set about in a
13 combination analysis/test program to verify pool scrubbing
14 for saturated pool conditions.

15 Basically this program involved development of the
16 firstprinciples model which you will find is very similar
17 to the one Arlen just described, generating sufficient test
18 data to verify that model and calculate suppression pool
19 DFs for the plant conditions under severe accidents.

20 I think Rich Denning did a very good job this
21 morning of describing the pathways in the Mark III, and
22 basically to refresh your memory we find for the standard
23 plant Mark III design we do in fact fail in the knuckle region.
24 It is a very point, maintains the drywell suppression pools.

25 Our relief is through two safe relief valves and
then transits through the horizontal vents in case of pipe

n17

1 breaks or releases after vessel failure.

2 (Slide)

3 Then we tended to concentrate on the saturated pool
4 condition. Although if you look at the probability of
5 various sequences for a Mark III plant, you find majority
6 of events actually involve subcooled pools. But, because
7 credit was not being given for saturated pool scrubbing,
8 we concentrated our test program on a saturated condition.

9 (Slide)

10 I've already mentioned the major elements of that
11 program. First of all to develop a first principal model,
12 we conductes single bubble mass transfer scrubbing tests,
13 hydrodynamic testing to characterize the bubble shape, rise
14 velocity and size, and finally calculating suppression pool
15 DFs.

16 (Slide)

17 The model was a combination of mass transfer
18 of particulate scrubbing, and of course the hydrodynamics
19 that characterize the bubble itself.

20 (Slide)

21 Arlen has just gone through the major mass
22 transfer processes, sedimentation, inertial deposition, that
23 is the centrifugal force that Arlen was just talking about.
24 And Brownian diffusion.

25 (Slide)

end mm
jl fls

1 As Arlen indicated, the DFs are calculated, the
2 mass transfer coefficients are calculated for a particle size
3 and integrated over particle size diffusion to get the total
4 DF.

5 (Slide)

6 In terms of mass transfer testing, we used dry air
7 as the carrier gas in a sub-cooled pool. So, we carried out
8 these tests at isothermal conditions. Therefore, we were
9 simulating the saturated pool, where you had no condensation
10 of the steam. But we have since realized -- and I think it
11 is pretty true throughout the industry -- that there is no
12 such thing as a saturated pool at the discharge location. You
13 always have a height of water; and as such, you're only
14 thermally saturated at the surface of the pool.

15 Since many of these cases we are talking about, 13 to
16 18 feet of pool depth, could be quite substantially sub-cooled
17 at the discharge location. And you do, in fact, get steam
18 condensation.

19 (Slide)

20 However, again, I can only state that's a major
21 conservatism in our model in that we don't take into account
22 the steam condensation.

23 The single-bubble scrubbing experiments that we did,
24 we took europium oxide, suspending it in the nitrogen or
25 compressed air carrier gas, injected single well-spaced bubbles

1 into a column of water. The column is one foot by one foot
2 by six feet. We can vary height. We can vary bubble size.
3 And as a result of varying bubble size, we saw different
4 bubble shapes.

5 I'll be talking a little bit about what kind of
6 a difference that makes.

7 We measured the inlet stream with an impact sampler
8 to get the particle size distribution on the inlet. We also
9 measured the outlet stream with an impact sampler to measure
10 the outlet particle distribution. This allowed us to get a
11 DF as a function of particle size. As Arlen indicated, that
12 particle size is by far the most important parameter.

13 We varied bubble size from about .4 to 1.4 centi-
14 meters. That is about the range you would expect for stable
15 bubbles rising in a large suppression pool after the bubbles
16 have gone through an initial breakup period.

17 We varied particle concentrations, although we
18 kept them low to avoid agglomeration effects. We were testing
19 three dominant mass transfer processes. We varied submergence
20 height. As I mentioned, tests were done at isothermal condi-
21 tions, although we did do one test at elevated temperatures
22 to see if there was any effect.

23 We varied the particle size distribution over about
24 .05 to 3 micron, actual diameters.

25 (Slide)

MM:jl 22:3

1 As one would expect, the decontamination factor is
2 very sensitive to particle size. This is a typical single-
3 bubble scrubbing run, where these are the actual DFs measured
4 for the erupium oxide as a function. Again, this is true
5 particle size. This is a theoretical prediction, using a
6 spherical bubble bottle.

7 I think we all tend to agree that the minimum of
8 the curve, no matter what you do, seems to come about to
9 .1 to .3 microns in size.

10 (Slide)

11 If could find a way to get Battelle-Columbus to
12 up their particle size, it would make life easier.

13 Actually, I think what happened is we presented them
14 with our curve and showed them a minimum. They then went
15 about calculating particle sizes.

16 (Laughter.)

17 As I mentioned, we also determined DF as a function
18 of scrubbing height. As one would expect, there's an
19 exponential dependence on scrubbing height for distribution
20 of particles.

21 One thing we observed was as you vary bubble size
22 -- and that's what these different symbols indicate, are the
23 different bubble sizes -- we saw an order of magnitude
24 difference in the scrubbing efficiency. And this troubled us
25 because it turned out the larger bubbles were giving better

1 scrubbing.

2 Now, if you use the classical spherical models of
3 Fuchs, as you go to a large bubble you get poorer scrubbing.

4 So, what we did is we did a closer examination of
5 exactly what the bubbles were. And what we found were as the
6 bubble deviates in size from about a .3 centimeter equivalent
7 volume bubble, the bubbles tend to flatten. They are no
8 longer spherical. They become elliptical. They move into a
9 transition of more of a spherical cap. They become almost
10 lenticular in shape, as you go from about a 1 centimeter to
11 1.4 centimeter bubble. They look a lot like frisbees rising
12 through the water.

13 Many of you have seen the films we have of these
14 bubbles. They are so far from a spherical bubble that there
15 really is no comparison.

16 As you would expect, once you flatten this bubble,
17 you shorten the distance that the particles have to travel.
18 So, you would expect better scrubbing. And, in fact, that's
19 what elliptical bubble models do predict, better scrubbing.

20 The lines on here are for the spherical model, and
21 you can see the trend of the data is in exact reversal of the
22 trend of the spherical prediction.

23 Here they go to larger sizes, get poorer scrubbing.
24 Fractions of data shows the reverse trend.

25 So, that prompted us to begin modeling using an

1 elliptical model.

2 (Slide)

3 I'm just going to go a little further into the
4 hydrodynamics.

5 We were very concerned, especially in the case of
6 the standard plant design, where we had very large, 27-inch,
7 horizontal dents, that we might actually get 27-inch bubbles.
8 We didn't think we'd get very good scrubbing with those
9 bubbles.

10 So, we conducted a test program to determine for
11 various flow rates, various discharge configuration, what
12 would be the bubble distribution, the final stable size of the
13 bubble, how long would it take it to break up, what would be
14 the rise velocity of the squarm of bubbles, and how could we
15 characterize that bubble distribution as a function of height
16 in the pool.

17 (Slide)

18 We found out there's no such thing as a large stable
19 bubble on the mass flow rates one would predict for severe
20 accident conditions.

21 If you take a horizontal vent, initially you can
22 grow a large bubble. As soon as that bubble is released from
23 the charging source, the bottom catches up with the top. The
24 bubble shatters into a multitude of very tiny -- about half-
25 centimeter bubbles.

1 MR. HOLTZCLAW: My name is Kevin Holtzclaw. Debra
2 brought me along because she is a little bit uncertain of
3 presenting this portion of the model which Fred Moody, our
4 hydrodynamics expert, normally covers. I have to admit I am
5 a very poor substitute for Fred Moody, so don't ask me any
6 tough questions. I can go a little bit through what we saw
7 on the hydrodynamics portion of our test program and how we
8 actually went back and tried to do some modeling to predict
9 the things that we saw.

10 (Slide)

11 And it's contained on the next couple of charts
12 here.

13 The first thing in our observation, we observed
14 the growth of these large bubbles, their release, and
15 ultimately their breakup and then their resultant sizes of
16 the small bubbles that we are actually scrubbing the
17 fission products from.

18 Another key element is identification of the
19 velocity or the transit time that the bubbles existed
20 within the pool in order to allow the scrubbing of the
21 particles from the bubbles.

22 In order to model some of these things, we first
23 of all wanted to be able to identify potential breakup
24 mechanisms. That is why these large bubbles were breaking
25 up into the small bubbles. If we could go back into the

TAYLOR ASSOCIATES
1625 I Street, N.W. - Suite 1004
Washington, D.C. 20006
(202) 293-3950

1 literature and find reasons for this, it would give us a
2 lot better feel for the things that we're seeing.

3 Also, it would give us some capability of
4 predicting the ultimate bubble size and the velocity or
5 transit time, which would then allow the application of our
6 single bubble scrubbing test results.

7 (Slide)

8 This is one chart that just briefly identifies
9 some of the mechanisms that Fred has considered in our
10 evaluation. One of the things was just being able to
11 identify this bubble shape and the fact that the bubbles
12 themselves are not spheres as utilizing the Fuchs-type
13 analysis.

14 In actuality, you can do some very simple
15 analytical work in potential flow to identify the fact that
16 you will experience this bubble flattening process. In
17 fact, if you look at just a bubble in a flow field and you
18 can identify the stagnation point and you can quickly see
19 that you need to have the velocity of the trailing portion
20 of the bubble moving actually faster than the velocity of
21 the leading edge, which ends up giving you the ellipsoidal
22 bubble shape or, in fact, even a lenticular bubble shape
23 that we see in our actual tests.

24 Dr. Moody has gone through a good deal of work
25 in trying to identify different bubble breakup mechanisms,

1 and he's actually applied some of his own names to these.
2 He's got an aerodynamic type of mechanism where you
3 actually have a bubble which is acting essentially like an
4 airfoil in a flow field. We have lift forces exceeding the
5 surface tension forces.

6 This then identifies the minimum bubble size
7 under this kind of a mechanism. So what he's done is gone
8 through and defined a number of different mechanisms to try
9 to identify what you would ultimately believe to be the
10 stable bubble size. This ends up giving us a stable bubble
11 size approximately the same as that which we're seeing in
12 the test program, something on the order of half a
13 centimeter.

14 He's also looked at a number of other more
15 classical breakup mechanisms, things like Helmholtz-Taylor
16 stabilities and items like this to again try to identify
17 what you would ultimately end up with in stable bubble
18 sizes.

19 He has done some work in incorporating this into
20 an energy analysis where you can equate the draft for
21 surface tension forces and combine all the bubble breakup
22 processes that he's come up with in order to balance out
23 this energy force and identify the sizes and bubble
24 velocities.

25 (Slide)

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1625 I Street, N.W. - Suite 1004
Washington, D.C. 20006
(202) 293-3950

1 In order to try to get some feel for how good
2 the analysis is relative to things that we saw in the
3 tests, we have compared two special literature cases that
4 is usually for very, very small bubble cases or very large
5 cases, and gotten some relatively good comparison with our
6 calculations.

7 We have also made some comparisons to the
8 testing that Debra mentioned earlier. We have shown some of
9 the parameters for comparison here, primarily, the bubble
10 rise velocities we estimated from looking at our test films
11 and observations, rise velocities of bubble clusters that
12 Arlen was talking about a little while ago, on the order of
13 about 5 feet per second for the types of flowrates that we
14 would be encountering under severe accident condition.

15 And the bubble rise velocities we calculated
16 based on some of this relatively crude modeling puts us in
17 that same ballpark, within 3 to 5 feet per second bubble
18 rise velocities -- I am sorry, swarm rise velocities.

19 (Slide)

20 The next facet of our overall program was to put
21 all this together and perform decontamination factor
22 calculation. We used the model we have identified for each
23 particle size in the swarm, and then we summed the particle
24 size DFs over distribution to obtain the total DF. That is
25 shown kind of schematically in our next chart.

1 (Slide)

2 This shows a bubble swarm rising in a pool.

3 Again, we calculate over the bubble swarm over particle
4 size distribution to arrive at a total DF.

5 (Slide)

6 Just to show you some fairly typical results,
7 these were for some of our BWR-6 analyses. Depending on
8 what the flow path was for going down through the safety
9 relief valve discharge lines through the quenchers into the
10 pool, we would encounter typical parameters such as these.
11 Velocities submergence heights being fairly critical
12 parameters, using a 5.1 AMMD particle size distribution, we
13 would calculate very significant DFs, on the order of 1×10
14 to the 4th.

15 For the case of horizontal vent discharges, now
16 we are dealing with both aerosols emanating from thorium
17 interactions with the internals materials in the reactor
18 vessel as well as interactions with the concrete using
19 different particle size distributions typical of these two
20 types of distributions.

21 We would obtain decontamination factors on the
22 order of about 100, values like on the order of 2×10 to
23 the 3rd.

24 (Slide)

25 Overall, from the results of the program, some

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1625 I Street, N.W. - Suite 1004
Washington, D.C. 20006
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1 of the analysis parameters that we have defined that are
2 very significant in the resulting calculations are the
3 bubble swarm diameters, the submergence height, obviously.
4 Arlen, I think, also indicated, and I think the Battelle
5 people also indicated, the significance of that parameters
6 in the calculations earlier this morning.

7 Also, the bubble rise velocity and particle
8 size. Particle size I think has been mentioned very
9 frequently today, as being very important in identifying
10 pool scrubbing factors. Based on our analyses, we have
11 incorporated into studies for standard plant design, we
12 used realistic decontamination factors anywhere from values
13 on the order of 600 to greater than 10 to the 4th.

14 I think that was about all we had to present.

15 MR. SILBERBERG: Thank you, Debra and Kevin.

16 Do we have some questions?

17 MR. COBBLE: What happens when the temperature in
18 the pool changes that it changes surface tensions? Does
19 that help decontamination factor?

20 MS. HANKINS: As I indicated, our model is for
21 the noncondensing cases, so we don't really include heat
22 transfer into it. If you were to include heat transfer
23 terms in the model, what happens in the terms of the
24 hydrodynamics, you would predict because you have a lower
25 surface tension you would actually end up with smaller

1 stable size bubbles. So stable size would go down.

2 MR. COBBLE: The other question is what happens
3 to surface tension when the pool becomes saturated with
4 gas? Do you do experiments?

5 If I remember correctly, gases change surface
6 tension of the water too. But even if you keep the
7 temperature the same, are there any data on what happens in
8 the gas tension or surface tension? That apparently is
9 important to the calculation.

10 MR. COOPER: Could I comment on that? I think the
11 surface tension is, what, 72 times per centimeter and the
12 size of droplets presumably by analogy, the size of bubbles
13 changes with the square root of that.

14 If you take a look at the temperature dependence
15 of surface tension, it really is quite weak. The addition
16 of surface-active agents can change surface tension. Even
17 there you see at most a factor of 2 change. So I don't
18 think this is going to turn out to be a big issue.

19 You might check. There has been a recent very
20 nice book out from Clift on bubbles.

21 MS. HANKINS: Clift, Brace, and Weber.

22 MR. COOPER: Yes. You might also look in the
23 analogy with bubbles because the same Weber number ought to
24 control.

25 Finally, I calculate an impaction parameter and

1 a ratio of settling distance to bubble size, and settling
2 to me, using something in analogy to what you are doing,
3 seems to have to outweigh impaction greatly. what have you
4 found?

5 MS. HANKINS: The same result that Arlen
6 presented. The dominant term for between about .2 microns
7 to about 1 micron in size is inertial.

8 MR. COOPER: I calculate 5 microns.

9 MS. HANKINS: For 5 microns I agree.
10 Segimentation, absolutely.

11 MR. COOPER: Maybe that's where the disagreement
12 is.

13 MS. HANKINS: If Battelle would give us 5 micron
14 particles, I would love it.

15 MR. BERNERO: we won't let them.

16 MR. COOPER: The thing that surprises me is that
17 both should go with diameter squared as the aerodynamic
18 diameter. They should scale on down together.

19 MR. VOGEL: I might just scope what the EPRI
20 scrubbing program is just for completeness here.

21 We have under way at Battelle-Columbus -- and
22 Mike and Jim are involved in this program -- a work
23 involving this probing, and I have a feeling that certainly
24 by winter we are going to have some appreciable data.

25 The Battelle so far have been aimed at 2/10ths

1 of a micron particle size. As Debra says, this has been
2 focused very well on the most difficult one.

3 In general, we are finding decontamination
4 factors in the neighborhood of 4 or 5 all the way up to
5 almost a thousand. And the important variables are the
6 amount of steam in the bubble, which, of course, you get
7 condensation. And that collapses the bubble, which is
8 discrete, and that gives you very good scrubbing. We are
9 varying submergence and so on.

10 I must admit that since I am involved with the
11 program, that I have perhaps slowed the model development
12 down a little bit, and perhaps the reason for this is that
13 I felt we would only have to develop one model. You know
14 how it goes, you get a model developed, then you get the
15 experimental data and then you've got to go redevelop your
16 model. So that's where we are on that program.

17 Our own model, as it now stands, gives somewhat
18 higher decontamination factors, by and large, than post
19 buzz does, but I can't get very much exercised about that.
20 I think it will converge.

21 MR. SILBERBERG: Thank you.

22 Jim Gieseke has a few comments.

23 MR. VOGEL: Do you want to say something about
24 the EPRI program? Go ahead if you want to.

25 MR. SILBERBERG: No. Just some comparison.

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1625 I Street, N.W. - Suite 1004
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1 MR. GIESEKE: I just wanted to mention, it was
2 alluded to the fact that there are some comparisons in the
3 works between the various codes. You have heard that there
4 are three codes available for the calculated pool
5 scrubbing.

6 (Slide)

7 These are what Dick just mentioned that they
8 have developed at EPRI as being the supracode. I think SAI
9 worked with EPRI in the development of that code. The one
10 we heard from Arlen is the NRC-sponsored work at
11 Battelle-northwest, the SPARC code.

12 I don't know if you have a name for your code.

13 MR. HANKINS: DCON.

14 MR. GIESEKE: I didn't know, so I just called it
15 General Electric.

16 (Laughter)

17 What we're trying to do is just pick some
18 generic type of conditions that go along with BWR
19 ex-quencher, as an example, to make comparisons among the
20 codes.

21 The other thing that has been offered is the
22 possibility that some of the experimental results that Dick
23 has mentioned, we have worked with Richard Olberg on this,
24 and there will be some experimental cases identified that
25 will also be used in comparing the codes.

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1 We started to make a go-around comparison with
2 the codes, and we found there are slight differences among
3 all the codes. For instance, Arlen talked about the
4 condensation on soluble particles is in that code, is not
5 in the others. There are some with injection deposition and
6 not in the others. There are some that calculate the
7 bubble size internally and out. There are some that
8 calculate the aspect ratio internally. The other one,
9 Arlen's, you fixed that at the beginning.

10 So there are all these differences among the
11 codes, and it's going to take a few iterations, I think, to
12 sort out, to get some cases where everyone agrees to do the
13 calculation the same way just to get some feeling for how
14 close the codes are.

15 But we're trying to work towards understanding
16 what the differences are and see if there are major
17 differences in the calculations or whether they are fairly
18 close.

19 MR. VOGEL: Why don't we just take the
20 experimental data and plot it up on a log?

21 MR. GIESEKE: Fine with me. It's certainly a lot
22 easier for me.

23 (Laughter)

24 MR. COOPER: We could take the theoretical
25 results and plot them.

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1625 I Street, N.W. - Suite 1004
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1 (Laughter)

2 MR. SILBERBERG: Thanks, Jim.

3 Before closing, I would like to briefly note
4 what the order of business is for tomorrow and some
5 contributions that we will need first thing in the morning
6 from all of you here.

7 At this point, I think I will spare you all the
8 chairman's summary and closing remarks, because the
9 chairman's comments at this point -- and I will save those
10 for tomorrow.

11 I would very much appreciate if, starting first
12 thing in the morning, we will maybe go around the table as
13 we did last time in January for maybe a 2-minute summary
14 statement, preliminary statement. We recognize the boiler
15 review is still ongoing. I don't want to hold you to that.
16 But 2-minute summary statement of what you think are key
17 points that you would like to make at this point and based
18 on what you heard today as well as some material that you
19 might peruse through tonight, what topics do you think need
20 some further discussion at this meeting, you know,
21 tomorrow, so that we can prioritize our time in our
22 discussion tomorrow.

23 And I then will ask the invited observers to
24 take similarly 2 minutes but only to add new inputs over
25 and above what the panel at the table has contributed. We

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1625 I Street, N.W. - Suite 1004
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1 will try to do that within the first hour tomorrow morning.

2 And then, based on that, we will then proceed
3 with further discussion of key points or perhaps maybe have
4 some additional presentations, backup presentations by the
5 Battelle people. We may even bring the tellurium issue to
6 the table from the Oak Ridge work, or any other subject, as
7 well as what -- and I think then to close it tomorrow we
8 will then try to refocus again and try to summarize where
9 you think the attention should be placed between now and
10 next time. We are in the completion of the BWR study by
11 Battelle-Columbus.

12 with that, I would like to thank you for your
13 patience and your indulgence. We wish you a good evening.
14 We will meet tomorrow again at 8:30. Thank you.

15 (Whereupon, at 5:40 p.m., the meeting was
16 adjourned.)
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25

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1625 I Street, N.W. - Suite 1004
Washington, D.C. 20006
(202) 293-3950

END
7.23

CERTIFICATE OF PROCEEDINGS

This is to certify that the attached proceedings before the
NRC COMMISSION

In the matter of: PEER REVIEW MTG.

Date of Proceeding: MAY 24, 1983

Place of Proceeding: Washington, D.C.

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

Mimie Meltzer
Official Reporter - Typed

Mimie Meltzer
Official Reporter - Signature

VOLUME I

APPENDIX

THE TRAP-MELT CODE

APPENDIX

THE TRAP-MELT CODE

The philosophy and logic structure of the TRAP-MELT code are discussed in the main body of this report. Here we present detailed expressions of the mechanistic treatment for reference purposes. This treatment remains essentially that contained in the published TRAP-MELT manual* and the reader is referred to that document for additional insight.

Master Equation

The master equation set of the TRAP-MELT model is:

$$\begin{aligned} \frac{d}{dt} M_{im}^k &= S_{im}^k + \sum_{n \neq m} n_{\beta im}^k M_{in}^k \\ &\quad - \sum_{n \neq m} n_{\beta im}^k M_{im}^k \\ &\quad + \sum_{j \neq i} i_{F jm}^k M_{jm}^k \\ &\quad - \sum_{j \neq i} j_{F im}^k M_{im}^k \end{aligned} \quad (1)$$

where

- M_{im}^k = Mass of radionuclide species k in volume i and state m
- S_{im}^k = Source rate of species k in volume i and state m
- $n_{\beta im}^k$ = Transfer coefficient for transport of species k in volume i from state m to state n
- $j_{F im}^k$ = Transfer coefficient for transport of radionuclides in state m from volume i to volume j .

For a given species k and volume i , therefore, Equation (1) gives, in order of appearance of the terms on the righthand side, the mass source rate to state m , the mass transport rate to state m from other states in volume i , the mass transport rate from state m to other states in volume i and the mass transport rates to and from state m due to flow in and out of volume i .

If m signifies a surface state, $n_{\beta_{im}}^k$ represents a mass release rate, P . At the present stage of TRAP-MELT, all these terms are set to zero. If m signifies a volume state, $n_{\beta_{im}}^k$ can be written as

$$n_{\beta_{im}}^k = \overline{v_d} \frac{A_i}{V_i} \quad (2)$$

where v_d is deposition velocity of a given mechanism and A_i is the appropriate deposition surface area. V_i is the volume of the control volume in question. The bar indicates the average over particle mass distribution (if m signifies a particle state) and surface areas.

Each control volume is assumed homogeneously mixed. Mass transport due to flow between volumes can therefore be expressed by

$$j_{F_{im}} = j_{\dot{m}_i} / \rho_{si} V_i \quad (3)$$

where

$j_{\dot{m}_i}$ = Steam mass flow rate from volume i to volume j (input to TRAP-MELT)

ρ_{si} = Density of steam (and hydrogen) in volume i .

Deposition Velocities

(1) Particle settling due to gravity

$$\tau = \frac{\rho_p d^2 C}{18\mu} = \text{particle response time} \quad (4)$$

$$v_d = \tau g$$

where

ρ_p = Particle density
 d = Particle diameter
 C = Cunningham slip correction factor
 μ = Dynamic viscosity of carrier gas
 g = gravitational acceleration.

TRAP-MELT distinguishes between settling across and against steam flow. If settling is against the flow, then

$$\begin{aligned} v_d &= v_d - u & u < v_d \\ &= 0 & u \geq v_d \end{aligned} \quad (5)$$

where u = steam flow velocity.

(2) Particle deposition due to diffusion from turbulent flow (Davies*, theoretical expression)

$$v_+ = \frac{Sc^{-2/3}}{14.5 \left[\frac{1}{6} \ln \frac{(1+\phi)^2}{1-\phi+\phi^2} + \frac{1}{\sqrt{3}} \tan^{-1} \frac{2\phi-1}{\sqrt{3}} + \frac{\pi}{6\sqrt{3}} \right]} \quad (6)$$

$$\phi = Sc^{1/3}/2.9$$

$$u_+ = \left(\frac{f}{2} \right)^{1/2} u$$

$$f = 0.0014 + 0.125 Re^{-0.32}$$

$$v_d = v_+ u_+$$

Here

Sc = Schmidt number = ν/D

ν = Kinematic viscosity of steam

D = Diffusivity of particle in steam

Re = Steam Reynolds number in the volume of interest

f = Fanning friction factor

u_+ = Steam friction velocity.

*Davies, C. N., Aerosol Science, Academic Press (1966).

- (3) Particle deposition due to impaction from turbulent flow (Liu and Agarwal, modified by Lee*).

An empirical correlation of Liu and Agarwal, extended to small particles by Lee, gives:

$$v_+ = 6 \times 10^{-4} \tau_+^2 + 2 \times 10^{-8} \text{ Re} \quad \tau \leq 0.1 \quad (7)$$

$$= 0.1 \quad \tau > 0.1$$

$$\tau_+ = \tau u_+^2 / \nu$$

$$v_d = v_+ u_+$$

- (4) Particle deposition due to diffusion from laminar flow (Gormley and Kennedy**).

Laminar flow contradicts the general assumption of homogeneously mixed control volumes that is fundamental to TRAP-MELT. In order to, nevertheless account for deposition under such conditions, a fictitious deposition velocity is introduced that, when used in TRAP-MELT, gives the same rate of deposition as would be calculated by a differential treatment of plug flow. For pipe flow, it can be shown that this deposition velocity is:

$$v_d = \left(1 - \frac{M_o}{M_i}\right) \frac{R}{2L} u \quad (8)$$

where

R = Pipe radius

L = Pipe length

M_i = Particle mass concentration entering pipe

M_o = Particle mass concentration leaving pipe.

* Gieseke, J. A., et al, NUREG/CR-1264, BMI-2041 (1979).

**Gormley, P. G. and Kennedy, M., Proc. R. Ir. Acad. 52A, 163 (1949).

According to the theoretical analysis (substantiated by numerous experimental investigations) of Gormley and Kennedy:

$$\frac{M_o}{M_i} = 0.8191e^{-7.31h} + 0.0975e^{-44.6h} + 0.0325e^{-114h} \quad (9)$$

$$h > 0.0156.$$

$$\frac{M_o}{M_i} = 1 - 4.07h^{2/3} + 2.4h + 0.446h^{4/3}$$

$$h < 0.0156$$

$$h = LD/2 uR^2$$

$$= Pe^{-1} L/R$$

where $Pe = \text{Peclet number} = Sc \times Re.$

(5) Particle deposition due to thermophoresis (Brock*).

Brock's theoretical treatment of particle deposition in a temperature gradient, ∇T , at a wall surface gives:

$$v_d = - \frac{3}{2} v \psi C \frac{\nabla T}{T}$$

where

$$\psi = \left(\frac{1}{1 + 3C_m Kn} \right) \left(\frac{k_g/k_p + C_t Kn}{1 + \frac{2}{3} k_g/k_p + 2 C_t Kn} \right) \quad (10)$$

C_m = Steam momentum slip coefficient

C_t = Temperature jump coefficient

Kn = Particle Knudsen number

k_g = Thermal conductivity of gas (steam + hydrogen)

k_p = Thermal conductivity of particle.

*Brock, J. R., J. Colloid Sci., 17, 768 (1962).

Note that for large particles, $Kn \rightarrow 0$ and

$$\psi \rightarrow \frac{k_g/k_p}{1 + \frac{2}{3} k_g/k_p},$$

yielding an order of magnitude variability in v_d , depending on the choice of k_p . In TRAP-MELT, the necessary temperature gradient in Equation (10) is derived from the simple pipe flow heat transfer correlation:

$$Nu = 0.021 Re^{0.8}, \quad (11)$$

using the identity

$$h\Delta T = k\nabla T. \quad (12)$$

$\Delta T = T_{\text{wall}} - T_{\text{gas}}$ is derived from input data. Nu is the Nusselt number.

(6) Vapor sorption on wall surfaces

-- Molecular iodine from steam to stainless steel surfaces (Genco*)

$$v_d = 9.0 \times 10^{-8} e^{8100/k_B T} \text{ (cm/sec)} \quad (13)$$

k_B = Boltzmann's constant.

-- Molecular tellurium on stainless steel 304 (SANDIA**)

$$v_d = 1.0 \text{ (cm/sec)} \quad (14)$$

-- Cesium iodide

$$v_d = 0. \text{ (No data available)} \quad (15)$$

-- Cesium hydroxide (SANDIA**)

$$v_d = 0.01 \text{ (cm/sec)}. \quad (16)$$

* Genco, J. M., et al, BMI-1863 (1969).

** Elrick, R. M. and Sallach, R. A., "High Temperature Fission Product Chemistry and Transport in Steam", Proc. of the Internat'l Meeting on Thermal Nuclear Reactor Safety, August 29-September 2, 1982, Chicago, Illinois.

Species Phase Change

In each control volume, each chemical species is permitted to condense on (or evaporate from) particles and wall surfaces according to the mass transport rate equations:

$$\frac{dC_s}{dt} = - \frac{A_w k_w}{V} (C_s - C_w^s) - \frac{\langle A_p k_p \rangle}{V} (C_s - C_p^s)$$

$$\frac{dM_w}{dt} = A_w k_w (C_s - C_w^s) \quad (17)$$

$$\frac{dM_p}{dt} = \langle A_p k_p \rangle (C_s - C_p^s)$$

where

$C_s = \frac{M_s}{V}$ = concentration of the nuclide vapor in steam

M_s = Total mass of the nuclide vapor in steam

V = Volume of the control volume

M_w = Total mass of nuclide vapor condensed on walls

M_p = Total mass of nuclide vapor condensed on aerosol particles

C_w^s = Equilibrium vapor concentration of the nuclide at the temperature of the wall surfaces (assumed independent of pressure)

C_p^s = Equilibrium vapor concentration of the nuclide at the temperature of the steam (assumed independent of pressure and particle surface curvature)

A_w = Area of wall surfaces

A_p = Surface area of aerosol particle

k_w = Mass transfer coefficient for nuclide transfer between steam and wall surfaces-steam interface

k_p = Mass transfer coefficient for nuclide transfer between steam and particle surface-steam interface

k_w is taken from the Sherwood number (Sh) correlation for turbulent pipe flow (Dittus Boelter):

$$Sh = 0.023 Re^{0.83} Sc^{0.33} \quad (18)$$

Sc = Schmidt number

$$k_p = D/r$$

with r a particle radius. $\langle A_p k_p \rangle$ is the average value of $A_p k_p$ over the particle size distribution in the control volume of interest.

Equations (17) are solved analytically on the assumption that $\langle A_p k_p \rangle$ changes little over a master time step. This is borne out in practice.

The effect of condensation/evaporation on the particle size distribution is taken into account by noting the total mass (summed over all chemical species considered) transferred to/from the particle state according to Equations (17) over a master time step. This quantity is distributed over the discretized particle size distribution such that each size class is augmented/diminished in proportion to its associated mass transfer rate.

Required vapor pressure data (C_w^s , C_p^s) for I_2 , CsI, CsOH, and Te are presently incorporated in the code.

Particle Agglomeration

The aerosol component of the radionuclides tracked by TRAP-MELT is distributed among 20 size classes. Agglomeration among particles in these size classes is treated by a method developed in the QUICK aerosol behavior code* and since validated against numerous experiments. The coupling of this treatment to the flow equations of the TRAP-MELT code is described in the body of this report. Here we exhibit the agglomeration mechanisms considered.

*Jordan, H., et al, "QUICK Users' Manual", NUREG/CR-2105, BMI-2082 (1981).

Brownian Agglomeration

Defining the agglomeration kernel, K_{ij} , by

$$R_{ij} = K_{ij} N_i N_j \quad (19)$$

such that R_{ij} is the rate of agglomeration of the N_i particles per unit volume in size class i with the N_j particles per unit volume in size class j , the kernel for Brownian coagulation can be written:

$$K_{ij} = 4\pi k_B T (B_i + B_j) (r_i + r_j) \quad (20)$$

where

$$B_i = \frac{C}{6\pi\eta r_i}$$

and r_i is a characteristic particle radius for size class i .

Gravitational and Turbulent Coagulation. Following Saffman and Turner*, the combined kernel for gravitational, turbulent shear, and turbulent inertial agglomeration can be written

$$K_{ij} = 2\sqrt{2}\pi (r_i + r_j) [\epsilon_{ij}^2 (\tau_i - \tau_j)^2 \frac{1.3E^{3/2}}{v^{1/2}} + \frac{1}{3} \epsilon_{ij}^2 (\tau_i - \tau_j)^2 g^2 + \frac{1}{9} (r_i + r_j)^2 \frac{E}{v}]^{1/2}$$

where the as yet undefined quantities are:

$$\epsilon_{ij} = 1.5 \frac{r}{r + r'}^2 \quad \begin{aligned} r &= \min(r_i, r_j) \\ r' &= \max(r_i, r_j), \end{aligned}$$

*Saffman, P. G. and Turner, J. S., J. Fluid Mechanics, 1, 16 (1956).

the collision efficiency for hydrodynamic interactions and E the turbulent energy density dissipation rate. TRAP-MELT uses Laufer's expression*:

$$E = 0.03146 u^3 / (D Re^{3/8}).$$

*Taken from Delichatsios, M. A. and Probstein, R. F., MIT Fluid Mechanics Lab Publication #74-5 (1974).

PEER REVIEW COMMENTS
ON
BMI-2104 - VOL. 1 (SURRY)

Christopher P. Ryder
Accident Source Term Program Office
Office of Nuclear Regulatory Research

April 14, 1983

ACCIDENT SEQUENCES AND SYSTEM BEHAVIOR

<u>ISSUE</u>	<u>REVIEWER</u>	<u>AFFILIATION</u>
From a given sequence, alternate release pathways are not considered. Such pathways may result from breaks at a variety of locations in the primary system.	S. Levy	Levy, Inc.
For sequences that lead through the auxiliary building, retention by the auxiliary building is not considered.	J. L. Kelly E. P. Rahe B. R. Sehgal E. A. Warman H. Kouts	Univ. of Virginia Westinghouse EPRI Stone and Webster BNL
For the TMLB' sequence, the cause of the 89 psi pressure spike is not identified. If the cause is a hydrogen burn, the occurrence of such a spike is questionable because steam will likely attenuate the burn.	E. P. Rahe	Westinghouse

FISSION PRODUCT RELEASE FROM FUEL

<u>ISSUE</u>	<u>REVIEWER</u>	<u>AFFILIATION</u>
In addition to cesium iodide and tellurium, the release of other radionuclides should be investigated and discussed. Apparently aerosols of uranium, plutonium, and silver are not considered.	J. L. Kelly E. A. Warman D. O. Campbell	Univ. of Virginia Stone and Webster ORNL
The codes have cesium iodide and tellurium being released when the core melts. Indications are that these radionuclides are released before the core melts and that the release is completed when the core melts. Also, aerosol production may begin before the core slumps.	E. A. Warman	Stone and Webster
The maximum core temperature should be determined because the production of aerosols is temperature dependent.	A. W. Castleman	Penn. State Univ.
An estimate of the size of aerosol particles is based on experiments with NaCl solutions. From these experiments, it is predicted that sparged particles from the melt-concrete interaction would be 1 μ m. Because particle size is dependent on the square root of surface tension and the surface tension of the melt is much greater than the surface tension of aqueous NaCl, the 1 μ m particle diameter seems small.	D. W. Cooper	Harvard University
More study is needed on scaling up the results of experimental fission product releases.	A. W. Castleman	Penn. State Univ.
The aerosol particle sizes are assumed. It is not clear why a particular size distribution is chosen.	S. Levy	Levy, Inc.
It is erroneous to assume that control rod material will vaporize simultaneously and at the same rate. The composition of the vapors from the control rods will likely be different than the composition of the control rods. This is supported by data from TMI-2.	C. E. Johnson	Argonne

THERMAL HYDRAULICS

<u>ISSUE</u>	<u>REVIEWER</u>	<u>AFFILIATION</u>
High pressure ejection of molten fuel from the vessel is inadequately considered. Molten fuel striking water in the reactor cavity may fragment and rapidly transfer heat to the water; a steam spike would result.	A. B. Reynolds	
Hardware surfaces would be warmed by decay heat from radionuclides. This heat influences radionuclide deposition. The codes do not consider the decay heat-deposition phenomenon.	A. W. Castleman J. L. Kelly S. Levy E. P. Rahe A. B. Reynolds D. S. Rowe	Penn. State Univ. Univ. of Virginia Levy, Inc. Westinghouse Rowe, Assoc.
Flow in the upper plenum is inadequately modelled. Upper plenum flow influences the retention of fission products.	J. L. Kelly B. R. Sehgal	Univ. of Virginia EPRI
Mass and energy balance are not modelled.	H. Kouts A. B. Reynolds D. S. Rowe	BNL Rowe, Assoc.
The modelling of the boundary layer in relation to thermophoresis is not discussed.	A. B. Reynolds	

CHEMISTRY

<u>ISSUE</u>	<u>REVIEWER</u>	<u>AFFILIATION</u>
The codes have cesium iodide undissolved in the primary system. This is unrealistic in light of the copious amounts of water present.	E. A. Warman	Stone and Webster
Reaction cesium hydroxide on tellurium and stainless steel have been observed in the laboratory. These reactions are not modelled. The reactions are important because it is a way that fission products can be retained in the upper plenum.	B. R. Sehgal E. A. Warman	EPRI Stone and Webster
Chemisorption must be better understood and considered in the models.	A. W. Castleman D. O. Campbell	Penn. State Univ. ORNL
The elemental form of iodine is in the codes. This form of iodine is doubtful.	A. B. Reynolds	
High radiation fields produce ions. The differences in ion mobility result in a net charge on an aerosol. The charge differences lead to enhanced coagulating. The net charge leads to enhanced scattering. The computer codes do not account for ionization.	D. W. Cooper	Harvard University
It is unclear whether deposition is a reversible physical deposition or an irreversible chemisorption.	D. O. Campbell	ORNL
Before fission product chemistry can be modelled, it must be better understood.	D. O. Campbell	ORNL
Significant problems in the modelling of tellurium exist. For example, compounds of tellurium are not identified.	C. E. Johnson	Argonne

PRIMARY SYSTEM-TRANSPORT, DEPOSITION, AND REENTRAINMENT
OF AEROSOLS

<u>ISSUE</u>	<u>REVIEWER</u>	<u>AFFILIATION</u>
The effect that deposition (in pipes) has on flow is not modelled.	D. S. Rowe	Rowe, Assoc.
When aerosols pass through pipes at high speeds, turbulent deposition occurs. Turbulent deposition is not explicitly considered.	D. W. Cooper	Harvard University
The deposition of aerosols in primary piping and on vessel intervals is inadequately modelled.	E. A. Warman	Stone and Webster
The code fails to include retention by quench tank and the relief line downstream of the PORV.	E. P. Rahe	Westinghouse

CONTAINMENT-TRANSPORT, DEPOSITION, AND REENTRAINMENT
OF AEROSOLS

<u>ISSUE</u>	<u>REVIEWER</u>	<u>AFFILIATION</u>
The model predicts an aerosol concentration of $10^3/\text{lm}^3$ to to persist for thousands of seconds. This high concentration is unstable and should not persist long.	D. W. Cooper	Harvard University
Convection currents in the primary containment should keep the atmosphere well mixed; diffusion of vapors from hot to cold surfaces occur. This is not modelled.	D. W. Cooper	Harvard University
When substantial volume fraction of atmosphere containing aerosols are condensing on walls, diffusiophoresis should occur. This is not modelled.	D. W. Cooper	Harvard University
It is stated that particle size must be about $0.6\ \mu\text{m}$ for condensation on the particles to occur. Typically, condensation occurs on particles as small as $0.01\ \mu\text{m}$. Also, particles that contain soluble species will grow from condensation, even in an unsaturated atmosphere.	D. W. Cooper	Harvard University
Battelle inferred that spray droplet size does not have an appreciable effect on containment purging. It is expected that droplet size will have significant influence on purging.	A. B. Reynolds	
The model assumes that no convection flow is in the primary containment. This seems unrealistic.	T. Ginsberg	BNL

CONTAINMENT LOADS AND FAILURES

<u>ISSUE</u>	<u>REVIEWER</u>	<u>AFFILIATION</u>
A mechanistic model that has failure mode, failure location, and failure time, is needed.	J. L. Kelly E. A. Warman	Univ. of Virginia Stone and Webster
The model of the containment is a single zone. This is unrealistic and does not represent a "best estimate." Data from TMI-2 indicates that the atmosphere in the containment is heterogeneous.	E. A. Warman D. O. Campbell	Stone and Webster ORNL
In the model, the containment leak rate is 1%/day. The design basis for large dry PWR containments is 0.1%/day.	E. P. Rahe	Westinghouse

CODE VALIDITY AND SENSITIVITY

<u>ISSUE</u>	<u>REVIEWER</u>	<u>AFFILIATION</u>
Some of the modelling is oversimplified. Many instead of few control volumes might have been used to model long systems. Reactor internals, as they influence aerosol behavior, are inadequately modelled. Cesium iodide and tellurium should have been modelled so that they enter the vessel internals, piping, and pressurizer. The empirical release model, from NUREG-0772, is used in the CORSOR code but has questionable validity. Hydrogen burn would likely be attenuated by steam; this is not modelled in the MARCH 1.1 code.	J. L. Kelly A. B. Reynolds R. L. Ritzman D. S. Rowe B. R. Sehgal E. A. Warman	Univ. of Virginia SAI Rowe, Assoc. EPRI Stone and Webster
The codes out perform the current knowledge of the physical processes. Some portions of the codes are extremely sophisticated while other portions are extremely simplistic. Thus, the output is only as good as the input and the portions of the codes.	A. L. Cahn D. O. Campbell A. W. Castleman J. L. Kelly H. Kouts S. Levy G. Thompson	Bechtel ORNL Penn. State Univ. Univ. of Virginia BNL Levy, Inc. UCS
Uncertainties are inadequately treated. What they are and how they are to be resolved should be discussed.	T. Ginsberg W. D. Harrington H. Kouts R. L. Ritz E. P. Rahl G. Thompson	BNL Boston Edison BNL SAI Westinghouse USC
The results of CORRAL-2, NAUA, and industry codes are in disagreement. This should be discussed.	A. W. Castleman D. W. Cooper A. B. Reynolds	Penn. State Univ. Harvard University
A sensitivity analysis is needed for the analysis of aerosol deposition and resuspension.	A. W. Castleman H. Kouts	Penn. State Univ. BNL
The methodology is inconsistent. The results are thought of as "best estimate" but some calculations are conservative and some sequences are worse case.	D. O. Campbell W. D. Harrington B. R. Sehgal	ORNL Boston Edison EPRI

CODE VALIDITY AND SENSITIVITY (Continued)

<u>ISSUE</u>	<u>REVIEWER</u>	<u>AFFILIATION</u>
The assumption that the core instantaneously melts through the vessel after slumping is questionable.	E. P. Rahe	Westinghouse
The quoted volume of the auxiliary building seems small.	E. P. Rahe	Westinghouse
The melting of the control rod is simulated in an experiment using tin and steel. However, tin and steel melt at temperatures that are several hundred degrees hotter than melting temperatures of control rod materials. The validity of this simulation is questionable.	D. O. Campbell	ORNL
The codes produce results that are conflicting. For some sequences, the results from updated models are similar to results from the WASH-1400 study. Other codes that produce differing results should be producing similar results. These discrepancies must be rectified.	W. O. Harrington R. R. Hobbins H. Kouts	Boston Edison EG&G BNL
The results of the code should be verified against TMI-2 data.	A. L. Cahn D. O. Campbell T. Ginsberg A. B. Reynolds D. S. Rowe B. R. Sehgal G. Thompson	Bechtel ORNL BNL Rowe, Assoc. EPRI UCS
A "dry" sequence is assumed. This is unlikely.	H. Kouts B. R. Sehgal	BNL EPRI

REPORT STRUCTURE AND ORGANIZATION

<u>ISSUE</u>	<u>REVIEWER</u>	<u>AFFILIATION</u>
The objective and purpose of the report should be more explicit.	D. S. Rowe	Rowe, Assoc.
Equations 7.2 and B-9 should be expressed more conventionally.	D. W. Cooper C. E. Johnson	Harvard University Argonne
An updated review of the data is needed.	A. B. Reynolds	
The results should be highlighted.	D. S. Rowe	Rowe, Assoc.
The methodology and the equations should be discussed.	R. L. Ritzman D. S. Rowe	SAI Rowe, Assoc.
The report should be published with caution. Many qualifying statements are needed. A position on the highly controversial topic of containment failure should be taken. At best, the report should be considered on an interim measure.	D. O. Campbell J. L. Kelly A. B. Reynolds	ORNL Univ. of Virginia
The basis for the gap release needs to be stated.	A. W. Castleman	Penn. State Univ.
Temperature is expressed in both the Fahrenheit scale and the Celsius scale. One should be chosen.	E. P. Rahe	Westinghouse
The Surry plant is not representative of the current large dry PWR containments.	E. P. Rahe	Westinghouse
The fission product release is dependent on the location of a break in the primary system. Though this is in the research, this is not stated in the conclusions.	E. P. Rahe	Westinghouse

REPORT STRUCTURE AND ORGANIZATION (Continued)

<u>ISSUE</u>	<u>REVIEWER</u>	<u>AFFILIATION</u>
The calculations and the assumptions are not placed in an adequate perspective.	E. P. Rahe	Westinghouse
The terms "deposition mechanism" and "deposition term" are poorly defined (p5-16).	D. O. Campbell	ORNL

SUPPRESSION POOL SCRUBBING SPARC CODE

**A.K. POSTMA
P.C. OWCZARSKI
W.K. WINEGARDNER**

BATTELLE PACIFIC NORTHWEST LABORATORY

MAY 24, 1983

OVERVIEW OF SPARC DEVELOPMENT

- **PART OF PNL PROGRAM ON
PERFORMANCE OF ENGINEERED
SAFETY SYSTEMS UNDER SEVERE
ACCIDENT CONDITIONS**

**POOLS, SPRAYS, ICE, FILTERS,
COOLERS**

- **HIGH PRIORITY, LIMITED TIME**
- **PRELIMINARY - SUBJECT TO
IMPROVEMENT**

GOALS OF MODELLING EFFORT

- REALISTIC PREDICTION OF PARTICLE SCRUBBING IN SUPPRESSION POOLS
- ACCOUNT FOR MAJOR PHENOMENA
 - PARTICLE SIZE DISTRIBUTION
 - POOL TEMPERATURE
 - POOL DEPTH
 - STEAM CONDENSATION/
EVAPORATION
- COMPATIBLE WITH TRAP-MELT AND MARCH

MODELLING APPROACHES CONSIDERED

- **BUBBLE SCRUBBING**
- **ENERGY DISSIPATED/UNIT
VOLUME OF GAS**
- **APPLICATION OF EXPERIMENTAL
DATA**

APPLICATION OF EXPERIMENTAL DATA

- **DATA BASE IS LIMITED**

- SATURATED POOLS

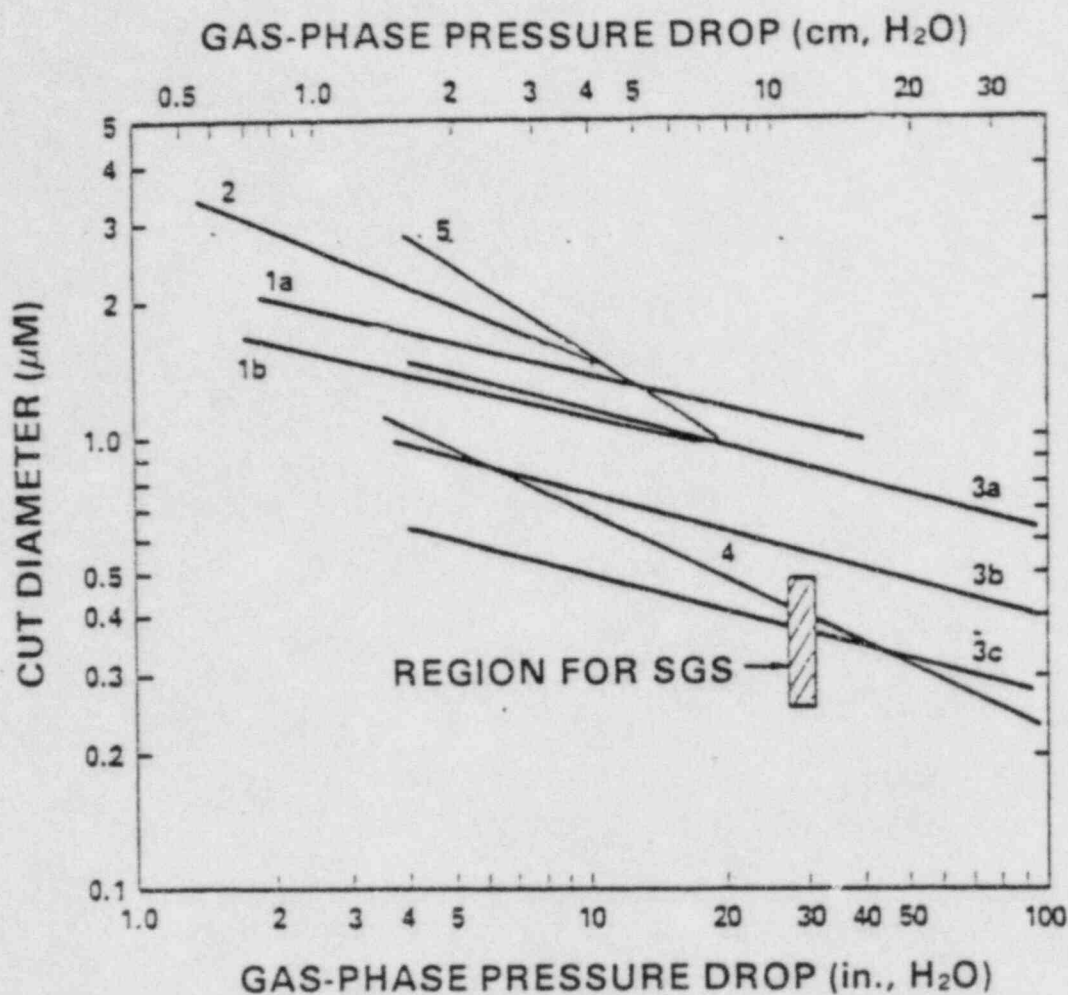
- STEAM/GAS RATIO

- PARTICLE SIZE EFFECT

- SIZE SCALE OF TESTS

- **TECHNICAL JUSTIFICATION OF
SELECTED DF WOULD BE DIFFICULT**

CUT DIAMETER VERSUS ENERGY



- 1a SIEVE-PLATE COLUMN, 0.2-in. HOLE DIAMETER
- 1b SIEVE-PLATE COLUMN, 0.125-in. HOLE DIAMETER
- 2 PACKED COLUMN, 1-in. RINGS OR SADDLES
- 3a FIBROUS PACKED BED, 0.012-in. DIAMETER FIBERS
- 3b FIBROUS PACKED BED, 0.004-in. DIAMETER FIBERS
- 3c FIBROUS PACKED BED, 0.002-in. DIAMETER FIBERS
- 4 GAS-ATOMIZED SPRAY
- 5 MOBILE BED, 1 TO 3 STAGES, HOLLOW SPHERES

CUT DIAMETER VS ENERGY METHOD

- **SIMPLE, REQUIRES LITTLE INPUT**
- **SUPPORTED BY DATA OBTAINED FOR SUBMERGED GRAVEL SCRUBBER**
 - MECHANISTIC MODELS GREATLY UNDERPREDICTED EFFICIENCY**
- **WOULD NOT ACCOUNT FOR STEAM CONDENSATION, GEOMETRY, POOL TEMPERATURE, PARTICLE GROWTH**
- **ENERGY METHOD SHOULD BE RETAINED AS A BASIS FOR COMPARISON**

BUBBLE SCRUBBING MODEL

- **FUCHS DESCRIBES BUBBLING MODEL**
 - SEDIMENTATION**
 - INERTIAL DEPOSITION**
 - DIFFUSIONAL DEPOSITION**
- **DOES NOT EXPLICITLY MODEL REMOVAL IN BUBBLE FORMATION REGION**
- **BUBBLE SIZE IS CRITICAL INPUT PARAMETER**
- **BUBBLE CIRCULATION IS A CRITICAL FACTOR**
- **IMPORTANT DEPLETION MECHANISMS CAN BE MODELLED**

DEPLETION MECHANISMS IN SPARC

- **CONDENSATION OF STEAM**
- **SEDIMENTATION**
- **CENTRIFUGAL DEPOSITION**
- **DIFFUSION**
- **STEAM EVAPORATION INTO RISING BUBBLE**
- **GROWTH OF SOLUBLE PARTICLES**
- **ENTRAINMENT OF POOL LIQUID**

DECONTAMINATION FACTOR

$$DF = \frac{\text{AEROSOL MASS ENTERING}}{\text{AEROSOL MASS LEAVING}}$$

$$DF = \frac{1}{\text{PENETRATION}} = \frac{1}{1\text{-FRACTIONAL EFFICIENCY}}$$

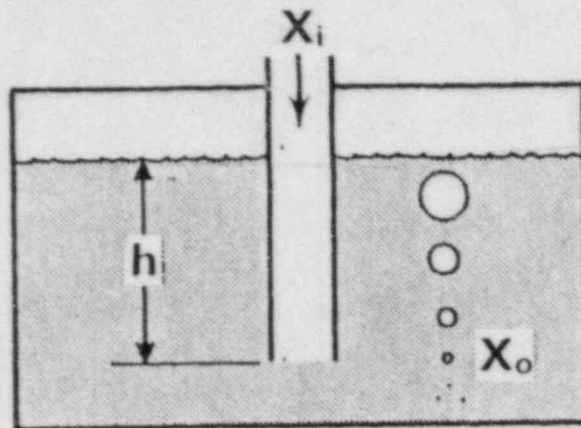
FOR A SINGLE PARTICLE SIZE

$$P_0 = P_1 P_2 \dots P_N \quad \text{AND} \quad DF_0 = DF_1 DF_2 \dots DF_N$$

FOR AN AEROSOL POPULATION

$$P = \sum_{i=1}^{i=n} F_i P_i = \sum_{i=1}^{i=n} F_i / DF_i = 1 / DF$$

DEPOSITION DUE TO STEAM CONDENSATION



ASSUMPTIONS:

BUBBLES ATTAIN THERMAL
EQUILIBRIUM NEAR OUTLET

NON-CONDENSIBLE GAS INVENTORY
IS CONSTANT

$$\text{FRACTION OF GAS CONDENSED} = 1 - \frac{X_i}{X_o}$$

$$\text{ASSUMING AEROSOLS GO WITH GAS, } DF = \frac{X_o}{X_i}, DF \geq 1$$

$$X_o = 1 - \frac{P_w}{P_T} = 1 - \frac{P_w}{P + \rho h}$$

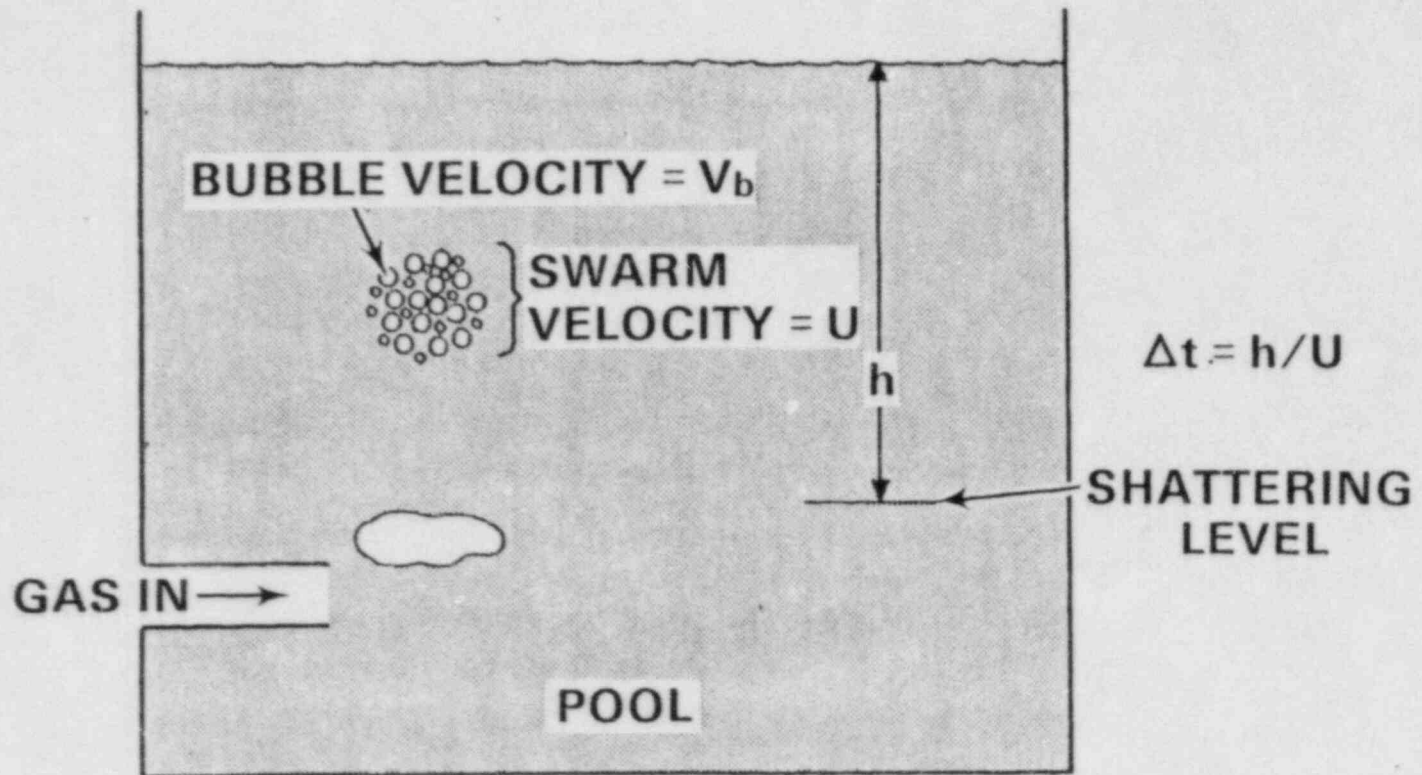
X = MOLE FRACTION OF NON-CONDENSIBLES

P_w = VAPOR PRESSURE OF WATER IN POOL

P = ATMOSPHERE PRESSURE

h = SUBMERGENCE, ρ = WATER DENSITY

BUBBLE AND SWARM RISE VELOCITIES



STEAM EVAPORATION VELOCITY

- FUCHS CITES TESTS OF REMY TO ILLUSTRATE SIGNIFICANT IMPEDING EFFECT OF EVAPORATION INTO BUBBLES
- INWARD FLUX EXPECTED FOR RISING BUBBLES
- WATER VAPOR FLUX COMPUTED FROM PENETRATION THEORY
 - ΔT ACROSS LIQUID FILM
 - ΔC ACROSS GAS FILM
 - FLUX DIRECTED NORMAL TO SURFACE
 - FLUX INCREASES WITH HEIGHT IN POOL AND WITH POOL TEMPERATURE

POOL TEMPERATURE

- EVAPORATIVE COOLING COOLS POOL
BELOW NORMAL BOILING POINT

FOR 1 ATM., ASSUMING SATURATION OF
EXITING GASES:

<u>$T_i, ^\circ\text{C}$</u>	<u>X_i</u>	<u>$T_e, ^\circ\text{C}$</u>
1000	1.0	77.4
500	1.0	68.0
1000	0.1	98.3

- REALISTIC POOL TEMP NEEDED FOR STEAM
EVAP. VELOCITY
- SPARC ALLOWS EQUIL. TEMP OR USER
INPUT

PARTICLE GROWTH BY WATER SORPTION

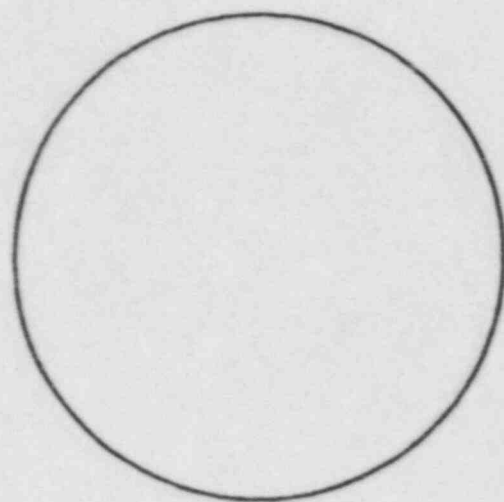
- SOLUBLE PARTICLES ABSORB WATER AND GROW IF RELATIVE HUMIDITY IS GREATER THAN CRITICAL VALUE
- AT EQUILIBRIUM VAPOR PRESSURE IN SOL'N DROP EQUALS WATER VAPOR PRESSURE IN ATMOSPHERE
- USING FLETCHER'S FORMULA:

DRY PARTICLE RADIUS, μm	EQUIL. DROP RADIUM, μm	
	H=0.9	H=0.99
0.01	0.0195	0.0295
0.1	0.195	0.425
1.0	1.95	4.45

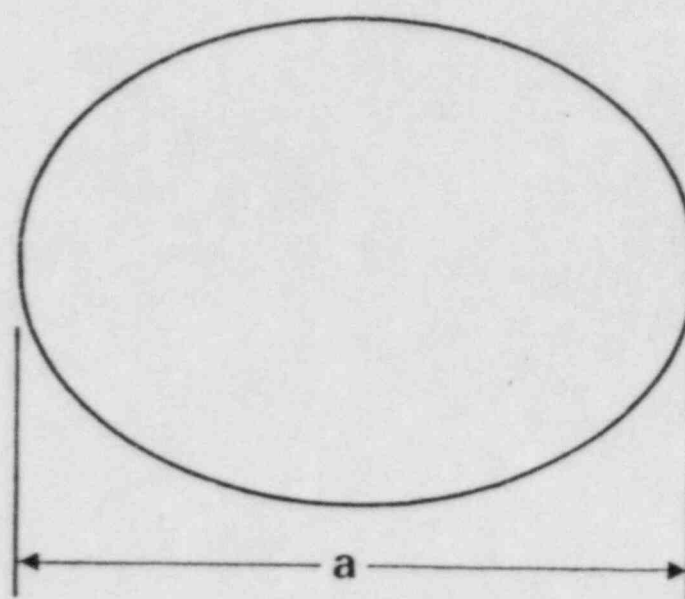
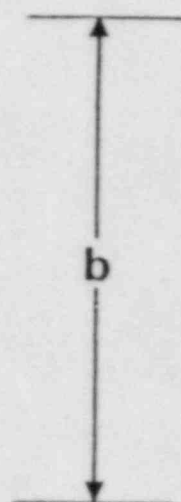
- SPARC ALLOWS FOR WATER UPTAKE BY SOLUBLE MATERIAL

BUBBLE SHAPES

a/b IS AN INPUT TO SPARC

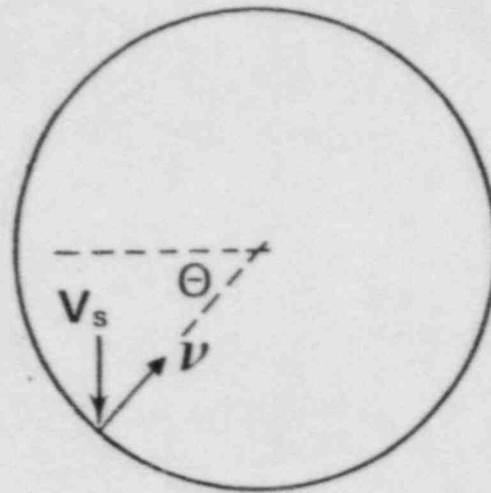


SPHERE



OBLATE SPHEROID

SEDIMENTATION



$$V = V_s - \nu \sin \theta$$

$$dA = 2\pi R^2 \cos \theta \sin \theta d\theta$$

$$\int V dA = \pi R^2 (V_s - 2/3 \nu)$$

$$DF = \exp \left[\frac{3/2 V_s - \nu}{D} \right] \Delta t, DF \geq 1$$

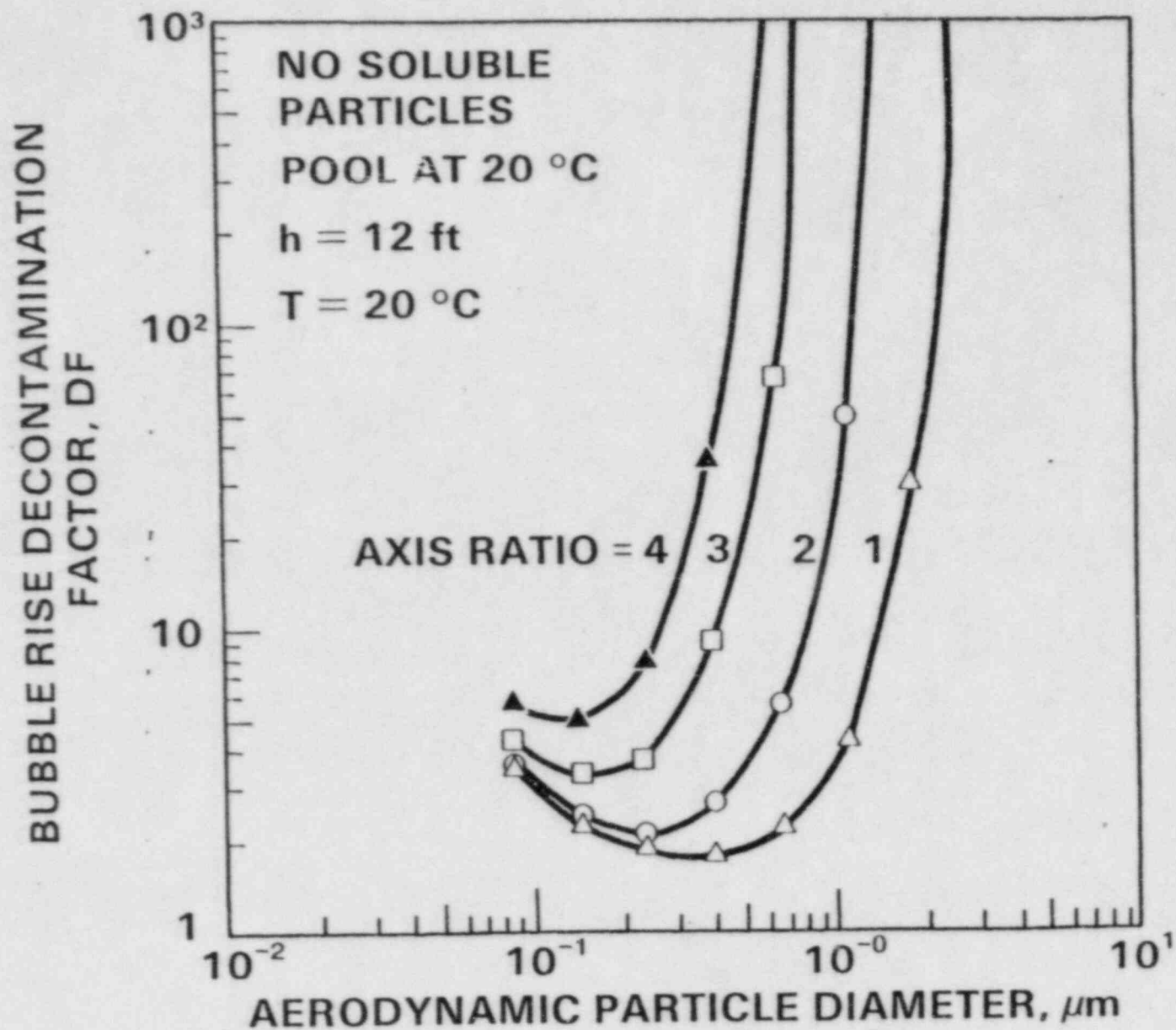
V_s = SETTLING VELOCITY

ν = STEAM EVAPORATION VELOCITY

D = BUBBLE DIAMETER

Δt = TIME FOR SWARM RISE

SPARC PREDICTIONS



KEY INPUTS TO SPARC

- PARTICLE SIZE DISTRIBUTION
- POOL TEMPERATURE (OR INLET GAS TEMPERATURE)
- PRESSURE ABOVE POOL
- EFFECTIVE SCRUBBING HEIGHT
- AVERAGE BUBBLE DIAMETER
- STEAM/GAS RATIO OF INLET GAS
- INLET GAS COMPOSITION (H_2 , H_2O , CO , CO_2)

KEY IMPROVEMENTS AND EVALUATIONS

- **INTERNAL PREDICTION OF BUBBLE SIZE DISTRIBUTION**
- **ENTRANCE IMPINGEMENT DEPLETION (BCL ADDITION)**
- **COMPARISON WITH OTHER CODES, MODELS**
EPRI, GE, ENERGY - CUT DIAMETER
- **COMPARISON WITH EXPERIMENTS**
- **ENTRAINMENT MODEL**
- **BUBBLE CIRCULATION**

SUMMARY AND CONCLUSIONS

- **SPARC CODE DEVELOPED IN SHORT TIME FRAME**
- **DOMINANT DEPLETION PROCESSES HAVE BEEN INCLUDED**
- **PREDICTED DF IS VERY DEPENDENT ON PARTICLE SIZE**
- **OVERALL POOL DF WILL DEPEND CRITICALLY ON AERODYNAMIC PARTICLE DIAMETER**
- **IMPROVEMENTS AND EVALUATIONS ARE UNDERWAY**

**RADIONUCLIDE RELEASE UNDER
SPECIFIC LWR ACCIDENT CONDITIONS --
VOLUME III, BWR, MARK III DESIGN**

PEER REVIEW MEETING

**U.S. Nuclear Regulatory Commission
Washington, D.C.**

MAY 24 & 25, 1983

Presentation Notes

PRESENTATION TOPICS

- INTRODUCTION (J.A. GIESEKE)
- SEQUENCE DESCRIPTIONS AND THERMAL HYDRAULICS
(R.W. DENNING)
- RELEASE FROM FUEL AND TRANSPORT IN REACTOR
COOLANT SYSTEM (M.R. KUHLMAN)
- SUMMARY (J.A. GIESEKE)

DESCRIPTION OF ACCIDENT SEQUENCES AND THERMAL-HYDRAULIC RESULTS

BWR -- MARK III DESIGN

PLANT SELECTION

GRAND GULF WAS USED IN RSSMAP ANALYSES.

SEQUENCE SELECTION

RISK DOMINANT SEQUENCES -- TC, TPI (TW), TQUV

CONTAINMENT FAILURE MODE

FAILURE PRESSURE -- 72 PSIA

LOCATION -- JUNCTION OF CYLINDRICAL WALL AND DOME

FOLLOWING PRIMARY CONTAINMENT FAILURE, ENCLOSURE
BUILDING WOULD NOT PREVENT MAJOR OUTLEAKAGE

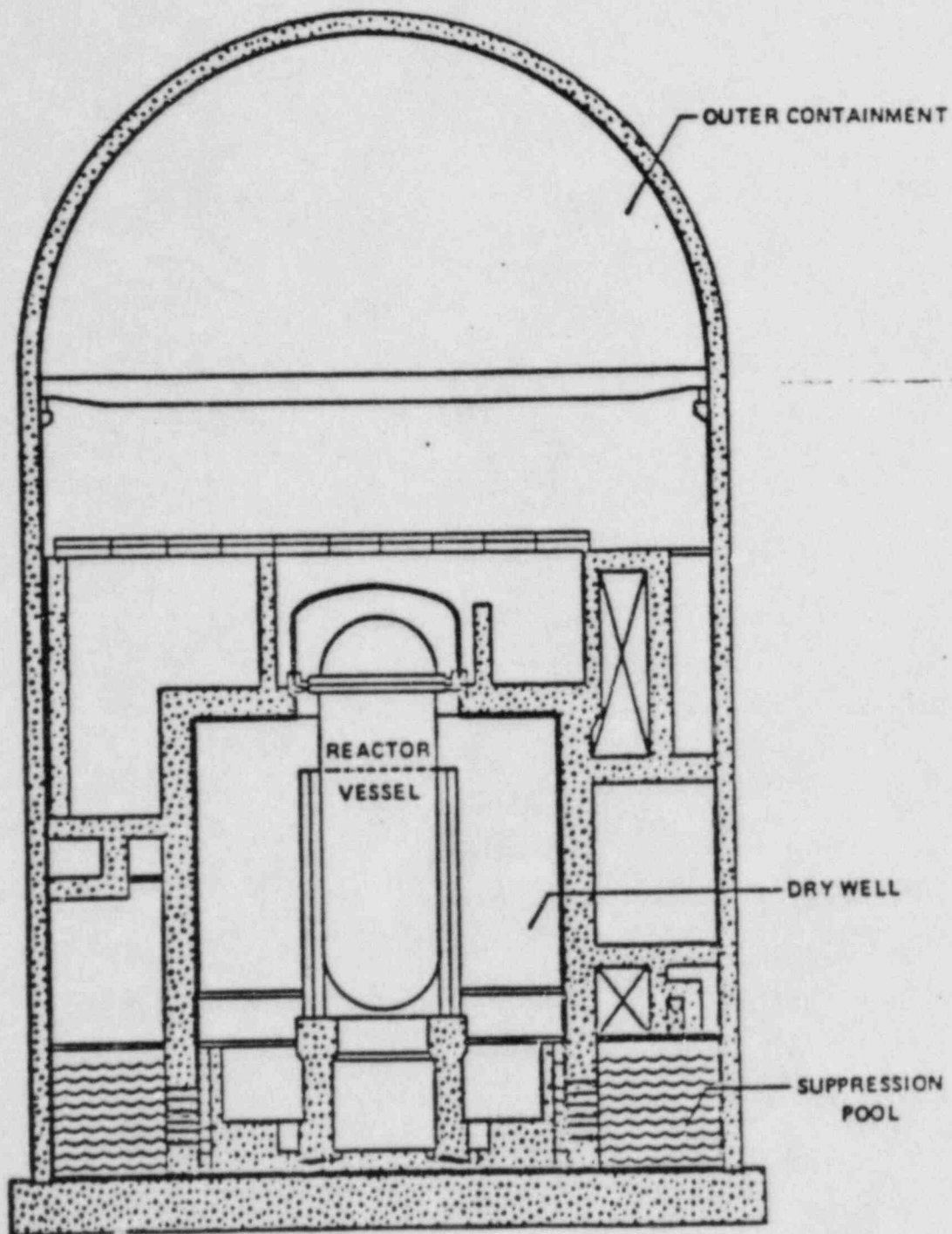


FIGURE 4.1 BWR MARK III CONTAINMENT DESIGN

SEQUENCE TC -- TRANSIENT WITH FAILURE TO SCRAM

	<u>TIME (MIN)</u>
CONTAINMENT FAILURE	80
BEGIN CORE MELT	118
PRESSURE VESSEL FAILURE	196

CONTAINMENT FAILURE MODE - γ'

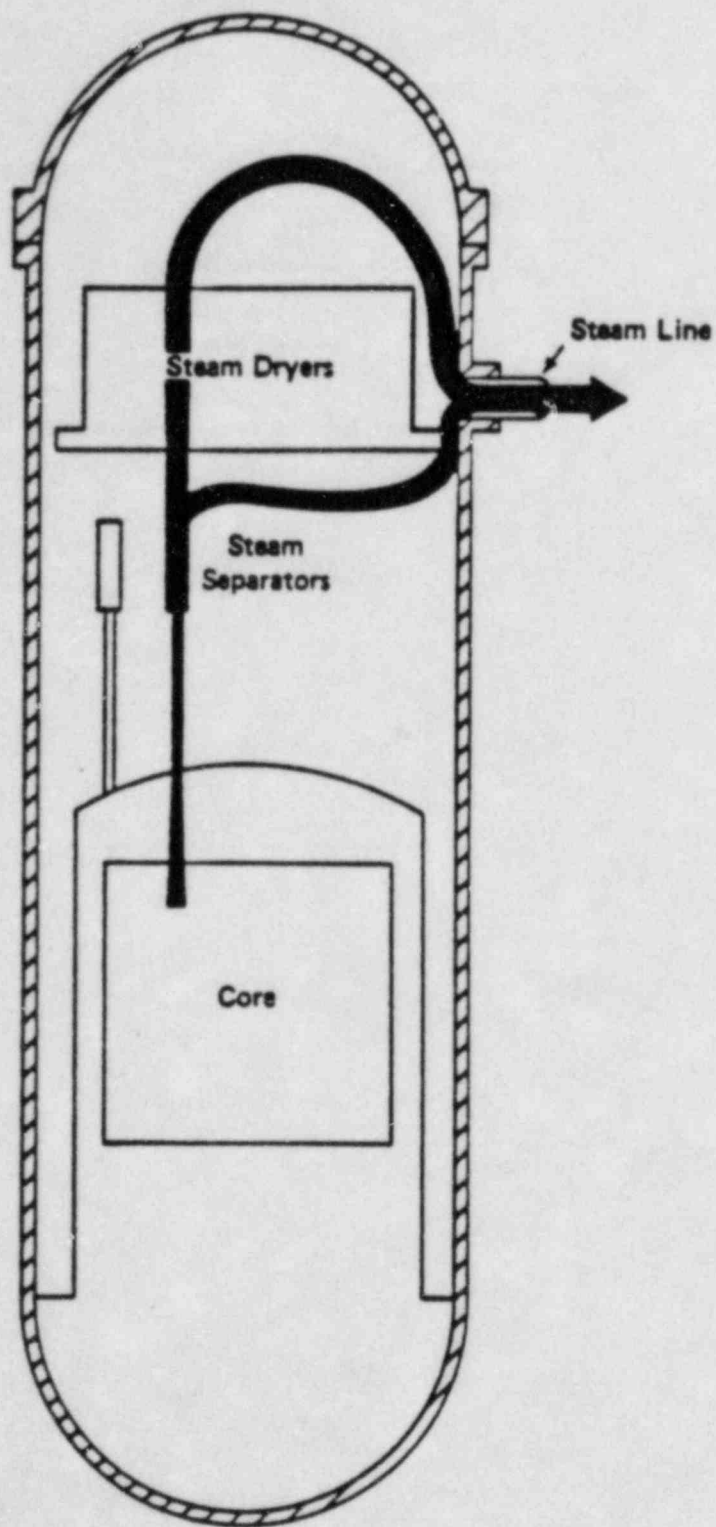


FIGURE 6.4 FLOWPATHS FOR FISSION PRODUCT TRANSPORT IN
RCS - SEQUENCES TC, TQUV, AND TPI

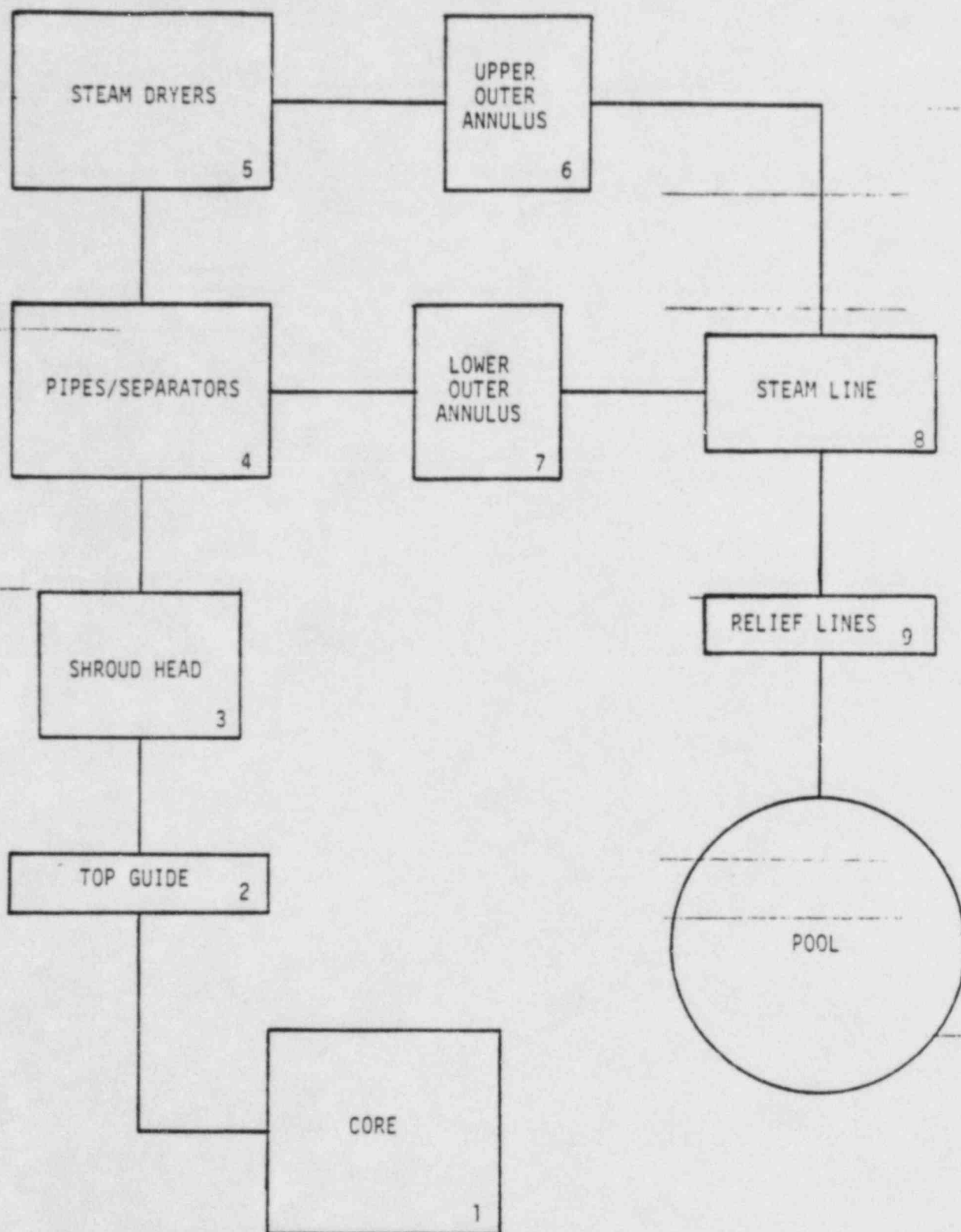


FIGURE 6.5 SCHEMATIC OF CONTROL VOLUMES FOR THE GRAND GULF SEQUENCES

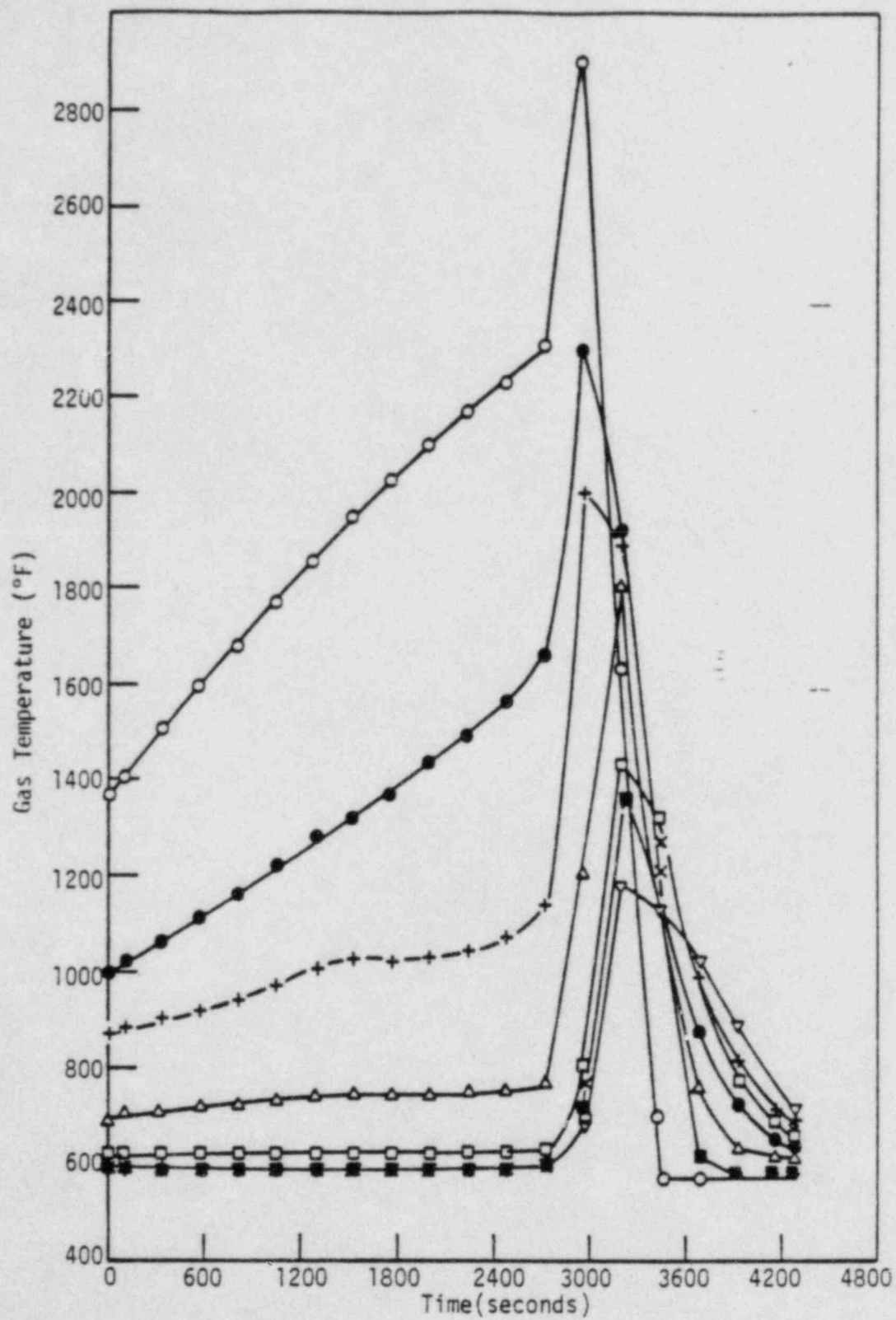


FIGURE 6.6 GAS TEMPERATURES IN RCS VOLUMES - SEQUENCE TC

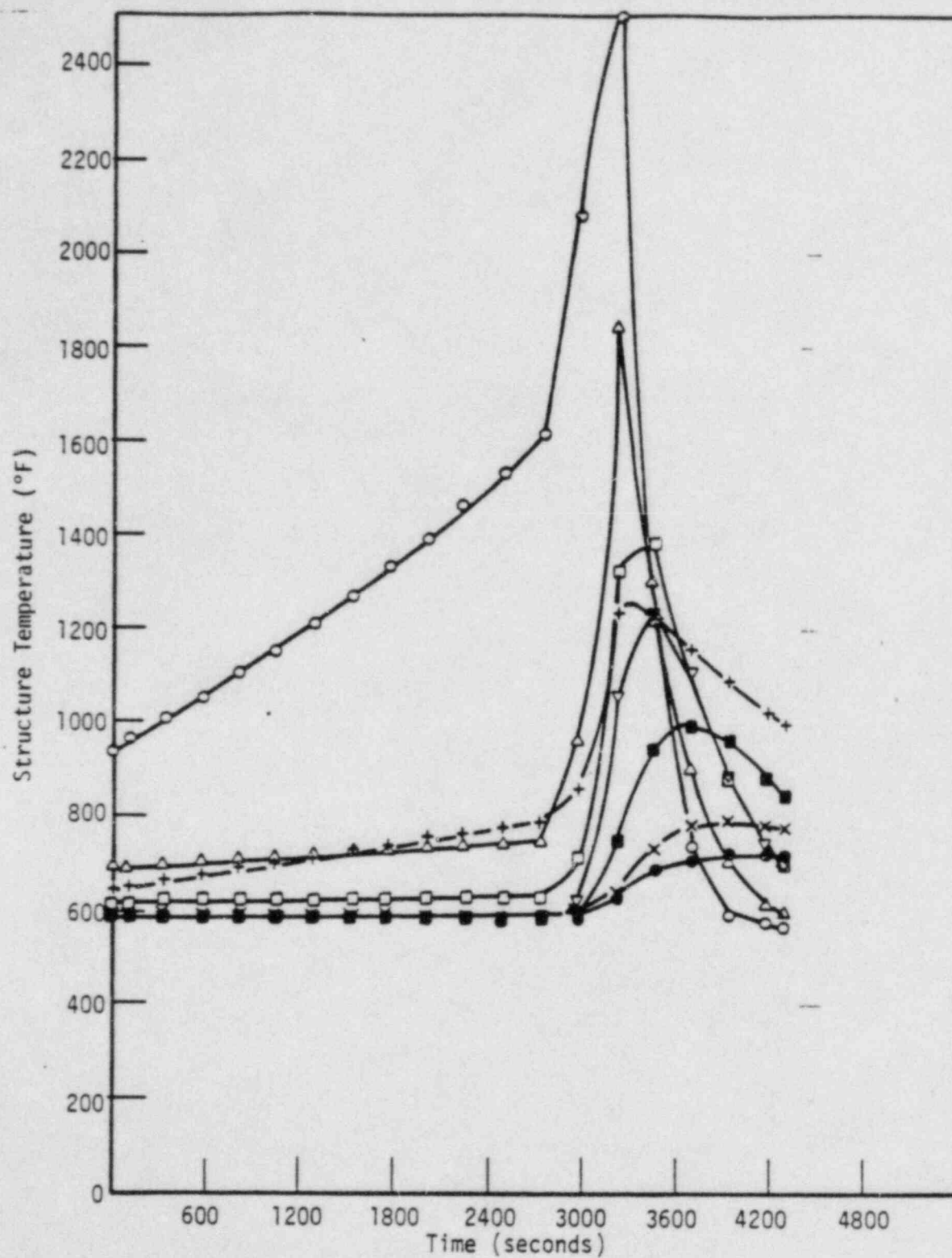


FIGURE 6.7 STRUCTURE TEMPERATURES IN RCS VOLUMES - SEQUENCE TC

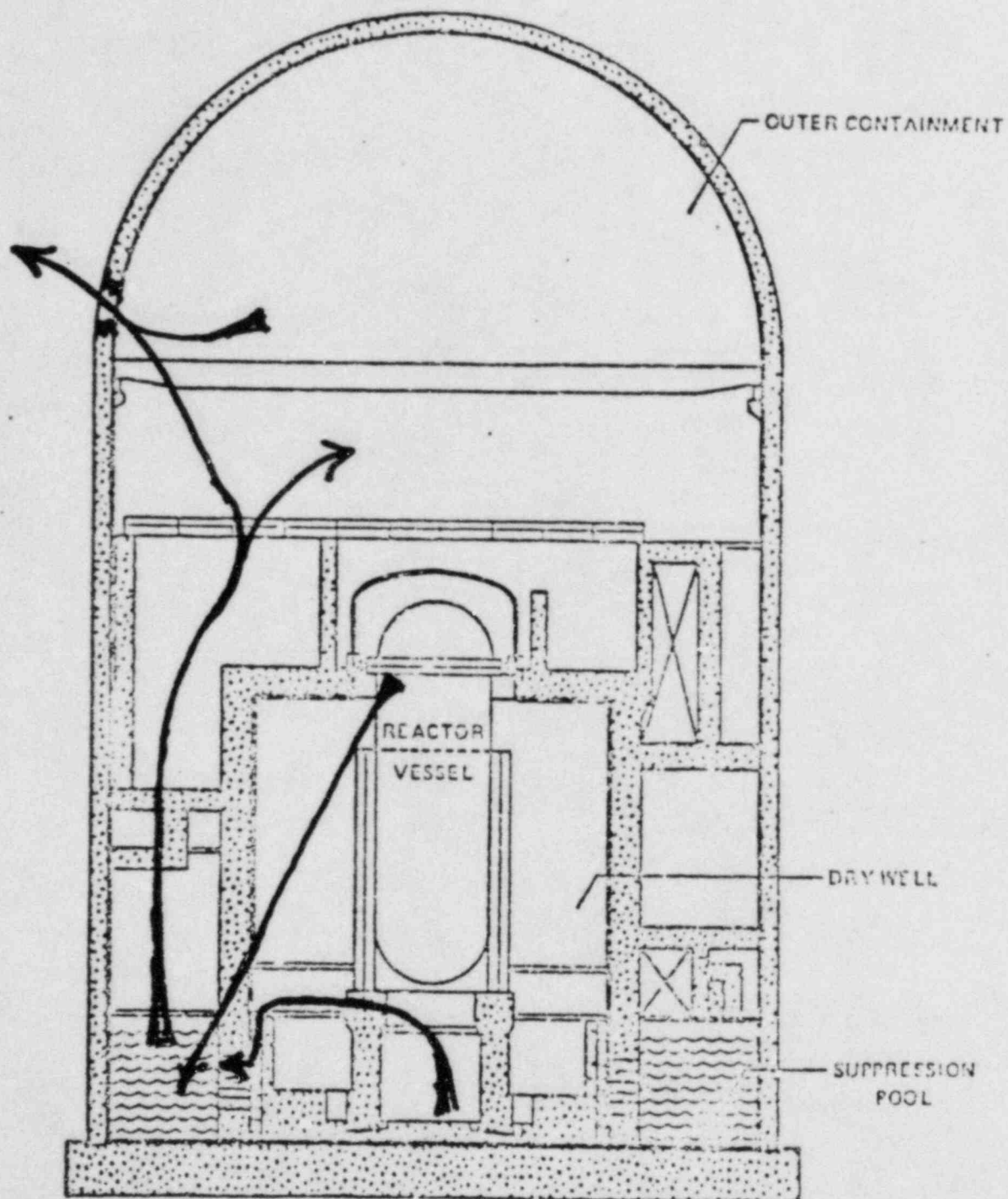


FIGURE 6.8 FLOWPATHS FROM THE VESSEL AND REACTOR CAVITY TO THE ENVIRONMENT

SEQUENCE TPI -- TRANSIENT WITH STUCK OPEN RELIEF VALVE
AND LOSS OF DECAY HEAT REMOVAL

	<u>TIME (MIN)</u>
CONTAINMENT FAILURE	1323
BEGIN CORE MELT	1635
PRESSURE VESSEL FAILURE	1953

FAILURE MODE - γ'

GRAND GULF TP1

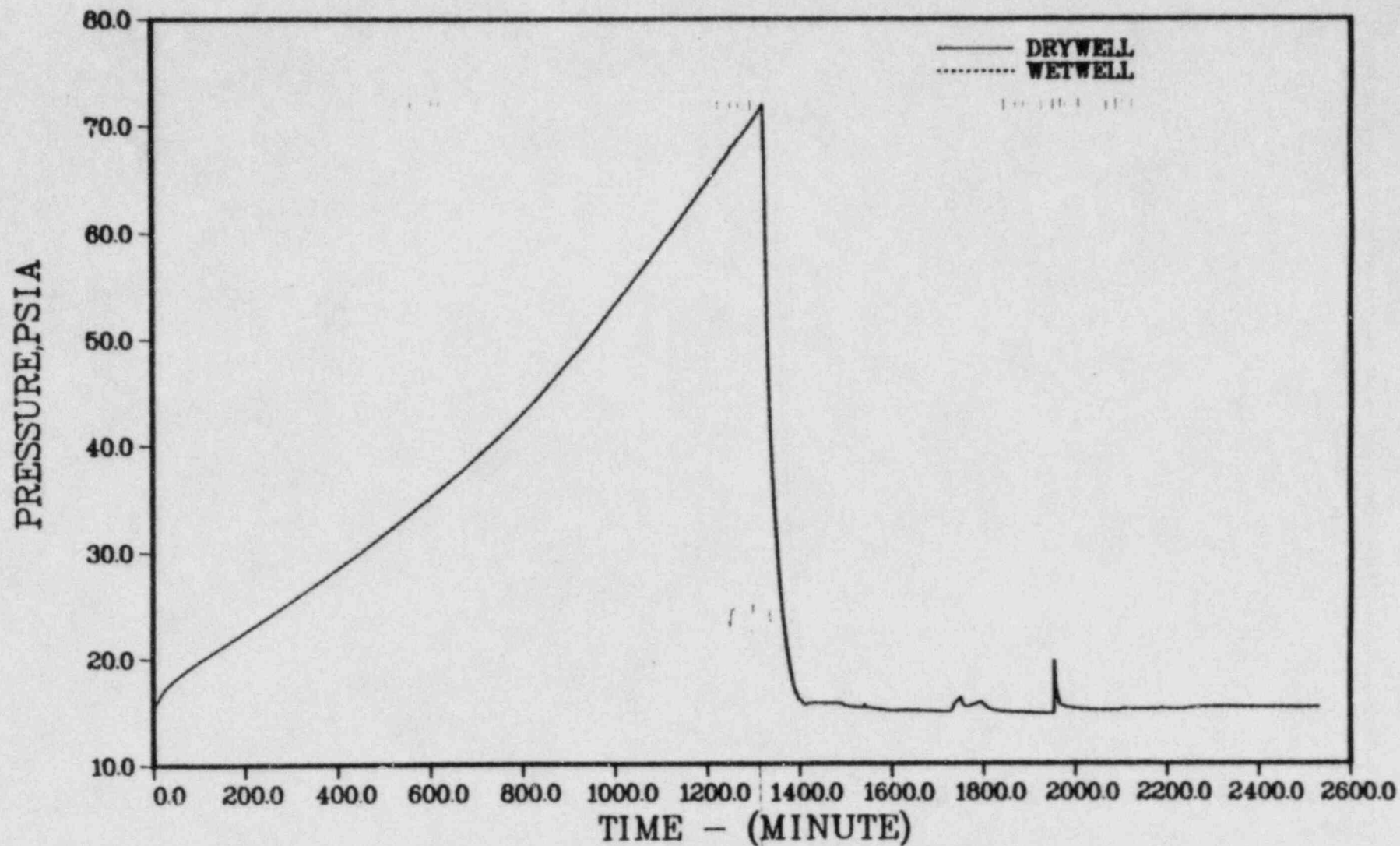


FIGURE 6.10 PRESSURES IN CONTAINMENT VOLUMES - SEQUENCE TP1

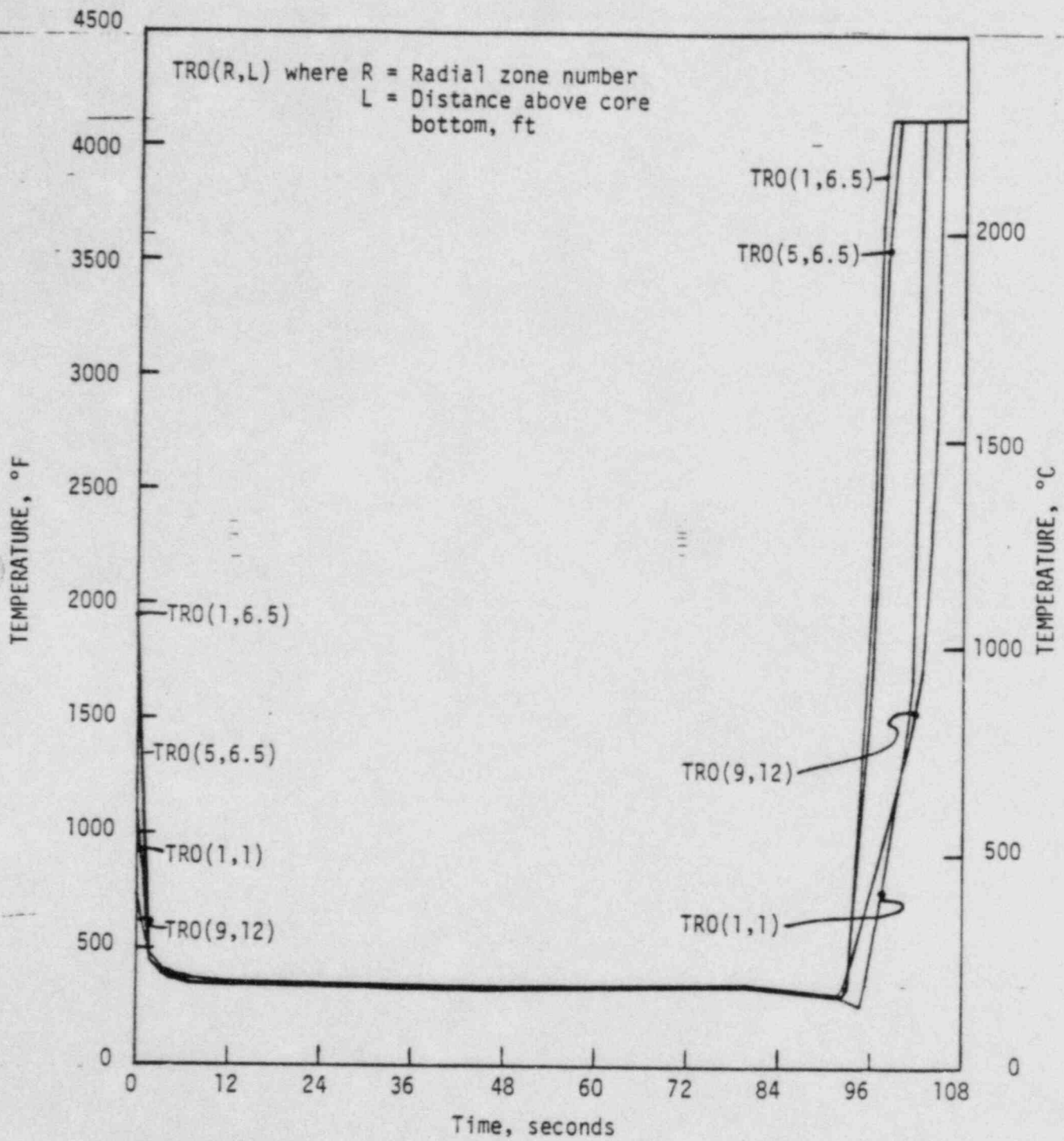


FIGURE 6.11 TEMPERATURES IN SELECTED FUEL REGIONS AS A FUNCTION OF TIME - SEQUENCE TPI

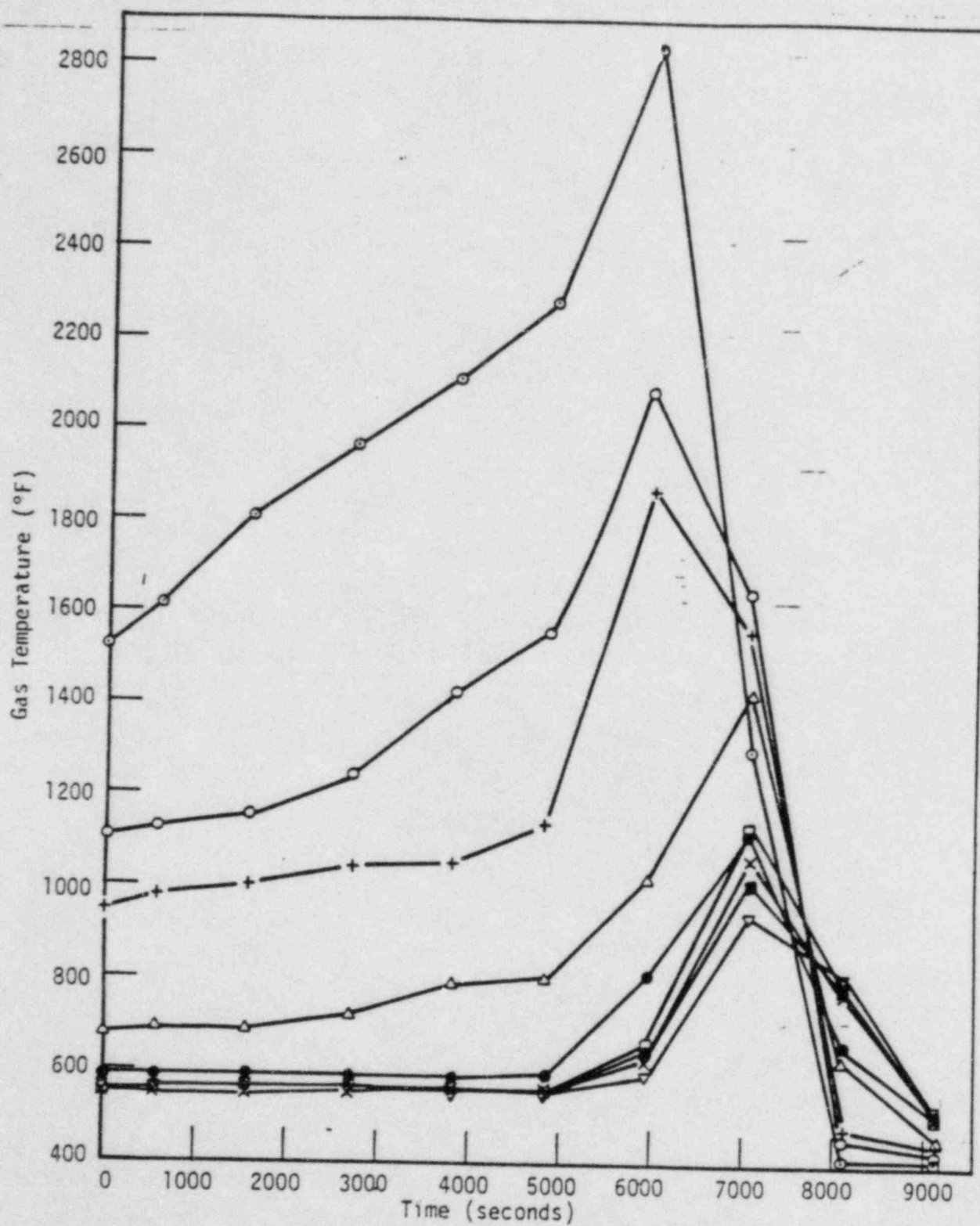


FIGURE 6.12 GAS TEMPERATURES IN RCS VOLUMES - SEQUENCE TPI

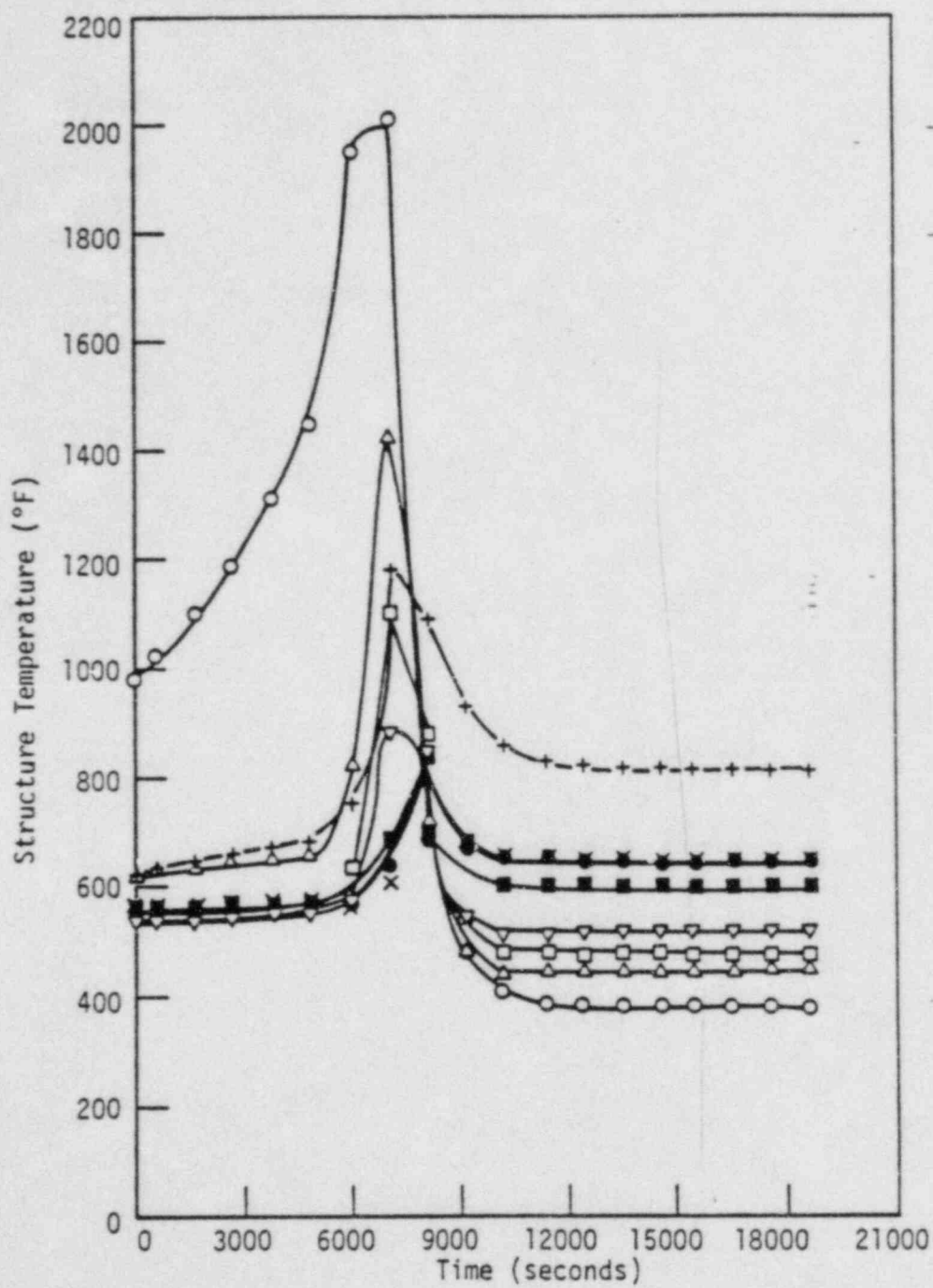


FIGURE 6.13 STRUCTURE TEMPERATURES IN RCS VOLUMES - SEQUENCE TPI

SEQUENCE TQUV -- TRANSIENT WITH LOSS OF ALL COOLANT MAKEUP

	<u>TIME (MIN)</u>
CONTAINMENT FAILURE	96
BEGIN CORE MELT	83
PRESSURE VESSEL FAILURE	240

FAILURE MODE - γ' (HYDROGEN BURN)

GRAND GULF TQUV

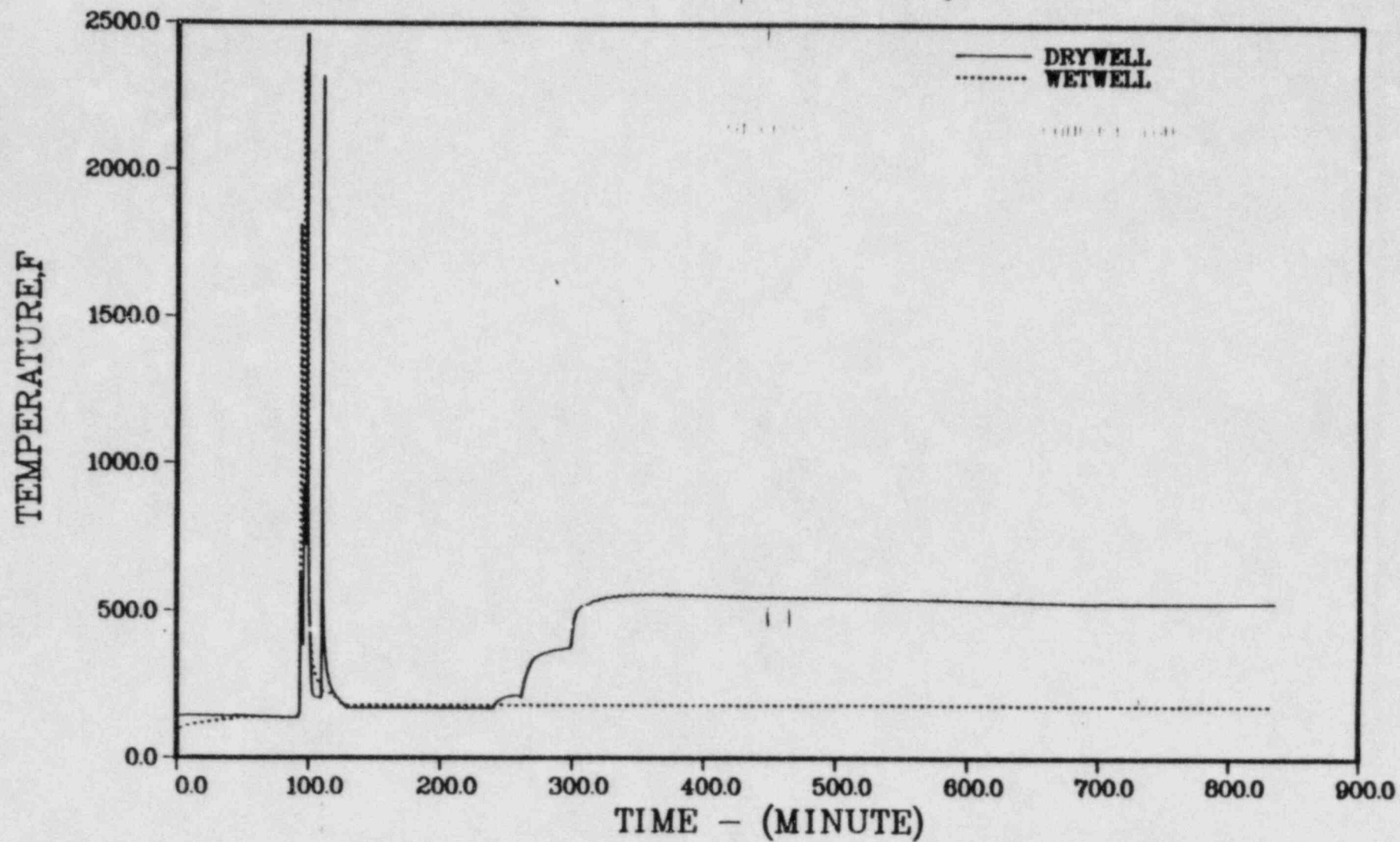


FIGURE 6.14 GAS TEMPERATURES IN CONTAINMENT VOLUMES - SEQUENCE TQUV

GRAND GULF TQUV

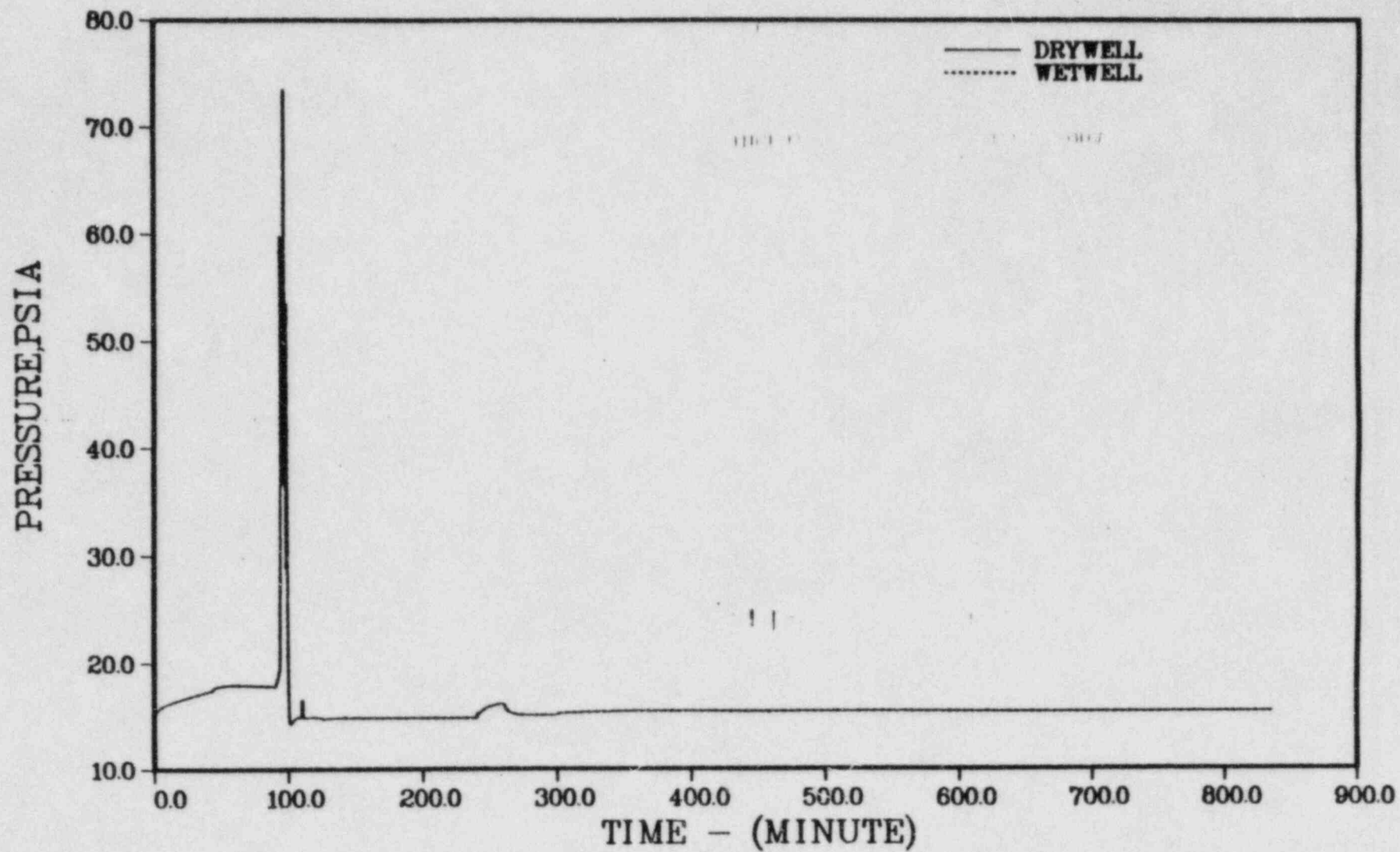


FIGURE 6.15 PRESSURES IN CONTAINMENT VOLUMES - SEQUENCE TQUV

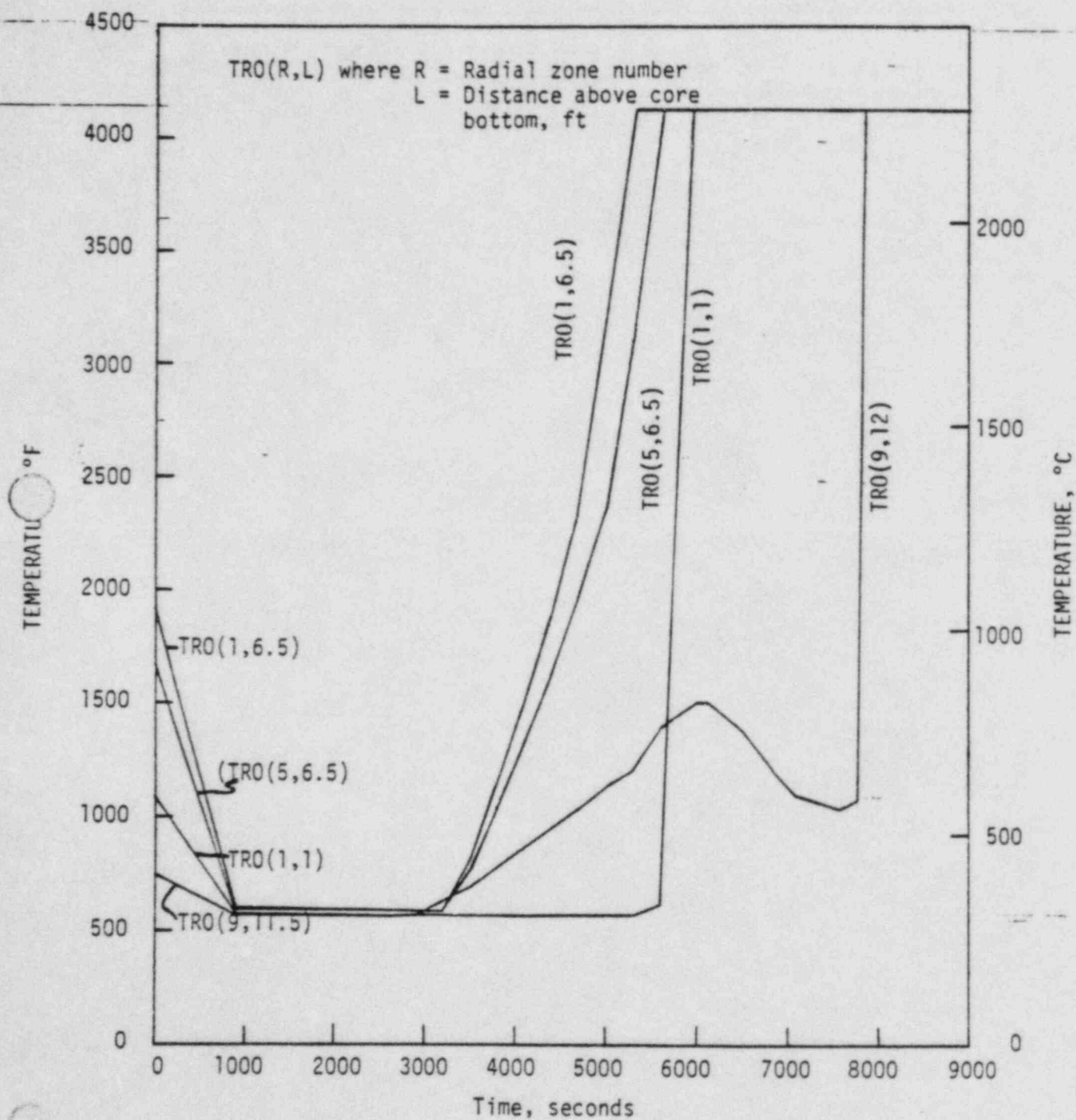


FIGURE 6.16 TEMPERATURES OF SELECTED FUEL REGIONS AS A FUNCTION OF TIME - SEQUENCE TQV

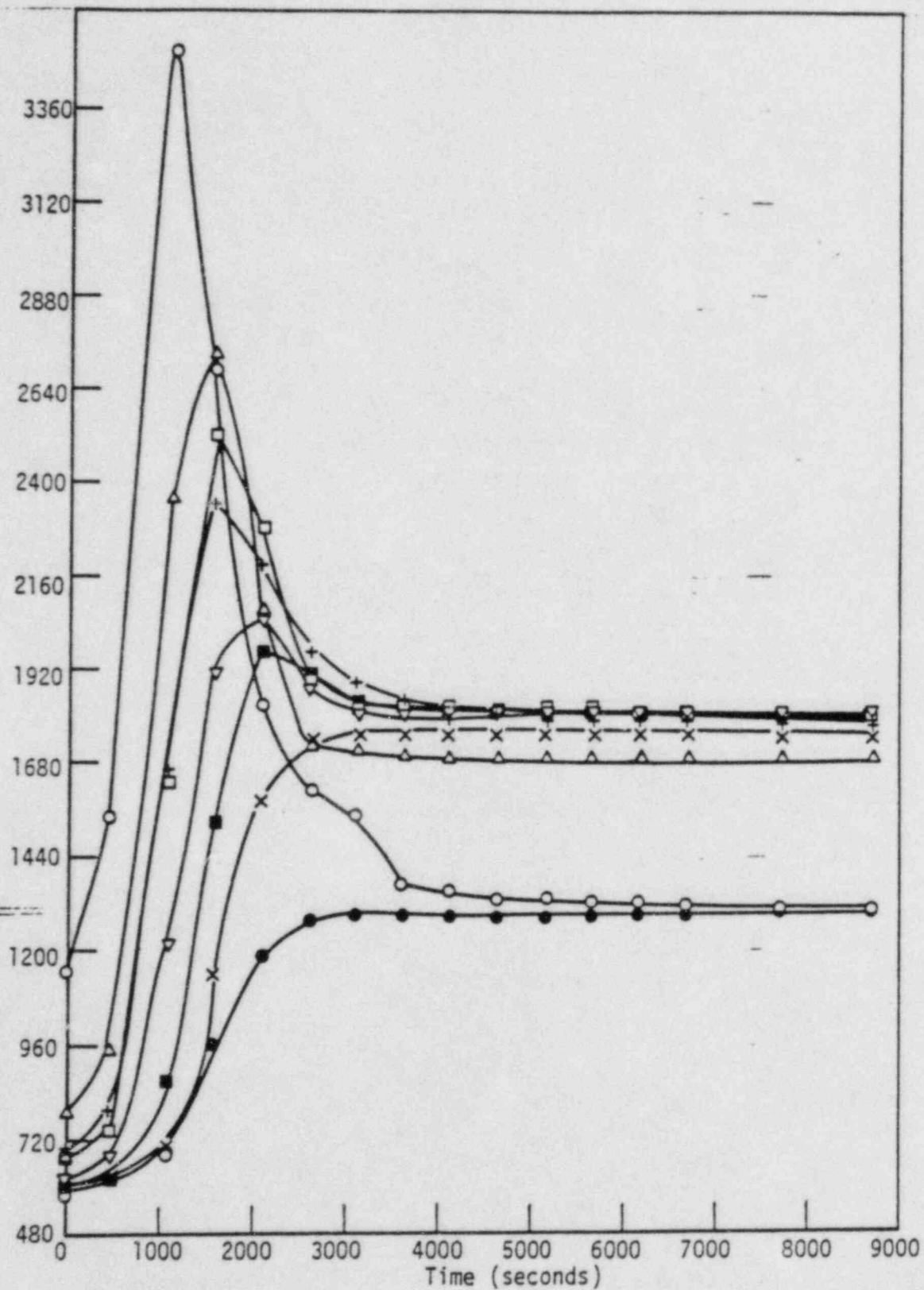


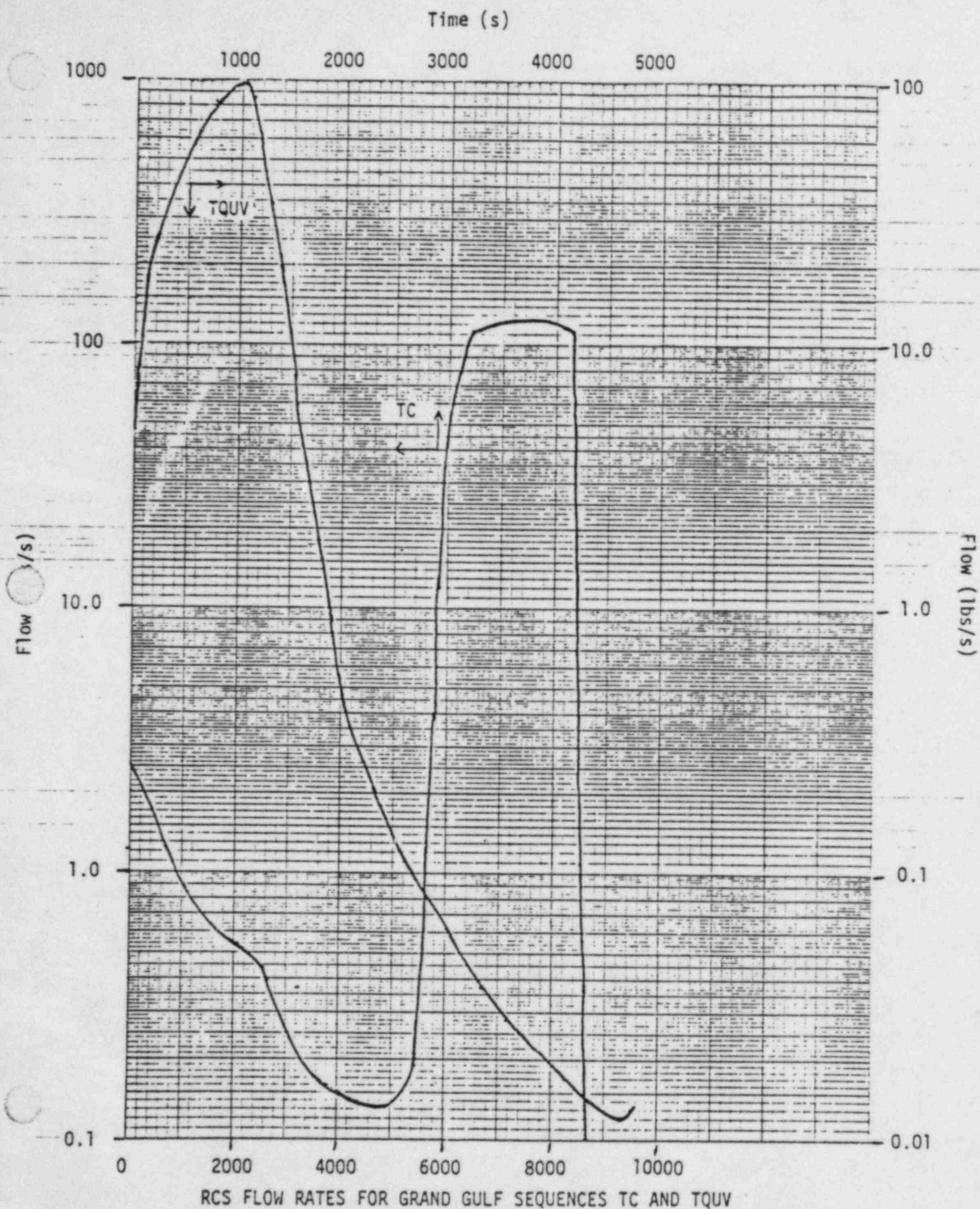
FIGURE 6.18 STRUCTURE TEMPERATURES IN RCS VOLUMES - SEQUENCE TQV

RCS TRANSPORT AND DEPOSITION
FOR THE GRAND GULF SEQUENCES
(TC, TQUV, TPI)

- RCS THERMAL-HYDRAULIC CHARACTERISTICS
- RELEASE FROM CORE
- RETENTION IN/RELEASE FROM RCS
- EMITTED PARTICLE SIZE

RCS EVENT SUMMARY FOR GRAND GULF SEQUENCES

	<u>CORE COVERY</u>	<u>MELT START</u>	<u>VESSEL DRY OUT</u>	<u>VESSEL FAILURE</u>	
TC	88	118	190	196	FLUSH OF RCS AT 168 (PARTIAL)
TOUV	46	83	123*	240	HIGH FLOWS TILL 126
TPI	1525	1635	1792*	1953	FLUSH OF RCS AT 1752



RCS FLOW RATES FOR GRAND GULF SEQUENCES TC AND TQUV

CORSOR PREDICTIONS OF MASSES OF SPECIES RELEASED FROM THE
CORE (TOTAL) AND TRAP-MELT PREDICTIONS OF MASSES RETAINED IN
THE RCS (RET) DURING THE TQUV SEQUENCE FOR THE GRAND GULF PLANT

TIME (s)	CsI		CsOH		Te		AEROSOL	
	RET (KG)	TOTAL (KG)	RET (KG)	TOTAL (KG)	RET (KG)	TOTAL (KG)	RET (KG)	TOTAL (KG)
500	0.7	8.2	5.8	56.5	0.4	.5	4.3	57.1
1000	2.0	19.6	48.4	115	1.8	1.8	38.2	219
1500	1.4	23.3	53.8	149	4.1	4.2	55.8	341
2000	1.4	23.6	54.1	150	6.1	6.2	57.3	385
3000	0.8	23.6	50.8	151	6.4	6.4	58.4	398
3990	0.2	23.7	47.5	151	6.4	6.4	58.8	399
4980	-	24.3	49.1	155	6.5	6.5	61.2	403
5980	0.0	26.5	53.5	169	6.7	7.0	72.4	420
6980	-	31.4	62.9	198	7.0	7.9	121	482
7970	0.1	35.6	76.0	222	7.6	9.7	284	660
8970	0.2	36.3	86.6	227	8.3	11.8	530	906
9470	0.2	36.3	90.4	227	8.7	13.0	655	1030

TABLE . CORSOR PREDICTIONS OF PERCENT OF INVENTORY EMITTED
BY CORE PRIOR TO VESSEL DRYOUT FOR THE THREE ACCI-
DENT SEQUENCES FOR GRAND GULF

Species	TQUV	TC	TPI	Inventory (kg)
Xe	0.66	1.00	0.97	412
Kr	0.66	1.00	0.97	27
I	0.66	1.00	0.97	18
Cs	0.67	1.00	0.97	220
Te	0.17	0.27	0.40	37
Sr	0.03	0.10	0.16	67
Ba	0.08	0.23	0.34	112
Ru	--	0.01	0.02	183
Mo	0.04	0.12	0.19	252
Zr (FP)	--	--	--	284
UO ₂ ^(a)	--	--	--	147000
Sn ^(a)	0.24	0.58	0.66	1190
Zr ^(a) Clad	--	--	--	78200
Fe ^(a)	0.01	0.02	0.04	9410

(a) Nonfission product species.

TABLE . CORSOR PREDICTIONS OF PERCENT OF INVENTORY EMITTED
BY CORE PRIOR TO VESSEL FAILURE FOR THE THREE ACCI-
DENT SEQUENCES FOR GRAND GULF

Species	TQUV	TC	TPI	Core Inventory (kg)
Xe	1.00	1.00	1.00	412
Kr	1.00	1.00	1.00	27.3
I	1.00	1.00	1.00	18
Cs	1.00	1.00	1.00	220
Te	0.34	0.28	0.53	37
Sr	0.08	0.10	0.20	67
Ba	0.23	0.24	0.46	112
Ru	0.01	0.01	0.02	183
Mo	0.16	0.13	0.31	252
Zr (FP)	--	--	--	284
UO ₂ (a)	--	--	--	147000
Sn (a)	0.59	0.59	0.82	1190
Zr (a) Clad	--	--	--	78200
Fe (a)	0.02	0.02	0.05	9410

(a) Nonfission product species.

MASSES (kg) OF SPECIES RELEASED AT
VESSEL DRY OUT AND VESSEL FAILURE
FOR GRAND GULF SEQUENCES

	<u>TC</u>	<u>TQUV</u>	<u>TPI</u>
Cs	186/220	148/220	213/220
I	14.9/17.7	11.7/17.7	17.1/17.7
Te	8.0/10.5	6.4/12.8	14.7/19.5
F.P. AERO	46.8/69.	19.1/73.6	100/148
Non F.P. AERO	776/1010	379/966	1286/1665



Battelle

Columbus Laboratories

CORSOR PREDICTIONS OF MASSES OF SPECIES RELEASED FROM THE
CORE AND TRAP-MELT PREDICTIONS OF MASSES RETAINED IN THE
RCS DURING THE TC SEQUENCE FOR THE GRAND GULF PLANT

(TIMES MEASURED FROM START OF CORE MELTING)

TIME (s)	CsI		CsOH		Te		AEROSOL	
	RET (KG)	TOTAL (KG)	RET (KG)	TOTAL (KG)	RET (KG)	TOTAL (KG)	RET (KG)	TOTAL (KG)
200	-	2.9	-	22.9	-	0.1	-	12.2
610	0.2	7.1	1.7	51.0	0.1	0.5	19.9	58.0
1020	1.1	11.5	8.2	76.8	0.2	1.2	88.1	.37
1420	2.1	15.4	15.1	102	0.3	2.1	187	241
1830	3.1	18.8	21.7	121	0.5	3.3	307	363
2240	3.8	21.4	26.6	139	0.6	4.6	437	498
2640	4.5	23.9	30.9	254	0.8	6.1	571	633
2850	5.8	25.5	39.8	163	3.5	6.8	630	704
3750	10	32.4	111	205	8.2	8.3	741	858
3660	13.5	35.4	114	223	9.3	9.4	755	984
4060	13.5	35.9	113	226	9.8	9.9	761	1040

TRAP-MELT PREDICTIONS OF PRIMARY SYSTEM RETENTION FACTORS (RF) AND VOLUME
SPECIFIC RETENTION FACTORS AS FUNCTIONS OF TIME FOR THE TC SEQUENCE FOR
THE GRAND GULF PLANT

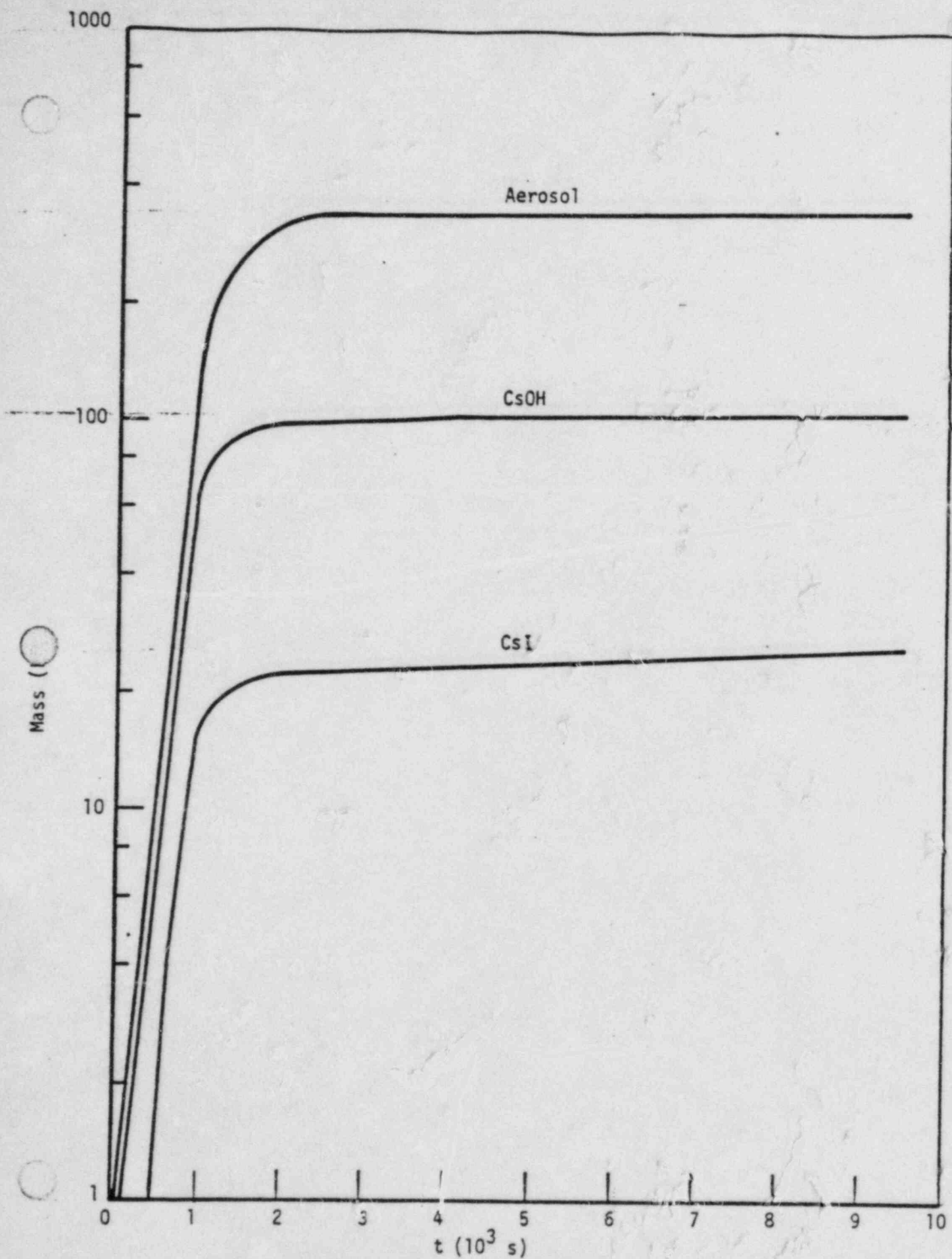
(TIMES MEASURED FROM START OF CORE MELTING)

TIME (s)	CsI			CsOH			Te		AEROSOL		
	RF	STEAM SEP	STEAM DRYERS	RF	STEAM SEP	STEAM DRYERS	RF	STEAM SEP	RF	CORE	STEAM SEP
200	--	--	--	--	--	--	.08	.08	--	--	--
610	.03	.03	--	.03	.03	--	.12	.12	.34	.32	.02
1020	.10	.09	.01	.11	.10	.01	.17	.17	.64	.60	.04
1420	.14	.12	.01	.15	.13	.01	.14	.14	.78	.73	.04
1830	.16	.14	.02	.18	.16	.02	.15	.15	.85	.80	.04
2240	.18	.16	.02	.19	.17	.02	.13	.13	.88	.84	.03
2640	.19	.17	.02	.20	.18	.02	.13	.13	.90	.87	.03
2850	.23	.21	.02	.24	.22	.02	.51	.50	.89	.86	.03
3250	.31	0.0	.24	.54	.22	.25	.99	.96	.86	.71	.11
3660	.38	--	.28	.51	.09	.33	.99	.96	.77	.62	.10
4060	.38	--	.27	.50	.09	.32	.99	.94	.73	.59	.09

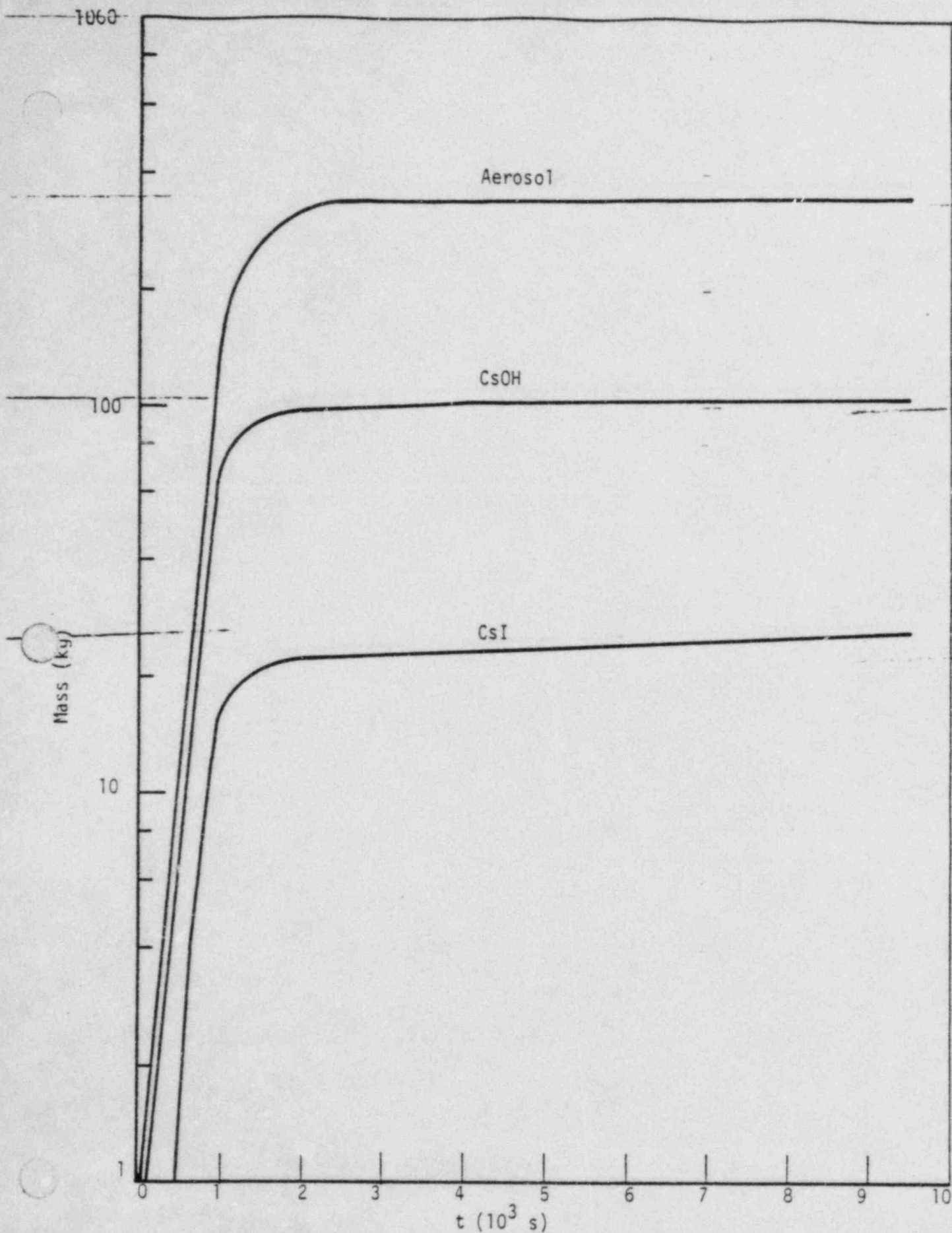
TRAP-MELT PREDICTIONS OF PRIMARY SYSTEM RETENTION FACTORS (RF) AND VOLUME
SPECIFIC RETENTION FACTORS AS FUNCTIONS OF TIME FOR THE TQV SEQUENCE FOR
THE GRAND GULF PLANT

(TIMES MEASURED FROM START OF CORE MELTING)

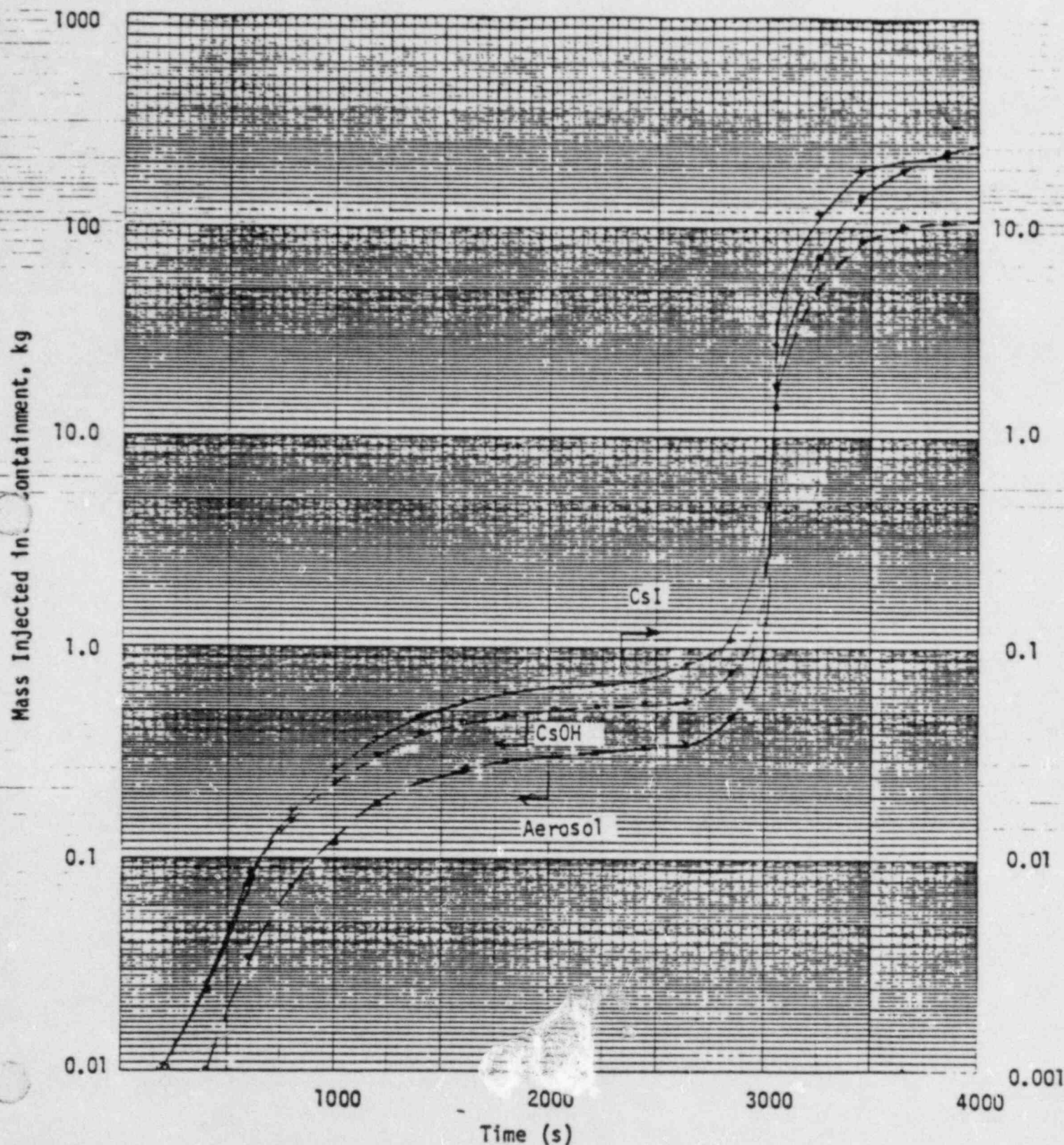
TIME (s)	CsI		CsOH			Te		AEROSOL	
	RF	STEAM DRYERS	RF	STEAM SEP	STEAM DRYERS	RF	STEAM SEP	RF	CORE
500	.09	.01	.10	.05	.04	.82	.80	.08	.02
1000	.10	.06	.42	.08	.22	.98	.90	.17	.08
1500	.06	.06	.36	.07	.23	.98	.80	.16	.10
2000	.06	.06	.36	.07	.22	.98	.81	.15	.09
3000	.03	.03	.34	.07	.23	.99	.81	.15	.09
4000	.01	.01	.31	.07	.23	.99	.81	.15	.09
6000	--	--	.32	.08	.22	.96	.79	.17	.12
8000	--	--	.34	.14	.19	.78	.66	.43	.39
9470	.01	--	.40	.19	.20	.67	.58	.64	.60



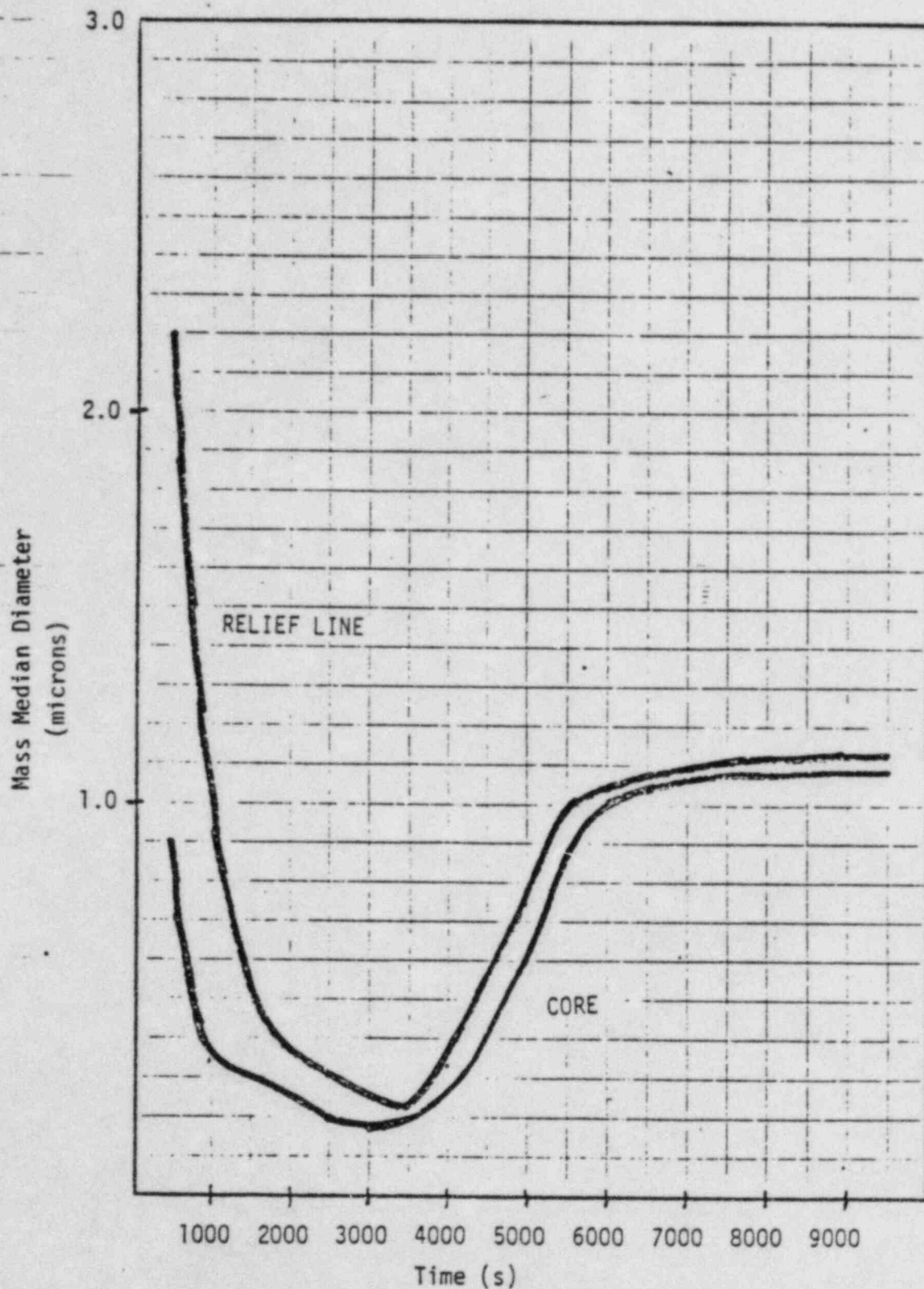
MASSSES INJECTED INTO SUPPRESSION POOL FOR GRAND GULF TQV



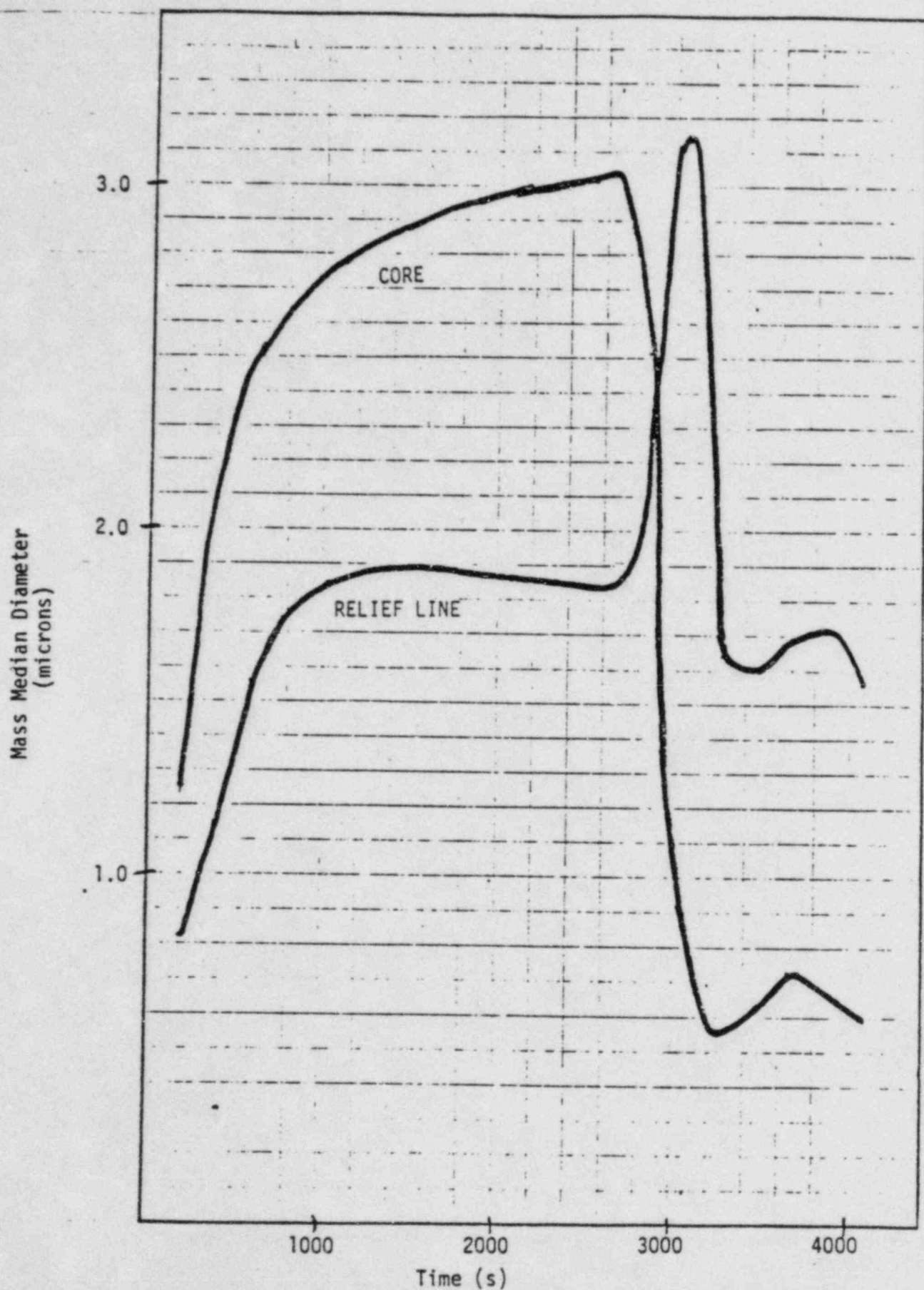
MASSSES INJECTED INTO SUPPRESSION POOL FOR GRAND GULF TOUV



TRAP-MELT PREDICTIONS OF MASS INJECTED INTO THE CONTAINMENT BY SPECIES AS A FUNCTION OF TIME FOR THE TC SEQUENCE FOR THE GRAND GULF PLANT



TRAP MELT PREDICTIONS OF MASS MEDIAN DIAMETER OF SUSPENDED PARTICLES AS A FUNCTION OF TIME FOR THE CORE AND RELIEF TIME FOR THE TQV SEQUENCE FOR THE GRAND GULF PLANT



TRAP MELT PREDICTIONS OF MASS MEDIAN DIAMETER OF SUSPENDED PARTICLES IN THE CORE AND AS A FUNCTION OF TIME FOR THE TC SEQUENCE FOR THE GRAND GULF PLANT

RETENTION MECHANISMS FOR SPECIES IN GRAND GULF SEQUENCES
(Fractional distribution of species at vessel failure)

	TC				TQUV			
	Cond	Chem	Aero	Susp	Cond	Chem	Aero	Susp
CsI	.18	--	.19	.01	0.	--	.01	.27
CsOH	.17	.12	.21	.01	0.	.40	0.	.14
Te	0.	.99	0.	.01	0.	.67	0.	.33
Aerosol	--	--	.73	.02	--	--	.64	.03

**RADIONUCLIDE RELEASE UNDER
SPECIFIC LWR ACCIDENT CONDITIONS --
VOLUME II, BWR, MARK I DESIGN**

PEER REVIEW MEETING

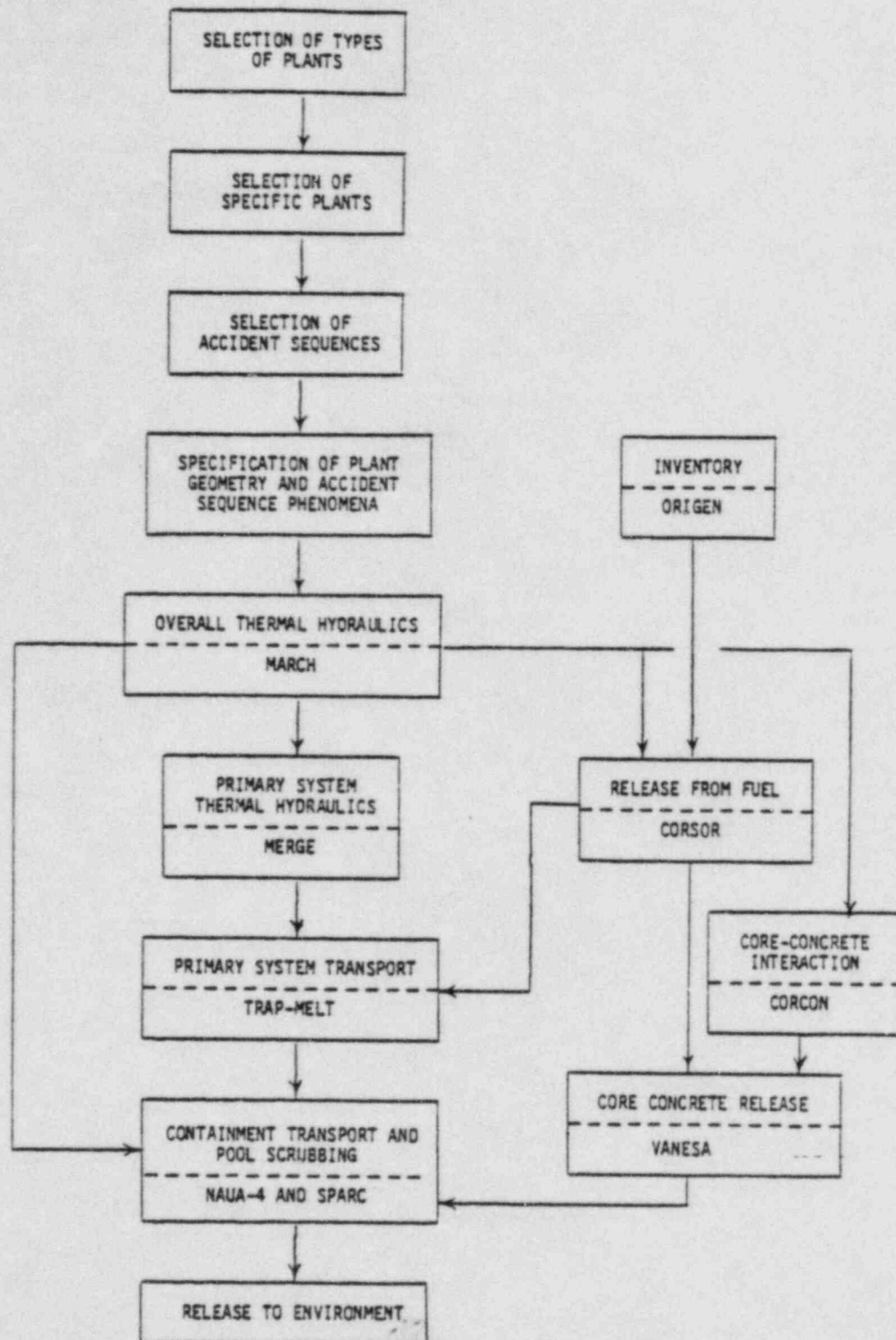
**U.S. Nuclear Regulatory Commission
Washington , D.C.**

MAY 24 & 25 , 1983

Presentation Notes

ACKNOWLEDGEMENTS

- GENERAL ELECTRIC
- EPRI
- ORNL
- SANDIA
- PNL



PRESENTATION TOPICS

- INTRODUCTION (J.A. GIESEKE)
- SEQUENCE DESCRIPTIONS AND THERMAL HYDRAULICS
(R.S. DENNING)
- RELEASE FROM FUEL AND TRANSPORT IN REACTOR
COOLANT SYSTEM (M.R. KUHLMAN)
- TRANSPORT IN CONTAINMENT AND ATTENUATION IN
SUPPRESSION POOLS (K.W. LEE)
- SUMMARY (J.A. GIESEKE)

DESCRIPTION OF ACCIDENT SEQUENCES AND THERMAL-HYDRAULIC RESULTS

BWR -- MARK I DESIGN

PLANT SELECTION

PEACH BOTTOM 2 WAS WASH-1400 REACTOR.

SEQUENCE SELECTION

RISK DOMINANT SEQUENCES -- TC, TW

LOCA SEQUENCE -- AE

DESCRIPTION OF MARCH 2

PARTICIPANTS

BCL, SNL, ORNL, BNL, TVA

CHANGES FROM MARCH 1.1

MODELS, CODE STRUCTURE, LANGUAGE, CORRECTIONS

IMPROVED MODELS

ANS DECAY HEAT

WATER AND STEAM PROPERTIES

HEAT TRANSFER CORRELATIONS IN CORE

DEBRIS COOLANT INTERACTIONS

ZIRCALOY-STEAM REACTION

STEEL-STEAM REACTION

HYDROGEN BURNING

BWR SHROUD MODEL WAS NOT USED IN THESE ANALYSES.

CONTAINMENT AND REACTOR BUILDING FAILURE MODES

WASH-1400

FAILURE PRESSURE -- 175 ± 25 PSIA

LOCATION -- WETWELL

AMES STUDY

FAILURE PRESSURE -- 132 PSIA

LOCATION -- DRYWELL

DESCRIPTION OF REACTOR BUILDING

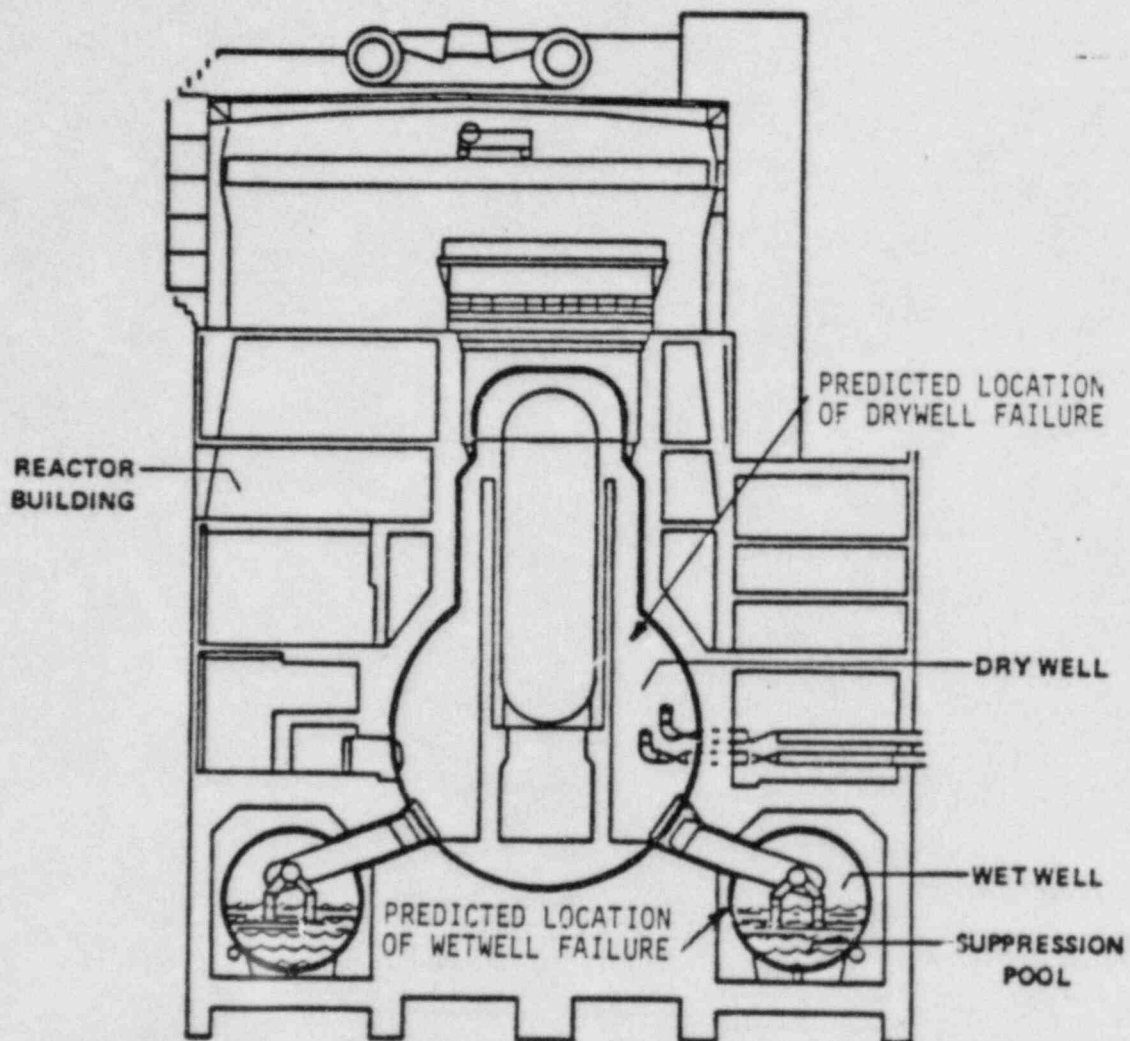


FIGURE 4.1. BWR MARK I CONTAINMENT DESIGN

SEQUENCE AE -- LARGE LOCA WITH FAILURE OF ECC

	<u>TIME (MIN)</u>
BEGIN CORE MELT	12
CONTAINMENT FAILURE	34
REACTOR VESSEL FAILURE	126
CONTAINMENT FAILURE MODE -- γ'	

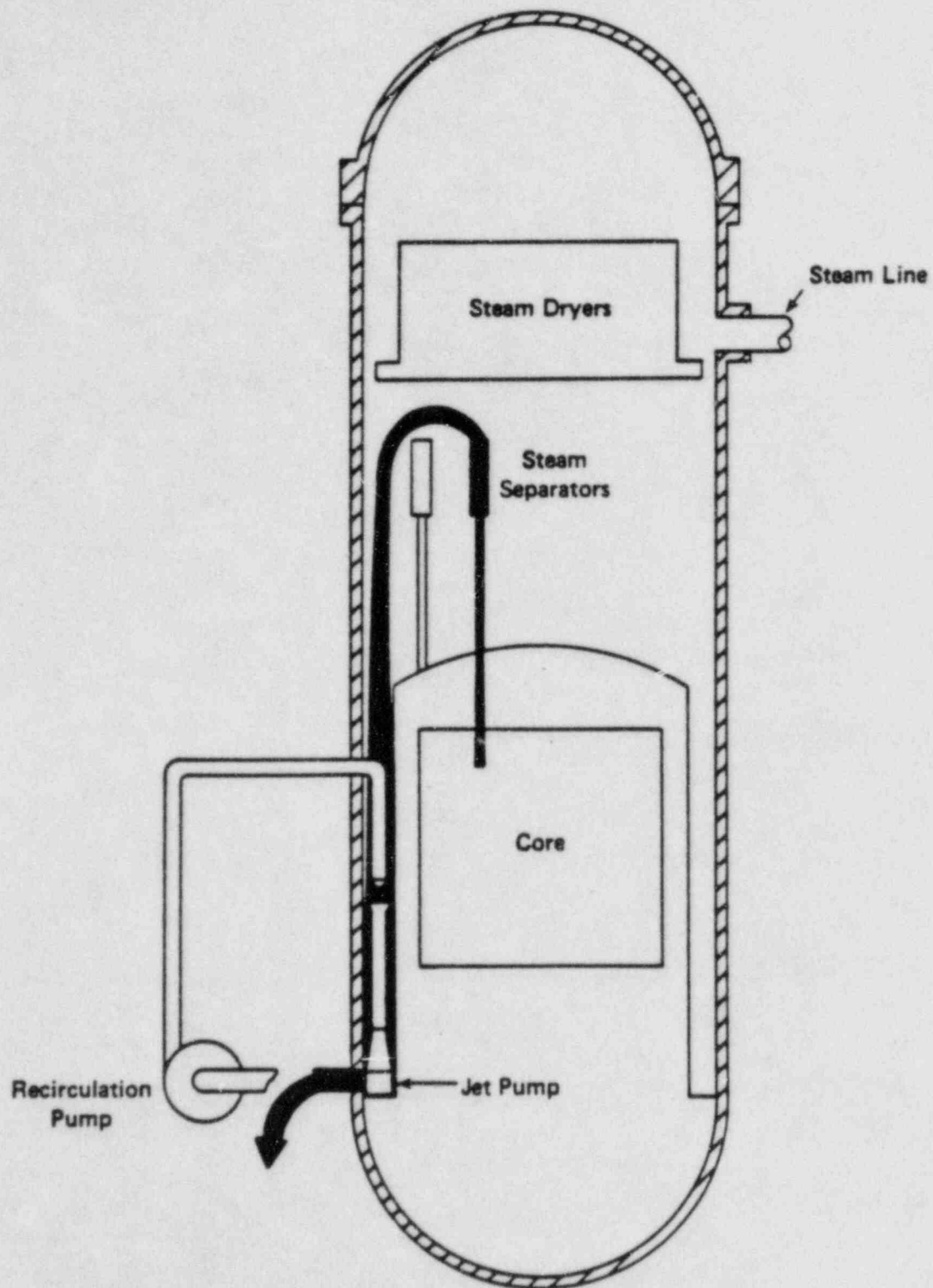


FIGURE 6.2 FLOWPATH FOR FISSION PRODUCT TRANSPORT IN THE RCS -
SEQUENCE AE

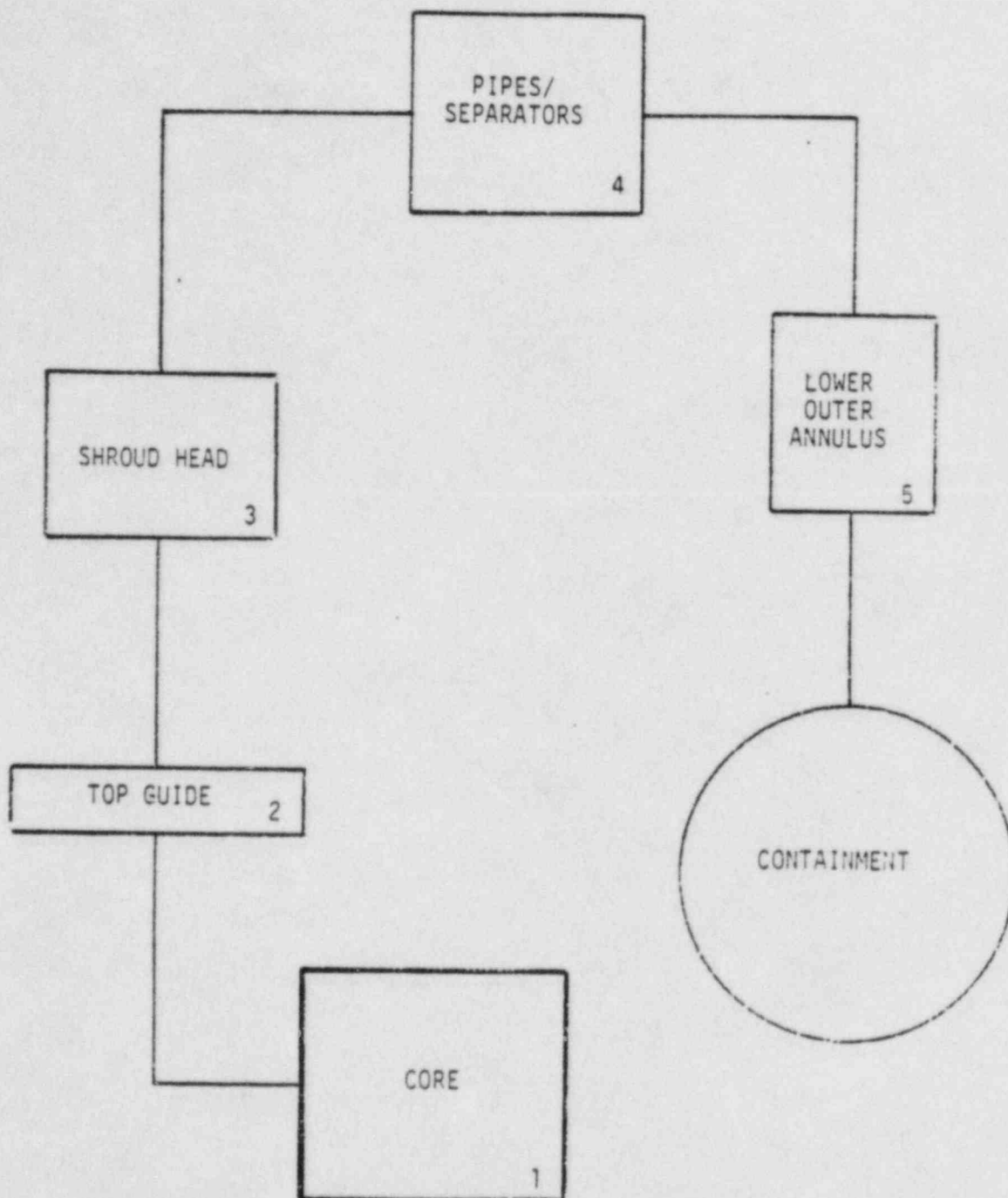


FIGURE 6.3 SCHEMATIC OF CONTROL VOLUMES FOR THE PEACH BOTTOM AE SEQUENCE

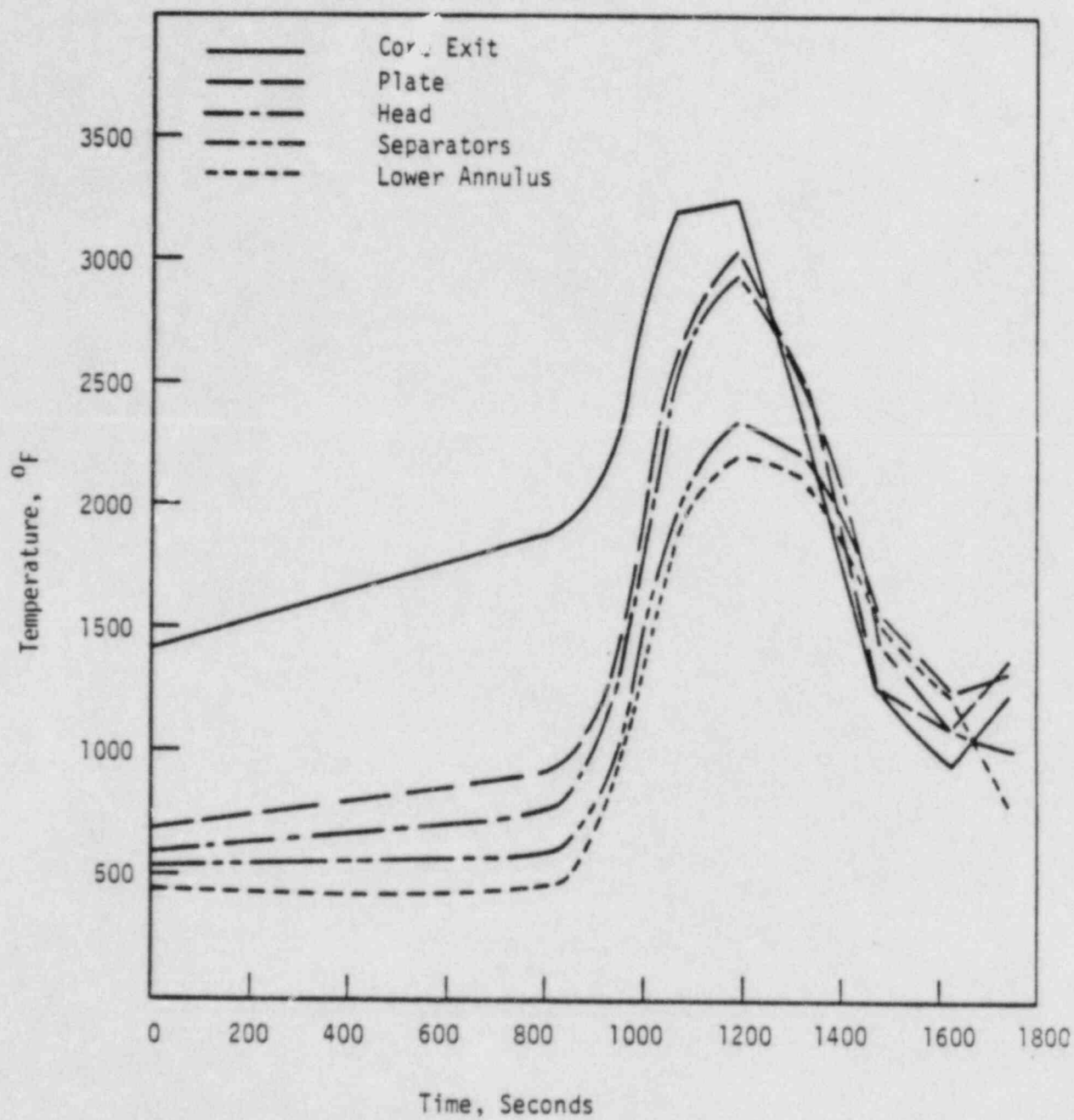


FIGURE 6.4 GAS TEMPERATURES IN RCS VOLUMES - SEQUENCE AE

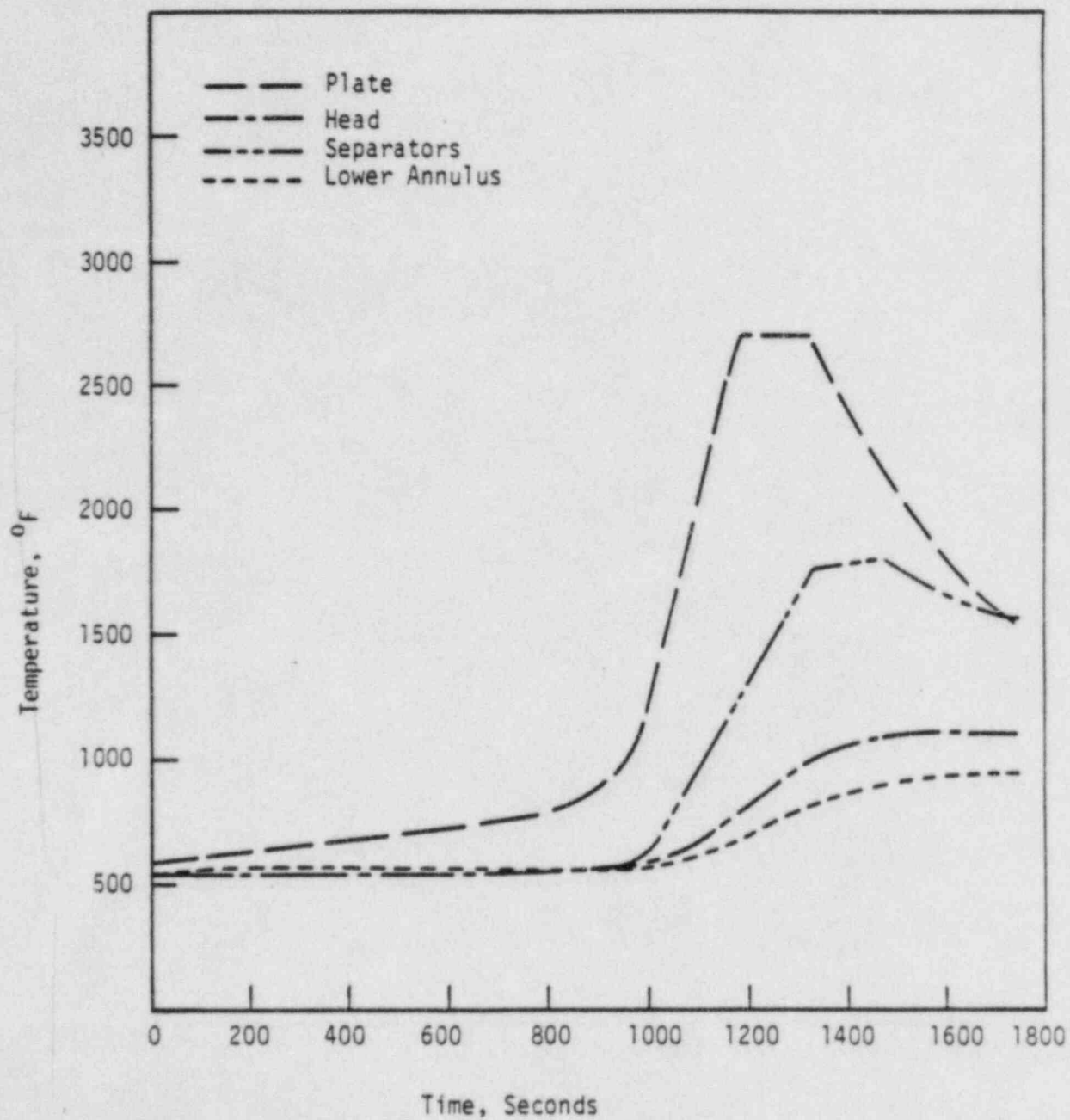


FIGURE 6.5 STRUCTURE TEMPERATURES IN RCS VOLUMES - SEQUENCE AE

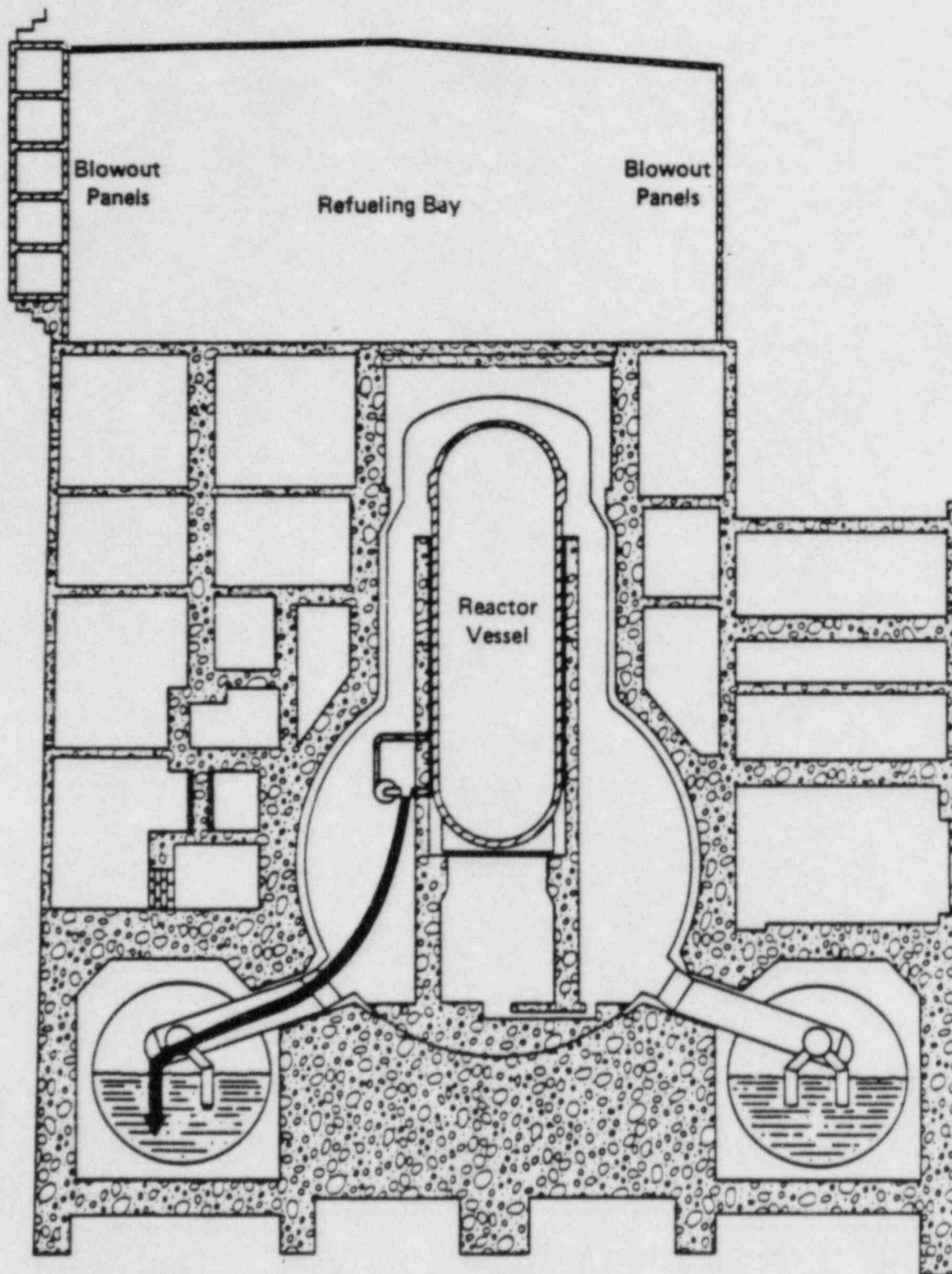


FIGURE 6.6 FLOWPATH FOR FISSION PRODUCT TRANSPORT BEFORE CONTAINMENT FAILURE - SEQUENCE AE

PEACH BOTTOM AE

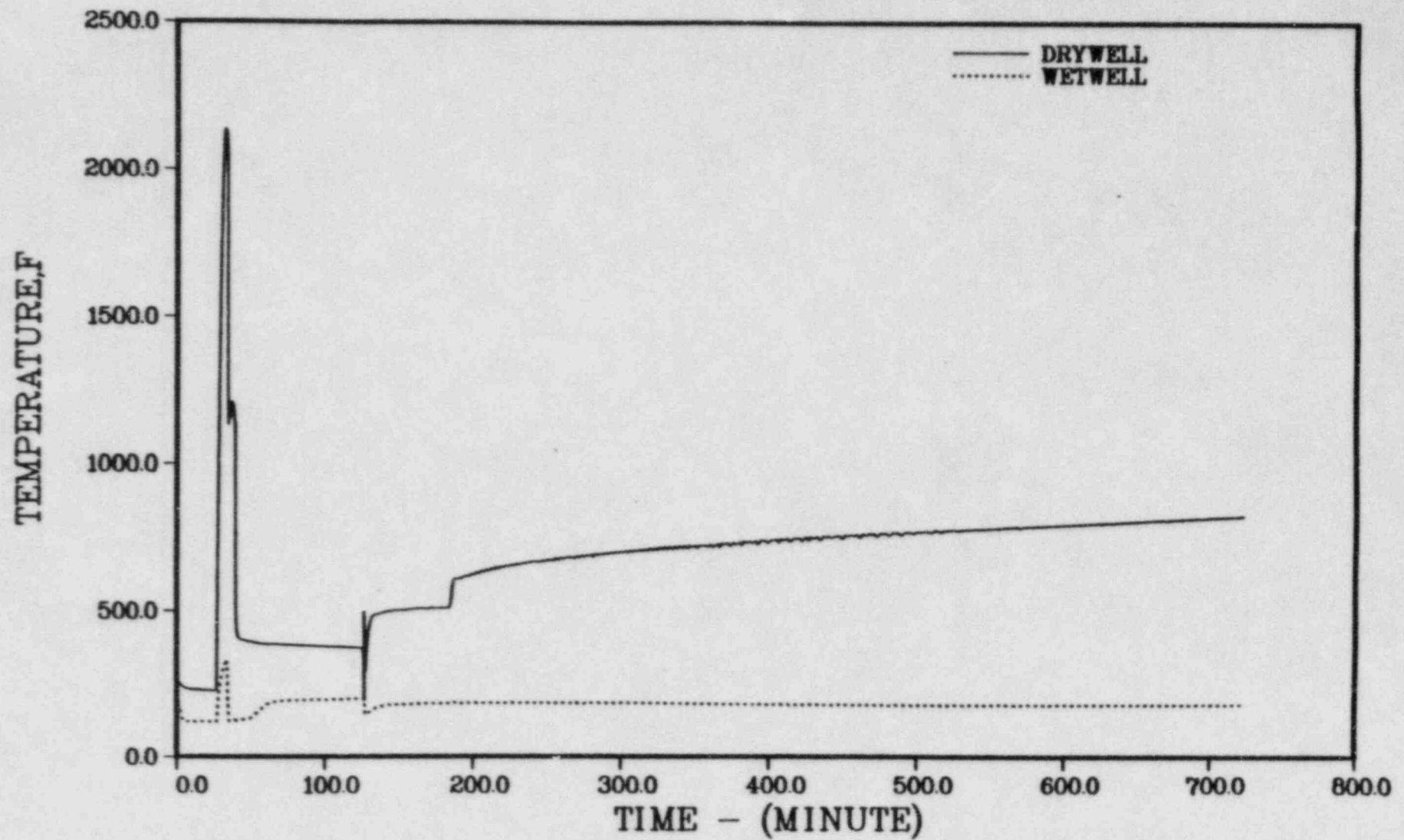


FIGURE 6.7 TEMPERATURES IN CONTAINMENT VOLUMES - SEQUENCE AE

PEACH BOTTOM AE

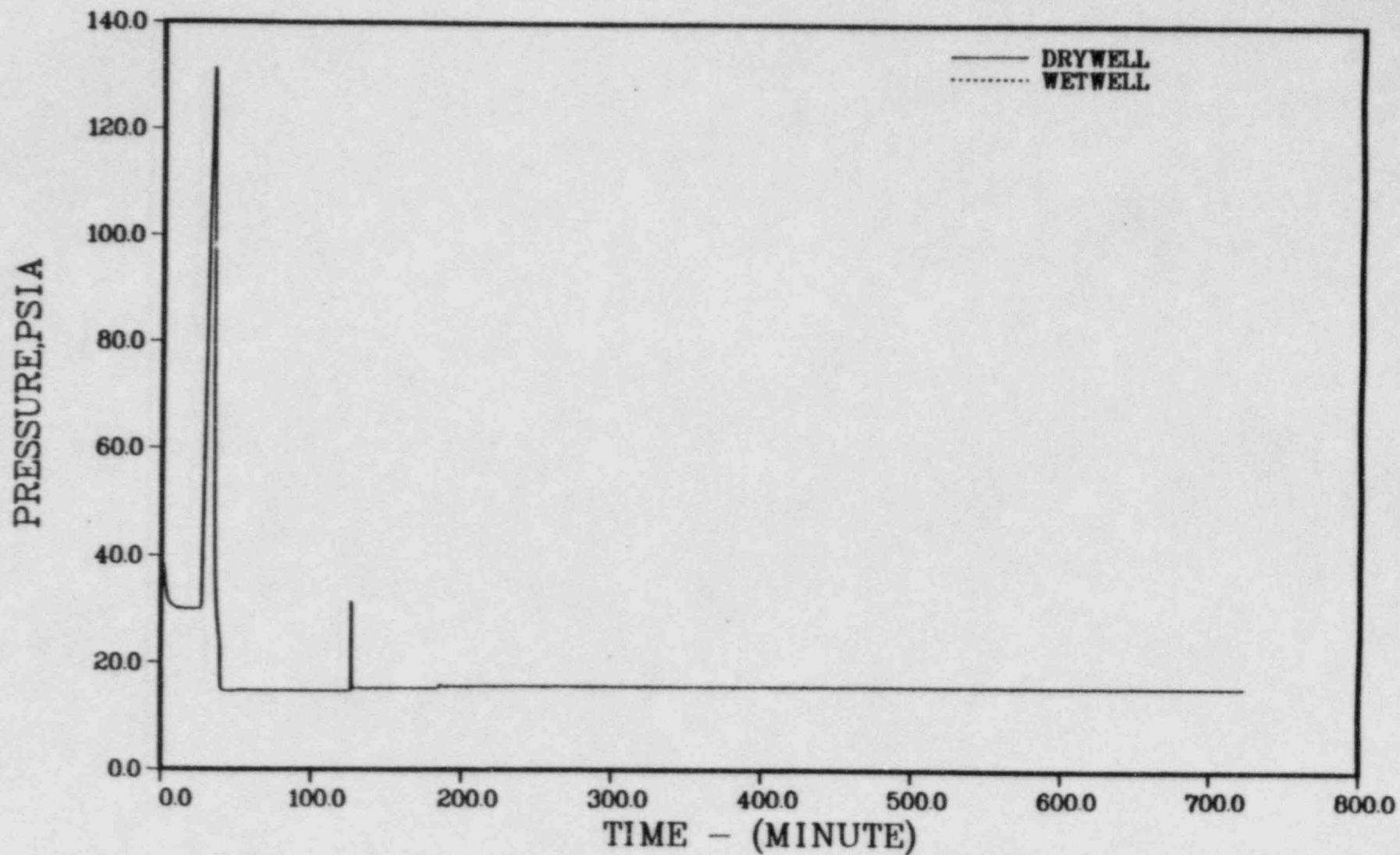


FIGURE 6.8 PRESSURES IN CONTAINMENT VOLUMES - SEQUENCE AE

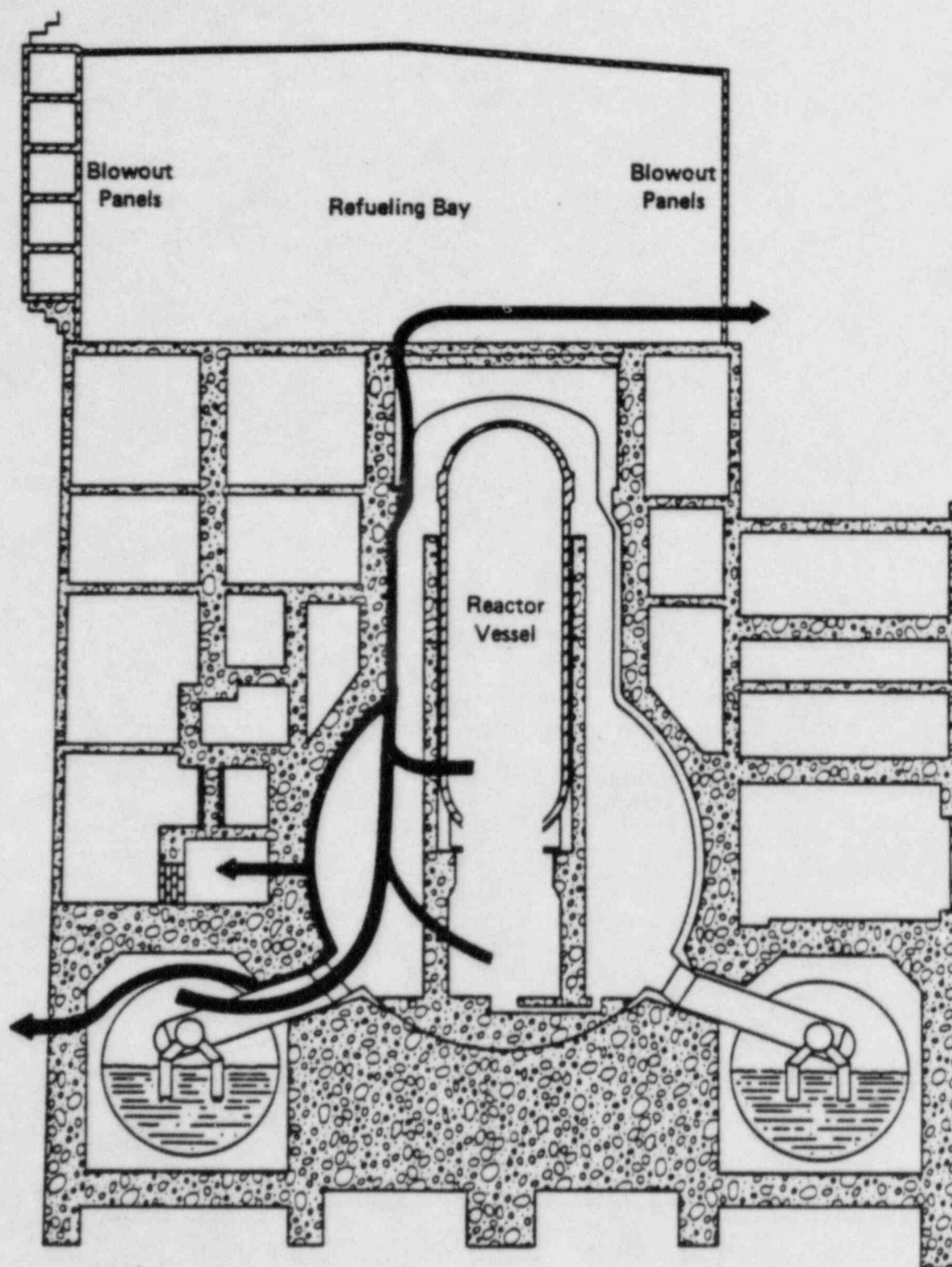


FIGURE 6.9 FLOWPATHS FOR FISSION PRODUCT TRANSPORT AFTER CONTAINMENT FAILURE - SEQUENCE AE

SEQUENCE TC -- TRANSIENT WITH FAILURE TO SCRAM

	<u>TIME (MIN)</u>
CONTAINMENT FAILURE	58
BEGIN CORE MELT	94
PRESSURE VESSEL FAILURE	217

CONTAINMENT FAILURE MODES - γ' , γ

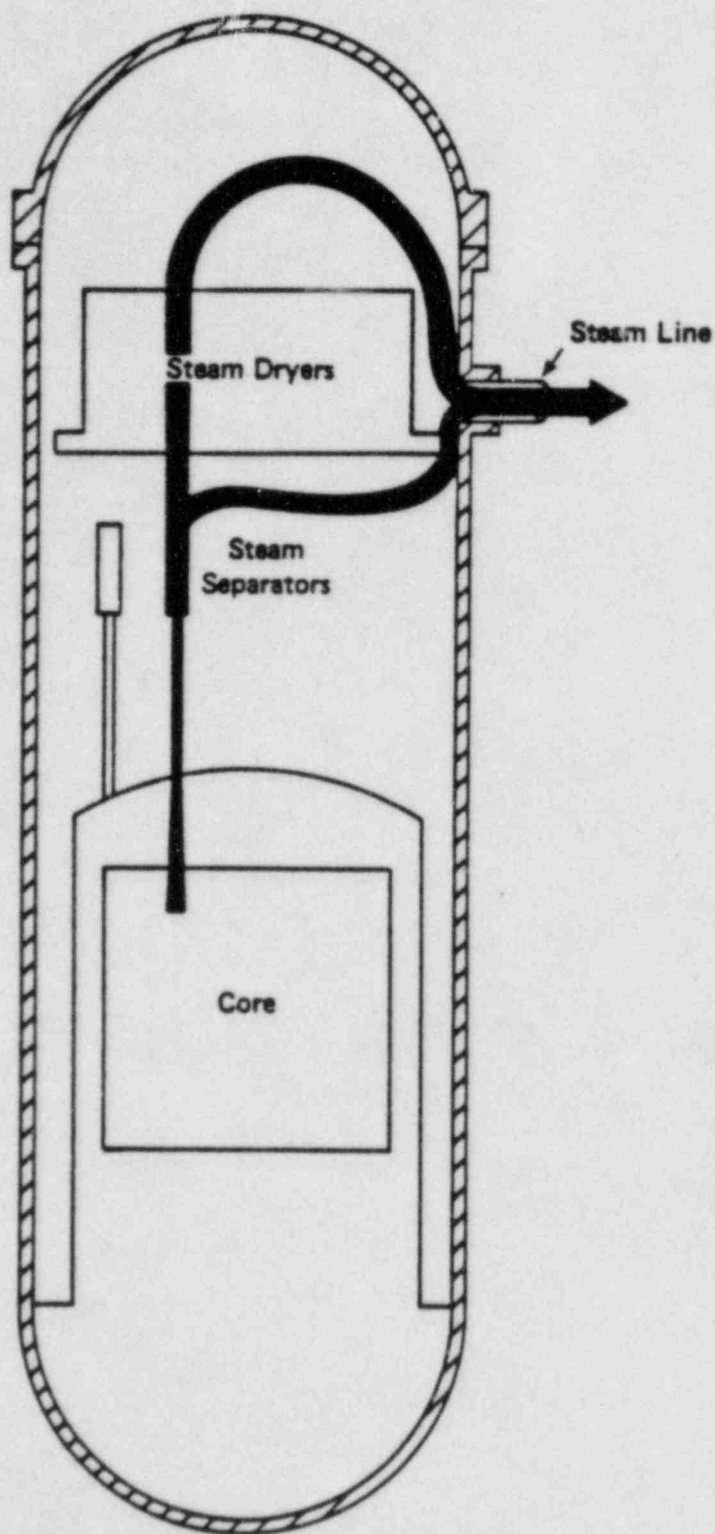


FIGURE 6.11 FLOWPATHS FOR FISSION PRODUCT TRANSPORT IN
RCS - SEQUENCES TC AND TW

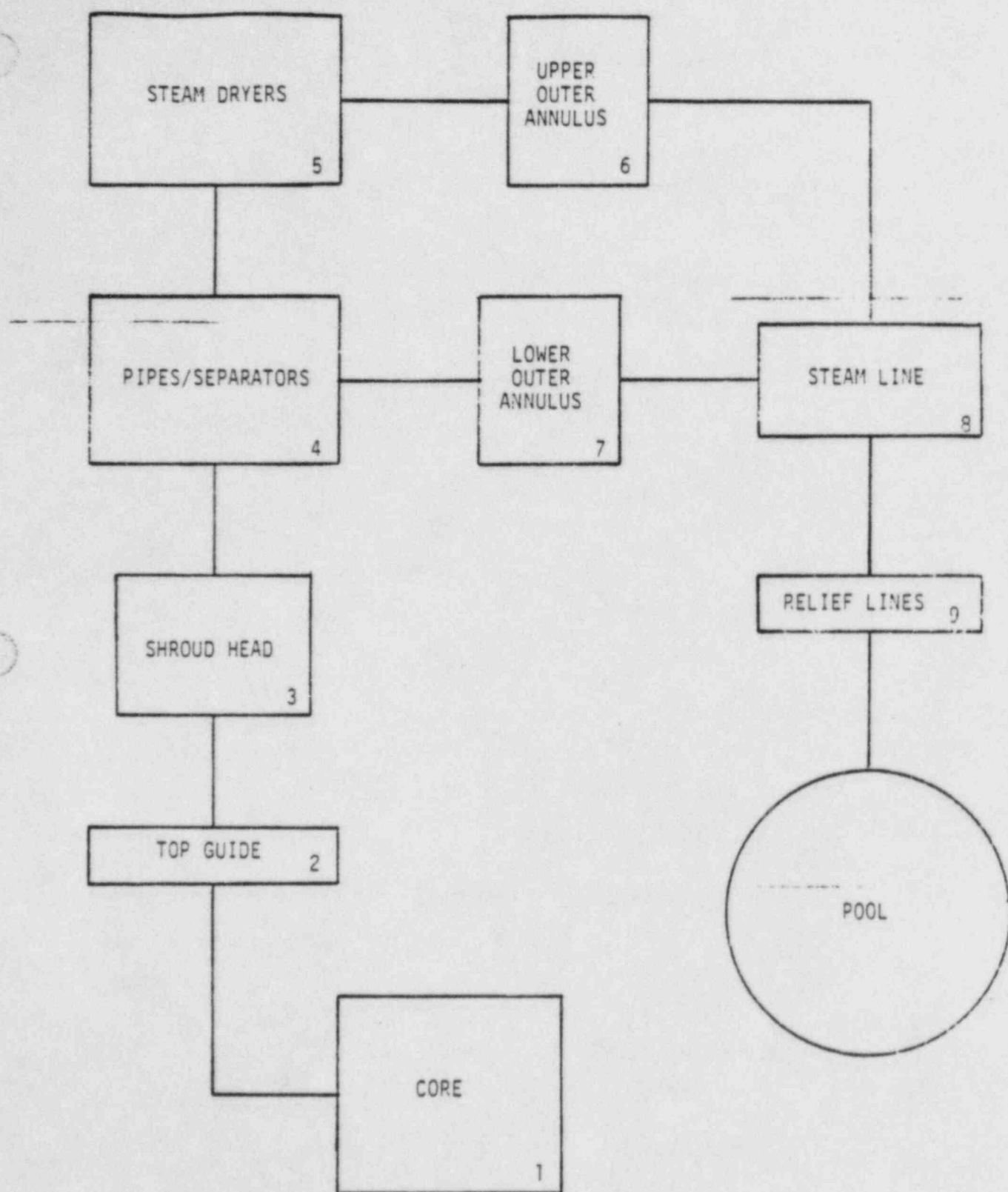


FIGURE 6.12 SCHEMATIC OF CONTROL VOLUMES FOR THE PEACH BOTTOM TC AND TW ACCIDENT SEQUENCES

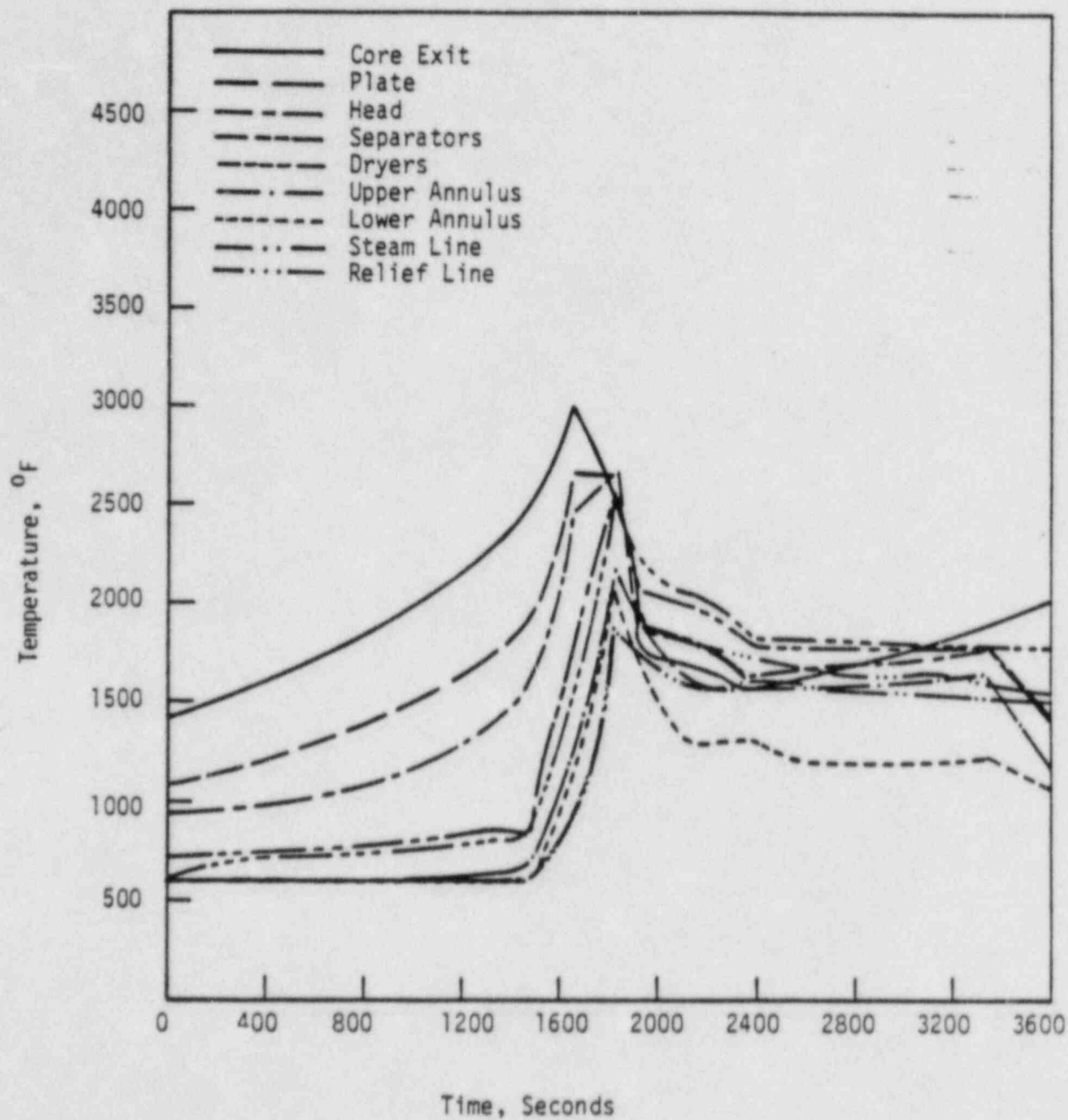


FIGURE 6.13 GAS TEMPERATURES IN RCS VOLUMES - SEQUENCE TC

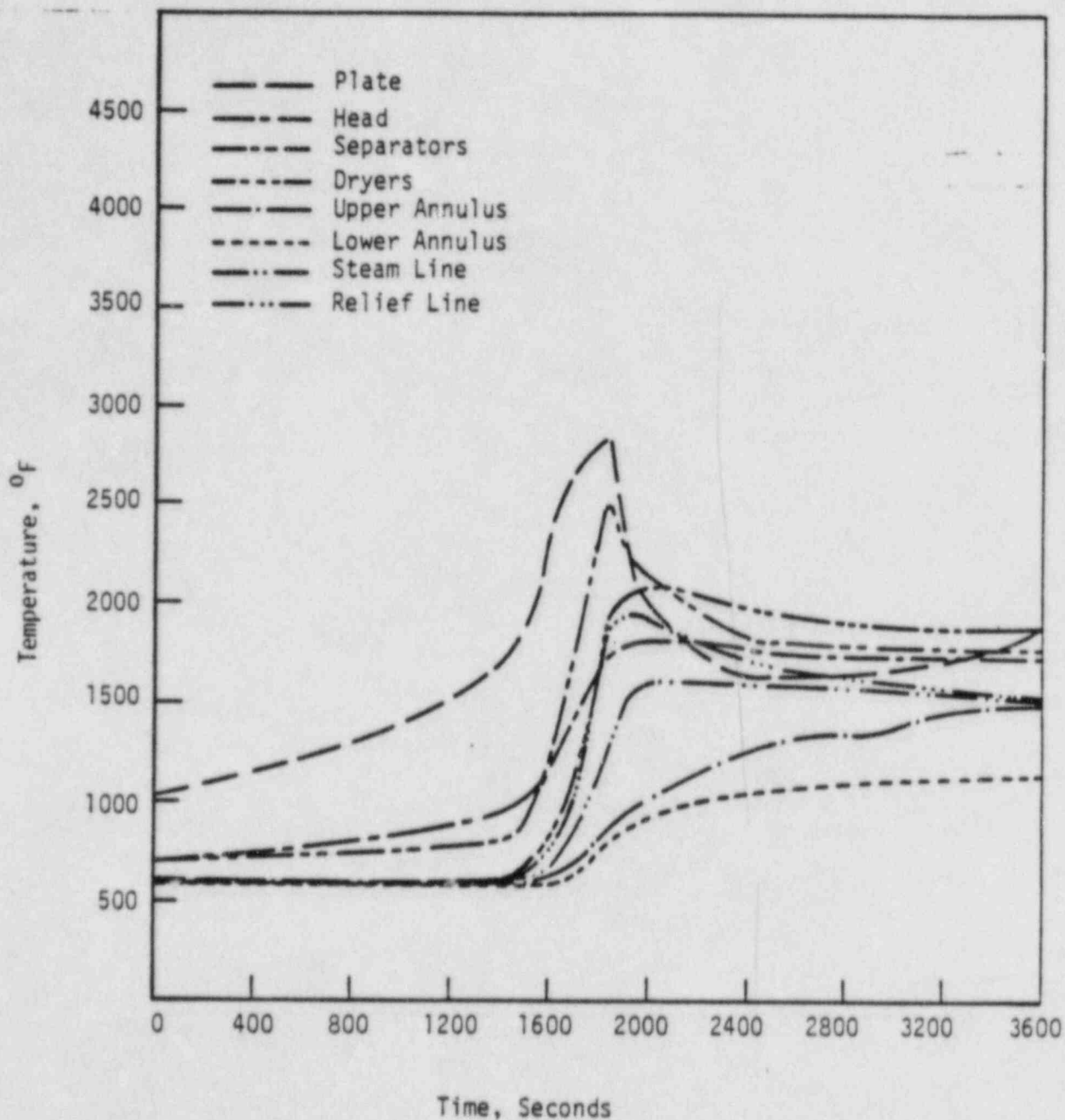


FIGURE 6.14 STRUCTURE TEMPERATURES IN RCS VOLUMES - SEQUENCE TC

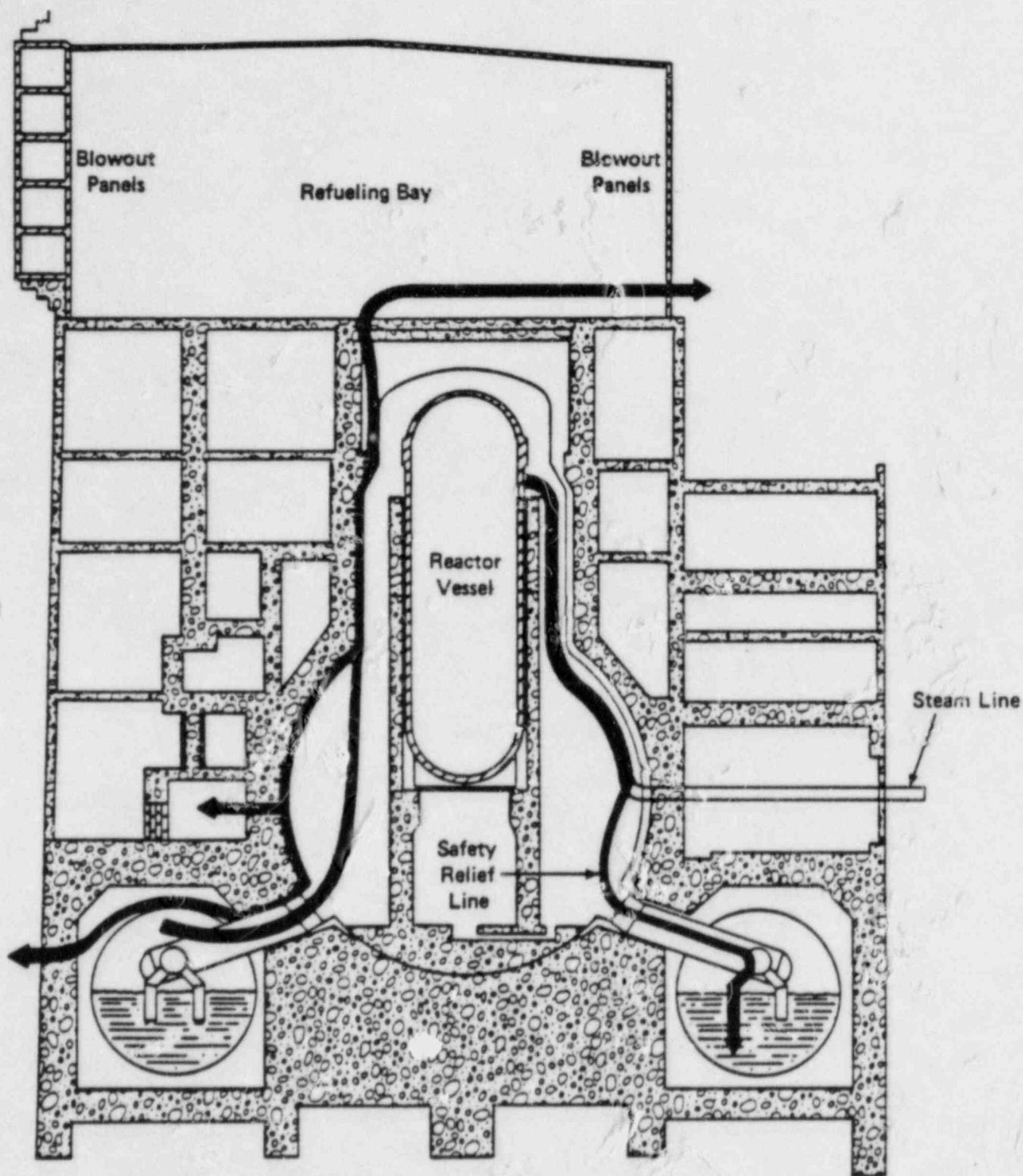


FIGURE 6.15 FLOWPATH FOR FISSION PRODUCT TRANSPORT BEFORE VESSEL FAILURE - SEQUENCES TC AND TW

PEACH BOTTOM TC

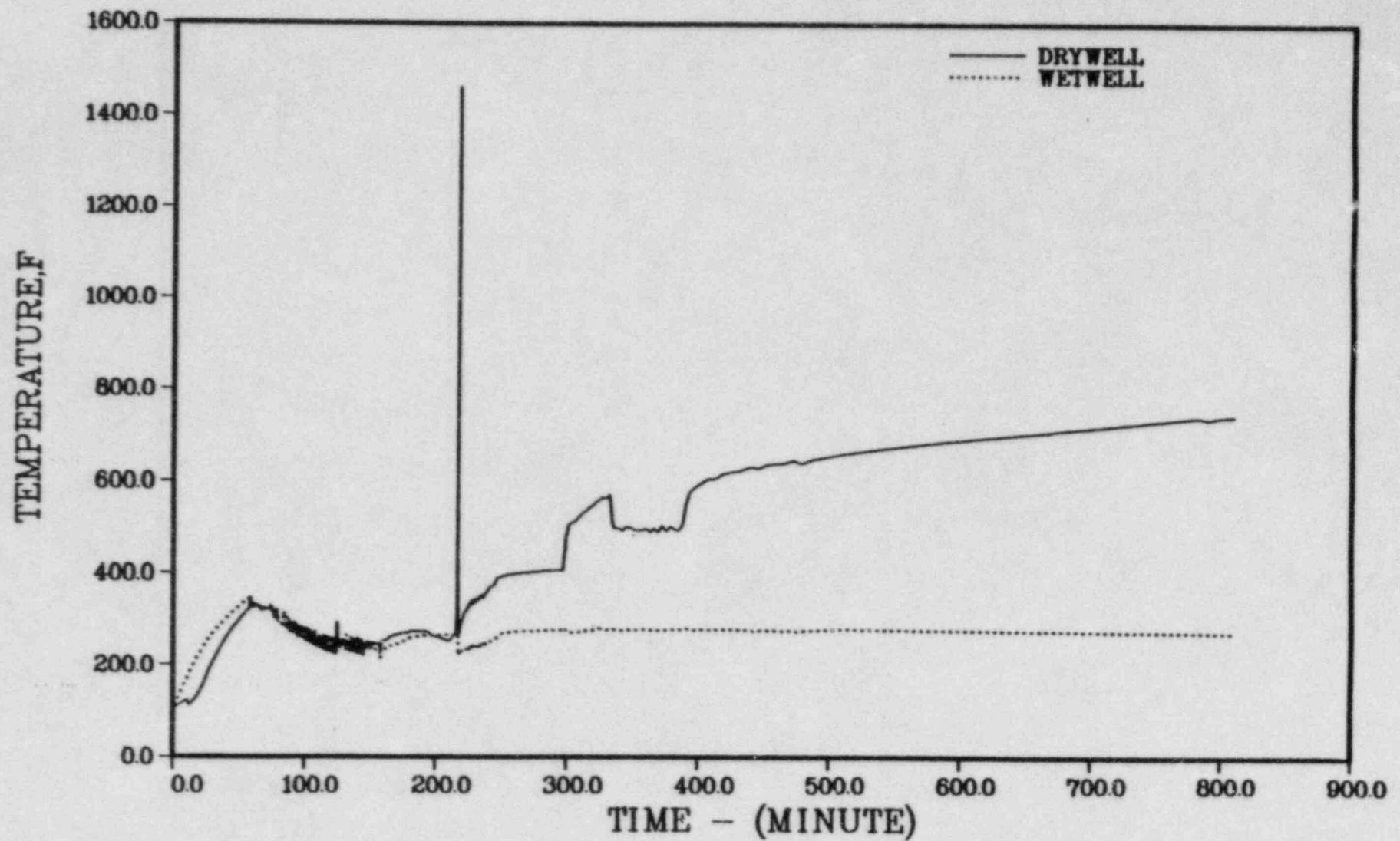


FIGURE 6.16 GAS TEMPERATURES IN CONTAINMENT VOLUMES - SEQUENCE TC

PEACH BOTTOM TC

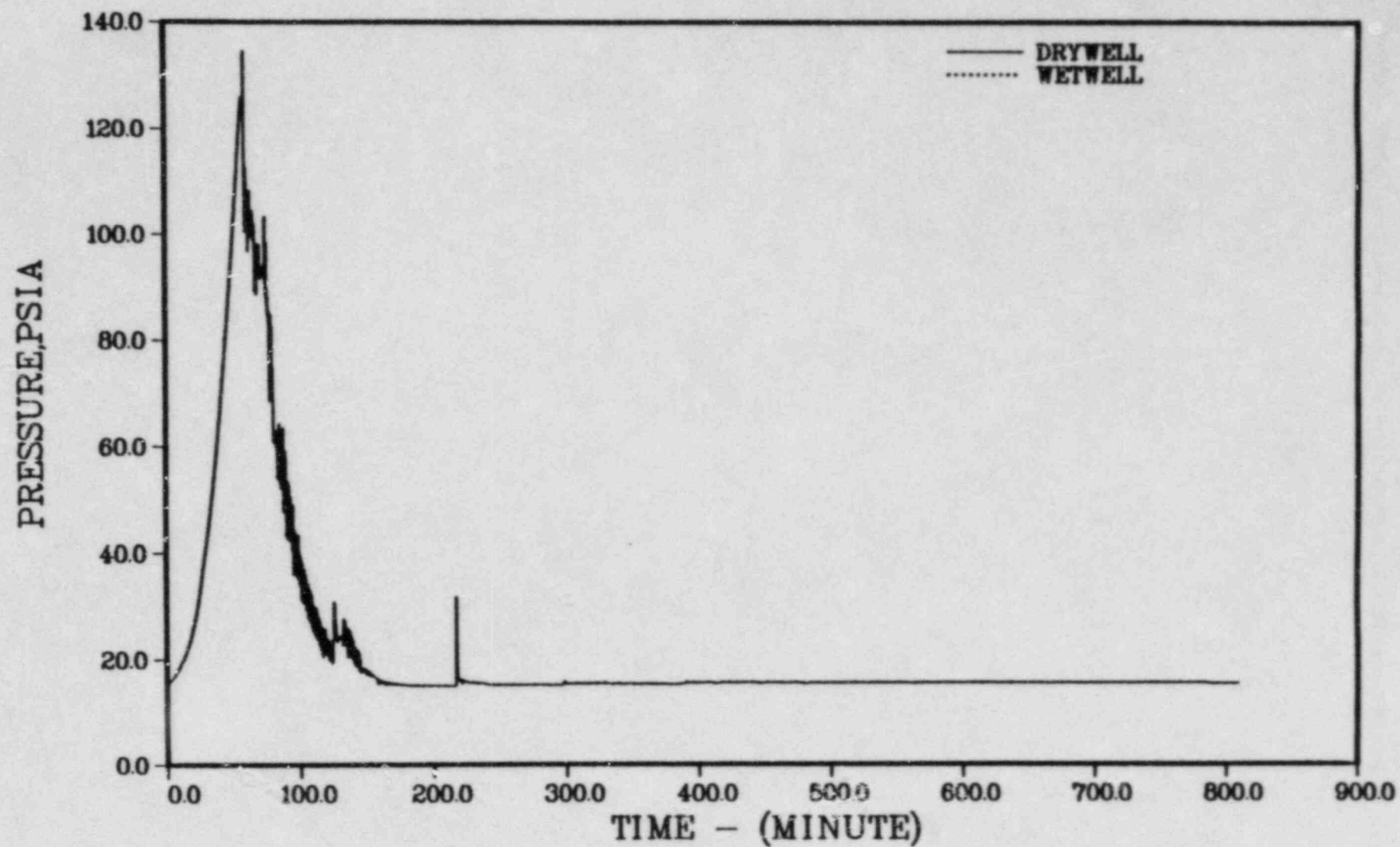


FIGURE 6.17 PRESSURES IN CONTAINMENT VOLUMES - SEQUENCE TC

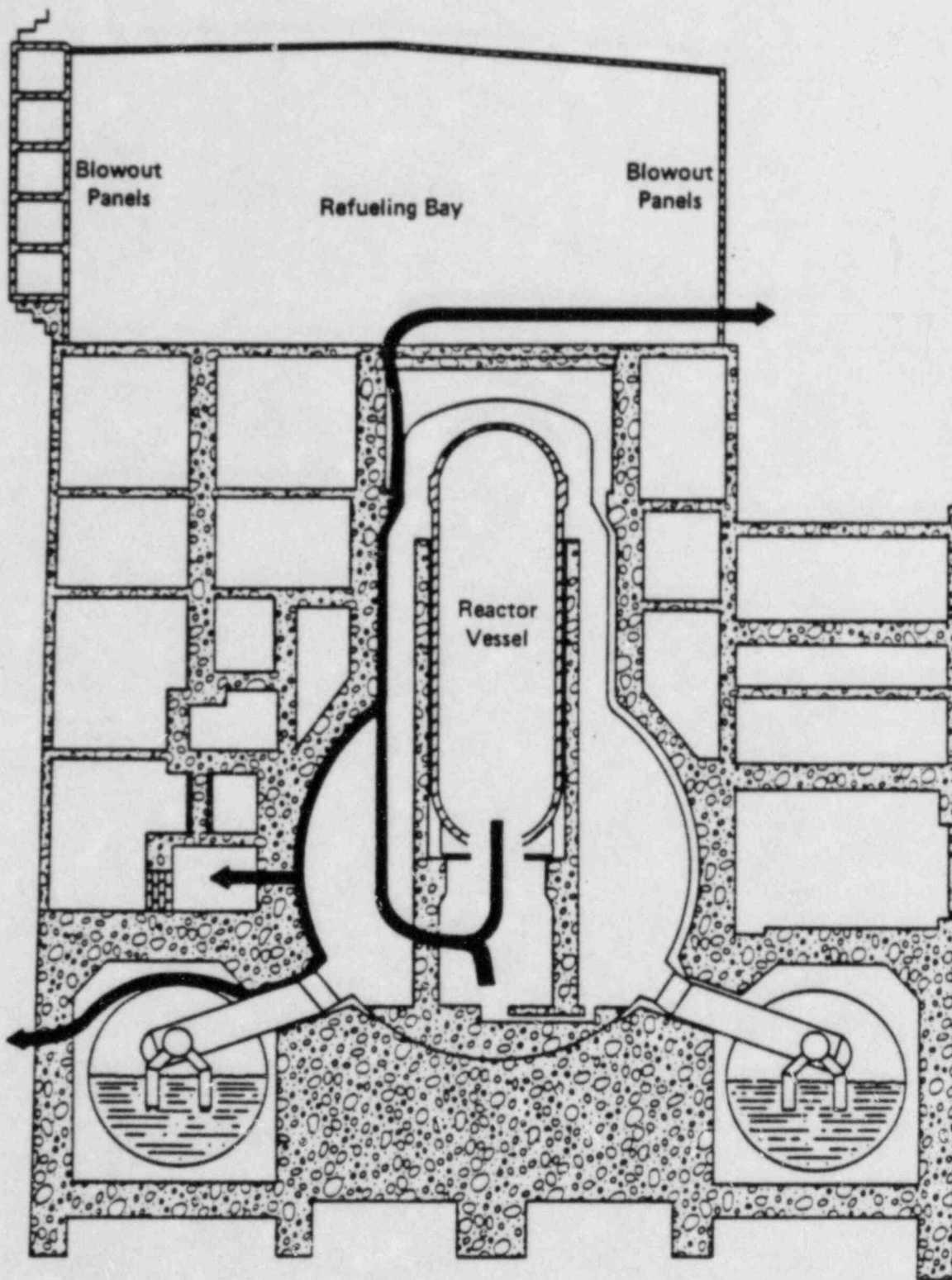


FIGURE 6.18 FLOWPATH FOR FISSION PRODUCT TRANSPORT AFTER VESSEL FAILURE - SEQUENCES TC AND TW

SEQUENCE TW -- TRANSIENT WITH LOSS OF DECAY HEAT REMOVAL

	<u>TIME (MIN)</u>
CONTAINMENT FAILURE	1756
BEGIN CORE MELT	2748
REACTOR VESSEL FAILURE	3055

CONTAINMENT FAILURE MODE -- γ'

PEACH BOTTOM TW

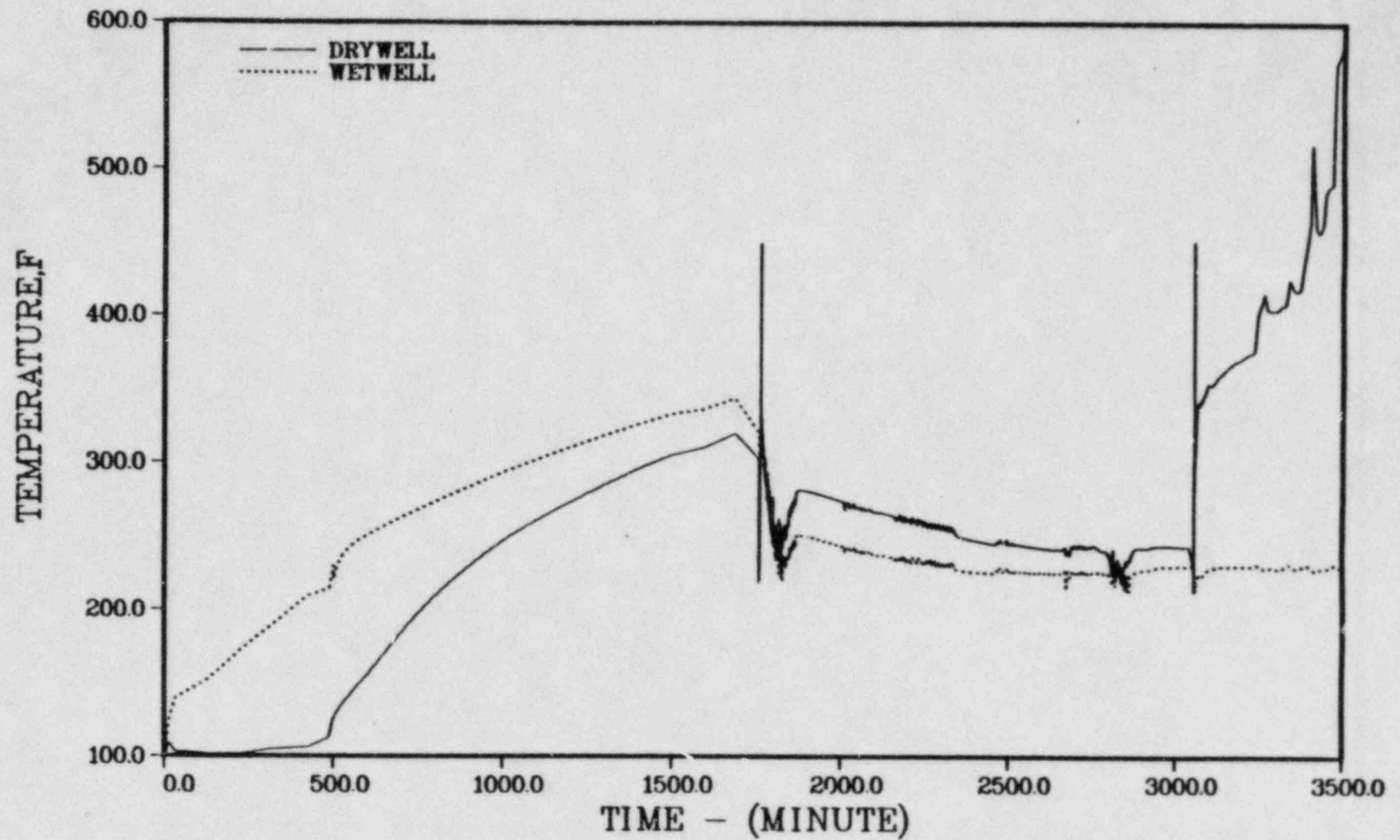


FIGURE 6.23 GAS TEMPERATURES IN CONTAINMENT VOLUMES - SEQUENCE TW

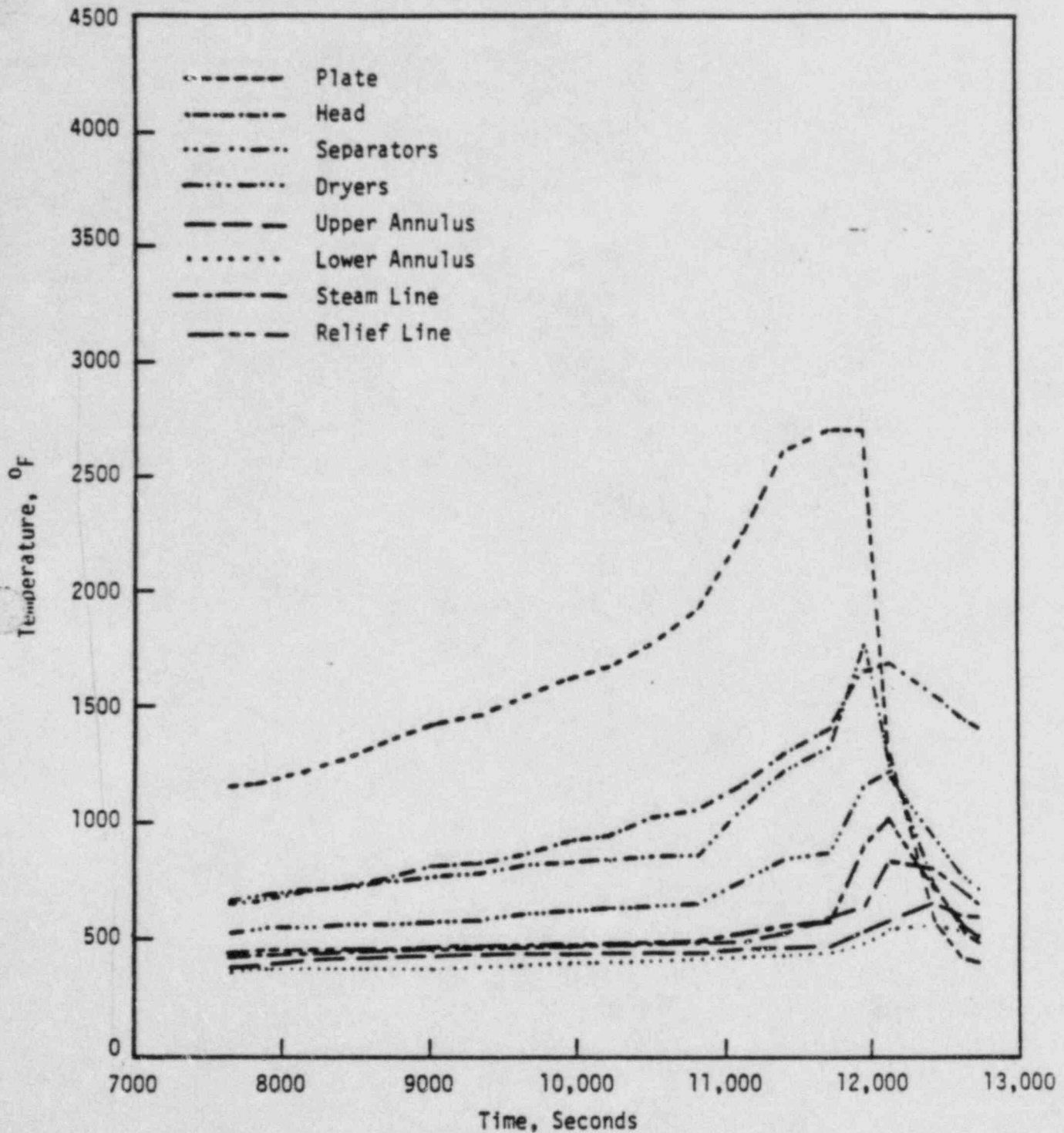


FIGURE 6.24. STRUCTURE TEMPERATURES IN RCS VOLUMES - SEQUENCE TW

PEACH BOTTOM TW

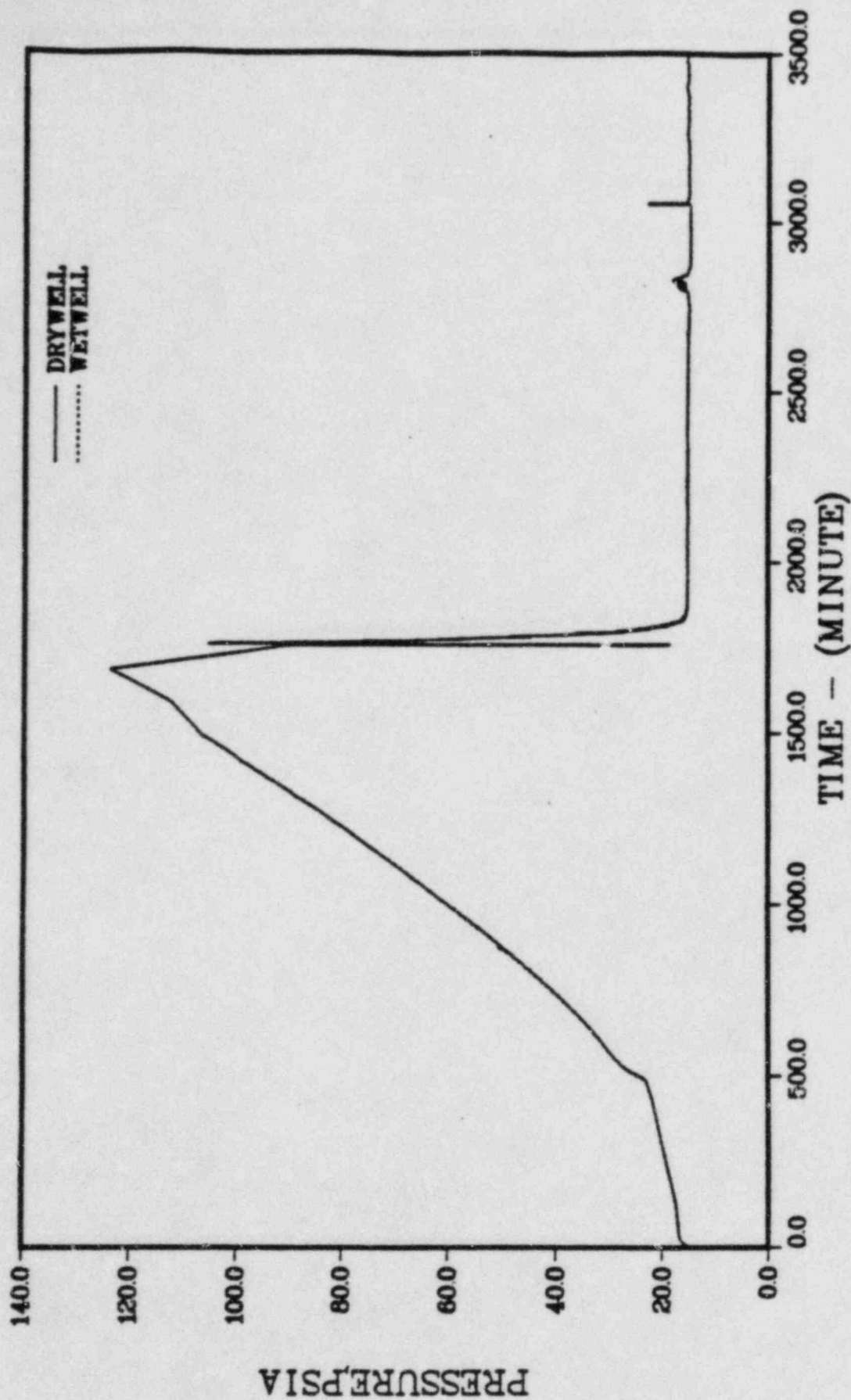


FIGURE 6.25. PRESSURE IN CONTAINMENT VOLUMES - SEQUENCE TW

PEACH BOTTOM TW

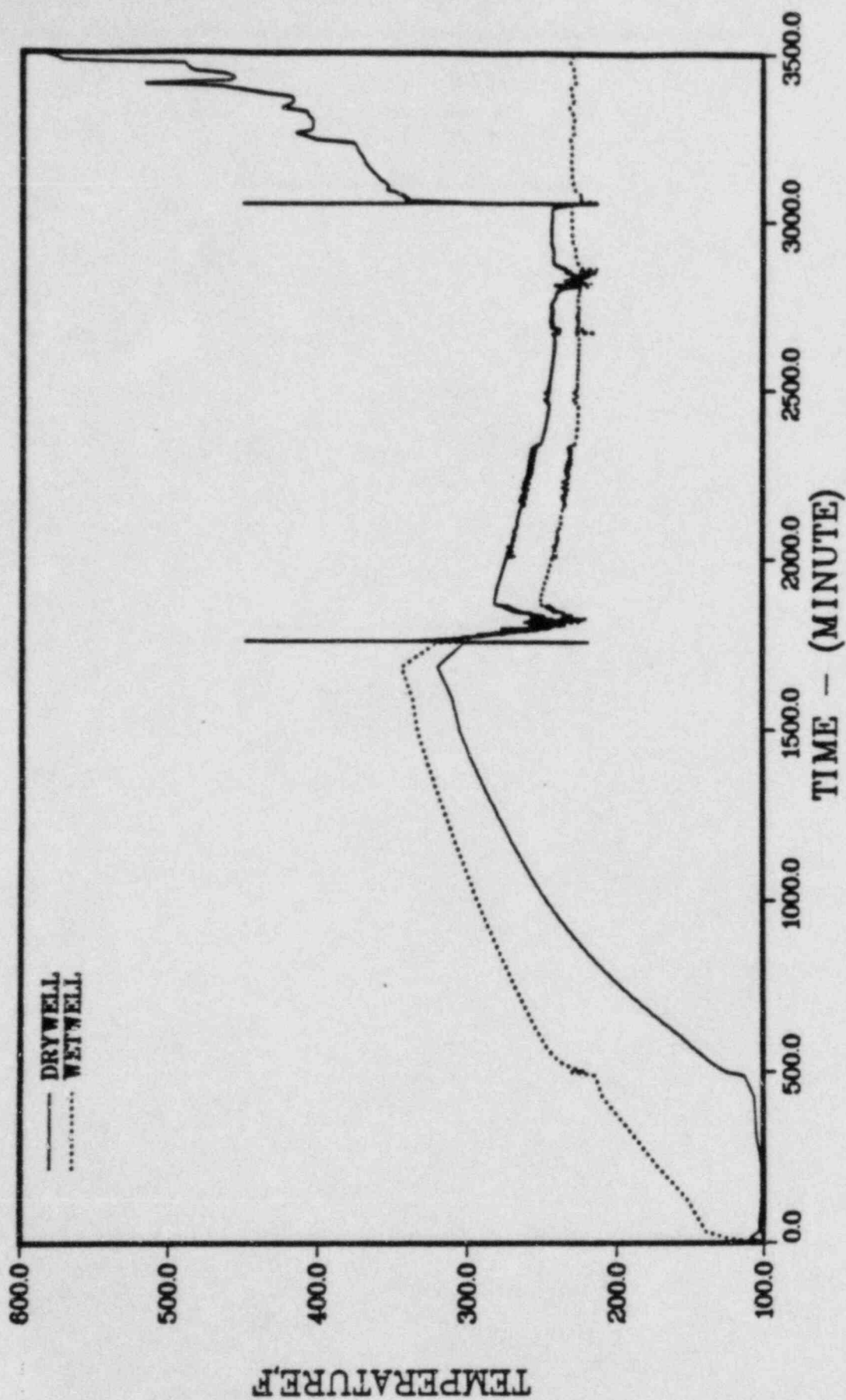


FIGURE 6.26. GAS TEMPERATURES IN CONTAINMENT VOLUMES - SEQUENCE TW

KEY MODELING UNCERTAINTIES

TIME OF CONTAINMENT FAILURE.

LOCATION OF CONTAINMENT FAILURE.

RCS THERMAL-HYDRAULICS.

RESPONSE OF REACTOR BUILDING.

RCS TRANSPORT AND DEPOSITION
FOR THE PEACH BOTTOM SEQUENCES:
AE, TC, TW

- RCS THERMAL-HYDRAULIC CHARACTERISTICS
- RELEASE FROM CORE
- RETENTION IN/RELEASE FROM RCS
- EMITTED PARTICLE SIZE

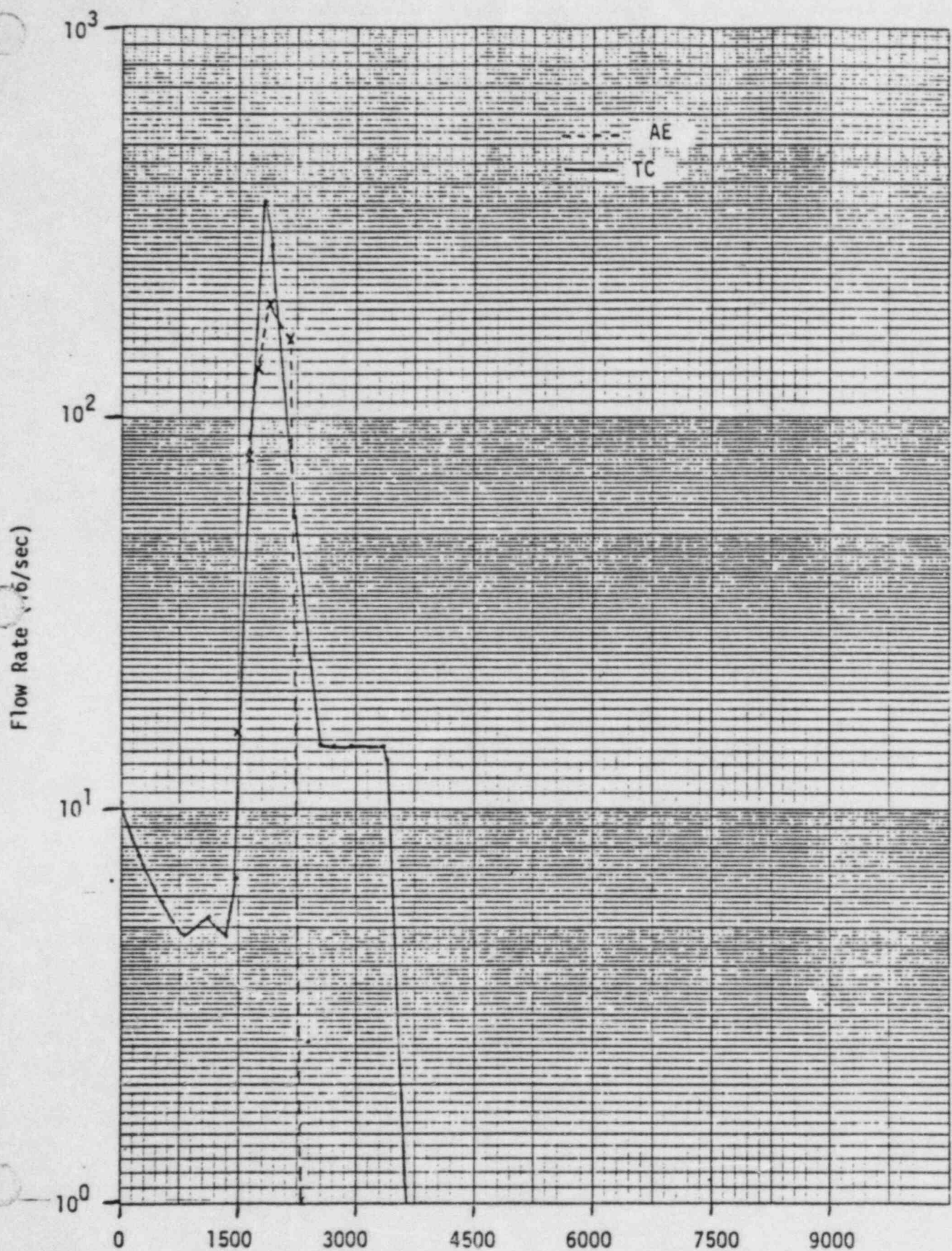
PEACH BOTTOM

RCS THERMAL-HYDRAULIC CHARACTERISTICS

- SIMILAR THERMAL RESPONSE TO THAT EXHIBITED IN SURRY ANALYSES
- GAS FLOW RATES OF SIMILAR MAGNITUDES, BUT SIGNIFICANTLY DIFFERENT TIMING
- DIFFERENT CORE MELTING MODEL LEADS TO DIFFERENT CORE THERMAL HISTORY

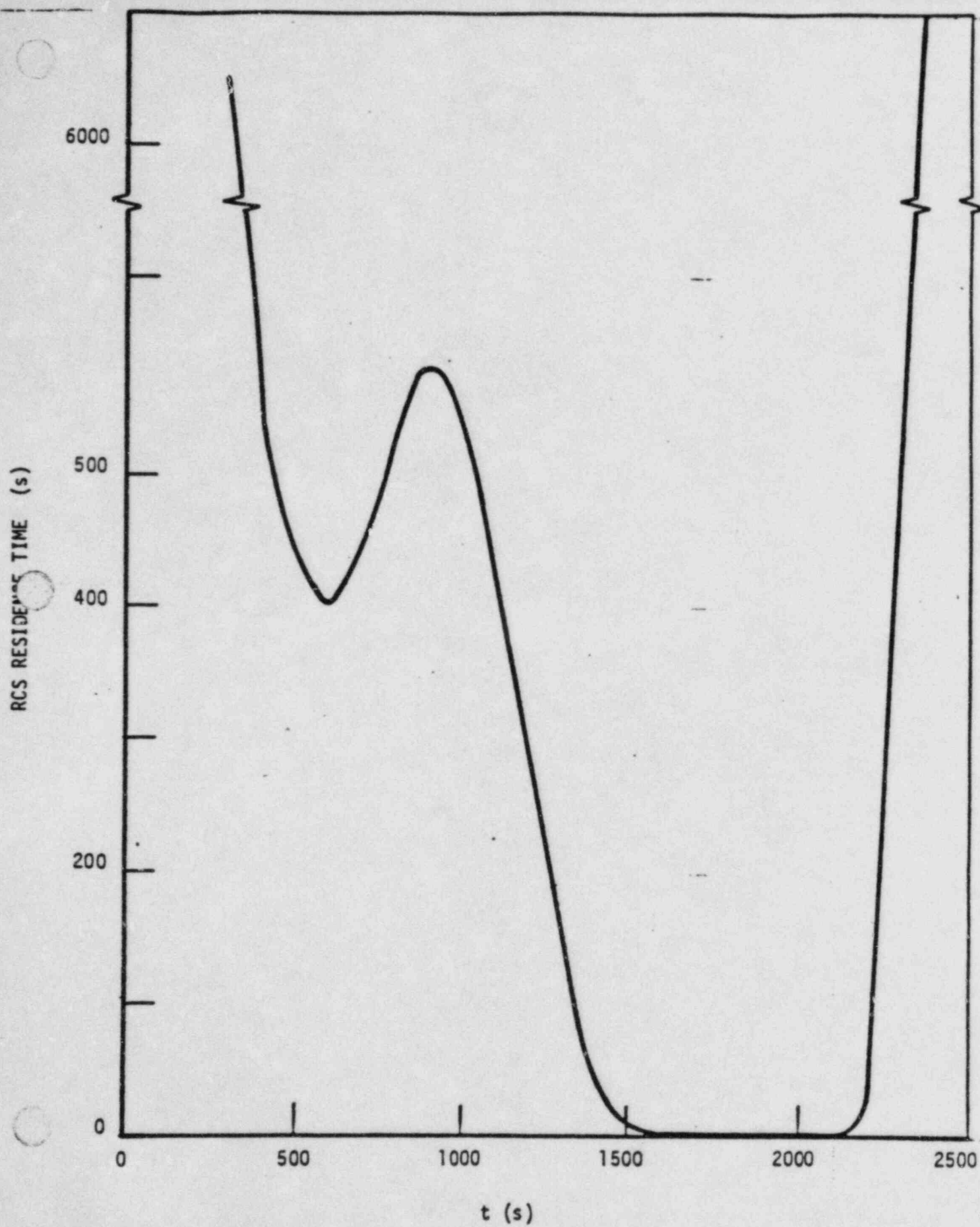
RCS EVENT SUMMARY FOR PEACH BOTTOM SEQUENCES

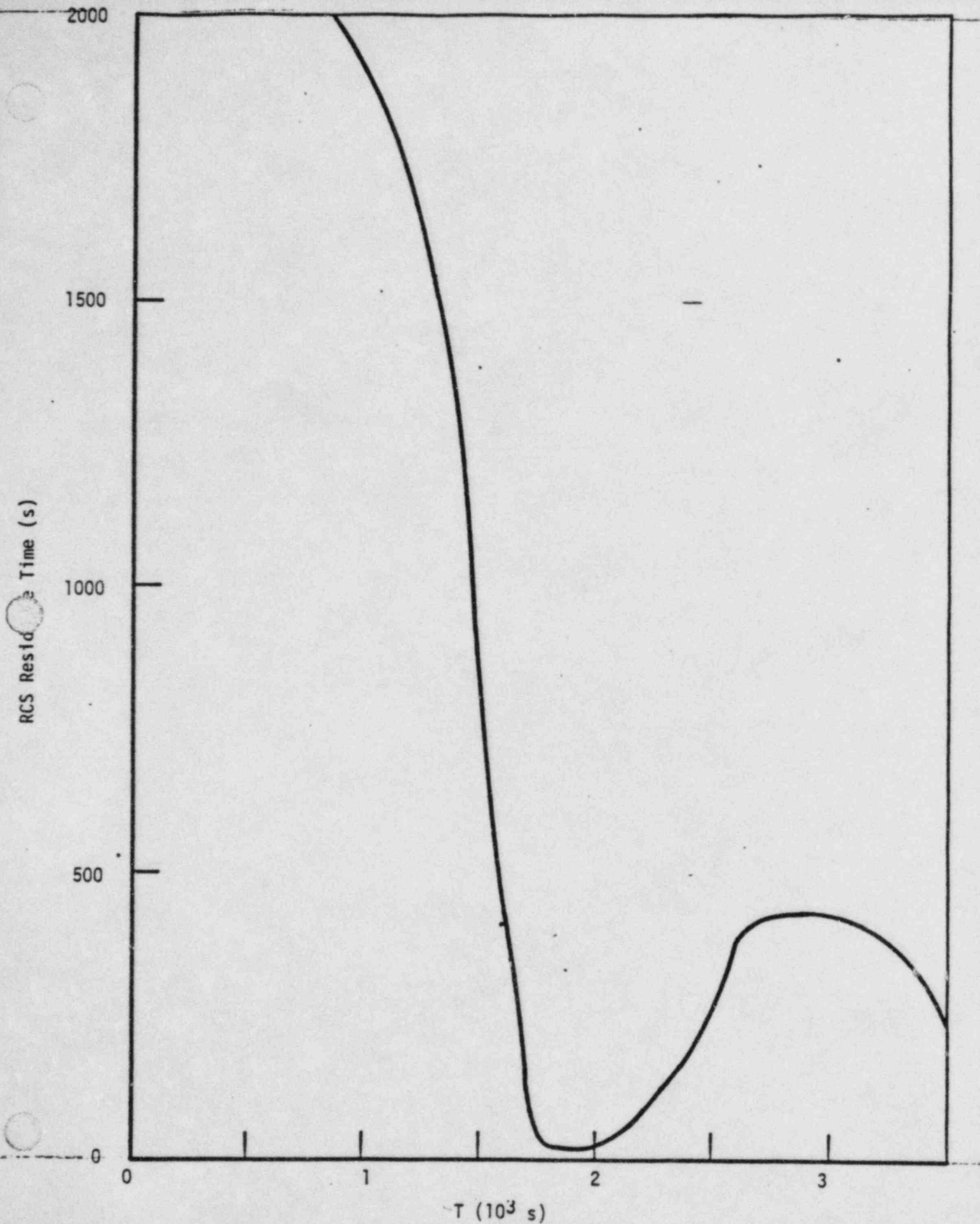
	<u>CORE UNCOVERY</u>	<u>MELT START</u>	<u>VESSEL DRY OUT</u>	<u>VESSEL FAILURE</u>	
AE	1.5	12	40	118	FLUSH OF RCS AT 37
TC	73	95	156	217	FLUSH OF RCS AT 122
TW	2622	2751	2834	3060	FLUSH OF RCS AT 2826



RCS FLOW RATES FOR PEACH BOTTOM SEQUENCES AE AND TC

RCS RESIDENCE TIMES FOR PEACH BOTTOM AE SEQUENCE

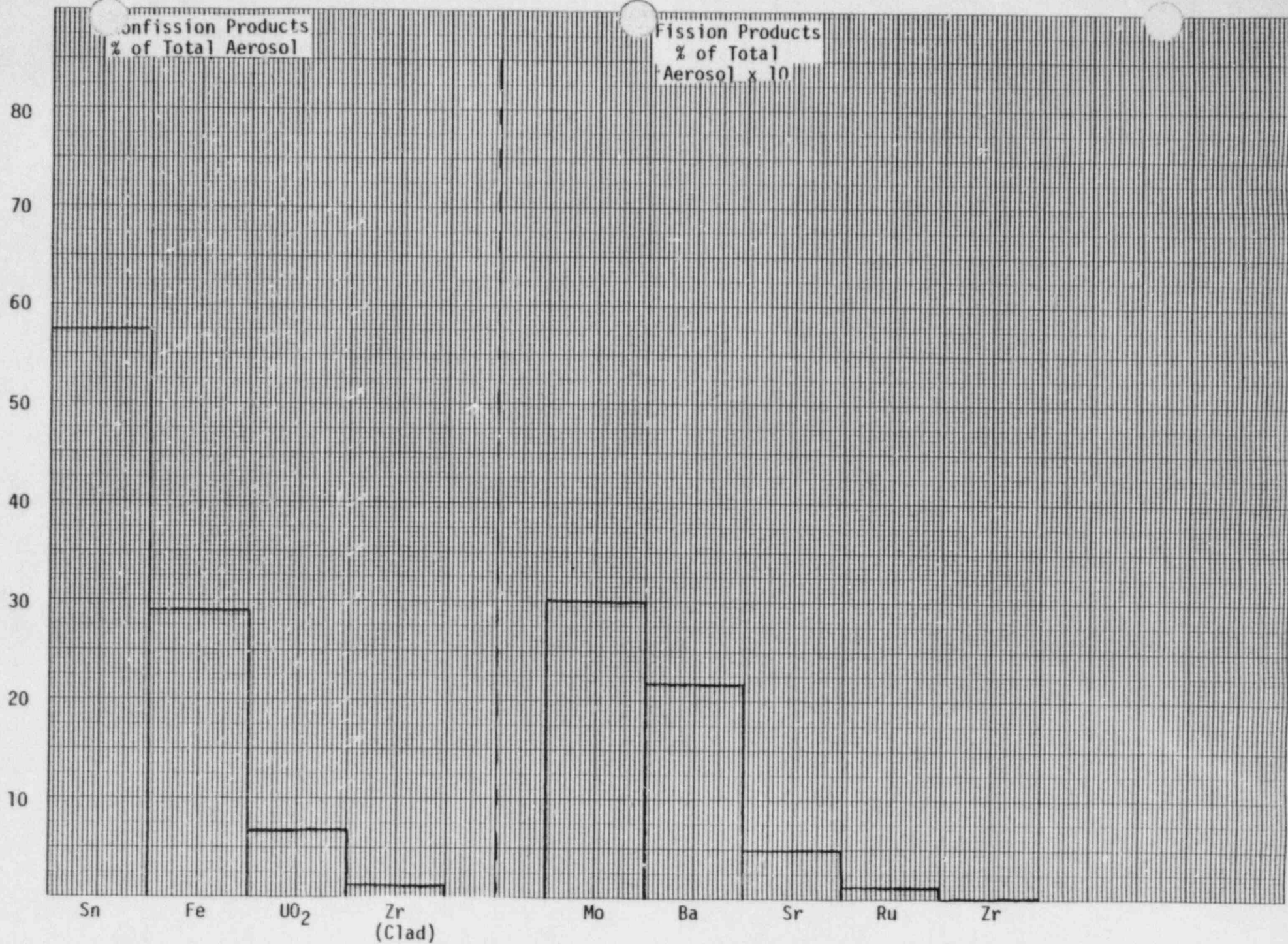




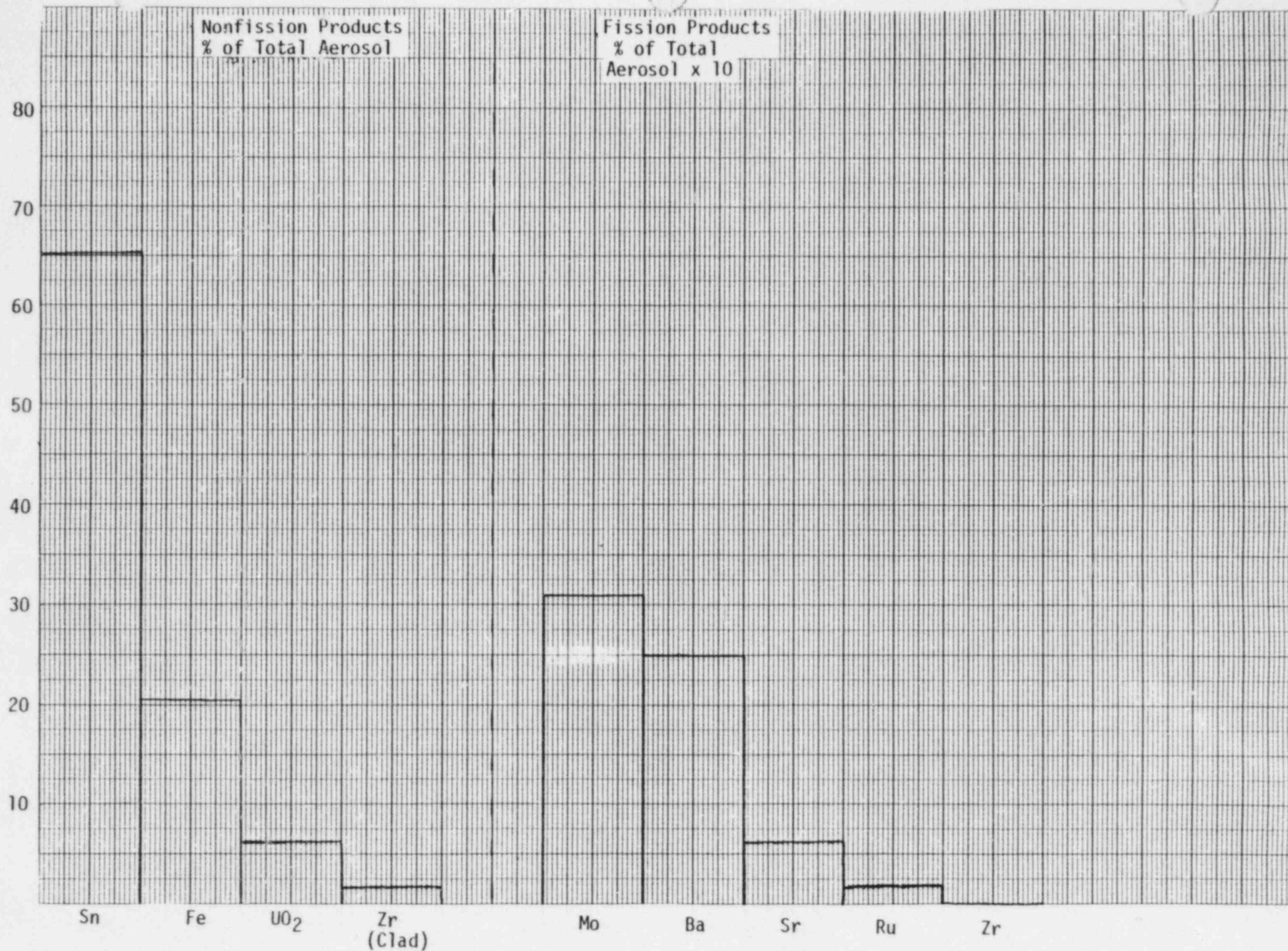
RCS RESIDENCE TIMES FOR PEACH BOTTOM TC SEQUENCE

MASSSES (kg) OF SPECIES RELEASED AT
VESSEL DRY OUT AND VESSEL FAILURE
FOR PEACH BOTTOM SEQUENCES

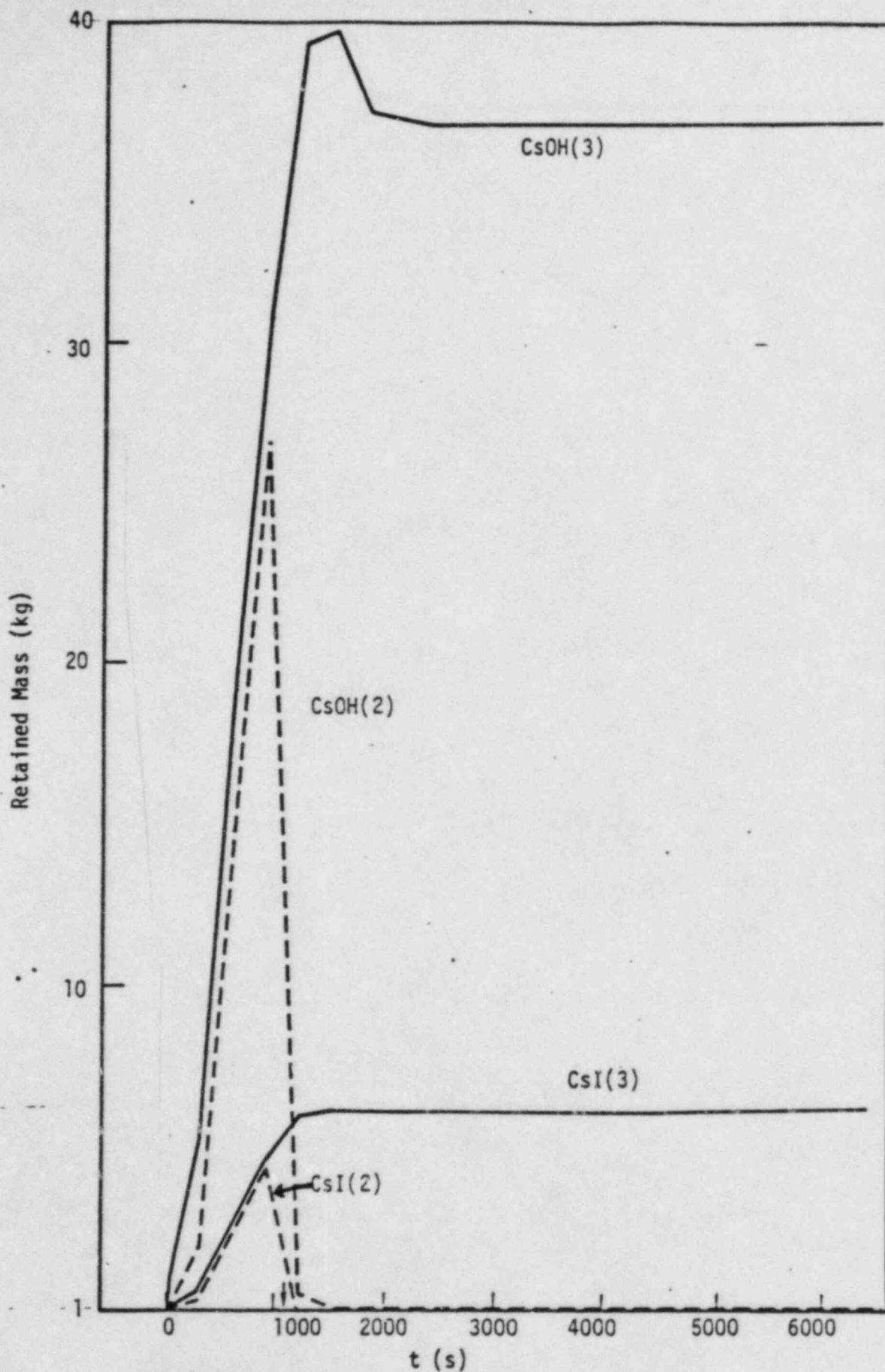
	<u>AE</u>	<u>TC</u>	<u>TW</u>
Cs	165/207	156/164	196/207
I	13.1/16.6	12.4/13.1	15.7/16.6
Te	3.5/7.7	5.8/7.0	14.4/17.0
F.P. AERO.	15.8/51.7	23.2/33.1	49.6/76.1
Non F.P. AERO.	337/839	488/609	998/1238



PEACH BOTTOM TC AEROSOL COMPOSITION AT (T = 260)

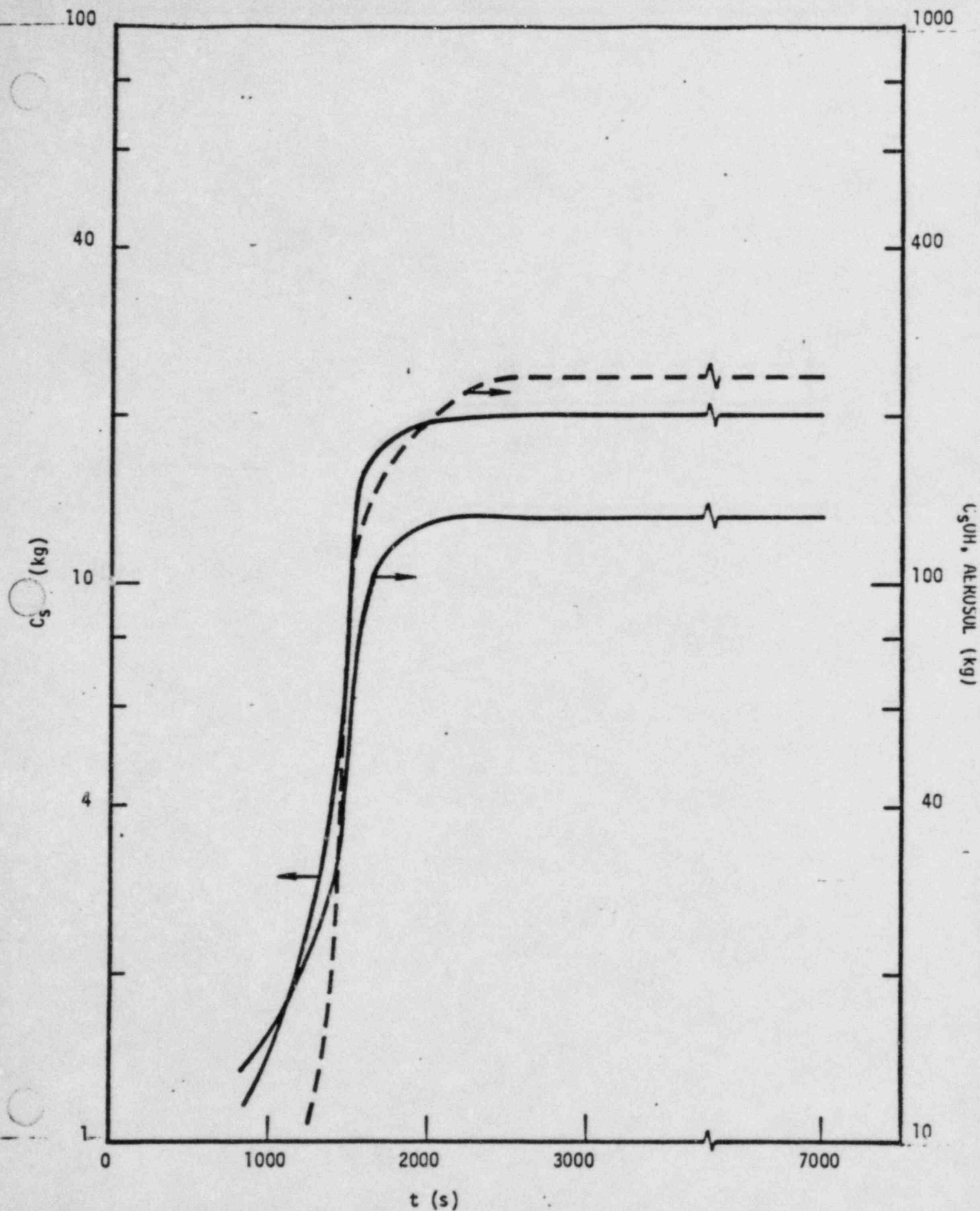


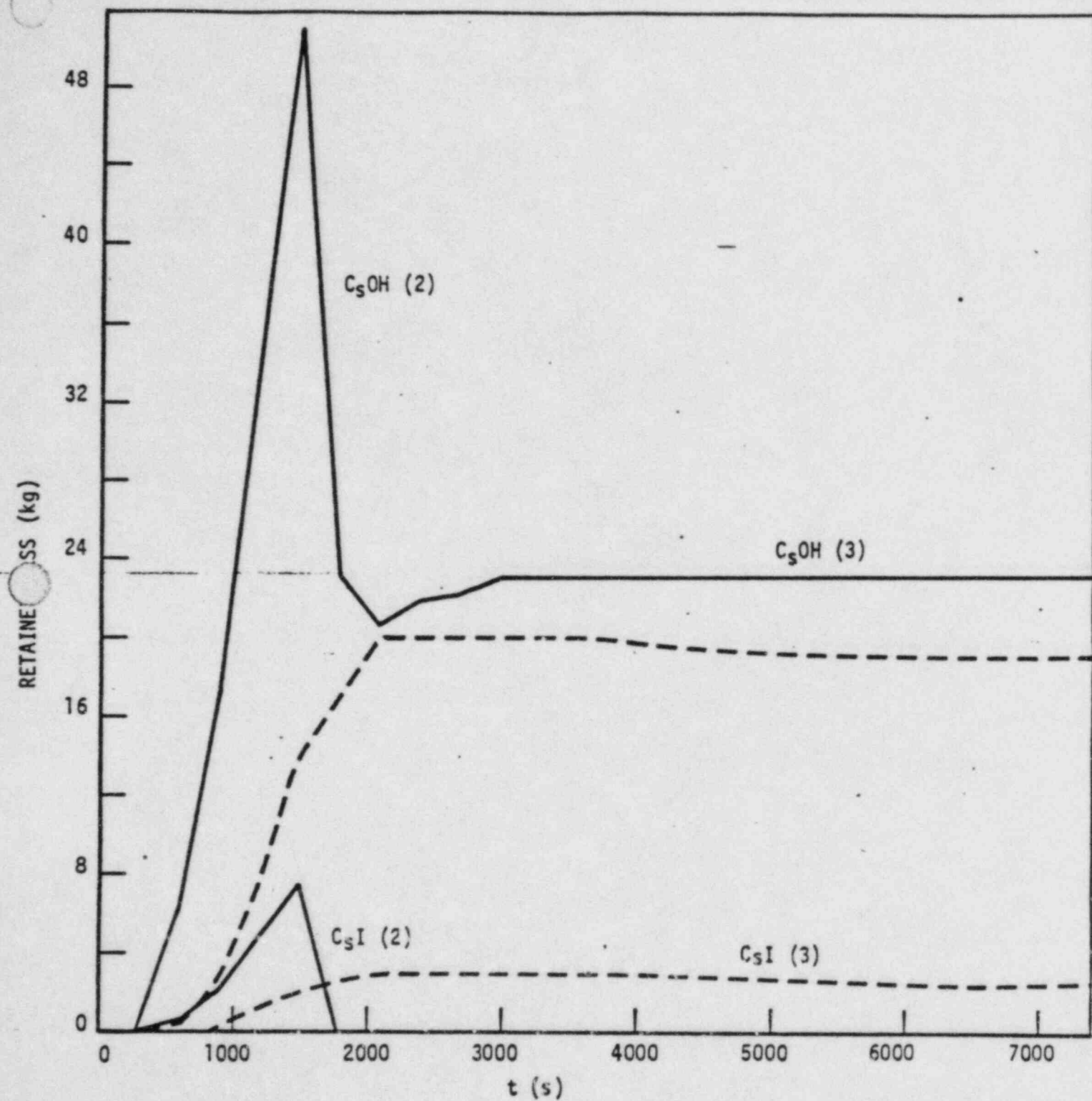
TC GRAND GULF COMPOSITION OF AEROSOL EMITTED AT (TIME 196)



MASS RETAINED IN VOLUMES 2 AND 3 FOR PEACH BOTTOM AE

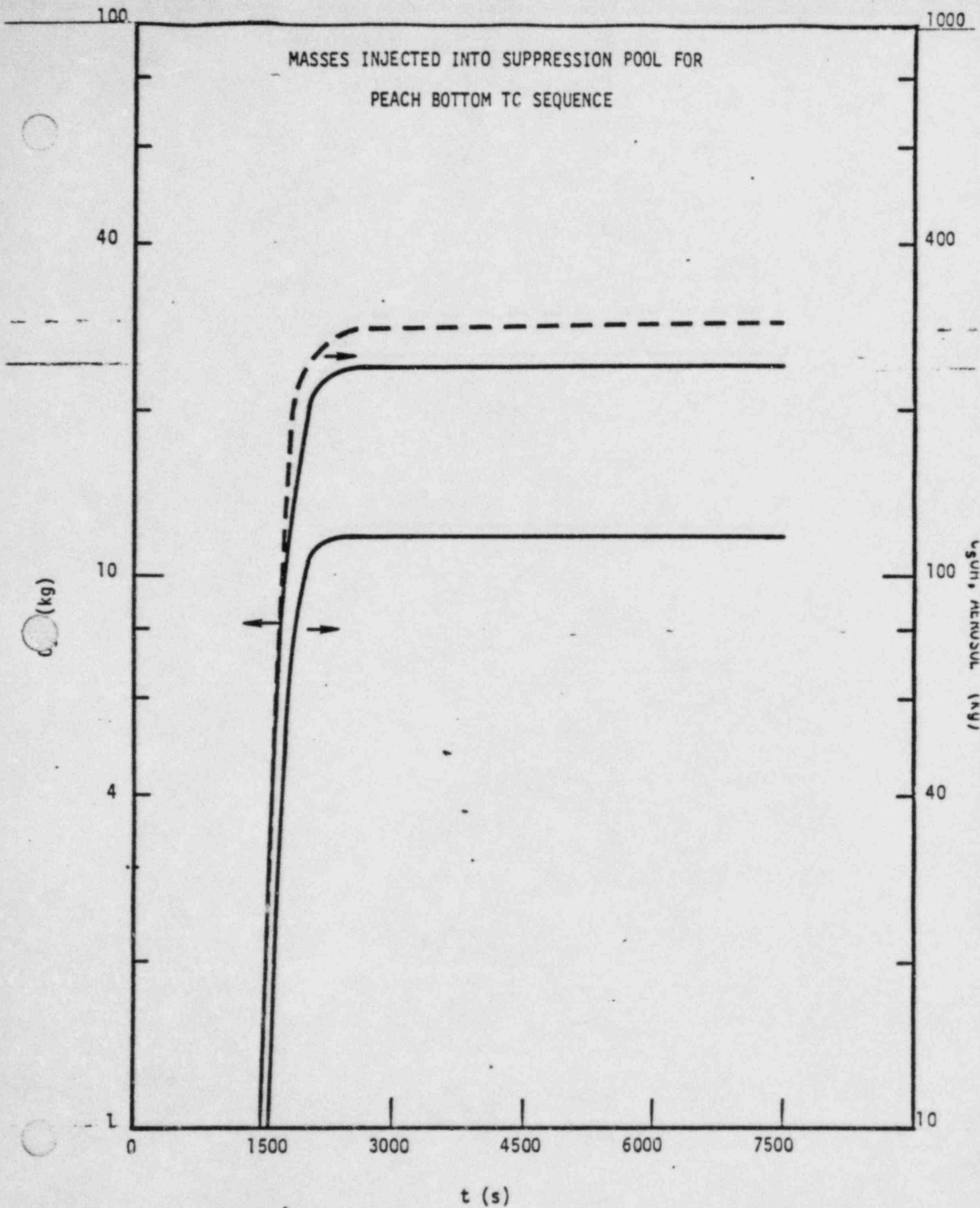
MASSES INJECTED INTO DRYWELL FOR PEACH BOTTOM AE SEQUENCE

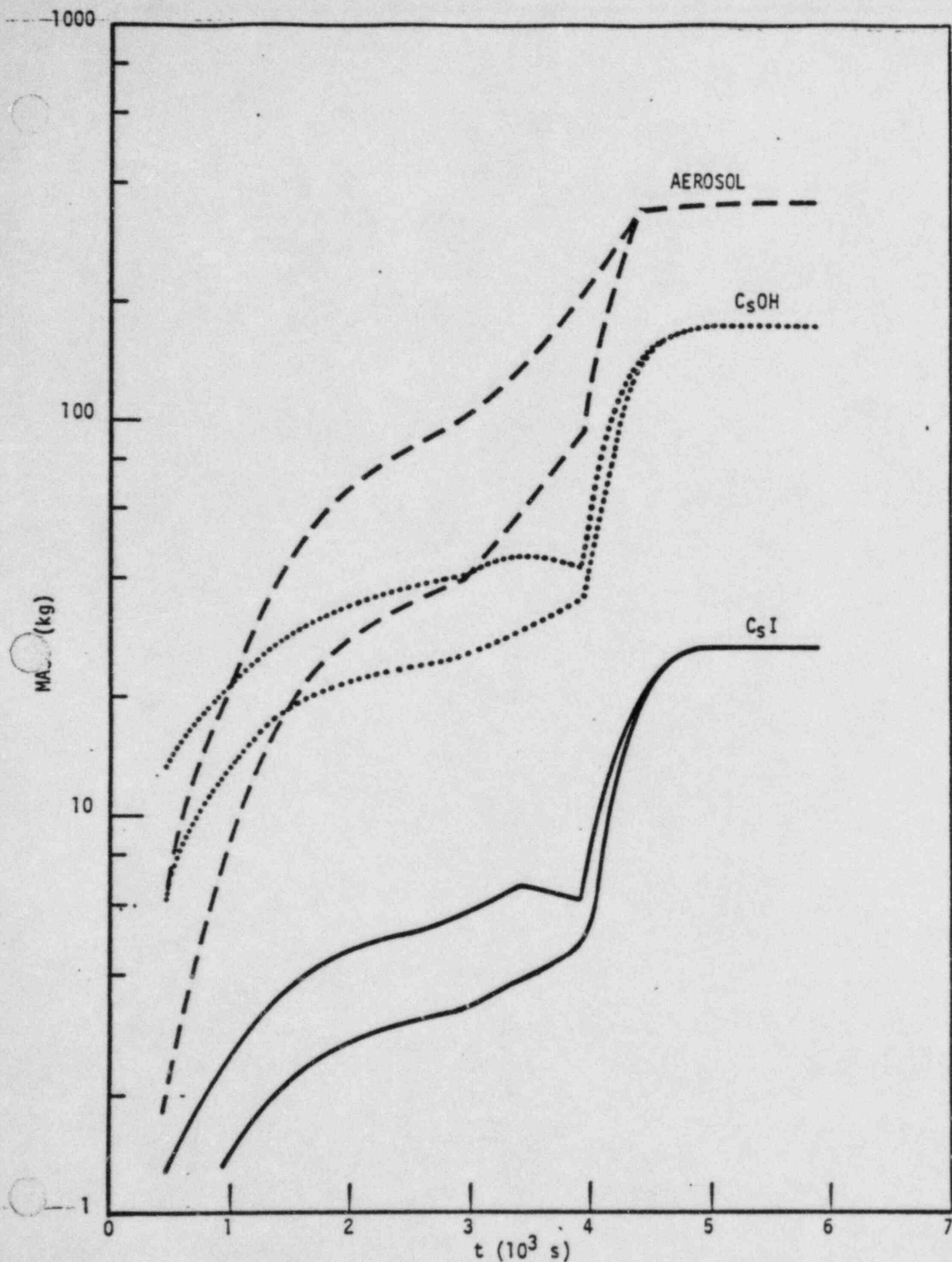




MASSSES OF C_5I AND C_5OH RETAINED IN VOL 2 AND 3 FOR
PEACH BOTTOM TC SEQUENCE

MASSSES INJECTED INTO SUPPRESSION POOL FOR PEACH BOTTOM TC SEQUENCE

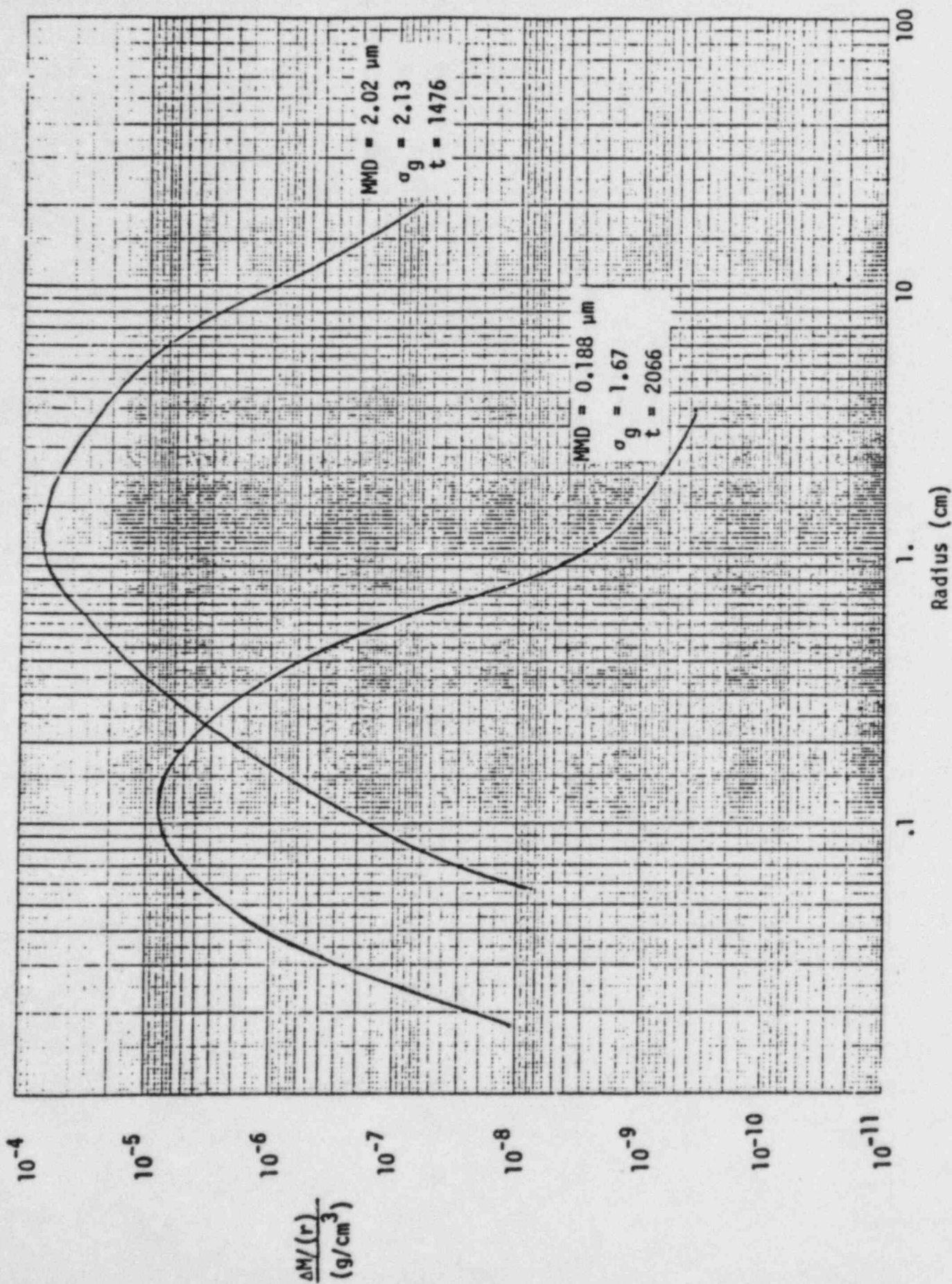




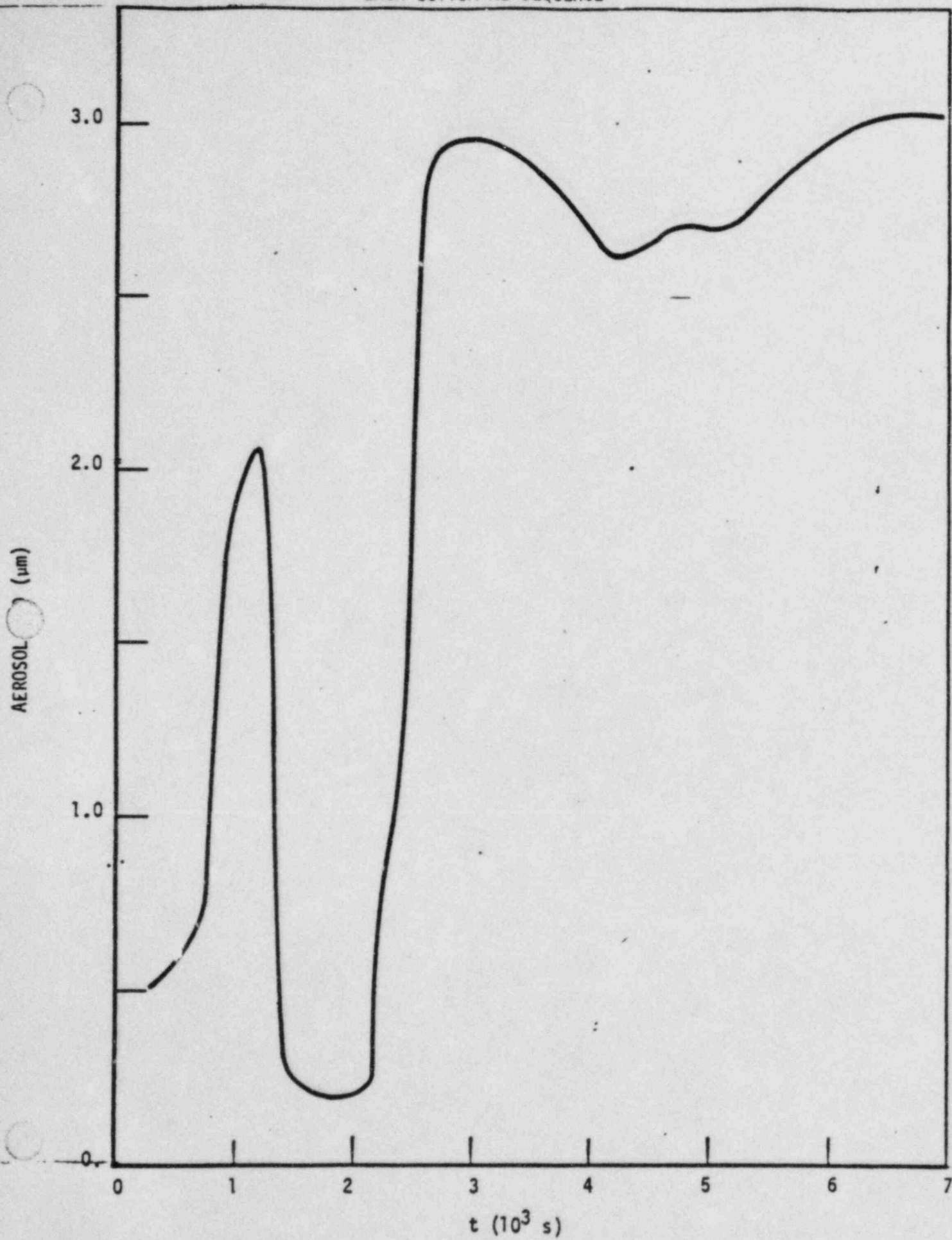
TOTAL SUSPENDED MASSES, AND RCS-ESCAPED MASS FOR
PEACH BOTTOM TW SEQUENCE

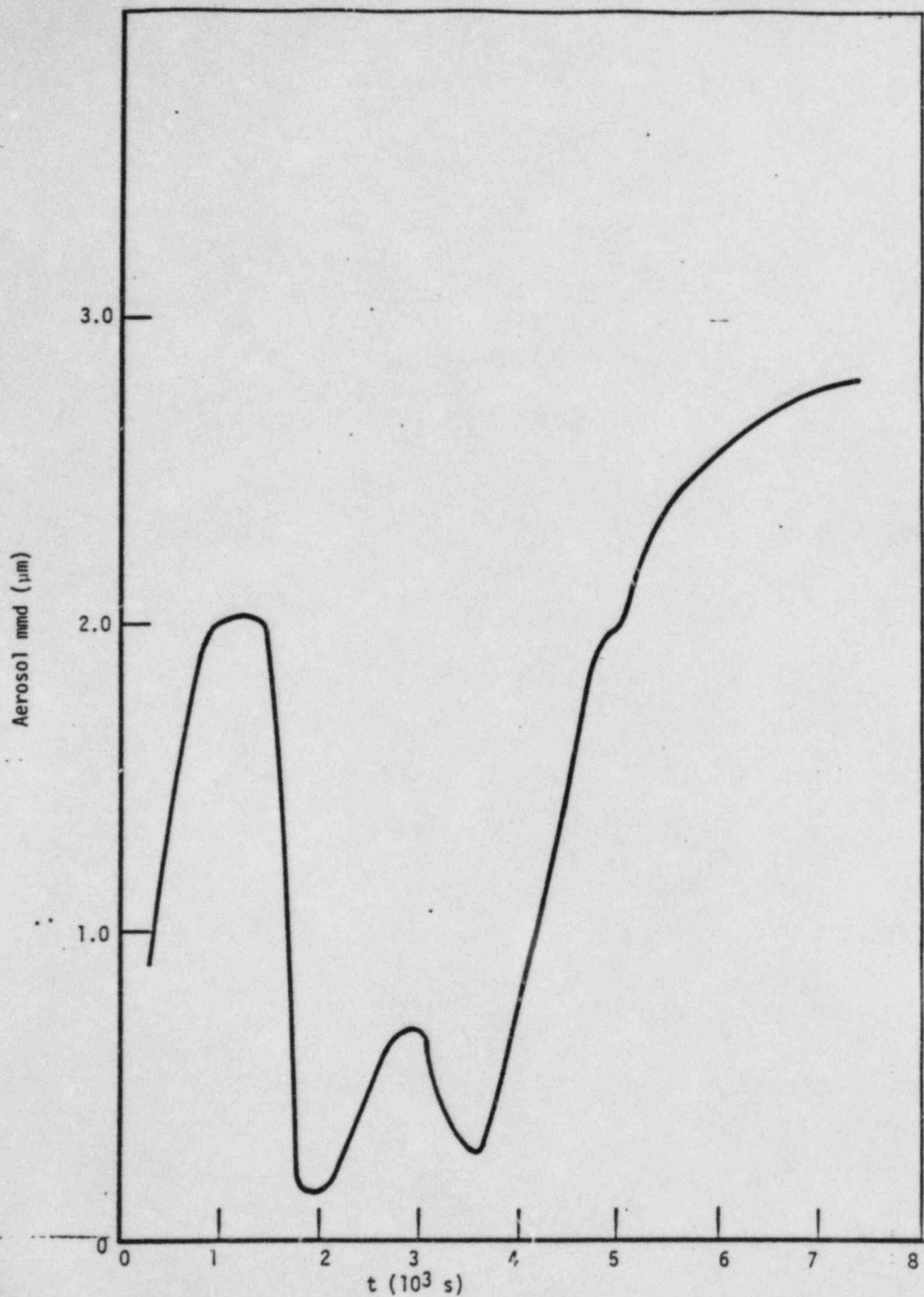
RCS RETENTION MECHANISMS FOR PEACH BOTTOM SEQUENCES
(FRACTIONAL DISTRIBUTION OF SPECIES AT VESSEL FAILURE)

	AE			TC			TW*		
	VAP.	AER.	SUSP.	VAP.	AER.	SUSP.	VAP.	AER.	SUSP.
CsI	.04	.14	.22	.01	.10	.06	0.	.16	0.
CsOH	.06	.13	.14	.16	.10	.06	.02	.15	0.
Te	.14	0.	.53	.80	0.	.18	.97	0.	0.
AERO.	-	.69	.04	-	.51	.04	-	.65	0.



AEROSOL MASS MEDIAN DIAMETER IN CORE REGION FOR
PEACH BOTTOM AE SEQUENCE





AEROSOL MASS MEDIAN DIAMETER IN CORE REGION FOR PEACH BOTTOM TC SEQUENCE

CONTAINMENT CALCULATION

- AEROSOL AGGLOMERATION
- GRAVITATIONAL SETTLING
- DIFFUSIONAL SETTLING
- STEAM CONDENSATION ONTO PARTICLES
- DIFFUSIOPHORESIS
- SOURCE
- LEAKAGE

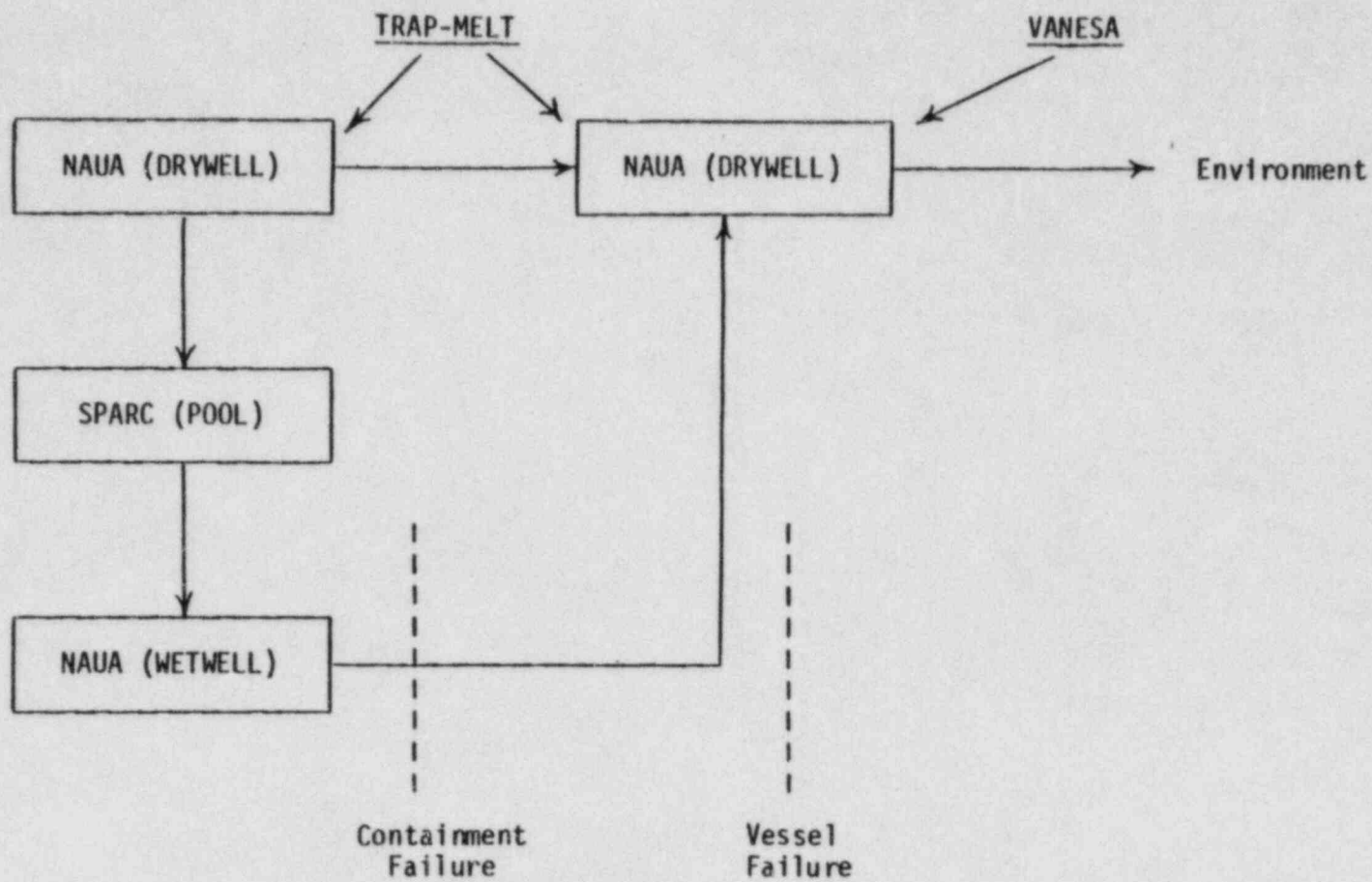
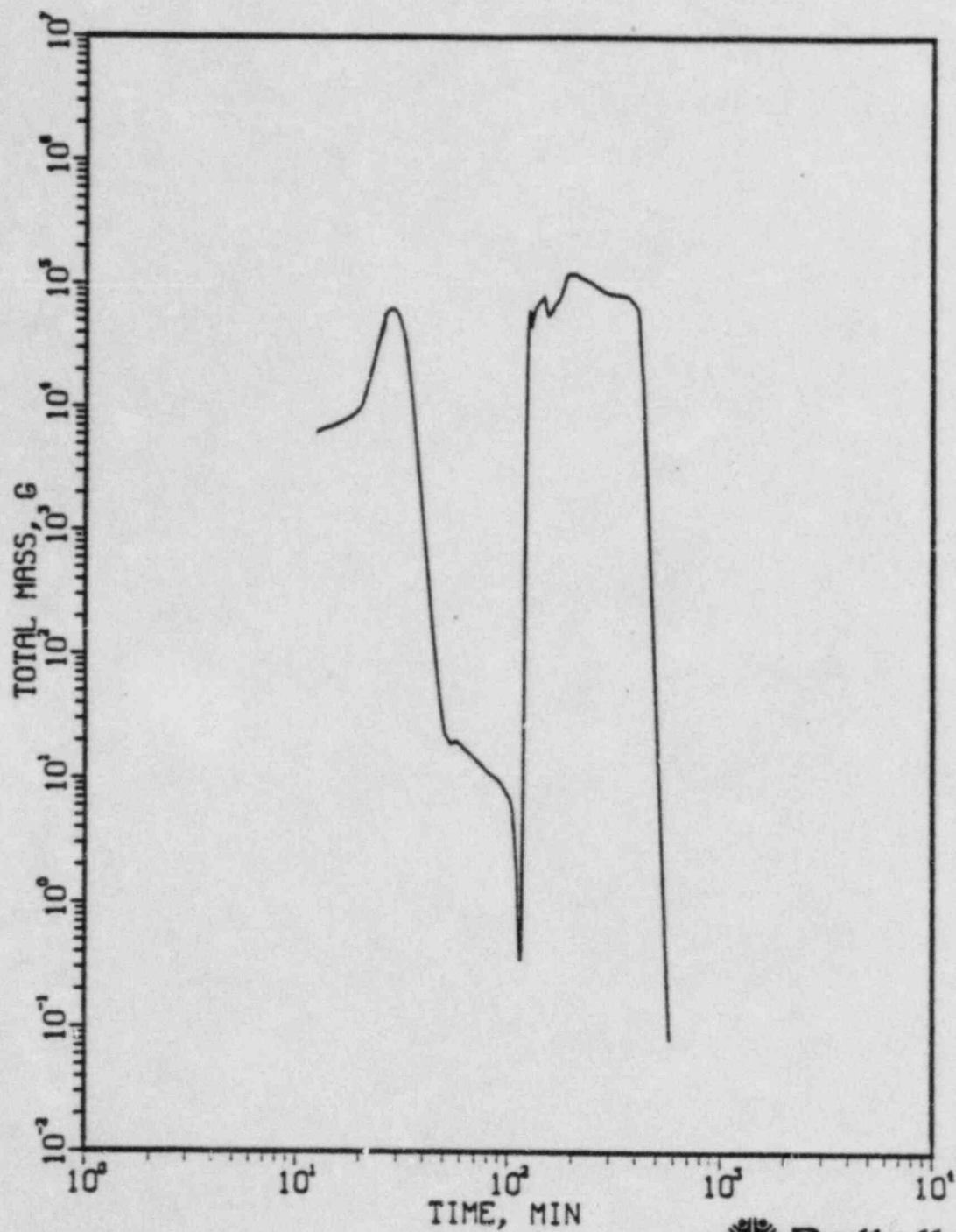


FIGURE 7.1. NAUA AND SPARC CALCULATION PATHS USED FOR PERFORMING ANALYSES OF AE SEQUENCE

PBAE GAMMA DRYWELL CASE

AIRBORNE

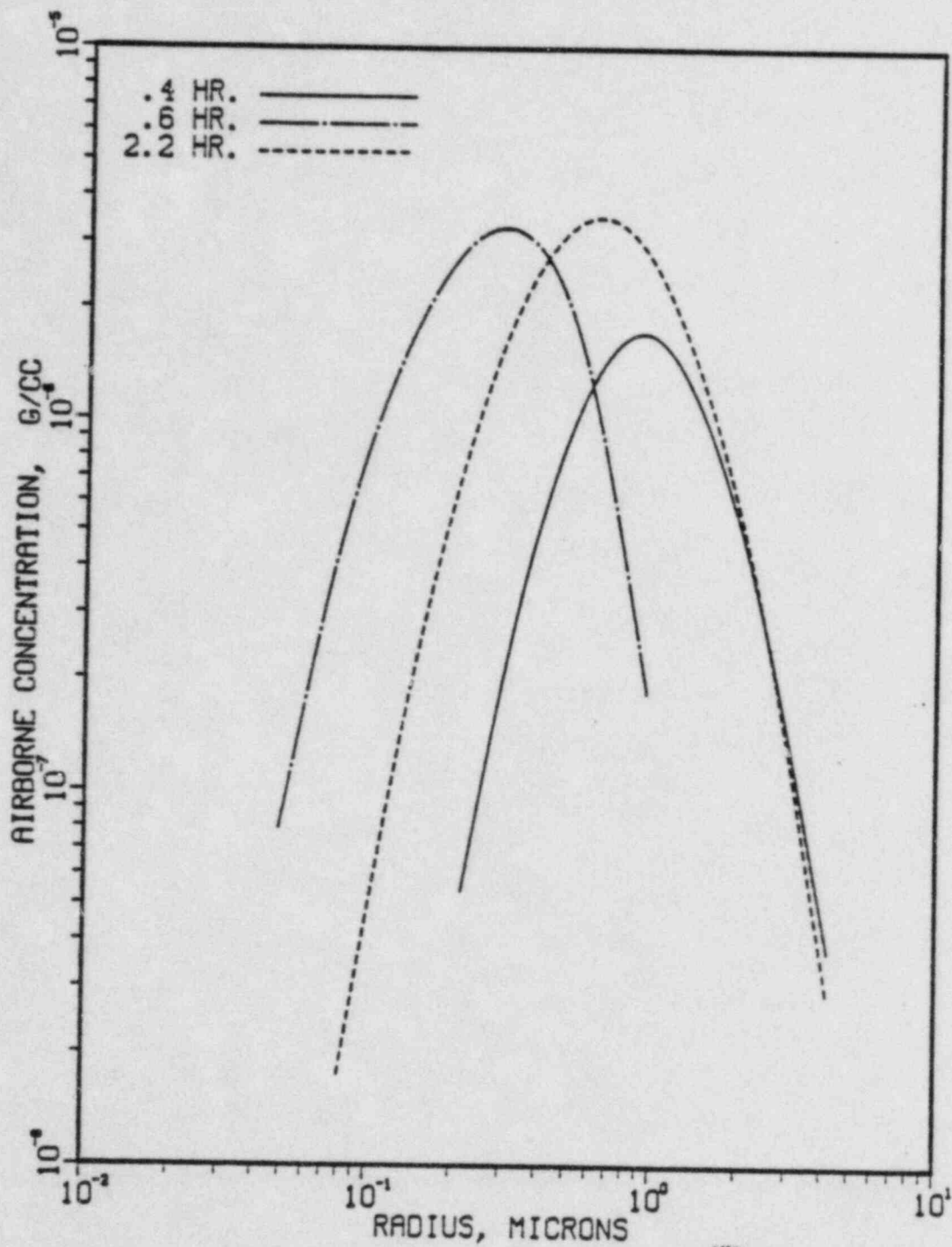


Battelle

Columbus Laboratories

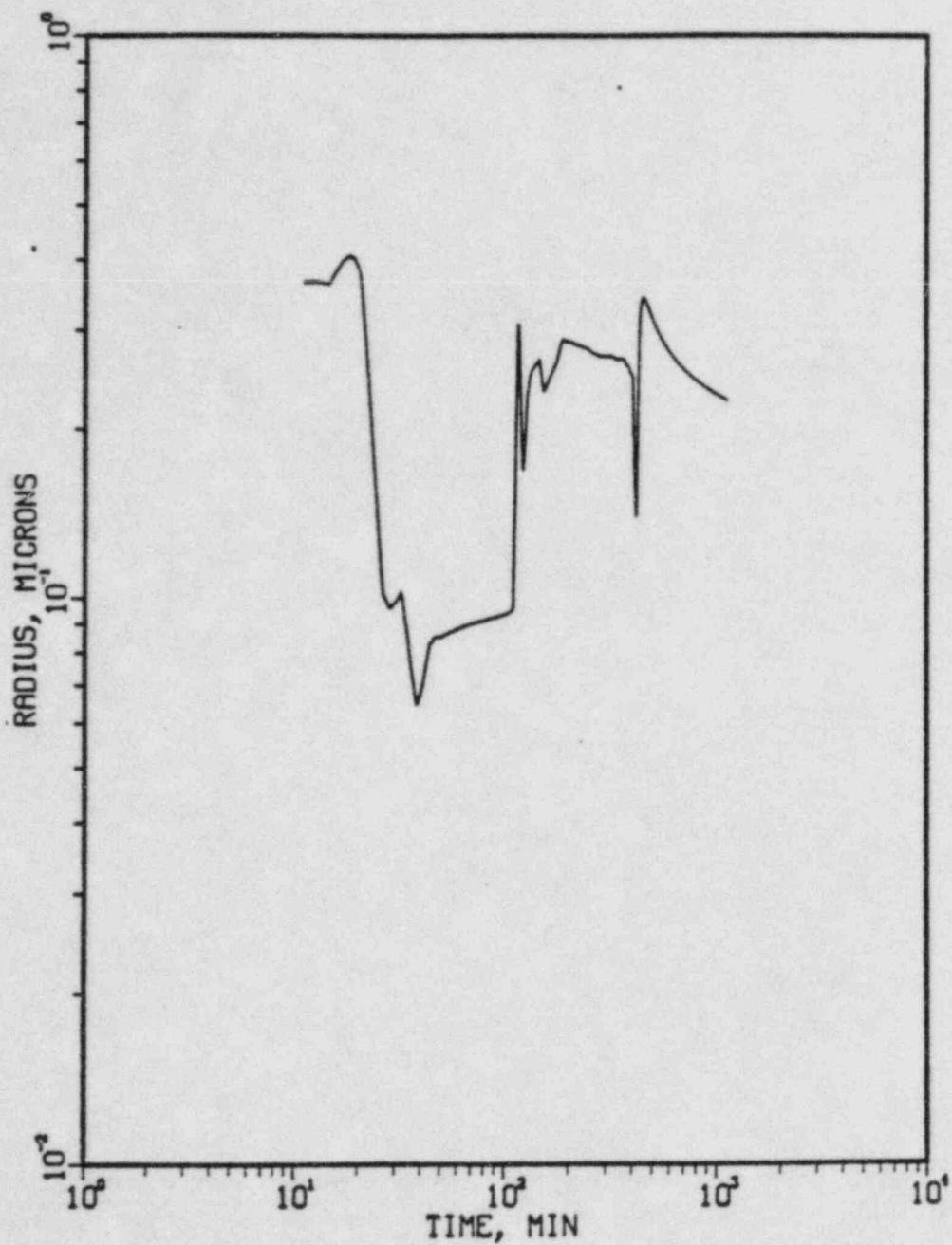
AE GAMMA DRYWELL CASE

PARTICLE SIZE DISTRIBUTIONS



PBAE GAMMA DRYWELL CASE

AVG. PARTICLE RADIUS



SUPPRESSION POOL MODELING

- CONDENSATION OF STEAM
- INERTIAL DEPOSITION
- DIFFUSION
- GRAVITATIONAL SETTLING
- PARTICLE GROWTH DUE TO PRESSURE DECREASE (NEGATIVE DEPOSITION)
- INJECTION IMPINGEMENT
- SOLUBILITY OF PARTICLES

TABLE 7.9. DECONTAMINATION FACTORS CALCULATED AS A FUNCTION OF PARTICLE SIZE AND OF TIME FOR AE SEQUENCE

Time (min)	Particle Diameter, μm					DF Based on Total Mass
	0.1	0.6	1.0	6	10	
14.3	4.1	388	$10^{5(a)}$	10^5	10^5	164
18.9	3.9	307	10^5	10^5	10^5	125
27.4	2.6	374	10^5	10^5	10^5	7
33.3	14.7	55,900	10^5	10^5	10^5	34

(a) A decontamination factor larger than 10^5 is assumed to be 10^5 .

Pool depth: 4 ft
Bubble diameter: 0.75 cm
Aspect ratio: 1:3

TABLE 7.7. DISTRIBUTION OF TOTAL SOLID PARTICULATE MASS (KG) AT VARIOUS TIMES, AE

Time (min)	Event	Drywell		Pool Captured	Wetwell	Environment
		Suspended	Deposited			
12	Melt start					
20		10	18	0.11	-0	--
34	Cont fails	29	29	285	-1.0	--
35		8.4	29	285	-1.0	23
40	Vessel dry					
50		0.023	30		-0	75
58	Core collapse					
80		0.012	30	285	-0	75
118	Head fails					
120		17	48	285	-0	100
420		25	1380	285	-0	2755
1200	End of accident	--	1390	285	-0	2755

TABLE 7.8. DISTRIBUTION OF SPECIES AT 20 HOURS AFTER ACCIDENT, AE

Species	Fraction of Core Environment				
	RCS	Pool	Drywell	Wetwell	Environment
CsI	0.18	0.47	0.14	-0	0.21
CsOH	0.19	0.45	0.15	-0	0.21
Te	0.02	0.02	0.29	-0	0.67

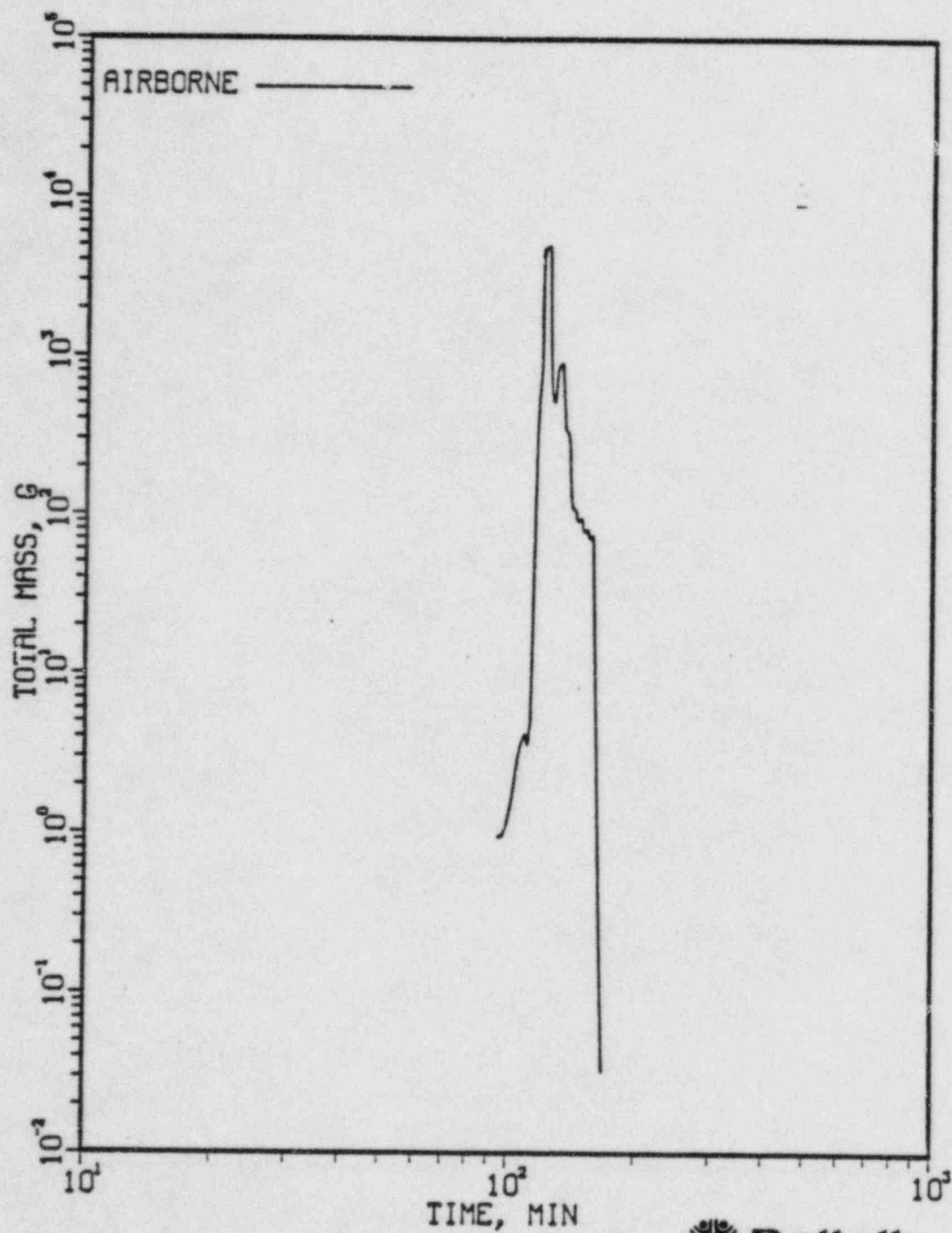
TABLE 7.10. DECONTAMINATION FACTOR CALCULATED AS A FUNCTION OF PARTICLE SIZE AND OF TIME FOR TC

Time (min)	Particle Diameter, μm					DF Based on Total Mass
	0.1	0.6	1.0	6.0	10	
96.2	1.6	2×10^4	$10^5(a)$	10^5	10^5	120
99.2	5.7	1110	10^5	10^5	10^5	285
104	3.4	10^5	10^5	10^5	10^5	170
121.7	1.3	292	10^5	10^5	10^5	8.4
131.5	1.2	19	1.1×10^4	10^5	10^5	1.7
156.3	1.2	13	3610	10^5	10^5	6.5

(a) A decontamination factor larger than 10^5 is assumed to be 10^5 .

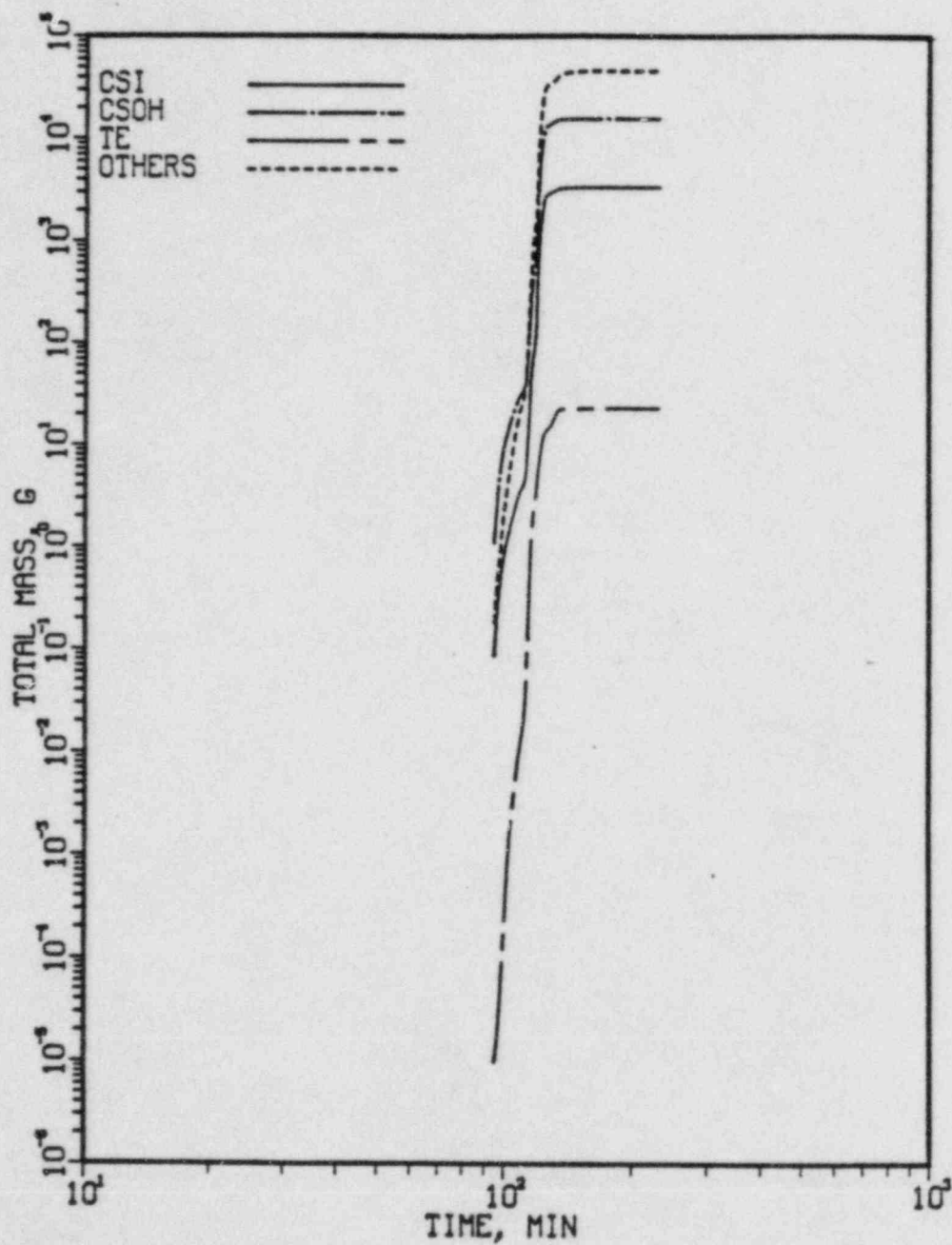
Pool depth: 6.5 ft (198 cm)
Bubble diameter: 0.75 cm
Aspect ratio: 1:3

PBTC GAMMA WETWELL CASE



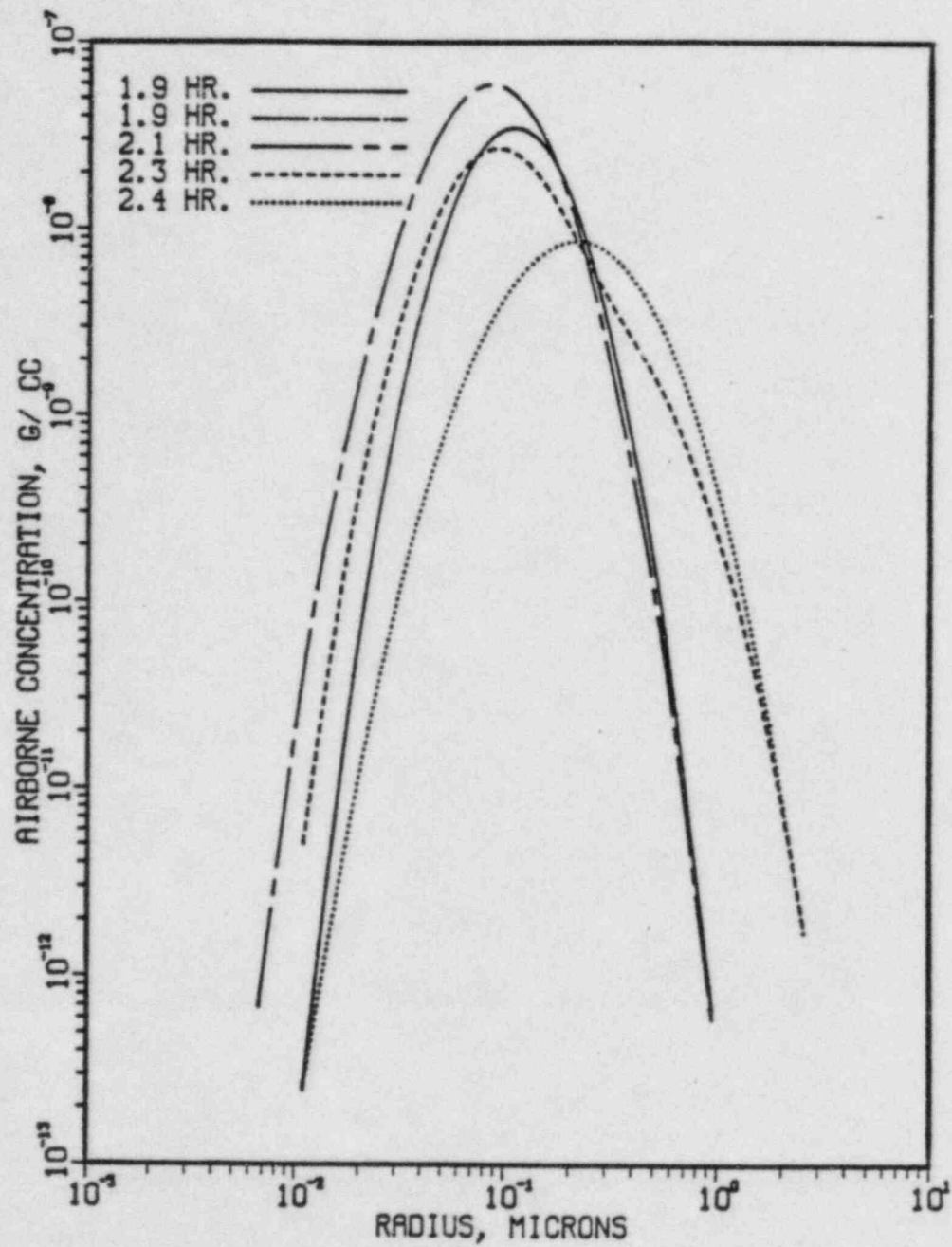
PBTC GAMMA WETWELL CASE

ACC. LEAKED NUCLIDES



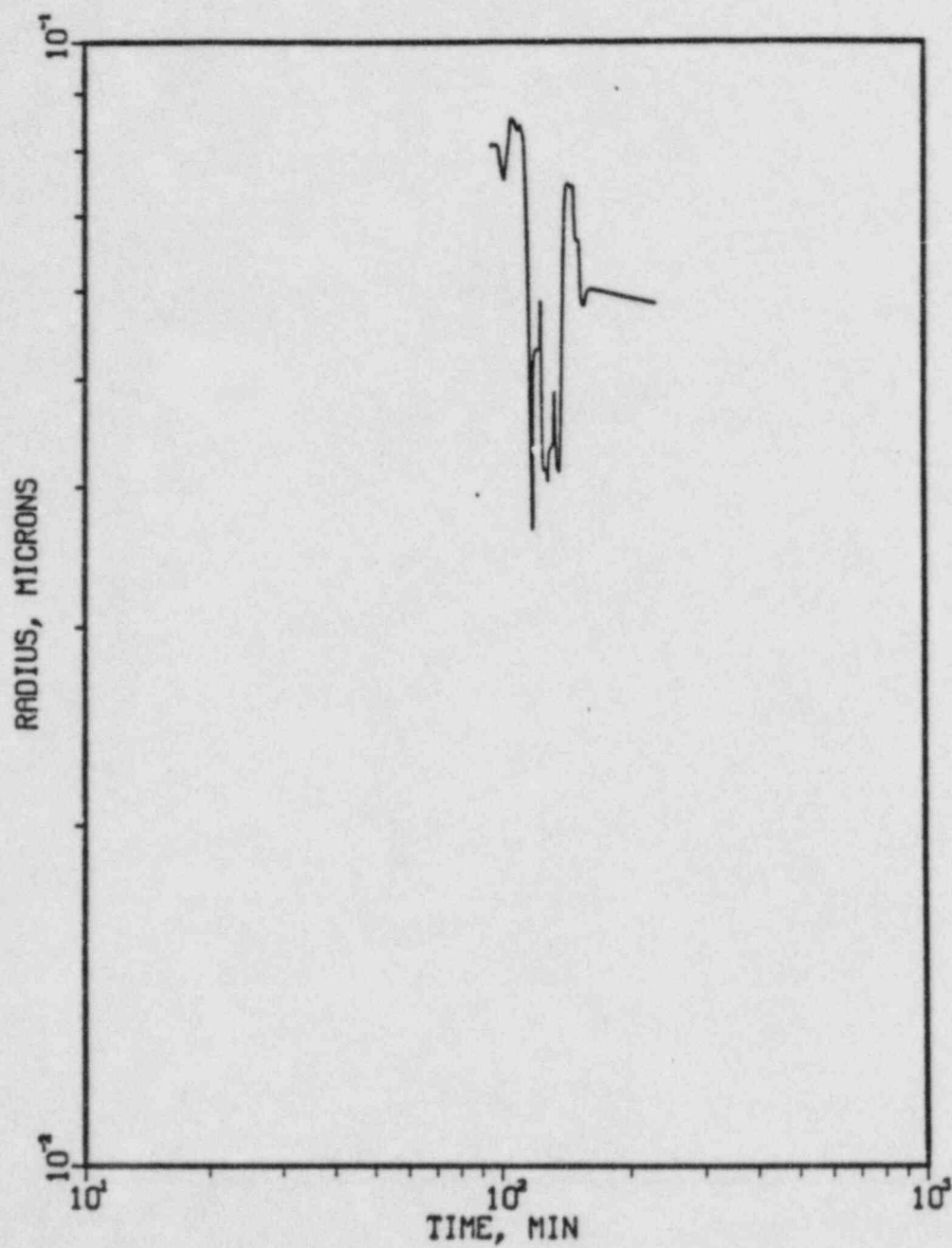
PBTC GAMMA WETWELL CASE

PARTICLE SIZE DISTRIBUTIONS



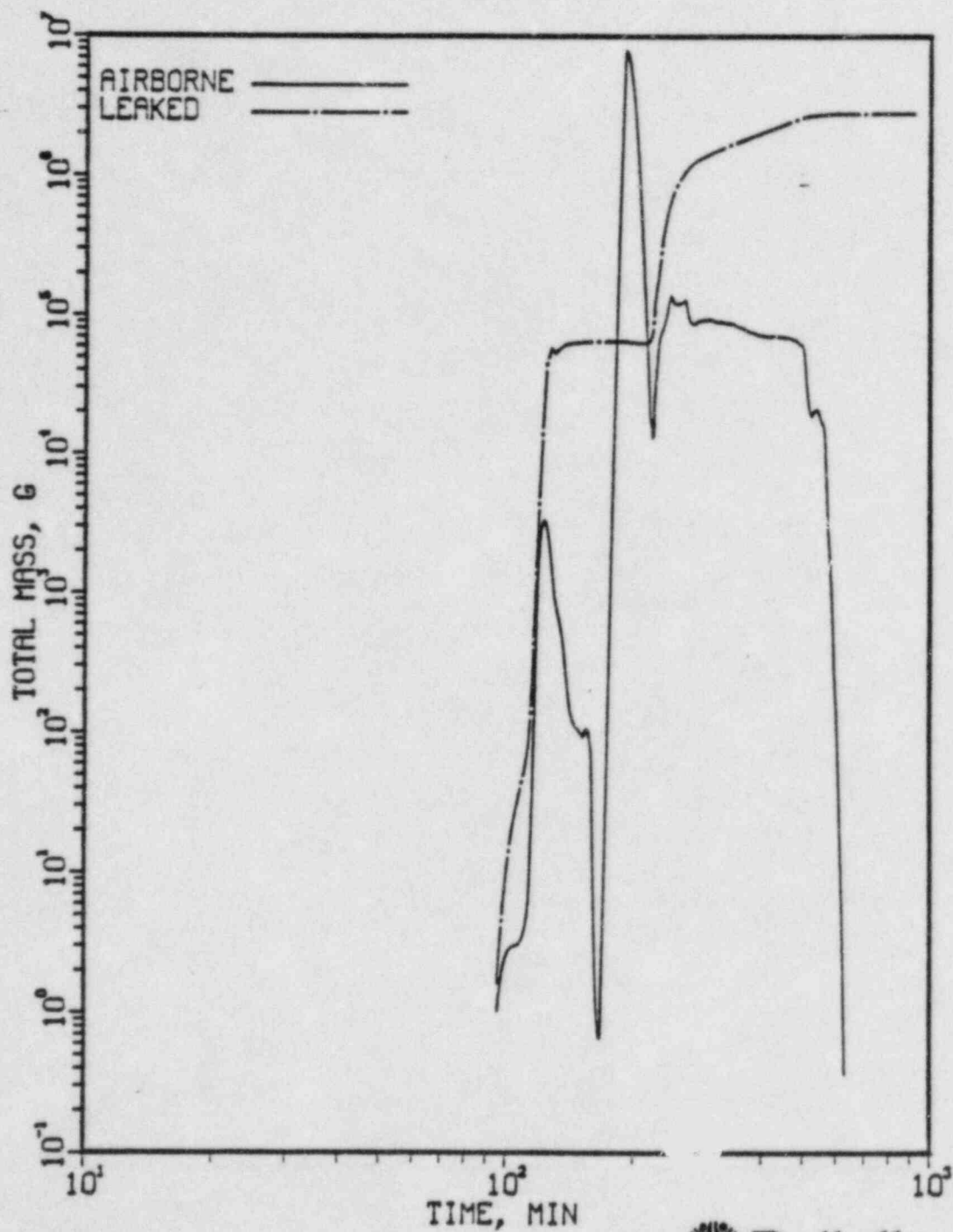
PBTC GAMMA WETWELL CASE

AVG. PARTICLE RADIUS



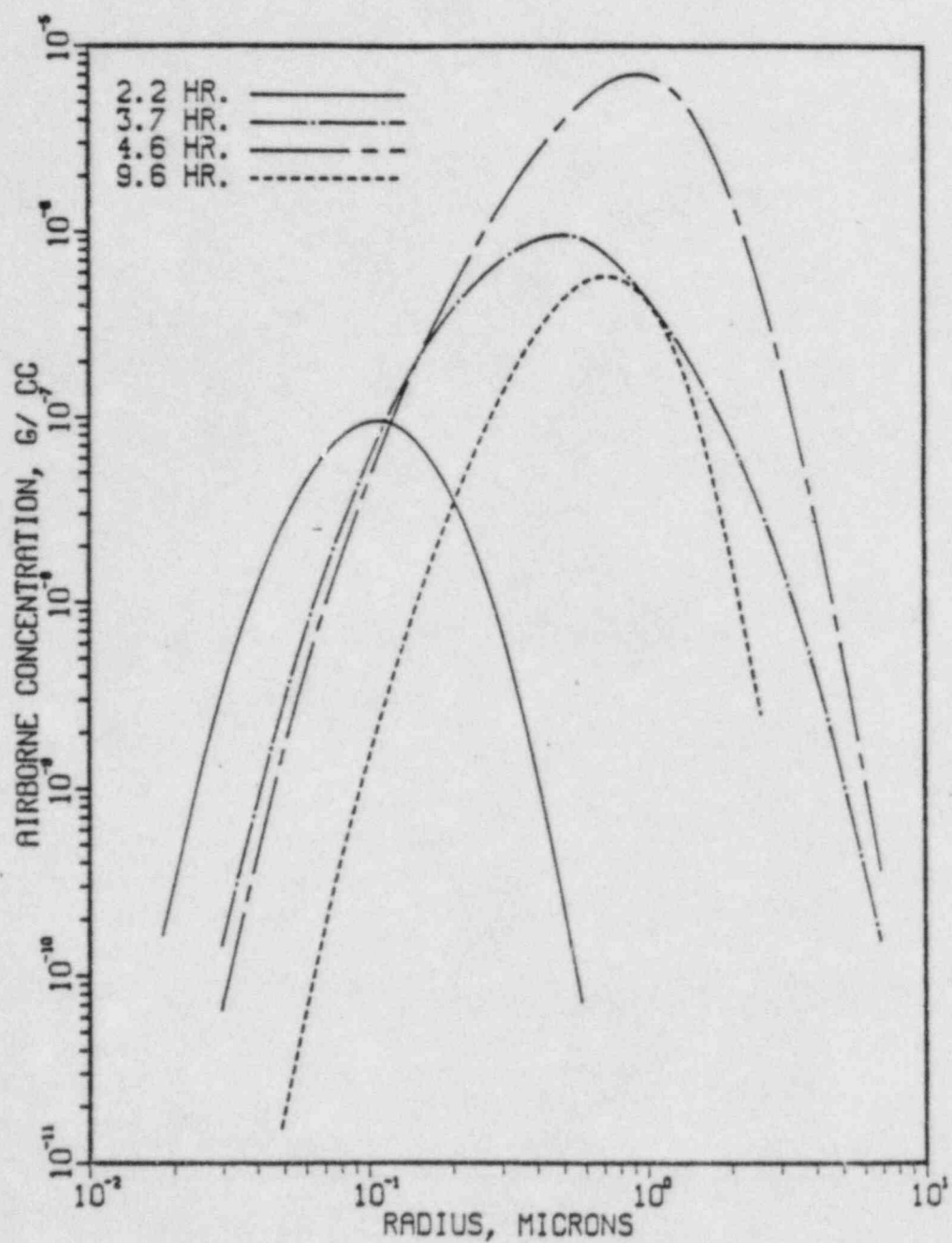
PBTC GAMMA DRYWELL CASE

AIRBORNE AND LEAKED MASSES



PBTC GAMMA DRYWELL CASE

PARTICLE SIZE DISTRIBUTIONS



PBTC GAMMA DRYWELL CASE

AVG. PARTICLE RADIUS

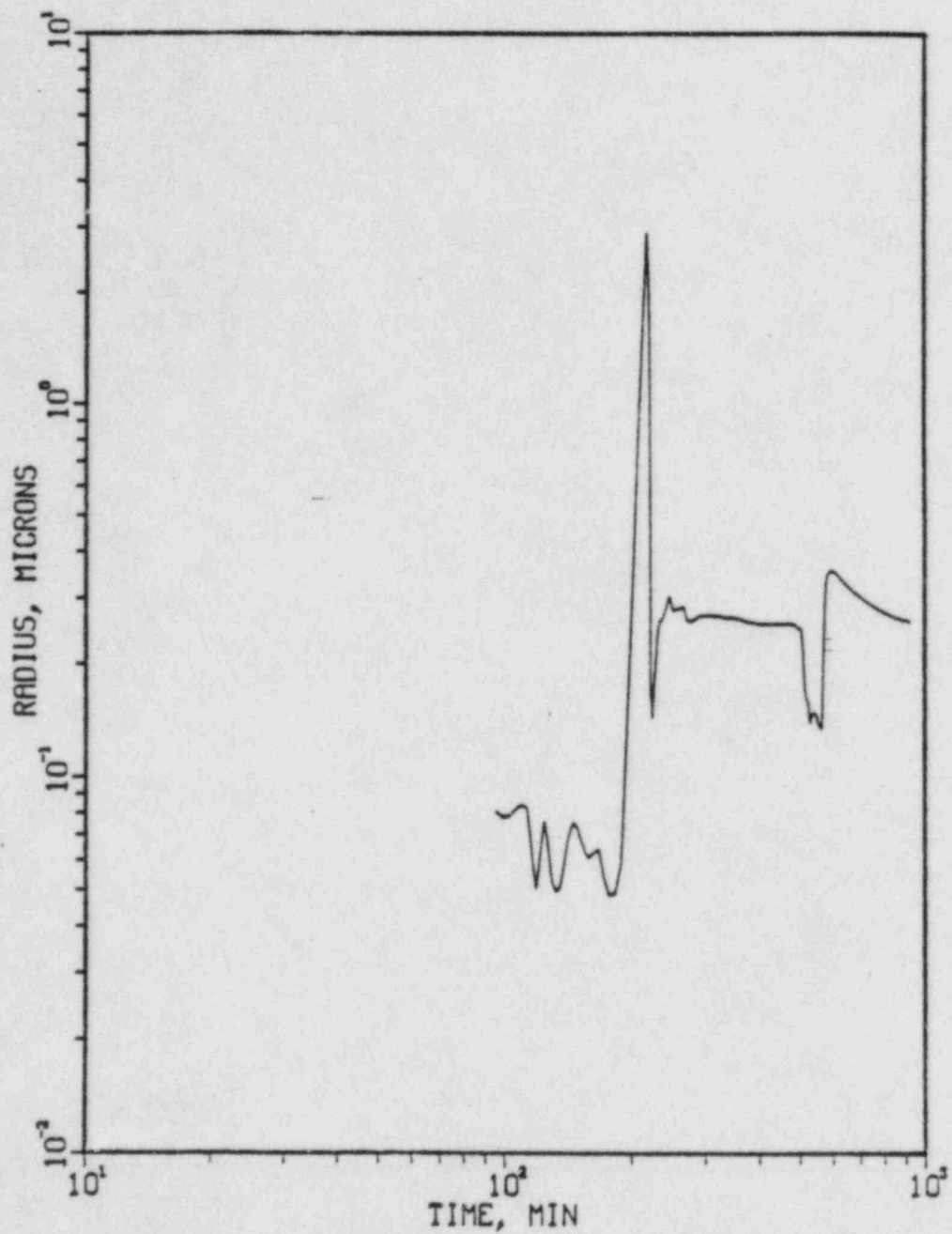
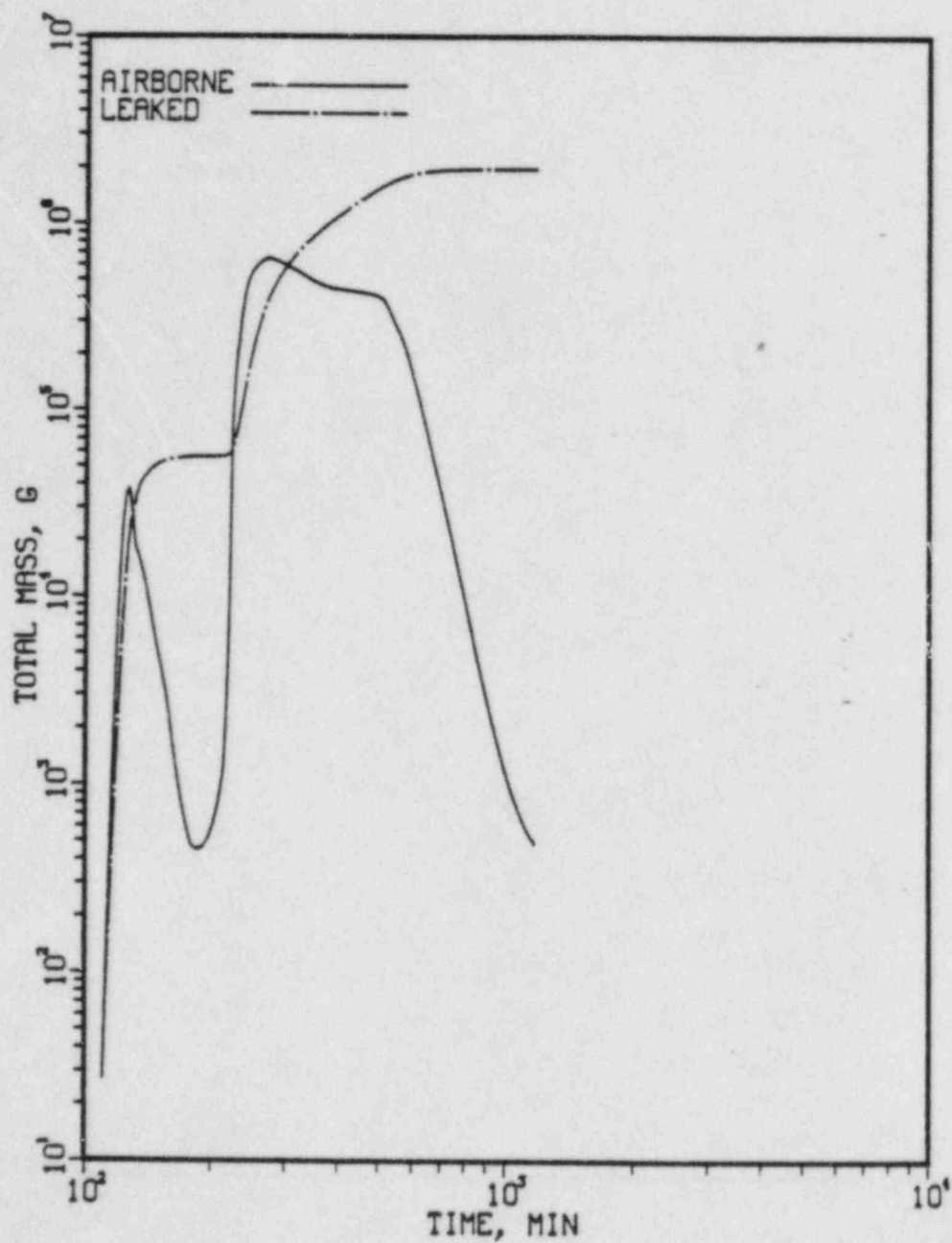


TABLE 7.11. DISTRIBUTION OF SPECIES AT 20 HOURS AFTER ACCIDENT, TCY¹

Species	Fraction of Core Inventory				
	RCS	Pool	Drywell	Wetwell	Environment
CsI	0.085	0.54	0.04	-0	0.34
CsOH	0.2	0.48	0.035	-0	0.29
Te	0.16	0.0047	0.17	-0	0.32

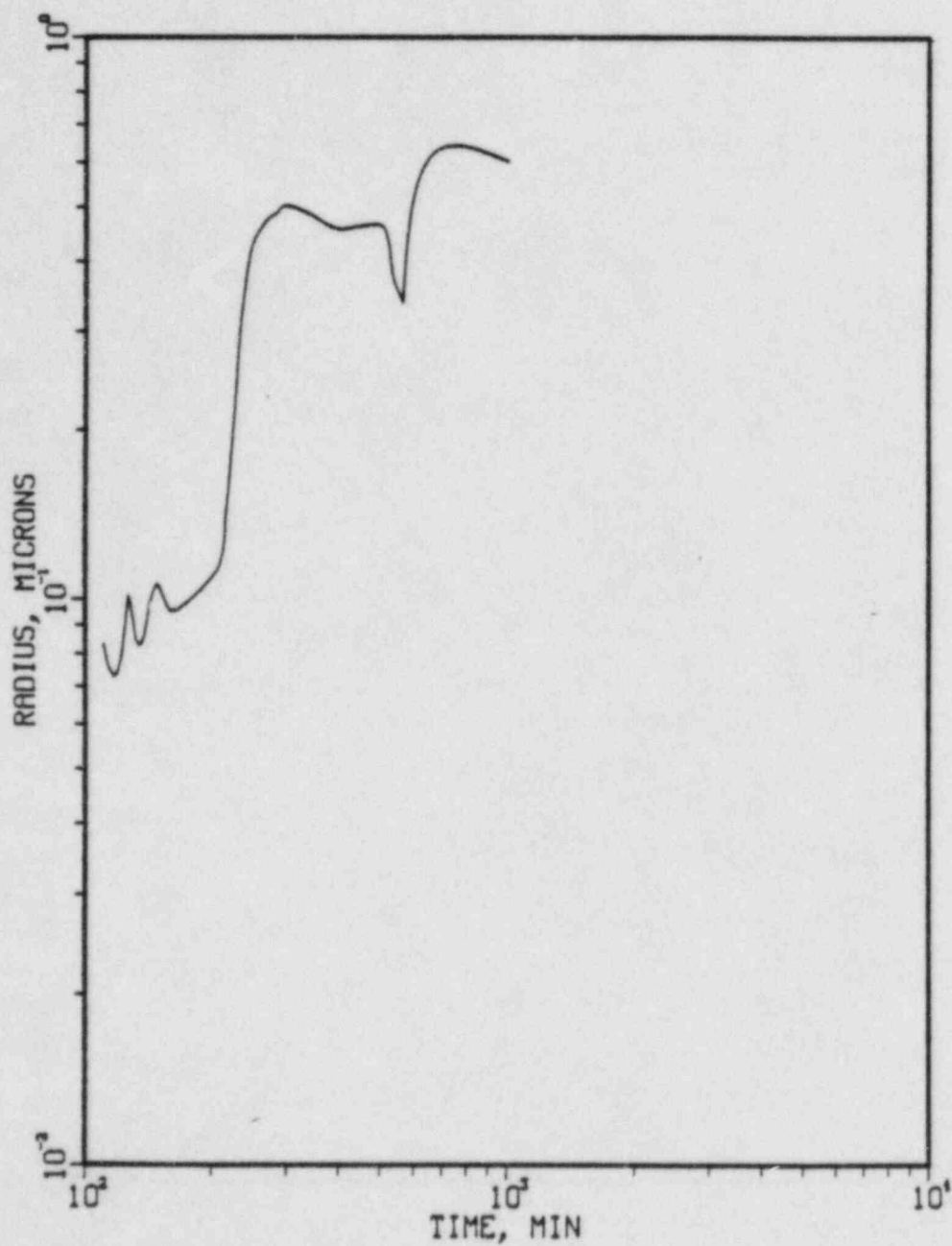
PBTC GAMMA REACTOR BUILDING

AIRBORNE AND LEAKED MASSES



PBTC GAMMA REACTOR BUILDING

AVG. PARTICLE RADIUS



Battelle

Columbus Laboratories

TABLE 7.12. DISTRIBUTION OF SPECIES AT 20 HOURS AFTER ACCIDENT, TCY

Species	Fraction of Core Inventory						Environment
	RCS	Pool	Drywell	Wetwell	Reactor Bldg	SGTS	
CsI	0.085	0.54	0.04	0	0.088	0.058	0.20
CsOH	0.20	0.48	0.035	0	0.075	0.049	0.16
Te	0.16	0.0047	0.16	0	0.098	0.013	0.21

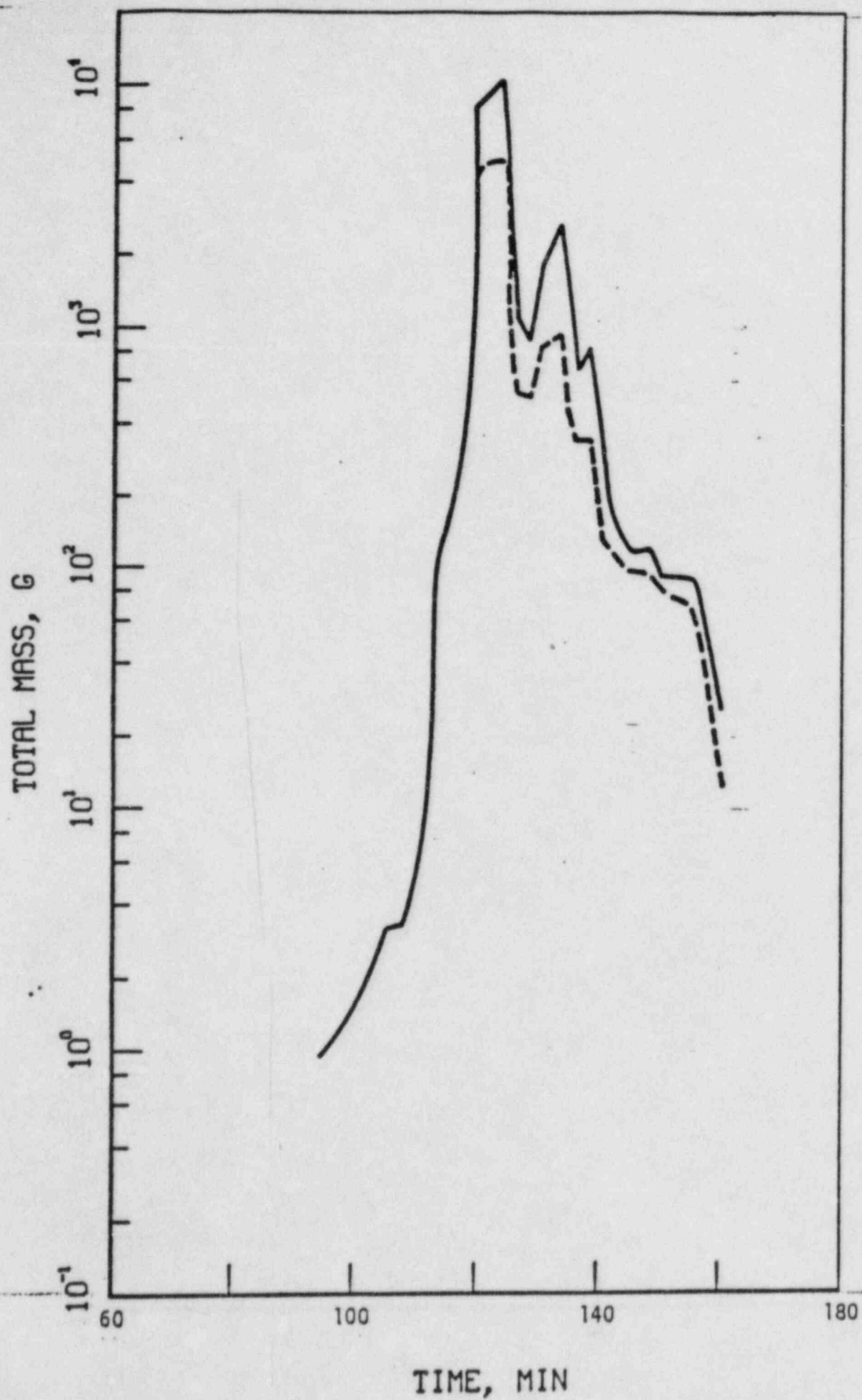


TABLE 7.13. WASH-1400 RELEASE CATEGORIES

Release Category	Fraction of Core Inventory Released						
	Xe-Kr	I	Cs-Rb	Te-Sb	Ba-Sr	Ru	La
BWR 1	1.0	0.4	0.4	0.7	0.05	0.5	5×10^{-3}
BWR 2	1.0	0.9	0.5	0.3	0.1	0.03	4×10^{-3}
BWR 3	1.0	0.1	0.1	0.3	0.01	0.02	3×10^{-3}
BWR 4	0.6	8×10^{-4}	5×10^{-3}	4×10^{-3}	6×10^{-4}	6×10^{-4}	1×10^{-4}

TABLE 7.14. COMPARISON OF SEQUENCES ASSIGNED TO BWR 2

Sequence	Fraction of Core Inventory Released			
	Xe-Kr	I	Cs-Rb	Te-Sb
BWR 2	1.0	0.9	0.5	0.3
AEY ¹	1.0	0.2	0.2	0.7
TCY ¹	1.0	0.3	0.3	0.3
TWY*				

*Being analyzed at the time this report was being prepared.

TABLE 7.15. COMPARISON OF SEQUENCES ASSIGNED TO BWR 3

Sequence	Fraction of Core Inventory Released			
	Xe-Kr	I	Cs-Rb	Te-Sb
BWR 3	1.0	0.1	0.1	0.3
TCY	1.0	0.2	0.2	0.2

5/1/89
slides

KEY PEER REVIEW COMMENTS
IMPACTING ASTPO PLANNING

- o DATA BASE SUPPORTING CODES AND CODE VALIDATION NOT VISIBLE
- o UNCERTAINTY AND SENSITIVITY ANALYSIS NEEDED
- o IMPROVED ESTIMATES OF CONTAINMENT LOADS AND RESPONSE NEEDED
(EARLY MODE QUESTION)
- o IMPROVED MODELING OF RCS UPPER PLENUM NEEDED

ELEMENTS OF THE
REASSESSMENT OF
TECHNICAL BASES FOR SOURCE TERMS

- ELEMENT 1: SUMMARY OF THE DATA BASE FOR VALIDATION
OF CODES TO PREDICT RELEASES
(NRC CONTRACTORS - ORNL LEAD)
- ELEMENT 2: SOURCE TERM ESTIMATES FOR SELECTED PLANTS
AND ACCIDENT SEQUENCES (BCL)
- ELEMENT 3: THOROUGH PEER REVIEW OF THE PRECEDING
SCIENTIFIC BASIS FOR REASSESSMENT
- TECHNICAL EXPERTS REVIEW
 - BROAD-BASED REVIEW BY INDEPENDENT
SCIENTIFIC ORGANIZATION
- ELEMENT 4: APPRAISAL OF THE RISK AND REGULATORY
SIGNIFICANCE OF REASSESSED SOURCE TERMS

ELEMENT 2 SCOPE

- o SOURCE TERM ESTIMATES DOCUMENTED BY 5 LWR PLANTS BY BCL (BMI-2104)
 - SURRY (LARGE HIGH PRESS. CONTAINMENT-PWR)
 - PEACH BOTTOM (BWR MARK I)
 - GRAND GULF (BWR MARK III)
 - SEQUOYAH (ICE CONDENSER-PWR)
 - ZION (LARGE HIGH PRESS.-PWR)
- o SELECTED ACCIDENT SEQUENCES

ELEMENT 4 SCOPE

- o APPRAISAL OF ELEMENT 1 AND 2 PRODUCTS
- o STATE-OF-THE-ART CONTAINMENT LOADS AND RESPONSE
(NRC STAFF AND CONTRACTORS)
- o UNCERTAINTY AND SENSITIVITY ANALYSIS
(NRC CONTRACTORS)
- o REVIEW/APPRAISAL OF IDCOR AND ANS SOURCE TERM RESULTS
(NRC CONTRACTOR AND NRC STAFF)
- o TRAC RCF UPPER PLENUM ANALYSIS (LANL)
- o APPRAISAL OF PEER REVIEWS
- o NUREG-0956 (SEQUEL TO NUREG-0772)
 - DRAFT FOR COMMENT (JUNE 1984)
 - FINAL (DECEMBER 1984)

SCHEDULE SUMMARY

ELEMENT 1: CODE VALIDATION REPORT - AUGUST 1983

ELEMENT 2: 5 PLANT REPORTS (DRAFT) - SEPTEMBER 1983

ELEMENT 3: PEER REVIEWS - MAY 1984

ELEMENT 4: NUREG-0956 - JUNE 1984 (DRAFT)
- DECEMBER 1984 (FINAL)

EXPERTS' PEER REVIEW SCHEDULE

CURRENT

JANUARY 1983	SURRY
MAY 1983	INITIAL PEACH BOTTOM + GRAND GULF
JULY 1983	COMPLETE PEACH BOTTOM, GRAND GULF + SEQUOYAH
AUGUST 1983	SURRY (REVISED) + ZION + CODE VALIDATION REPORT

POSSIBLE ADDITIONAL

NOVEMBER 1983	CONTAINMENT LOADS/RESPONSE SPECIALISTS
NOVEMBER 1983	UNCERTAINTY ANALYSIS

7. RESULTS AND DISCUSSION

7.1 Introduction

Results of calculations for the transport and deposition of radionuclides are presented and discussed in this section. The plants and sequences selected for consideration were discussed in Chapter 4, the analytical and calculational methods were described in Chapter 5, and the assumptions and bases for the calculations were described in Chapter 6. Results presented in this chapter include the deposition and release from the reactor coolant system of radionuclides leaving the core region. These results are based on TRAP-MELT code calculations. Also included as results are the masses of radionuclides airborne and deposited in the containment and suppression pool, as well as the airborne materials leaked to the environment. These results are based on SPARC calculations for retention in the suppression pool and NAUA-4 calculations for transport in the containment and reactor buildings.

Three system sequences are considered in the analyses: AE, TC, and TW. In each case an overpressure failure mode was analyzed in which failure of the primary containment was assumed to result in a direct pathway of release to the environment. This is the most severe failure mode (referred to as γ') for each of the system sequences from the viewpoint of the magnitude of fission product source term to the environment. For the TC sequence, the potential influence of reactor building retention mechanisms was examined for the failure mode in which the reactor building maintains its integrity following failure of the primary containment. Retention in the reactor building is also a possibility for the AE and TW system sequences. No attempt is made in this report to estimate the relative likelihoods of the γ' and γ failure modes.

7.2 Transport and Deposition in Reactor Coolant System (RCS)

The analyses of the transport and deposition within the RCS of materials released from the melting core have been performed using the TRAP-MELT code which was described in Volume I of this report. The time frame of interest in the RCS for core meltdown accidents such as those considered here spans the period of time starting with the onset of core melting and ending with failure of the bottom head of the RPV. For accidents involving only minor fuel damage, the gap release term, which occurs prior to melting of fuel, may be the major release and require careful consideration. For the accidents examined here, however, this release term is insignificant in comparison with the melt release and the period immediately prior to the onset of core melting is not considered. Rather, the gap releases calculated by CORSOR are added to the initial material emitted by the melting core.

Releases from the melting core and their behavior in the RCS are simulated beyond the time of core collapse in these analyses. This differs from the simulations presented in Volume I of this report wherein the source to the RCS was assumed to go to zero when the core slumped into the residual water in the lower plenum. In the analyses of the Peach Bottom sequences presented here, the slumping of the core has been simulated in MARCH on a nodal basis as discussed earlier. This change and the presence of much greater below core structures in the BWR pressure vessel dictate that emission from nodes which have left the core be included in the analyses.

Another significant difference in the RCS phenomenology for the BWR sequences is the existence of a significant time period following RPV dry out. During this period, the melting core emits into an essentially stagnant RCS, since there is no water available to provide the steam as a carrier. The duration of time between vessel dryout and bottom head failure is predicted by MARCH to be 78, 104, and 225 minutes for the AE, TC, and TW sequences, respectively. This residence time will be seen to result in significant attenuation of the aerosol.

It should be recognized that the uncertainties in the behavior of the molten core in the lower plenum region are quite large. The analyses performed by the MARCH 2 code for this phase of the accident are greatly simplified. The rates of steam production as molten core material enters the lower plenum and the duration of time to failure of the reactor vessel have large associated uncertainties.

The heatup of the RCS structures downstream of the core is not modeled following dryout of the vessel. This is not expected to be a significant source of error since the surface temperatures in the core region are too high to permit condensation of the volatile species considered in these analyses prior to this period and there is little subsequent emission of these species from the core.

At the time of bottom head failure, the materials suspended in the RCS are assumed to exit the primary system through the bottom head without further attenuation. This results in a short duration "puff" release of aged material into the drywell at the time of vessel failure. Re-entrainment of previously deposited particles or vapors is not considered to occur during this process.

One further aspect of the time frame of the primary system analyses which should be noted is that the primary system is not considered in the analyses after the molten core has left the RPV. Air ingress into the RPV and deposition of materials evolved during the core-concrete interaction is not considered, nor is the primary system considered as a potential source of fission products due to re-evolution of previously deposited materials.

The analyses presented in the following section are subject to many of the same uncertainties which were discussed in Volume I of this report. Principal among these are the source rates of materials emitted by the core, and the details of the flow patterns in the RCS. An additional aspect of the flow or, more precisely, the lack of flow during these sequences which represents a source of uncertainty is the duration of the "stagnant" phase of in-vessel portion of the melt down.

The results of the analyses of the AE, TC, and TW sequences for the Peach Bottom plant are discussed separately in the following

sections. The flow paths, associated geometry, and the timing of the core-melt period in the RCS can be found in Chapter 6.

7.2.1 RCS Transport and Deposition for Sequence AE

This sequence resembles, in several respects, the AB sequence analyzed for the Surry plant in Volume I of this report. The principal similarity between these two is that, due to the location of the assumed large break, the materials released from the melting core transit only a very limited portion of the primary system during their release to the "containment". Here, the notion of "containment" is a bit more involved than was the case for the PWR and this will be discussed at length later in this document. The primary system components of interest here are the core region, the steam separators, and the lower annulus to the intake of the recirculation loop.

Table 7.1 presents the total masses (Total) of the species of interest which have been emitted into the RCS as a function of time during the in-vessel portion of the melt. These values, of course, increase monotonically with time, though not linearly due to the nature of the release process. It is interesting to note that, on this time scale, vessel dryout occurs at $t = 1710$ s. Thus, about 20 percent of the CsI and CsOH are emitted into a stagnant RCS, and over 50 percent of the Te and aerosol are emitted during this period. This table also indicates that the mass of vapor species retained in the RCS first increases, then decreases as surfaces in the system heat up due to the high temperature steam flow out through the break. The aerosol retention does not exhibit any similar behavior since no resuspension mechanisms are included in the TRAP-MELT code. It is interesting to note the fairly dramatic increase in aerosol retention which occurs during the stagnant portion of this sequence. This is due to the agglomeration of the particles to form larger sizes and subsequently enhanced settling of the particles in the RCS. Of course, there is no similar mechanism for the vapor species and their retained amount remains essentially unchanged during this period.

TABLE 7.1. CORSOR PREDICTIONS OF MASSES OF SPECIES RELEASED FROM THE CORE (TOTAL) AND TRAP-MELT PREDICTIONS OF MASSES RETAINED IN THE RCS (RET) DURING THE AE SEQUENCE FOR THE PEACH BOTTOM PLANT

(Times Measured from Start of Core Melting)

Time (s)	CsI		CsOH		Te		Aerosol	
	Ret (kg)	Total (kg)	Ret (kg)	Total (kg)	Ret (kg)	Total (kg)	Ret (kg)	Total (kg)
270	0.9	5.9	7.4	46.7	0.1	0.3	4.6	30.0
570	5.0	11.7	33.5	81.7	0.4	0.8	34.7	90.8
870	8.9	17.2	57.6	115	1.0	1.6	86.7	188
1170	6.0	24.9	39.8	161	1.0	2.3	93.9	271
1470	6.1	26.0	39.2	168	0.8	2.9	95.7	311
3020	6.1	28.5	37.8	183	0.8	4.0	209	464
4230	6.1	30.1	38.4	194	0.9	4.5	265	518
5750	6.1	33.8	40.0	213	1.0	6.5	460	734
6360	6.1	33.8	40.8	217	1.1	7.7	615	889

Table 7.2 expresses these results in terms of retention factors (RF) which are simply defined as Ret/Total in Table 7.1. These values pertain to the entire RCS and are integral in nature, so that the final value (i.e., at $t = 6360$ s, which is the time at which bottom head failure occurs) can be taken to be the RCS retention factor which characterizes the sequence. The values listed under Lower Annulus for CsI, CsOH, and Te indicate the retention factor for that control volume. These values are also based on the total mass of the species emitted from the core and therefore do not represent true efficiencies of retention for the control volume.

The retention factors for the aerosol in the core and in the steam separators illustrate the basic features of the aerosol behavior. The retention in the core region is well under 10 percent until after vessel dryout occurs. Then, as the aerosol ages and the core continues to inject aerosol mass into the stagnant system, the removal of aerosol mass in the core becomes increasingly effective. This is also indicated by the increase in the aerosol mass median diameter which is calculated from the discrete aerosol size distribution followed through the TRAP-MELT calculations. At $t = 1800$ s, the mass median diameter is $0.188 \mu\text{m}$, and by $t = 4800$ s, it has increased to $2.76 \mu\text{m}$, which, of course, leads to an enhanced removal rate for the aerosol via gravitational settling. A further note regarding the aerosol retention values in this table concerns the values of the retention in the steam separator. The decrease evident after $t = 1770$ should not be misinterpreted to indicate a resuspension of previously deposited aerosol. Rather, it is merely a consequence of the fact that the total aerosol mass emitted by the core has continued to increase while the amount retained in the steam separators is fixed, due to the absence of flow.

The source to the drywell for this sequence can be characterized as a fairly steady injection rate up to the time of vessel dryout. During this period, approximately 30 percent of the CsI, CsOH, and Te passing through the RCS is retained, as is just over half of the aerosol. There is then no source until the bottom head fails, at which time

TABLE 7.2. TRAP-MELT PREDICTIONS OF PRIMARY SYSTEM RETENTION FACTORS (RF) AND VOLUME SPECIFIC RETENTION FACTORS AS FUNCTIONS OF TIME FOR THE AE SEQUENCE FOR THE PEACH BOTTOM PLANT

Time (s)	CsI		CsOH		Te		Aerosol		Steam Sep
	RF	Lower Annulus	RF	Lower Annulus	RF	Lower Annulus	RF	Core	
270	.15	.10	.16	.11	.27	.06	.15	--	.06
570	.43	.22	.41	.23	.46	.12	.38	.02	.19
870	.52	.27	.50	.27	.65	.19	.46	.04	.22
1070	.24	.24	.25	.24	.43	.22	.35	.03	.17
1470	.23	.23	.23	.23	.28	.09	.31	.03	.15
3020	.21	.21	.21	.20	.20	.07	.45	.26	.10
4230	.20	.20	.20	.19	.20	.06	.51	.34	.09
5750	.18	.18	.19	.17	.16	.05	.63	.50	.07
6360	.18	.18	.19	.17	.14	.04	.69	.59	.06

the suspended materials in the RCS are injected into the drywell. No further emissions from the RCS are considered in these analyses.

7.2.2 RCS Transport and Deposition for Sequence TC

In this postulated accident sequence, the RCS is essentially at operating pressure up until bottom head failure, making this sequence somewhat analogous to the TMLB' sequence studied in Volume I for the Surry PWR. During the in-vessel phase of the meltdown the flow pathway exits the RCS through the relief lines which transmit the gases and fission products to the suppression pool. The flow pathway and relevant geometry were presented in an earlier section, so it is sufficient to simply restate that the flow passes through the steam separators and then splits, with about 85% considered to pass through the steam dryers, and the remainder bypassing the dryers via the outer annulus. These flows then merge at the steam lines and enter the relief lines to the pool.

Table 7.3 presents the total masses of the various species emitted from the core (Total) as functions of time during this sequence, and the mass retained in the RCS at any time. Following from the CORSOR results, these sources to the RCS are only on the order of half what the values for the AE sequence were predicted to be. Vessel dryout for this sequence occurs at $t = 3720$ on this time scale, by which time the CsI and CsOH emissions are nearly completed. The masses retained in this sequence are considerably less than for AE, partly due to the reduction in the source term for the RCS and partly due to the differing system thermal hydraulics. An interesting feature of this table is the larger retention predicted for CsOH, in comparison with the retention of CsI. The cause of this apparent discrepancy is that the mechanism of CsOH retention is chemisorption, which is not a viable process for CsI. This difference between CsI and CsOH retention is emphasized in Table 7.4, which contains the RCS retention factors, along with several volume specific values as defined above.

TABLE 7-3. CORSOR PREDICTIONS OF MASSES OF SPECIES RELEASED FROM THE CORE (TOTAL) AND TRAP-MELT PREDICTIONS OF MASSES RETAINED IN THE RCS (RET) DURING THE TC SEQUENCE FOR THE PEACH BOTTOM PLANT

(Times Measured from the Start of Core Melting)

Time (s)	CsI		CsOH		Te		Aerosol	
	Ret (kg)	Total (kg)	Ret (kg)	Total (kg)	Ret (kg)	Total (kg)	Ret (kg)	Total (kg)
300	--	2.0	0.8	19.6	--	0.1	0.3	8.7
890	3.0	7.8	23.2	55.6	0.4	0.6	28.5	80.6
1180	6.5	11.6	44.9	78.6	0.8	1.2	79.4	149
1480	10.3	15.6	69.5	103	1.5	2.0	155	242
2070	3.0	24.3	40.6	155	4.3	4.5	218	477
2360	3.0	24.9	42.1	159	4.9	5.1	219	493
2660	3.1	25.1	42.5	161	5.2	5.4	220	502
3250	3.1	25.2	43.6	162	5.5	5.7	221	509
3540	3.1	25.2	44.1	162	5.6	5.8	221	510
3870	3.1	25.3	43.4	162	5.6	5.8	221	510
5900	2.9	25.6	42.3	165	5.6	6.3	246	551
7380	2.9	26.6	42.6	170	5.6	7.0	327	641

TABLE 7.4. TRAP-MELT PREDICTIONS OF PRIMARY SYSTEM RETENTION FACTORS (RF) AND VOLUME SPECIFIC RETENTION FACTORS AS FUNCTIONS OF TIME FOR THE TC SEQUENCE FOR THE PEACH BOTTOM PLANT

Time (s)	CsI		CsOH		Te		Aerosol		
	RF	Lower Annulus	RF	Steam Dryers	RF	Steam Dryers	RF	Core	Steam Dryers
300	.02	--	.04	.03	.39	.36	.03	.02	.01
890	.38	.04	.42	.33	.56	.51	.35	.06	.23
1180	.55	.09	.57	.43	.67	.58	.53	.10	.33
1480	.66	.13	.67	.49	.76	.62	.64	.12	.38
2070	.12	.12	.26	.13	.96	.78	.46	.08	.25
2360	.12	.12	.26	.14	.96	.78	.44	.08	.24
2660	.12	.12	.26	.14	.96	.80	.44	.08	.24
3250	.12	.12	.27	.14	.96	.79	.43	.08	.24
3540	.12	.12	.27	.14	.97	.79	.43	.08	.23
3870	.12	.12	.27	.14	.97	.79	.43	.08	.23
5900	.11	.11	.26	.14	.89	.73	.45	.12	.22
7380	.11	.11	.25	.14	.80	.66	.51	.23	.19

The relatively large surface area of the steam dryers is reflected in their large contribution to the chemisorption of the CsOH and Te. These chemisorbed materials are considered to be irreversibly bound to the surface in all sequences examined here. The aerosol retention in this sequence exhibits similar behavior to that observed in the AE results, but on a less impressive scale. The increase in aerosol RF from 0.43 just before vessel dryout to 0.51 at the time of bottom head failure is, again, due to the aging of the particles in the stagnant core region of the RCS. That the increase in the RF is not greater than what appears in this table is due to the lower rate of aerosol generation predicted for this sequence.

7.2.3 RCS Transport and Deposition for TW Sequence

Tables 7.5 and 7.6 present the masses emitted, masses retained and RFs for the various species in the TW sequence. On the time scale given in these tables, vessel dryout occurs at $t = 5010$ s and bottom head failure is predicted by MARCH to occur at $t = 18540$ s. Analyses of this very long stagnant period have not yet been completed, but will appear in the next draft of this document.

7.3 Transport of Fission Products Through Containment

Results are presented in this section for analyses performed for the transport and retention of various fission products that leave the reactor coolant system. The various compartments of the reactor considered for these analyses include the suppression pool, the wetwell, the drywell, and the reactor containment building. The NAUA code that calculates transport of fission products in particulate form was utilized for the mentioned compartments except that the SPARC code was utilized for calculating the retention of fission product in the suppression pool.

Depending upon the compartment and the accident sequence to be dealt with, results of the MARCH, TRAP-MELT, and VANESA calculations

TABLE 7.5. CORSOR PREDICTIONS OF MASSES OF SPECIES RELEASED FROM THE CORE AND TRAP-MELT PREDICTIONS OF MASSES RETAINED IN THE RCS DURING THE TW SEQUENCE FOR THE PEACH BOTTOM PLANT

(Times Measured from Start of Core Melting)

Time (s)	CsI		CsOH		Te		Aerosol	
	Ret (kg)	Total (kg)	Ret (kg)	Total (kg)	Ret (kg)	Total (kg)	Ret (kg)	Total (kg)
490	--	1.0	0.2	7.6	--	0.1	1.9	7.7
980	0.2	2.5	1.4	17.6	0.2	0.2	7.4	27.1
1470	0.9	4.4	6.4	30.5	0.4	0.5	22.1	63.6
1960	2.4	6.5	16.7	45.6	0.9	1.0	55.5	121
2450	4.5	9.5	31.2	64.8	1.4	1.7	115	199
2940	7.7	13.5	51.0	88.6	2.2	2.8	202	300
3420	12.5	18.9	80.4	122	4.9	5.4	351	523
3910	21.3	29.9	136	190	11.3	12.4	734	965
4400	14.7	36.1	81.4	229	15.5	15.7	852	1190
4890	5.9	39.0	40.9	246	15.9	16.4	853	1270
5380	6.0	41.6	41.1	261	15.9	17.0	872	1340
5870	6.0	43.1	41.1	275	15.9	17.5	930	1390
6360	6.0	45.1	41.2	283	15.9	17.9	977	1440

TABLE 7.6. TRAP-MELT PREDICTIONS OF PRIMARY SYSTEM RETENTION FACTORS (RF) AND VOLUME SPECIFIC RETENTION FACTORS AS FUNCTIONS OF TIME FOR THE TW SEQUENCE FOR THE PEACH BOTTOM PLANT

(Times Measured from Start of Core Melting)

Time (s)	CsI			CsOH			Te		Aerosol			
	RF	Steam Dryers	Relief Lines	RF	Steam Dryers	Relief Lines	RF	Steam Sep	RF	Core	Steam Dryers	Relief Lines
490	--	--	--	.03	--	.01	.80	.91	.25	.23	--	--
980	.08	.03	.04	.08	.03	.04	.84	.76	.27	.21	.02	.03
1470	.20	.11	.07	.21	.10	.07	.84	.79	.35	.19	.08	.05
1960	.37	.20	.08	.37	.20	.08	.86	.80	.46	.15	.18	.06
2450	.47	.25	.07	.48	.26	.08	.82	.76	.58	.14	.24	.06
2940	.57	.28	.07	.58	.28	.07	.79	.75	.67	.16	.25	.05
3420	.66	.33	.07	.66	.33	.07	.91	.85	.67	.11	.29	.06
3910	.71	.35	.06	.72	.35	.07	.91	.85	.76	.10	.34	.06
4400	.41	.24	.07	.36	.18	.07	.99	.82	.72	.09	.32	.06
4890	.15	--	.06	.17	.01	.06	.97	.79	.67	.08	.30	.06
5380	.14	--	.06	.16	.01	.06	.94	.76	.65	.09	.29	.05
5870	.14	--	.06	.15	.01	.05	.91	.74	.67	.13	.28	.05
6360	.13	--	.05	.15	.01	.05	.89	.72	.68	.16	.27	.05

were utilized as the input required for the NAUA and SPARC calculations. Three species, CsI, CsOH, and Te, were distinguished in the calculations and all the other species were treated as one group. All species in this additional group were assumed to exist in the particulate form once they escape the reactor coolant system.

Dimensions of the compartment volumes were based on geometric data provided in the Peach Bottom 2 FSAR. The largest cross sectional area of a volume was used to estimate the floor area. This area directly affects the removal rate for particle sedimentation. For example, the cross section area of the spherical section based on a diameter of 67 ft (20.4 m) was used for the drywell calculation.

Three different accident sequences, AE, TC, and TW, were considered in the present calculations.

7.3.1 AE Sequence

This sequence involves a large pipe break accident resulting in loss of reactor coolant. The fission products released from the reactor coolant system enter the drywell through the lower annulus section and subsequently are allowed to enter the suppression pool to reach the wetwell. As the drywell fails due to the pressure built up by the release of gases from the reactor coolant system, the fission products released to the drywell no longer enter the suppression pool but become released to the failed reactor building or environment. Due to this event-dependent flow path of the fission product involving several physically separate compartments, the analyses for the AE sequence were sequentially performed as depicted by Figure 7.1 and this is briefly described as follows.

First, the NAUA code was utilized to calculate the behavior of particulates in the drywell. The calculation was suspended as the containment failure time is reached. The results of this NAUA calculation were then used with the SPARC code for calculating the scrubbing of fission products in the suppression pool. Finally, a separate NAUA calculation was performed to describe the behavior of the fission products in the wetwell. The input for this was the SPARC calculation results. To

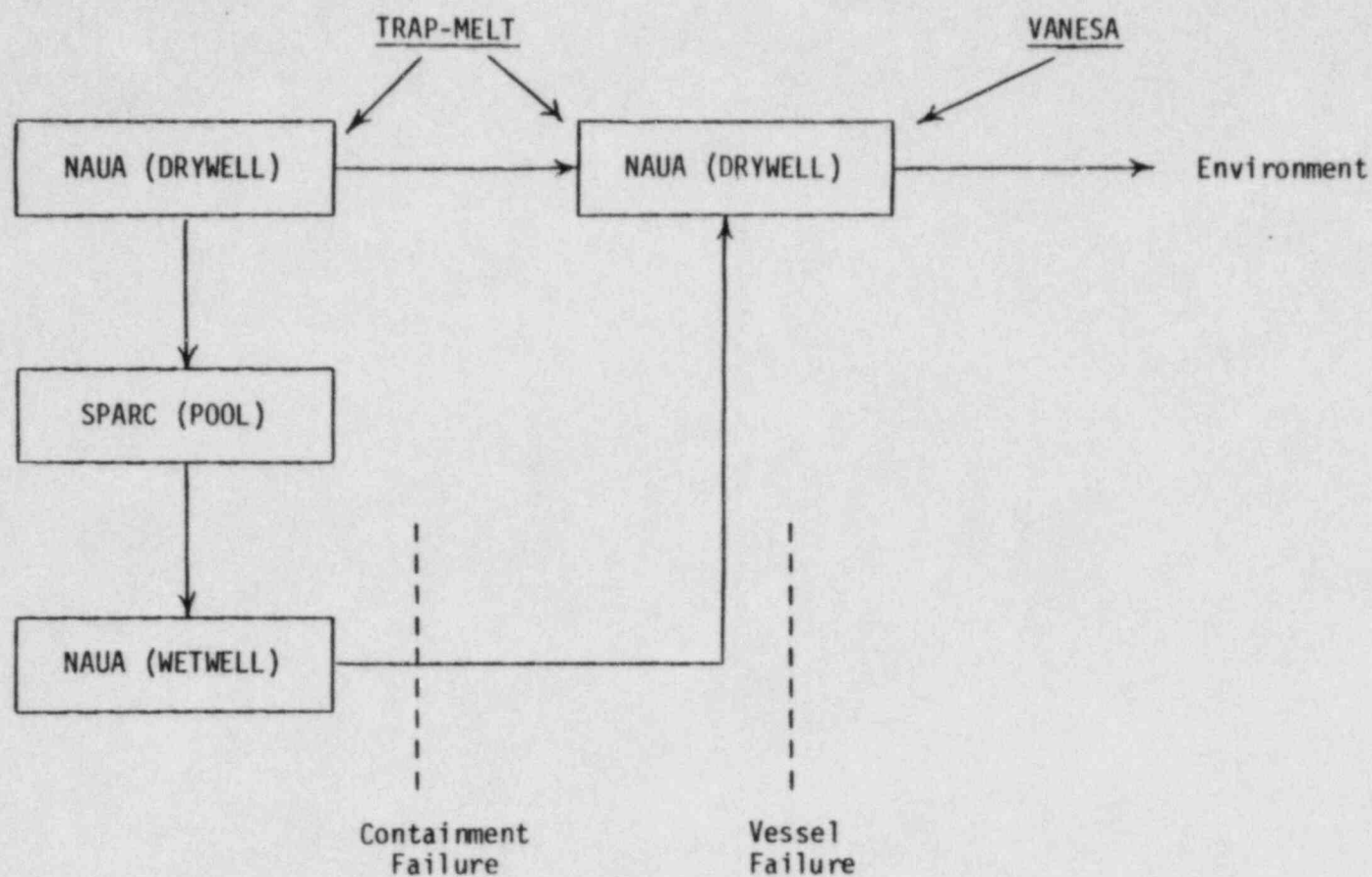


FIGURE 7.1. NAUA AND SPARC CALCULATION PATHS USED FOR PERFORMING ANALYSES OF AE SEQUENCE

cover the accident time beyond the containment failure time, the NAUA calculation that had been suspended was reactivated for the drywell. The source terms used for this resumed calculation are the TRAP-MELT calculation results, the separate NAUA calculation results for the wetwell, and the VANESA calculation results. Figure 7.2 shows the suspended mass concentration of particulates in the drywell. It is seen that the amount of the suspended particulate increases rapidly as the core starts melting at 12 minutes and the highest concentration results at a time of 34 minutes when the drywell fails. It should be realized that during this time period, a considerable amount of particulate enters the suppression pool and is captured. Distribution of the total particulate at various locations and at various times is listed in Table 7.7. As the drywell fails, the gas in the dry well is directed toward the environment and the particulate concentration in the drywell decreases rapidly due to this new leakage flow path. As the time elapses further and the head finally fails, the particles released through the bottom head cause the airborne particulate concentration to increase again and the amount leaked to the environment builds up (see Table 7.7). At a time of 1200 minutes (20 hours), the particulate released during the accident is located in the drywell, the suppression pool, and in the environment each with the amounts listed in Table 7.7.

The particle size distribution of aerosol suspended in the drywell at selected times is shown in Figure 7.3. It is noted that the mass median particle size of the aerosol ranges from 0.6 to 1 μm before the drywell fails. As will be discussed shortly, scrubbing of particulates by the suppression pool depends substantially on the size of particles that enter the pool. Combined with a particle density of 10 g/cc which was used in the present analysis, an aerosol with the above range of mass median diameter is found to be removed rather effectively by the suppression pool.

Since the release timing of individual fission product species may be different than that for the total particulate, the time-dependent amounts of CsI, CsOH, and Te were distinguished in the present calculation. Table 7.8 shows the calculated fractions of the core inventory of

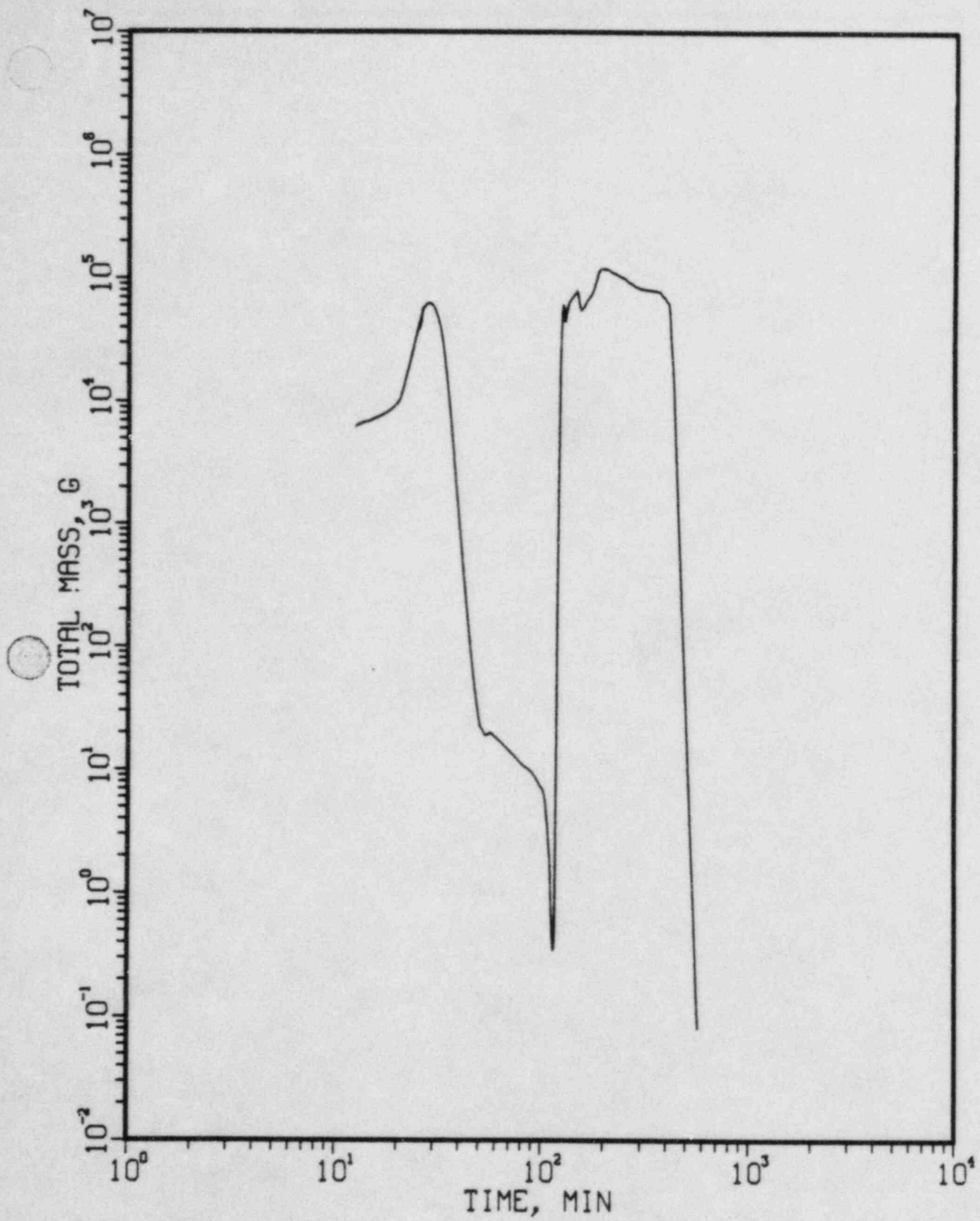


FIGURE 7.2. AIRBORNE CONCENTRATION IN THE DRYWELL AS A FUNCTION OF TIME, AE

TABLE 7.7. DISTRIBUTION OF TOTAL SOLID PARTICULATE MASS (KG) AT VARIOUS TIMES, AE

Time (min)	Event	Drywell		Pool Captured	Wetwell	Environment
		Suspended	Deposited			
12	Melt start					
20		10	18	0.11	-0	--
34	Cont fails	29	29	285	-1.0	--
35		8.4	29	285	-1.0	23
40	Vessel dry					
50		0.023	30		-0	75
58	Core collapse					
80		0.012	30	285	-0	75
118	Head fails					
120		17	48	285	-0	100
420		25	1380	285	-0	2755
1200	End of accident	--	1390	285	-0	2755

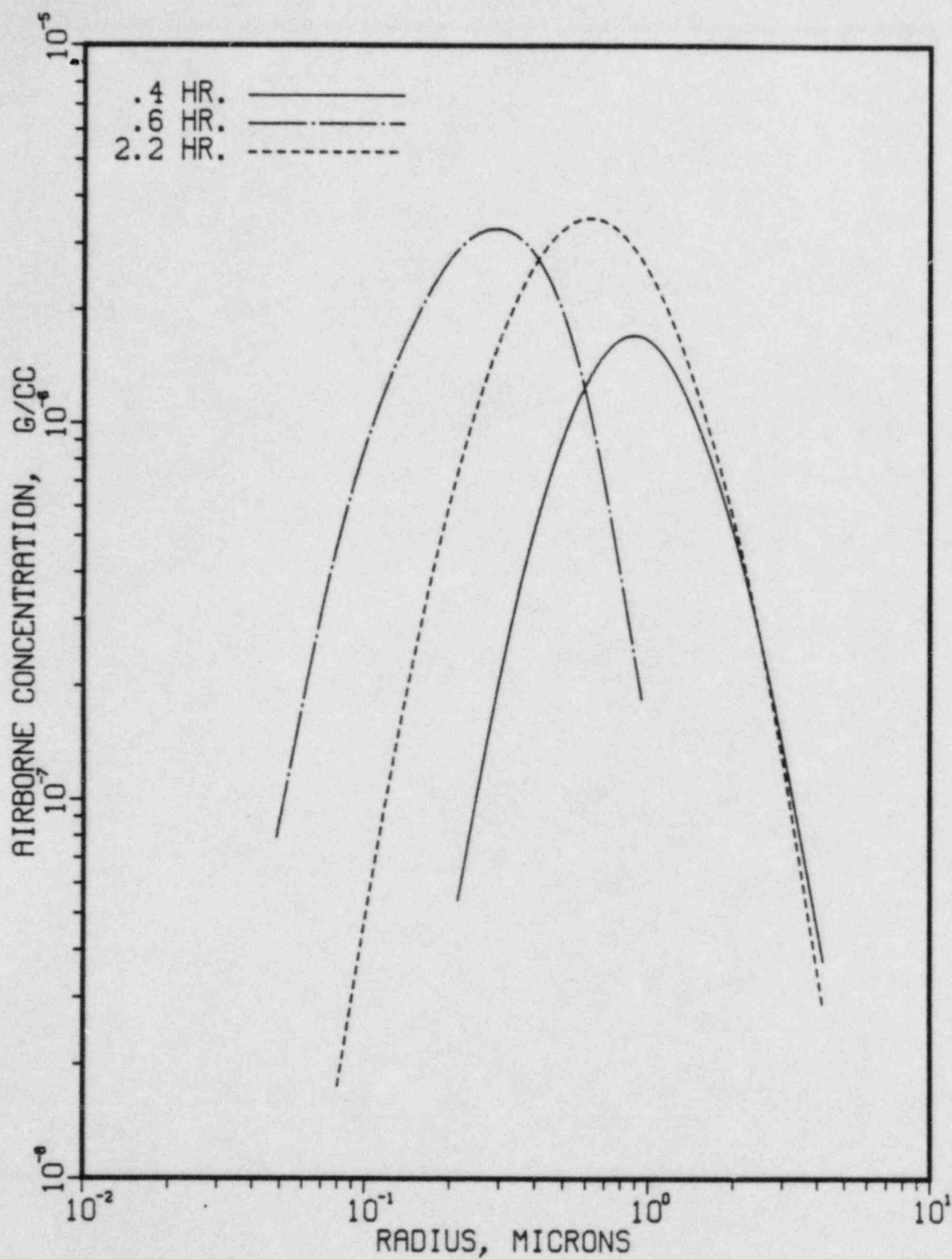


FIGURE 7.3. PARTICLE SIZE DISTRIBUTION OF AEROSOL SUSPENDED IN THE DRYWELL, AE

TABLE 7.8. DISTRIBUTION OF SPECIES AT 20 HOURS AFTER ACCIDENT, AE

Species	Fraction of Core Environment				
	RCS	Pool	Drywell	Wetwell	Environment
CsI	0.18	0.47	0.14	-0	0.21
CsOH	0.19	0.45	0.15	-0	0.21
Te	0.02	0.02	0.29	-0	0.67

each species found to reach various locations at the end of the accident. It is interesting to see that significant fractions of CsI and CsOH are captured by the suppression pool. As a result, about 20 percent is seen to escape the drywell to reach the environment.

The MARCH calculation results indicated that between the core melting period and the containment failure, the thermal hydraulic conditions are such that there is little supersaturation of water vapor in the drywell. The NAUA calculation also shows that the diffusiophoresis of fission products onto surfaces is not significant.

Collection in the suppression pool as calculated by the SPARC code indicated that the pool is indeed an effective means for scrubbing particulates. The SPARC code considers removal of particulates by sedimentation, inertial deposition, diffusion, and diffusiophoresis inside bubbles. In addition, particulates are allowed to grow by steam condensation, thus enhancing gravitational sedimentation and the inertial sedimentation. It has been speculated that particulates would be removed by an additional impaction mechanism just after the gas is discharged from a pipe for AE or from quencher holes for TC and TW into the pool water forming an impaction regime. For modeling this type mechanism, an existing theory for an impactor was added to the SPARC code.

The SPARC code calculation results showed that depending upon the size of particles, decontamination factors over a wide range can be obtained. Typical decontamination factors obtained from SPARC calculations are listed in Table 7.9.

7.3.2 TCγ' Sequence

This accident represents the sequence in which the containment fails first and the fission product released from the relief valve enters the suppression pool through the T quencher, passes through the wetwell and reaches the drywell before being released to the environment. As the reactor vessel fails, the fission products enter directly into the

TABLE 7.9. DECONTAMINATION FACTORS CALCULATED AS A FUNCTION OF PARTICLE SIZE AND OF TIME FOR AE SEQUENCE

Time (min)	Particle Diameter, μm					DF Based on Total Mass
	0.1	0.6	1.0	6	10	
14.3	4.1	388	$10^{5(a)}$	10^5	10^5	164
18.9	3.9	307	10^5	10^5	10^5	125
27.4	2.6	374	10^5	10^5	10^5	7
33.3	14.7	55,900	10^5	10^5	10^5	34

(a) A decontamination factor larger than 10^5 is assumed to be 10^5 .

Pool depth: 4 ft
Bubble diameter: 0.75 cm
Aspect ratio: 1:3

drywell and are then released to the failed reactor building or environment. The sequential use of various computer codes for calculating the transport of fission products is shown in Figure 7.4.

Since the first volume fission product encounter after being released from the RCS for the TC sequence is the suppression pool, the SPARC code was utilized to calculate the retention of fission products by the pool. The decontamination factors calculated are listed in Table 7.10. This table shows a particle size dependency that is similar to that shown previously for the AE sequence. Time variations of the calculated decontamination factor for 0.1 and 0.6 μm particles are, of course, due to the difference in the thermal hydraulic condition that prevails at the corresponding times.

Figure 7.5 is the suspended aerosol mass as a function of time for the drywell. Sharp increases in the mass concentration as shown in Figure 7.5 represent the initial core melting time and the bottom head failure time respectively. Figure 7.6 is the accumulated mass leaked outside the drywell shown by species. Figure 7.7 is the geometric number median radius of the aerosol mass suspended in the drywell. It is interesting to note that due to the presence of the suppression pool, which removes predominantly large particles, the particle size during the time up to bottom head failure is relatively small, while the size becomes large thereafter.

Table 7.11 is the calculated distribution of the CsI, CsOH, and Te that are located in the RCS, the suppression pool, the drywell, and the wetwell. The last column indicates that a fraction of core inventory between 0.29 to 0.34 is released to the environment. It is also noted that fractions of 0.58 for CsI and 0.48 for CsOH are captured in the suppression pool. The reason why the amount of Te captured by the suppression pool is low is because it is released to the drywell predominantly through the bottom head.

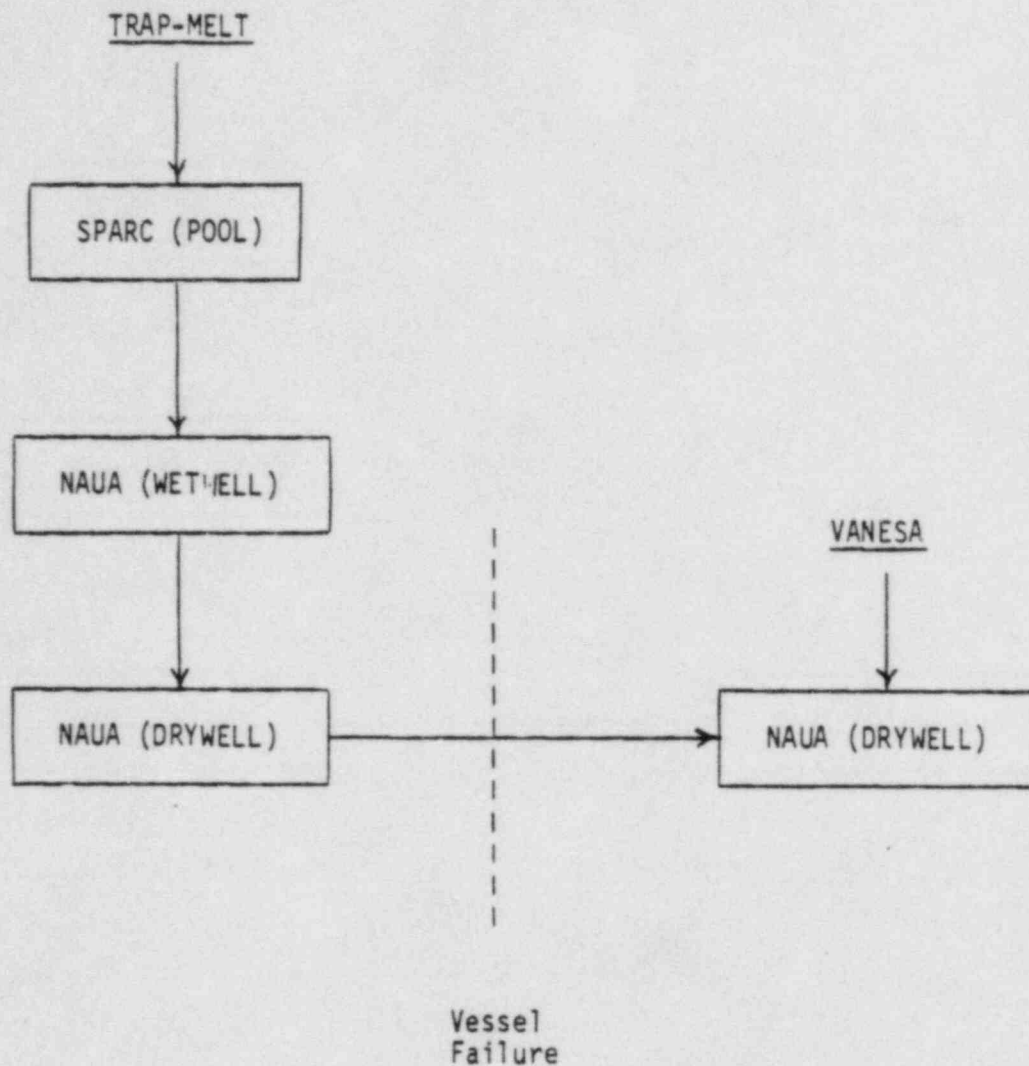


FIGURE 7.4. NAUA AND SPARC CALCULATION PATHS USED FOR PERFORMING ANALYSES OF TC AND TW SEQUENCES

TABLE 7.10. DECONTAMINATION FACTOR CALCULATED AS A FUNCTION OF PARTICLE SIZE AND OF TIME FOR TC

Time (min)	Particle Diameter, μm					DF Based on Total Mass
	0.1	0.6	1.0	6.0	10	
96.2	1.6	2×10^4	$10^5(a)$	10^5	10^5	120
99.2	5.7	1110	10^5	10^5	10^5	285
104	3.4	10^5	10^5	10^5	10^5	170
121.7	1.3	292	10^5	10^5	10^5	8.4
131.5	1.2	19	1.1×10^4	10^5	10^5	1.7
156.3	1.2	13	3610	10^5	10^5	6.5

(a) A decontamination factor larger than 10^5 is assumed to be 10^5 .

Pool depth: 6.5 ft (198 cm)

Bubble diameter: 0.75 cm

Aspect ratio: 1:3

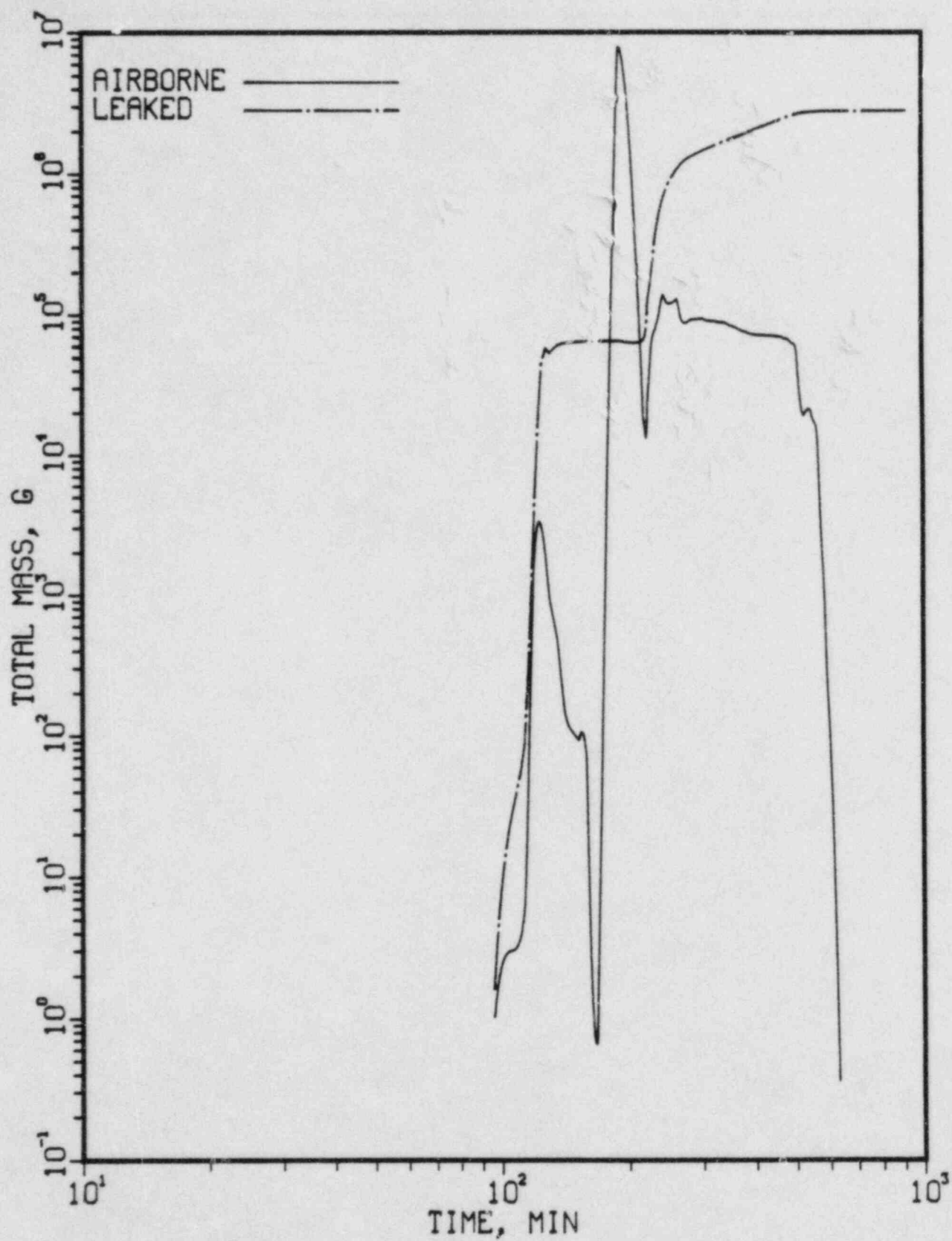
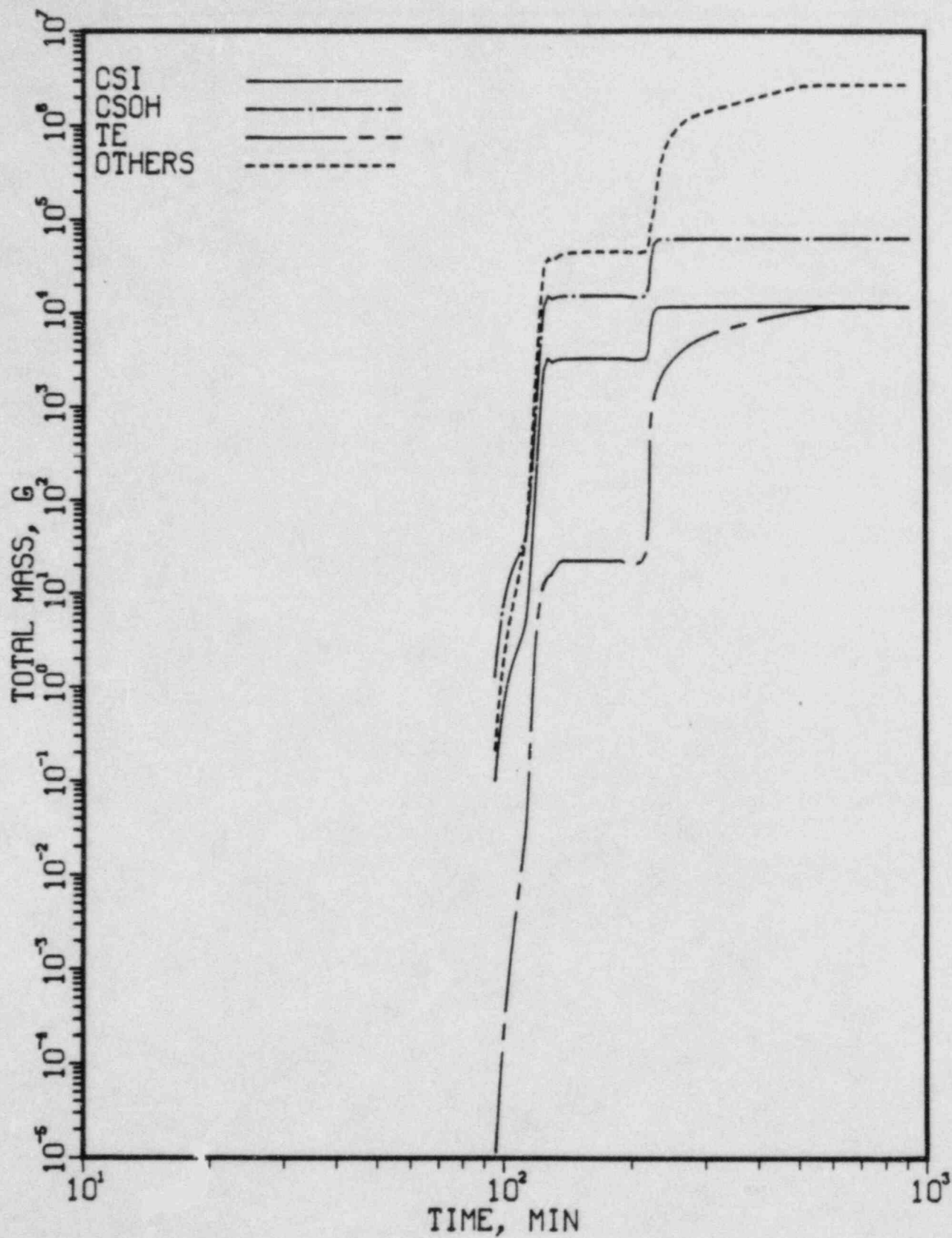


FIGURE 7.5. AIRBORNE AND LEAKED AEROSOL MASS FOR THE DRYWELL AS A FUNCTION OF TIME, TCY'

FIGURE 7.6. ACCUMULATED MASS LEAKED INTO ENVIRONMENT FOR VARIOUS SPECIES, TC_Y'

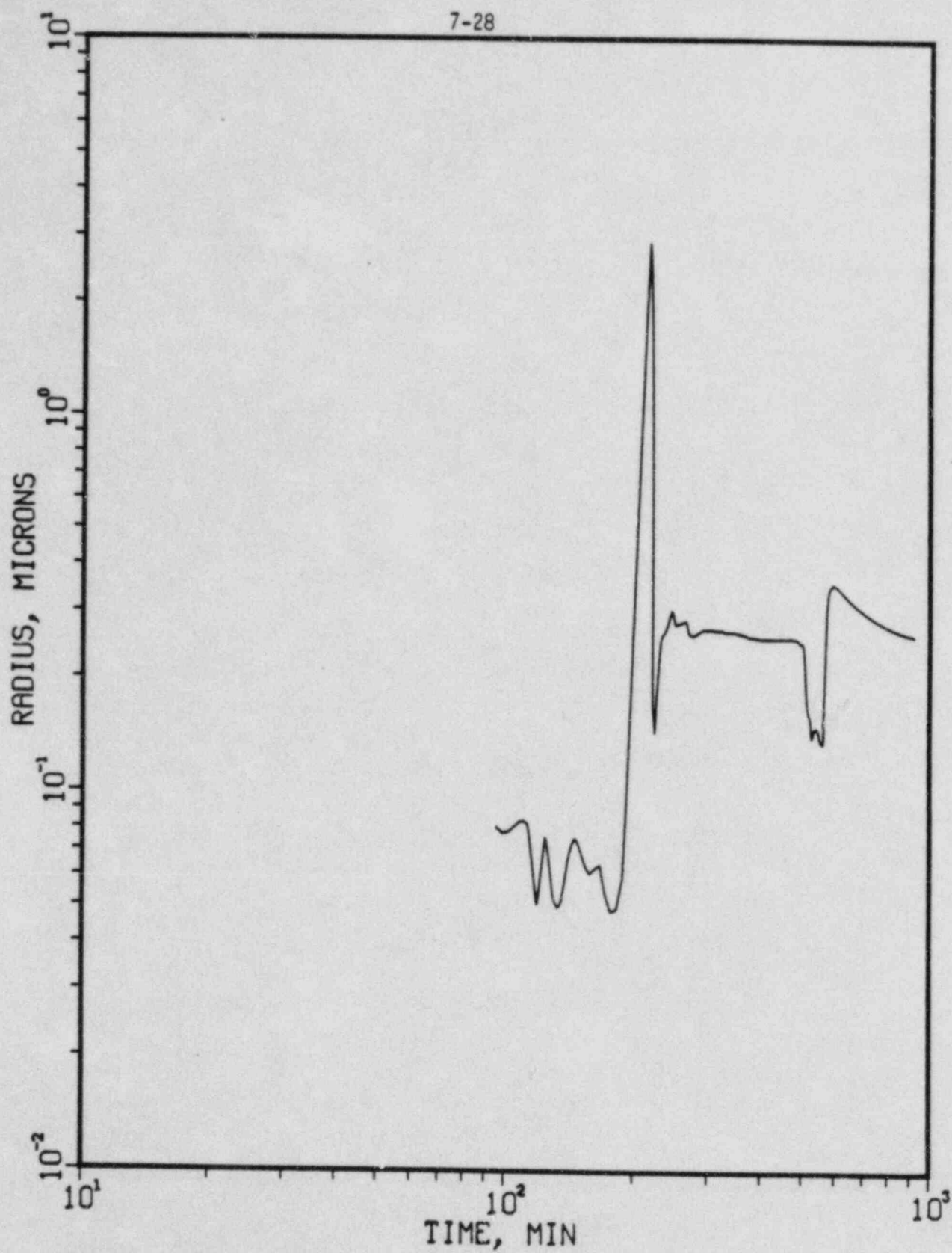


FIGURE 7.7. GEOMETRIC MEAN PARTICLE RADIUS IN DRYWELL, TCY'

TABLE 7.11. DISTRIBUTION OF SPECIES AT 20 HOURS AFTER ACCIDENT, TCY'

Species	Fraction of Core Inventory				
	RCS	Pool	Drywell	Wetwell	Environment
CsI	0.085	0.54	0.04	-0	0.34
CsOH	0.2	0.48	0.035	-0	0.29
Te	0.16	0.0047	0.17	-0	0.32

7.3.3 TC γ Sequence

This accident sequence is similar to the TC γ ' sequence except that the fission product released from the drywell is assumed to pass through the secondary containment (reactor building). Therefore, an additional calculation has been made simulating fission product behavior in the secondary containment. The flow path of fission product from the secondary containment is partly direct to the environment and partly through the Standby Gas Treatment System (SGTS) which consists of High Efficiency Particulate Assembly (HEPA) filters. The operation and the effectiveness of the SGTS are described in Appendix A. It was assumed in the present calculation that a constant volumetric flow rate of 25,000 cfm through the SGTS is maintained during the accident. A collection efficiency of 99.99 percent regardless of particle size was utilized. However, the filter banks were assumed to fail after 104 Kg of particulate matter was collected.

Figure 7.8 is the airborne mass plotted as a function of time for the secondary containment. As expected, a time dependency of the airborne mass very similar to that for the drywell as depicted by Figure 7.5 is seen to occur in the secondary containment.

Table 7.12 shows the distribution of the CsI, CsOH, and Te as calculated by the NAUA code. It is interesting to find that compared with Table 7.11 a fraction of core inventory ranging from 0.11 for Te to 0.14 for CsI is retained in the secondary containment and in the filter.

7.4 Discussion

In WASH-1400, the TW and TC system sequences dominated the predicted risk to the public for this reactor design. This dominance was a result of the estimated likelihood for these sequences as well as their consequences. The estimated mean core melt frequency for each sequence was $1 \times 10^{-5} \text{ yr}^{-1}$. This was compared with a median frequency of $5 \times 10^{-7} \text{ yr}^{-1}$ for the TQV system sequence which had the next highest frequency. The estimated median frequency for the AE sequence was $1 \times$

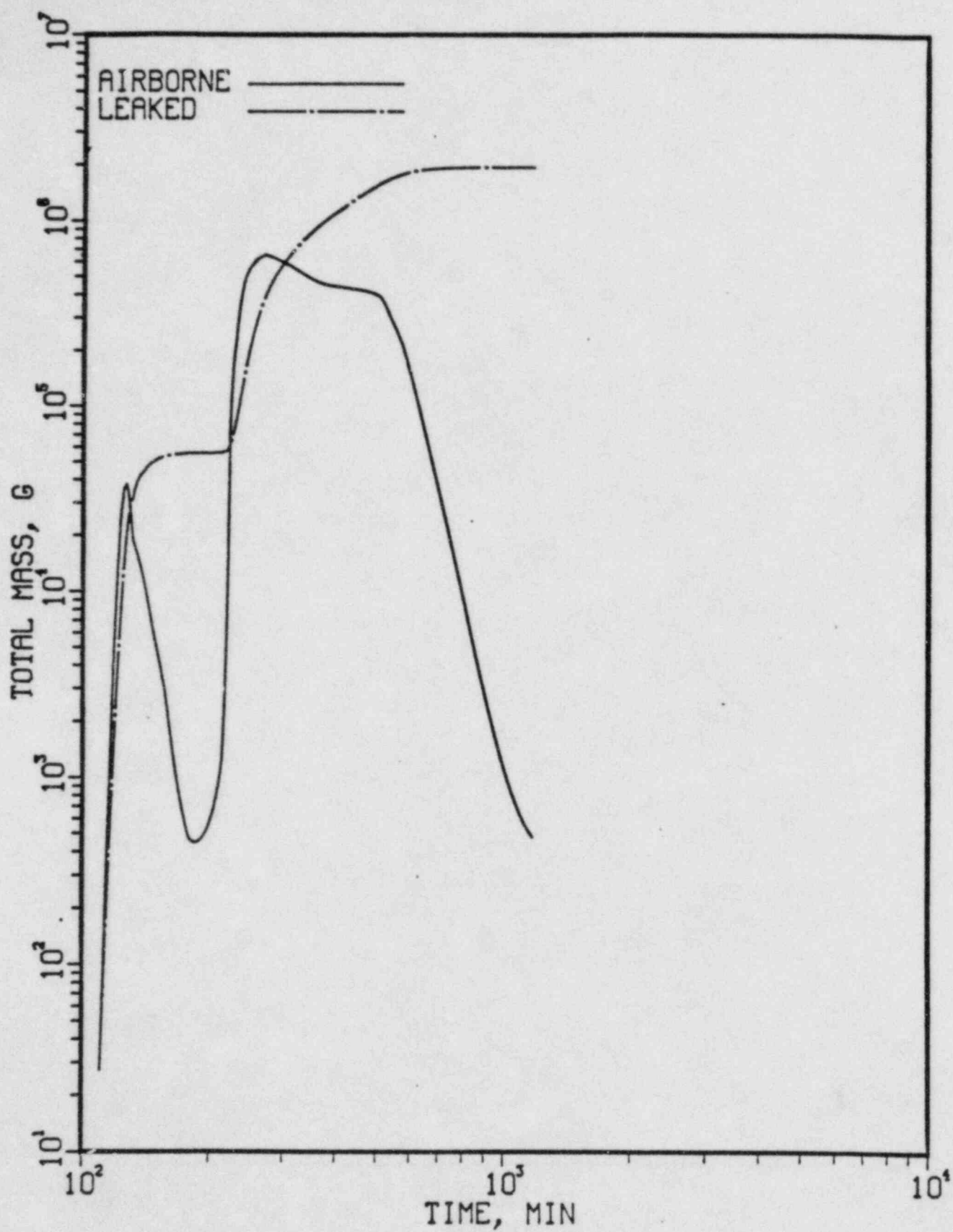


FIGURE 7.8. AIRBORNE MASS FOR THE SECONDARY CONTAINMENT AS A FUNCTION OF TIME, TCY

TABLE 7.12. DISTRIBUTION OF SPECIES AT 20 HOURS AFTER ACCIDENT, TCY

Species	Fraction of Core Inventory						Environment
	RCS	Pool	Drywell	Wetwell	Reactor Bldg	SGTS	
CsI	0.085	0.54	0.04	0	0.088	0.058	0.20
CsOH	0.20	0.48	0.035	0	0.075	0.049	0.16
Te	0.16	0.0047	0.16	0	0.098	0.013	0.21

10^{-7} yr^{-1} . Thus, the TW and TC system sequences were more than an order of magnitude higher in estimated frequency than the next most likely sequence and were two orders of magnitude more likely than the background of remaining sequences. This perspective on the importance of the TW and TC sequences has not changed substantially in the intervening years and is reflected in the results of the Accident Sequence Evaluation Program.

For the BWR sequences only four fission product release categories were used for core meltdown sequences as opposed to the seven categories used for the PWR. The time-integrated release fractions are shown in Table 7.13 for each of the release categories. Categories BWR 1 and BWR 2 involve very large fractions for the volatile fission products and are comparable in severity. The comparatively large release of ruthenium in the BWR 1 sequence is the result of fuel fragmentation, dispersal, and oxidation following a steam explosion that fails primary containment.

All of the in-vessel steam explosion failure sequences, α , were assigned to the BWR 1 category. Because of the low probability of steam explosions leading to containment failure (10^{-2}), this failure mode was not a major risk contributor in WASH-1400.

In general, the overpressure failure sequences with direct release to the environment, γ' , were assigned to Category BWR 2 and the overpressure failure sequences with deposition in the reactor building, γ , were assigned to Category BWR 3. This category is less severe than BWR 2, but would still result in major public consequences. Since 25 percent of overpressure sequences were assigned to γ' , the relative probabilities of the sequences in Category 2 and Category 3 in WASH-1400 were approximately in the ratio 1:3. An important exception to the assignment of failure modes to release categories was the treatment of the system sequence TC. The analyses performed for TC in WASH-1400 indicated that core meltdown would precede containment failure and that some retention of fission products would occur in the suppression pool. For this reason, TC γ and TC γ' were both assigned to Category 3, increasing its relative importance.

TABLE 7.13. WASH-1400 RELEASE CATEGORIES

Release Category	Fraction of Core Inventory Released						La
	Xe-Kr	I	Cs-Rb	Te-Sb	Ba-Sr	Ru	
BWR 1	1.0	0.4	0.4	0.7	0.05	0.5	5×10^{-3}
BWR 2	1.0	0.9	0.5	0.3	0.1	0.03	4×10^{-3}
BWR 3	1.0	0.1	0.1	0.3	0.01	0.02	3×10^{-3}
BWR 4	0.6	8×10^{-4}	5×10^{-3}	4×10^{-3}	6×10^{-4}	6×10^{-4}	1×10^{-4}

The final core melt release category, BWR 4, involves significantly reduced release fractions. At this level of in-plant attenuation, the actual values for the release fractions for the volatile fission products are not particularly important because the public health consequences would be dominated by the noble gases. The principal sequences in this release category involved isolation failures in which the small leakage rate from the primary containment could be treated by the SGTS prior to release to the environment. The likelihood of this mode of containment isolation failure was estimated to be small. The combination of low probability and low consequences made the contribution of Category BWR 4 to the public risk negligible. Thus, Categories BWR 2 and BWR 3 were the important risk contributors.

In Table 7.14 the release fractions for sequences TWY', TCY', and AEY' are compared with the WASH-1400 values. The lower release fractions are the result of predicted retention in the reactor coolant system and in the suppression pool. Because of the high temperatures in the reactor coolant system, the predicted retention for the volatile species is limited. The retention of the less volatile species as aerosols is more significant. In the transport of fission products through the suppression pool, it is assumed that all radionuclides other than the noble gases are in the form of aerosols. For the AEY' sequence, the decontamination factor is rather large for material carried into the pool prior to containment failure. After containment failure the flow path would no longer include the suppression pool.

In the TCY' and TWY' sequences, the release pathway is through the pool until the time of reactor vessel melt-through. The pool of water is saturated during this time period so the amount of decontamination is not as great as for the AE system sequence. As discussed earlier, the decontamination factor for the saturated pool is very sensitive to the size distribution of the aerosols and the resulting uncertainty in the release fractions in Table 7.14 is large.

The TCY sequence was analyzed in order to examine the potential effectiveness of the reactor building and SGTS in further mitigating the consequences of an accident when the structural integrity of

TABLE 7.14. COMPARISON OF SEQUENCES ASSIGNED TO BWR 2

Sequence	Fraction of Core Inventory Released			
	Xe-Kr	I	Cs-Rb	Te-Sb
BWR 2	1.0	0.9	0.5	0.3
AEY ¹	1.0	0.2	0.2	0.7
TCY ¹	1.0	0.3	0.3	0.3
TWY*				

*Being analyzed at the time this report was being prepared.

the reactor building is maintained following failure of the primary containment. The results for this sequence are compared with the release fractions for Category BWR 3 in Table 7.15. The effect of the reactor building systems can be determined by comparing the results for the TC γ and TC γ' sequences directly. The quantities of fission products, other than noble gases, that do escape to the environment are primarily the result of outleakage from the reactor building. The TC γ sequence analyzed did not consider the effect of the fire sprinkler system on further reducing the fission product source term if it were activated by the hot steam during blowdown of the primary containment. The sprinkler system would be expected to lead to a significant additional reduction in the source term both due to washout of airborne aerosols and due to steam condensation which would result in a net air in-leakage to the building. Eventually the mixing of air and hydrogen in this sequence would probably result in explosive conditions with the potential of destroying the reactor building. The consequences of the sequence would be very sensitive to the timing of the hydrogen burning event.

The analyses performed for the Peach Bottom 2 reactor indicate that the WASH-1400 release fractions in the high consequence BWR 2 category are overestimated for iodine, cesium, and the involatile fission products. The specific scenario analyzed to compare to the BWR 3 category resulted in comparable but slightly higher releases than in WASH-1400. Slight variations in modeling assumptions would have led to substantial additional retention, however. The implications of these results to the WASH-1400 perspective on risk depend on the relative likelihoods of the γ and γ' failure modes. If the reactor building were expected to withstand blowdown forces from the failure of the primary containment with a high degree of confidence, the risk could be reduced substantially. The uncertainties in the thermal, hydraulic, and structural response of the primary containment structure and the reactor building are very large, however. The scope of the current effort was oriented at developing an understanding of the consequences of a given accident scenario rather than estimating the likelihoods of alternative scenarios.

TABLE 7.15. COMPARISON OF SEQUENCES ASSIGNED TO BWR 3

Sequence	Fraction of Core Inventory Released			
	Xe-Kr	I	Cs-Rb	Te-Sb
BWR 3	1.0	0.1	0.1	0.3
TCY	1.0	0.2	0.2	0.2

The results presented in this report are referred to as best-estimate results. Sensitivity studies will be performed later in the program to provide perspective on the ranges of the uncertainties associated with the best-estimate values. In each phase of release and transport, important uncertainties exist. Changes in assumptions and models could affect the prediction of the environmental source term substantially.

In calculating the initial period of core heatup, the MARCH 2 code has been demonstrated to have reasonable accuracy. After fuel melting and slumping begins, the MARCH 2 code models very complex phenomena with very simple models. The maximum fuel temperature is probably under-predicted by MARCH 2 and the time at temperature is quite uncertain. As a result, the timing of release of volatile fission products and the magnitude and timing of release of less volatile fission products from the fuel could be affected by thermal hydraulic modeling deficiencies.

Thermal hydraulic modeling uncertainties also have a major impact on uncertainties in the transport of fission products in the reactor coolant system, primary containment and the reactor building. The temperatures and flows in the reactor coolant system directly influence the extent of retention. Indeed, the MARCH 2/MERGE results indicate temperatures that are just high enough to limit the retention of the volatile species CsI and CsOH . The predicted time, location, and mode of failure of the primary containment building also have a major influence on the predicted environmental source term. The predicted failure of the primary containment prior to pressure vessel melt-through, coupled with failure in the drywell region, resulted in a large fraction of the fission products bypassing the suppression pool in the AE sequence. The rate of generation of hydrogen, failure pressure for the primary containment, and location of failure (drywell versus wetwell) are sufficiently uncertain that the actual accident scenario could follow a pathway that could result in substantially greater attenuation in the suppression pool. Similarly for the TC and TW sequences, failure of the primary containment in the wetwell region could result in substantially less retention in the suppression pool.

The decontamination factor for the pool is itself quite uncertain even with well specified input thermal hydraulic conditions. The decontamination factor predicted by SPARC is very sensitive to aerosol size. A small shift in the predicted size distribution could change the results of the calculated aerosol retentions substantially.

Finally, the reactor building potentially has the capability to significantly reduce the environmental source term depending on its response to failure of the primary containment. The associated technical questions will be extremely difficult to resolve.

In conclusion, the reader should be careful not to assign greater significance to the single-valued best-estimate source terms that are provided in this report than warranted by the uncertainties in the underlying assumptions and methods of analysis.

RADIONUCLIDE RELEASE UNDER SPECIFIC LWR
ACCIDENT CONDITIONS -- VOLUME III
BWR, MARK III DESIGN

2. INTRODUCTION

This is the third volume of a report on "Radionuclide Release Under Specific LWR Accident Conditions" and is concerned with analyses performed for a BWR, Mark III design. The procedures employed for calculations reported in this volume were identical to those used previously in the preparation of Volume II of this report. This volume, then, represents a direct extension of the BWR, Mark I analyses of Volume II to the geometry and sequences of significance for a BWR, Mark III design. For continuity in reporting, the Introduction from Volume I follows.

The radiological effects associated with fission product release from commercial light water reactors during severe accident conditions have been the subject of considerable concern and the impetus for much research. As research has progressed, the physical processes controlling the magnitude of fission product releases have become more thoroughly understood and the ability to estimate fission product release has been improved.

The design bases and siting criteria for most of the existing population of U.S. reactors were based on the use of the TID-14844(2.1) assumptions regarding the release of fission products to the containment in a severe accident. Although representative of the state of knowledge at the time, a better understanding of the behavior of fission products in severe accidents has developed over the intervening years and many of the TID-14844 assumptions are now recognized as requiring re-evaluation. A more mechanistic treatment of fission product release was developed for the Reactor Safety Study (WASH 1400)(2.2) and since that time the WASH-1400 source term to the environment for accident sequences has been used extensively. Obtaining an improved characterization of the source of fission products to the environment in accidents is therefore an essential step in the comprehensive evaluation of current source term

assumptions and would serve as a basis for formulating impacts on and changes to licensing practice, emergency planning, safety goals and indemnification policy of revised source term. For this reason the NRC undertook a review of the state of knowledge regarding procedures available for predicting fission product release and transport and in June of 1981 issued the report "Technical Bases for Estimating Fission Product Behavior During LWR Accidents".(2.3)

As part of the "Technical Bases Report", the assumptions, procedures, and available data needed for predicting fission product behavior were evaluated and calculations were made of fission product attenuation along the various flow paths from the fuel to the environment. Because of the limitations of available computational tools at that time, release from the fuel and transport through various compartments along the flow paths were treated separately and therefore possible interactions were not considered. This procedure is the subject of the first major comment on the "Technical Bases Report" (NUREG 0772, Appendix F) and was recognized as a shortcoming of that report. The calculations and evaluations being presented here are intended to overcome this shortcoming as well as to provide analyses performed with improved computational procedures.

This report builds on previous NRC supported computer modeling work performed at Battelle-Columbus and experimental and model evaluation work performed at Oak Ridge, EG&G Idaho, Sandia, and Pacific Northwest Laboratories. Research efforts specifically directed toward increasing our understanding of fission product release and transport under severe accident conditions are currently under way at these laboratories as well as at other research installations around the world. It is anticipated that over the next few years considerable progress will be made in this area. Therefore this report must be considered as an expression of current knowledge with the expectation that validation or modification of the calculated fission product releases will be forthcoming.

It is to be recognized that this report describes an analytical approach for estimating radionuclide transport and deposition which incorporates physical and chemical processes on a mechanistic basis. This

approach is being evaluated for use in predicting fission product source terms for release to the environment on a specific case-by-case basis (reactor, accident sequence) and when verified would be expected to replace the generic tabular release fractions such as those given in Table 6, Appendix V, WASH 1400 where release fractions are given for broad classes of accidents and plant designs are lumped together.

The purpose of this report is then to:

- (1) Develop updated release-from-plant fission product source terms for four types of nuclear power plants and for accident sequences giving a range of conditions. The estimated source terms are to be based on consistent step-by-step analyses using improved computational tools for predicting radionuclide release from the fuel, and transport and depositions.
- (2) Determine the effects on fission product releases associated with major differences in input parameters associated with plant design and accident sequences.
- (3) Provide in-plant time and location dependent distributions of fission product mass for use in equipment qualification considerations.

It is not necessarily the intent of this work to produce an all encompassing definition of source terms but rather to make best estimates of source terms for a range of typical plants and several risk-significant sequences covering a wide range of conditions. These analyses were to be made with the best available techniques, in a consistent manner following along the release pathways for fission products, and at a level of detail consistent with current knowledge of pertinent physical processes. Based on state-of-the-art techniques, these best-estimate analyses should provide an indication of the conservatism inherent in current source term assumptions and guidance for the development of new source terms. It is important to note that the analytical procedures are developed and as a more extensive experimental base evolves. The preparation of this report, therefore, is an evolutionary process which

will be carried out over a period of time up to June, 1983, with verification and possibly revision of the procedures continuing over several years beyond that date.

References

- (2.1) DiNunno, J. J., et al, "Calculation of Distance Factors for Power and Test Reactor Sites", TID-14844 (March 23, 1962).
- (2.2) "Reactor Safety Study -- An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants", WASH-1400, NUREG-75/014 (October, 1975).
- (2.3) "Technical Bases for Estimating Fission Product Behavior During LWR Accidents", NUREG-0772 (June, 1981).

3. GENERAL APPROACH

The general philosophy behind this study is that mechanistic predictions of radionuclide release and transport are possible if proper modeling is performed to represent the physical and chemical processes occurring during LWR accidents. The study, then, represents an attempt at describing in a reasonably complete but tractable fashion the processes influencing the radionuclide release to the environment for selected plants and accident conditions. The general approach taken in this study was specified by the objectives which called for a consistent analysis of radionuclide behavior by following their transport along flow paths from their release into the core region up to their final release to the environment. Nevertheless, numerous decisions and assumptions were required for the analyses. These decisions included selections of plants and sequences for consideration, choices of analytical tools to be used as available or upgraded, evaluations and incorporation of experimental data, and determinations of major physical effects which would be considered on a parametric variation basis to illustrate the sensitivity of calculations to such variations. Such decisions and assumptions are discussed throughout this report as they arise in their technical context. However, some of the major considerations will be reviewed and the steps comprising the overall approach will be discussed in this section.

This study was based on selecting specific plants and accident sequences for consideration and then using consistent and improved analyses of fission product release from fuel, transport, and deposition to predict fission product release to the environment for these specific cases. The approach is comprised of a series of steps performed in sequence such that in the combined analysis, the results are specific to an individual set of accident conditions and each successive transport step is based on results from analyses of the previous step.

The first major step in the process was the selection of types of nuclear power plant designs to be considered and a specific plant to represent each type. The types to be considered were: large, dry PWRs;

Mark I BWRs; Mark III BWRs; and ice condenser type PWR designs. The specific plants chosen to represent each type are the Surry and Zion, Peach Bottom, Grand Gulf, and Sequoyah plants. These selections were made on a combined basis of typicality of design and availability of design details needed for analyses.

Accident sequences are being chosen for each plant design based on risk and on a desire to have a range of physical conditions represented by the analyses. The plants selected and the accident sequences anticipated for consideration are listed below:

PWR Large Dry
Containment
(Surry)

AB
S₂D
V
TMLB'

BWR Mark I
(Peach Bottom)

TC
AE
TW

BWR Mark III
(Grand Gulf)

TC
TPI
TQUV

PWR Ice Condenser
Containment
(Sequoyah)

S₂H (or S₂HF)
S₂D
TMLB'
TML

Following the selection of plants and sequences the required plant design data were collected and thermal hydraulic analyses performed for the accident sequences. Overall thermal hydraulic conditions on a time-dependent basis were estimated with the MARCH 2 code, (3.1) and detailed thermal hydraulic conditions for the primary system estimated with the MERGE code which was developed specifically for use in this program. The MERGE code was described in Volume I of this report.

The time-dependent core temperatures were used as input to another code developed for this program, CORSOR, which predicts time and temperature dependent mass releases of radionuclides from the fuel within

the pressure vessel. The latest version of CORSOR is described later in this Volume. Releases during core-concrete interactions of radionuclides remaining with the melt were provided by Sandia National Laboratories using their computer code VANESA. An updated description of the VANESA code is provided later in this volume.

Using the MARCH/MERGE predicted thermal hydraulic conditions and the CORSOR predicted radionuclide release rates as input, a newly developed version of the TRAP-MELT code, described in Volume I, was used to predict vapor and particulate transport in the primary coolant circuit.

Transport and deposition of radionuclides in the containment were calculated using the NAUA-4 (3.2) code.

The basic stepwise procedure described above is illustrated in Figure 3.1 which shows the relationships among the computational models. The calculations were of a "best estimate" type using input derived, to the extent possible, from experimental measurements. Types of data employed in the analyses include vapor deposition velocities, aerosol deposition rates, aerosol agglomeration rates, fission product release rates from fuel, particle sizes formed from vaporizing/condensing fuel materials, engineering correlations for heat and mass transfer, and physical properties of various fuel, fission product and structural materials.

References

- (3.1) Wooton, R. O., et al, "MARCH 2 Code Description and Users' Manual", Draft (December, 1982).
- (3.2) Bunz, H., Koyro, M., and Schock, W., "A Code for Calculating Aerosol Behavior in LWR Core Melt Accidents, Code Description and Users' Manual".

4. PLANT SELECTION AND ACCIDENT SEQUENCES

4.1 General Plant Description

The most recent U.S. BWR designs involve containment systems that employ a pressure suppression pool but in a different configuration than for the Mark I or Mark II designs. The specific plant selected for analysis in this study is the Grand Gulf Nuclear Station Unit 1.(4.1) Some of the data used to represent the plant have, however, been adapted from values provided in the General Electric Standard Safety Analysis Report (GESSAR)(4.2). The Grand Gulf Nuclear Station involves two twin units in a common facility with the sharing of some facilities. Each unit has a BWR/6 boiling water reactor (251-inch diameter vessel with 800 fuel assemblies) which was designed and supplied by the General Electric Company. The thermal power output of each unit is approximately 3800 MW and the net electrical output is approximately 1250 MW. Although there are some differences in the design of the Peach Bottom 2 reactor coolant system, the in-vessel meltdown behavior and transport of fission products within the reactor coolant system would be quite similar for the two plants for most accident sequences. A greater difference in accident behavior would result from differences in the physical layout of the plant external to the reactor coolant system.

The Mark III containment design employed in the Grand Gulf plant is illustrated in Figure 4.1. In this design, the suppression pool is located at the periphery of the containment. In the event of a loss of coolant accident, the water level in the channel internal to the weir wall would be depressed uncovering horizontal vent pipes. Steam in the drywell would then be relieved to the suppression pool through the vents. In the Mark III design, the vapor space of the wetwell actually forms an outer containment volume surrounding the drywell. The volume of the drywell, 270,000 ft³ (7650 m³) is comparable to but somewhat greater than the volume of the Peach Bottom drywell. The primary containment volume, 1.4 x 10⁶ ft³ (4.0 x 10⁴ m³), is substantially larger

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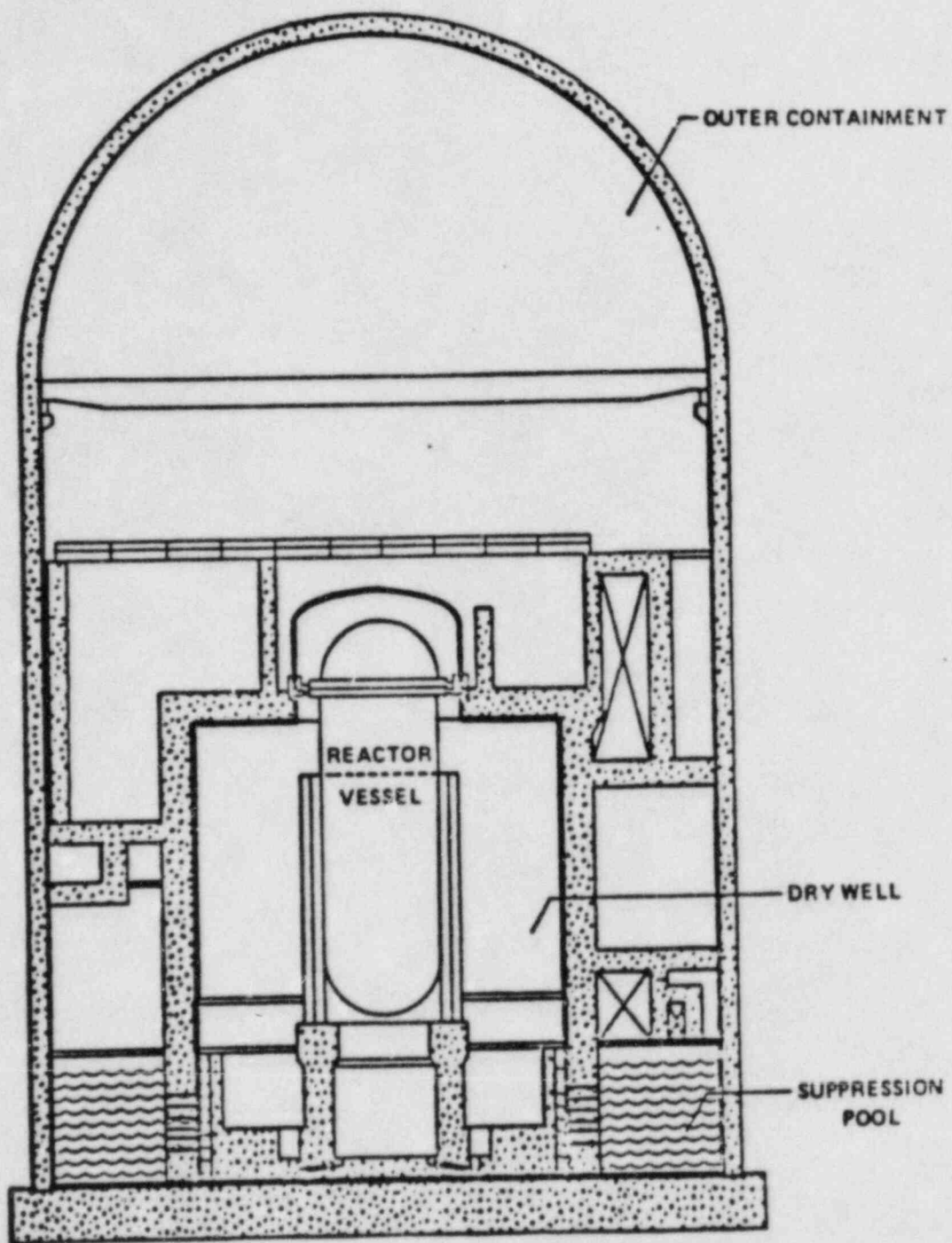


FIGURE 4.1 BWR MARK III CONTAINMENT DESIGN

than the wetwell vapor spaces in the Mark I and Mark II designs. The containment is a steel-lined, reinforced concrete structure.

The internal design pressures of the drywell and containment are 30 and 15 psig (0.2 and 0.1 MPa), respectively. In this study, it has been assumed that failure of the containment would occur at an internal pressure of 72 psia (0.5 MPa) based upon discussions with industry representatives. This failure pressure is considerably higher than the 45 psia (0.3 MPa) nominal value utilized in the RSSMAP analyses of Grand Gulf^(4.3) and is 3.8 times the design value. The expected location of failure is in the upper region of the containment at the junction of the cylindrical wall with the hemispherical dome. Little basis exists for predicting the leakage characteristics of the containment following failure. A large leakage was assumed to result for the purposes of this study. The effect of this assumption will be examined later in the program. Since the failure location was elevated with respect to the suppression pool, it was assumed that the latter would remain in place following failure.

The Standby Gas Treatment System at Grand Gulf provides for mixing between the auxiliary and enclosure building. The capacity of the system to exhaust to the atmosphere is quite small, however, 4000 cfm (1.9×10^3 l/s). It is expected that the enclosure building would fail shortly following failure of the primary containment. Other plant data used in the analyses are provided in Table 4.1.

4.2 Selection Basis and General Description of Accident Sequences

Three accident sequences were selected for analysis in this plant: TC, TPI, and TQUV. Table 4.2 relates the letters used to describe the accident sequence with the systems that are failed in the accident. These sequences are consistent with the dominant sequences identified by the ASEP (Accident Sequence Evaluation Program).^(4.4) The set does not include a pipe break accident which would involve a fission product pathway from the vessel to the drywell and then to the suppression pool by

TABLE 4.1. MARK III DATA

Nominal Power	3,833 MWt 13,082 x 10 ⁶ Btu/hr
Steam Pressure in Core	1040 psig (7.3 MPa)
Primary System Operating Temperature	555 F (290.6 C)
Primary System Total Coolant Inventory	25,940 ft ³ (734.6 m ³)
Liquid Volume in Vessel	3771 ft ³ (106.5 m ³)
Steam Volume in Vessel	9638 ft ³ (272.95 m ³)
Steam Volume in Recirculation Loop	827 ft ³ (23.4 m ³)
Reactor Coolant System Liquid Mass	6.815 x 10 ⁵ lbm (3.091 x 10 ⁵ kg)
Reactor Coolant System Steam Mass	24,000 lbm (10,886 kg)
Reactor Vessel	
Inside diameter	251 inches (6.375 m)
Inside height	73 ft (22.25 m)
Design pressure	1250 psig (8.7 MPa)
Design temperature	575 F (301.7 C)
Thickness (with clad)	6.265 inches (1.91 m)
Total Vessel Weight	1.945 x 10 ⁶ lb (882,233 kg)
Vent Pipes	
Number	135
Internal diameter	2.33 ft (0.71 m)
Jet Pumps	
Number	24
Internal diameter, throat	0.53 ft (0.16 m)
Internal diameter, diffuser	1.23 ft (0.37 m)

TABLE 4.1. (Continued)

Drywell

Free volume	270,100 ft ³ (7649 m ³)
Design temperature	330 F (165.6 C)
Internal design pressure	30 psig (0.31 MPa)

Suppression Pool

Water volume	136,000 ft ³ (3,851.5 m ³)
Design temperature	185 F (85 C)
Internal design pressure	15 psig (0.21 MPa)

Core

Equivalent diameter	15.96 ft (4.9 m)
Active fuel height	12.5 ft (3.8 m)
Total cross sectional area	169 ft ² (15.7 m ²)
Flow area of core	84.3 ft ² (7.8 m ²)
Number of fuel assemblies	800
Rods per assembly	62
Pitch	5.3×10^{-2} ft (0.016 m)
Assembly dimensions	5.46 inches square (0.14 m square)
Fuel rod diameter	4.025×10^{-2} ft (0.012 m)
Clad thickness of fuel rods	5.543×10^{-3} ft (0.002 m)
Total number of fuel rods	49,600
Core weight	
UO ₂	366,400 lbm (166,195 kg)
Zircaloy	174,700 lbm (79,242 kg)
Miscellaneous	30,450 lbm (13,812 kg)
Fuel pellet diameter	3.417×10^{-2} ft (0.104 m)
Diametral gap (fuel pellet to clad)	0.0045 inches (0.011 cm)

TABLE 4.2 KEY TO BWR ACCIDENT SEQUENCE SYMBOLS

-
-
- A - Rupture of reactor coolant boundary with an equivalent diameter of greater than six inches.
 - B - Failure of electric power to engineered safety features.
 - C - Failure of the reactor protection system.
 - D - Failure of vapor suppression.
 - E - Failure of emergency core cooling injection.
 - F - Failure of emergency core cooling functionability.
 - G - Failure of containment isolation to limit leakage to less than 100 volume percent per day.
 - H - Failure of core spray recirculation system.
 - I - Failure of low pressure recirculation system.
 - J - Failure of high pressure service water system.
 - M - Failure of safety/relief valves to open.
 - P - Failure of safety/relief valves to reclose after opening.
 - Q - Failure of normal feedwater system to provide core make-up water.
 - S₁ - Small pipe break with an equivalent diameter of about 2" - 6"
 - S₂ - Small pipe break with an equivalent diameter of about 1/2"-2".
 - T - Transient event.
 - U - Failure of high pressure coolant injection or reactor core isolation cooling system to provide core make-up water.
 - V - Failure of low pressure emergency core cooling system to provide core make-up water.
 - W - Failure to remove residual core heat.

Containment Failure Modes.

- α = steam explosion in reactor vessel.
 - β = steam explosion in containment.
 - γ = containment failure due to overpressure-release through reactor building
 - γ' = containment failure due to overpressure-release direct to atmosphere.
 - δ = containment isolation failure in drywell.
 - ξ = containment isolation failure in wetwell.
 - ζ = containment leakage greater than 2400 volume percent per day.
 - η = reactor building isolation failure.
 - θ = Standby Gas Treatment System failure.
-
-

way of the horizontal vents. Both the ASEP and GESSAR studies indicate the likelihood of pipe break accidents leading to core melt is very unlikely because of the diversity of water makeup sources available. For pipe break sequences in which the suppression pool remains subcooled during the period of fission product release, the suppression pool would be very effective in the scrubbing of fission products as in the TQUV case analyzed.

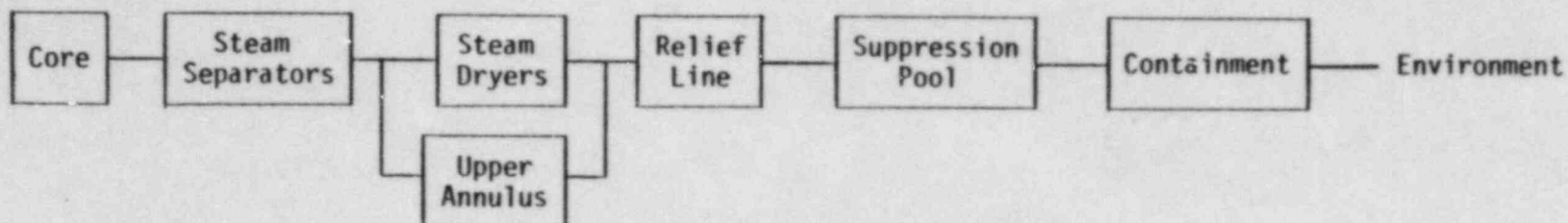
4.2.1 Sequence TC (Transient with Failure to Scram)

In this transient, the control rods fail to insert and the reactor stays at elevated power, dumping heat to the suppression pool. Since the assumed power level of the reactor (16 percent of full power) exceeds the heat removal capability for cooling the pool, the temperature of the pool rises and the pressure in the containment increases to the failure pressure. After the containment fails, the containment pressure decreases, the suppression pool boils, and the makeup pumps stop delivering coolant to the vessel. As the core heats up and melts, fission products released from the fuel flow with the gases through the steam separator (see Figure 4.2). The flow then divides with a major fraction, 85 percent, going through the steam dryers and the balance bypassing the steam dryers through an outer annular region. The flows then merge at the steam line and pass through a safety/relief valve and relief line. The flow exits the relief line into the suppression pool through a sparger. From the top of the suppression pool, gases and entrained aerosols disperse in the outer containment volume before leaking through the breach in containment. Although it is possible that the containment spray system could survive failure of the containment, this would be very difficult to demonstrate with confidence. In these analyses, it was assumed that the spray system would not operate.

The enclosure building would be expected to fail at the time of containment failure. The mode of failure of the enclosure building would be sensitive to the mode of failure of the containment building. It is assumed in the analyses that major failure of the enclosure

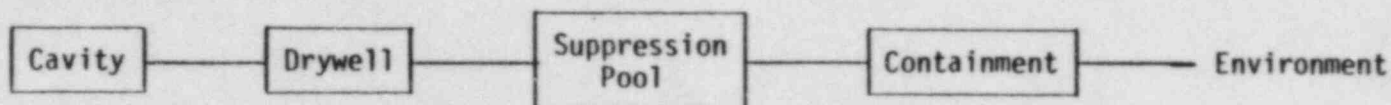
Phase 1. Up to Vessel Penetration (Containment failed prior to core melt).

Melt Release



Phase 2. After Vessel Penetration

Vaporization Release and Evolution from RCS



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FIGURE 4.2 FLOWPATHS FOR TC AND TW SEQUENCES

building results and that the leakage from the containment is direct to the environment.

Following melt-through of the reactor vessel, the fission products airborne in the vessel flow to the drywell as the system depressurizes. Fission products released with time from RCS surfaces would also enter the drywell. Attack of the concrete by the molten core also results in a source term to the drywell. The fission products are then carried to the suppression pool, to the outer containment volume, and through the break in containment to the environment.

4.2.2 Sequence TPI (Transient with Stuck Open Relief Valve and Loss of Decay Heat Removal)

In this sequence, a safety/relief valve sticks in the open position and the system depressurizes into the suppression pool. In addition, the residual heat removal system fails so that with the time the pool heats up and the containment pressure rises. As in the previous case, the containment fails prior to core melting, but, since the core is at decay heat power level, the time to fail is substantially longer (22 hours). This sequence is essentially the same as the TW sequence (transient with loss of decay heat removal) which was analyzed for the Peach Bottom design. The flow paths to the environment are illustrated in Figure 4.2. These paths are the same as described for the TC sequence.

4.2.3 Sequence TQUV (Transient with Loss of All Makeup Water)

This is a transient sequence in which all water makeup systems fail. It is assumed in the analysis that prior to depressurizing the reactor coolant system, the operators test the loss pressure pumps and determine that they are unavailable. The reactor coolant system is therefore maintained at pressure until the water level in the core reaches 2 feet. At this point, the RCS is depressurized. Thus, the core undergoes

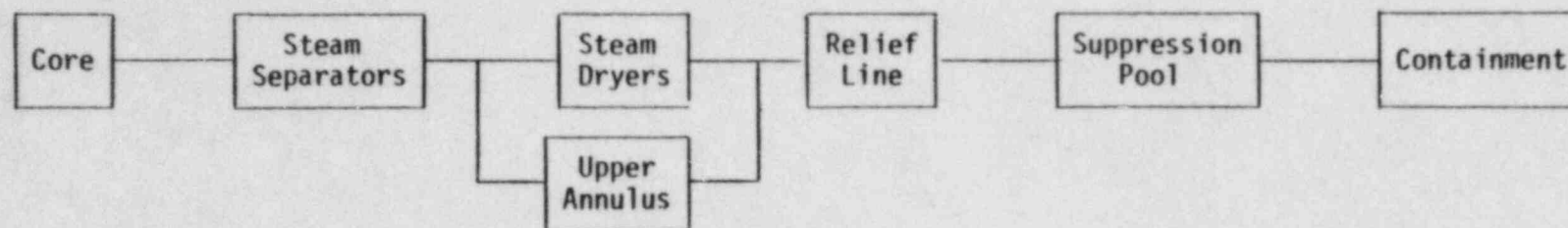
a heatup transient which is temporarily quenched at the time of depressurization due to level swell. The core subsequently uncovers and reheats.

The flow paths for fission product transport can be divided into three time phases (see Figure 4.3). Prior to vessel melt-through, the path is essentially the same as for the TC and TW sequences except that the containment is intact. Following vessel penetration but prior to containment failure, the pathway is from the cavity to the drywell, to the suppression pool, and to the containment. In this case, the suppression pool would be subcooled and potentially very effective in removing fission products. For this sequence, it is unlikely that the containment spray system would be operable considering the other systems that are failed.

In the analysis of the TQUV sequence it was assumed that hydrogen igniters were present and operable. The operation of these igniters led to the combustion of hydrogen released to the containment through the safety/relief valves. In the particular case considered, the burning of the hydrogen released during primary system depressurization was predicted to result in a pressure rise sufficient to lead to containment failure. The pressures resulting from such hydrogen burning can be sensitive to the rates of hydrogen release, hydrogen concentrations at ignition, containment compartmentalization, etc. In the absence of hydrogen burning containment would be predicted to fail due to the buildup of noncondensibles, both from the reaction of the Zircaloy as well as from the attack of the concrete by core debris. Failure due to the buildup of noncondensibles would take place much later in time than that predicted due to hydrogen burning. Following failure, the containment would blow-down to the environment. The pathway for any subsequent release would be from the cavity to the drywell, to the suppression pool, to the containment, and to the environment.

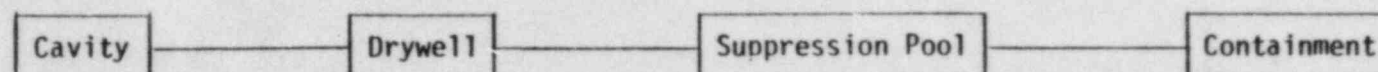
Phase 1. Up to Vessel Penetration

Melt Release



Phase 2. After Vessel Penetration to Containment Failure

Vaporization Release and Evolution from RCS



Phase 3. After Containment Failure

Vaporization Release and Evolution from RCS

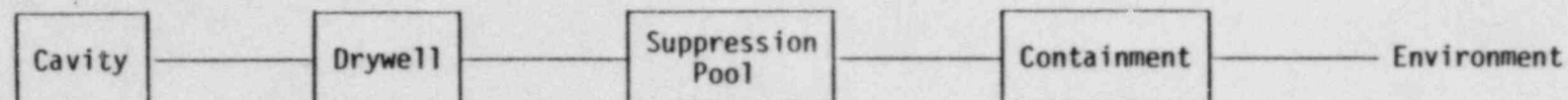


FIGURE 4.3 FLOWPATHS FOR SEQUENCE TQV

References

- (4.1) Grand Gulf Nuclear Station Units 1 and 2, Final Safety Analysis Report, Docket No. 50-416 (November, 1972).
- (4.2) GESSAR II, 238 Nuclear Island, Appendix 15D, BWR/6 Standard Plant Probabilistic Risk Assessment, Docket No. STN50-447.
- (4.3) Hatch, S. W., Cybulskis, P., and Wooton, R. O., "Reactor Safety Study Methodology Applications Program: Grand Gulf 1 BWR Power Plant", NUREG/CR-1659/4 of 4 (October, 1981).
- (4.4) Kolaczowski, A. M., et al, "Interim Report on Accident Sequence Likelihood Reassessment (Accident Sequence Evaluation Program)", Draft (February, 1983).

5. ANALYTICAL METHODS

The analytical methods employed in the calculations reported in this volume are represented by the MARCH 2, MERGE, CORSOR, TRAP-MELT 2, VANESA, SPARC, and NAUA-4 codes. These codes are as described in Volumes I and II of this report.

6. BASES FOR TRANSPORT CALCULATIONS

6.1 Plant Geometry and Thermal Hydraulic Conditions

The MARCH 2 and MERGE codes were used to predict the thermal hydraulic behavior of the three accident sequences evaluated. A summary of important reactor characteristics, containment parameters, and MARCH options is presented in Table 6.1.* The detailed parameters used to describe the reactor coolant system such as the masses, surface areas, volumes, etc., were primarily obtained from the General Electric Company. These results are not presented because of their proprietary nature.

6.1.1 Sequence TC

in the transient accident sequence TC, the reactor power level stabilizes at approximately 16 percent after isolation of the steam line. At this level the power exceeds the heat removal capacity for cooling the suppression pool. The pool heats up until at $\sim 1-1-1/3$ hr the failure level of the containment is reached. Makeup flow to the vessel is subsequently lost, the core becomes uncovered and fuel degradation occurs. Table 6.2 indicates times of key events and conditions in the containment as predicted by the MARCH 2 code. The temperatures and pressures in the containment volumes are shown in Figures 6.1 and 6.2. The temperatures of selected fuel regions are illustrated as a function of time in Figure 6.3.

The flow path for fission product release within the reactor coolant system is illustrated in Figure 6.4. Figure 6.5 is a schematic of the breakdown of control volumes used in the MERGE analysis. After leaving the steam separators the flow splits with a fraction (~ 85 percent) passing through the steam dryers and the balance bypassing the dryers. The differences between the geometries in the Peach Bottom and Grand Gulf reactor coolant systems are minor. The temperatures (Figures 6.6

*Tables are listed at the end of this section.

GRAND GULF TC

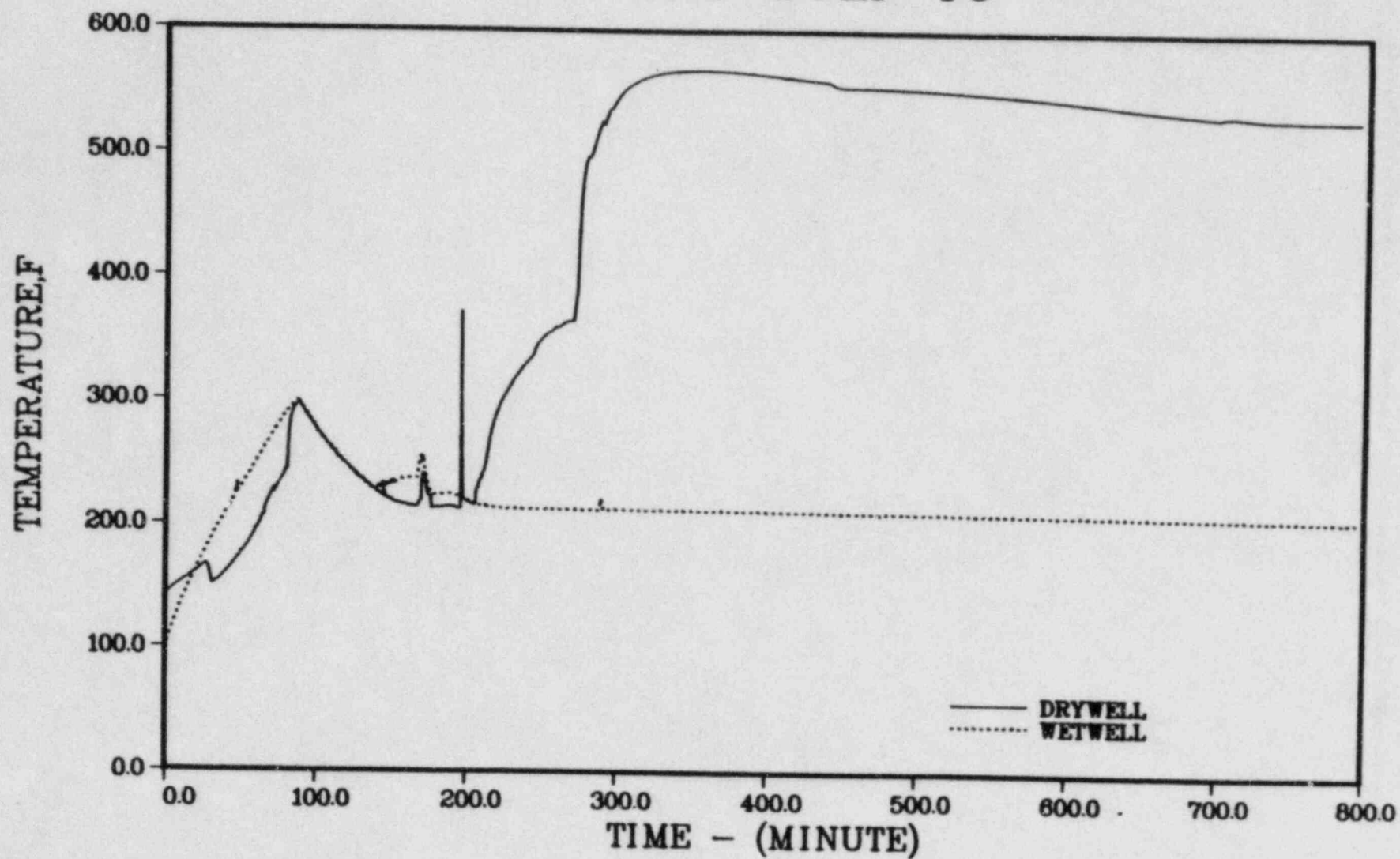


FIGURE 6.1 GAS TEMPERATURES IN CONTAINMENT VOLUMES - SEQUENCE TC

GRAND GULF TC

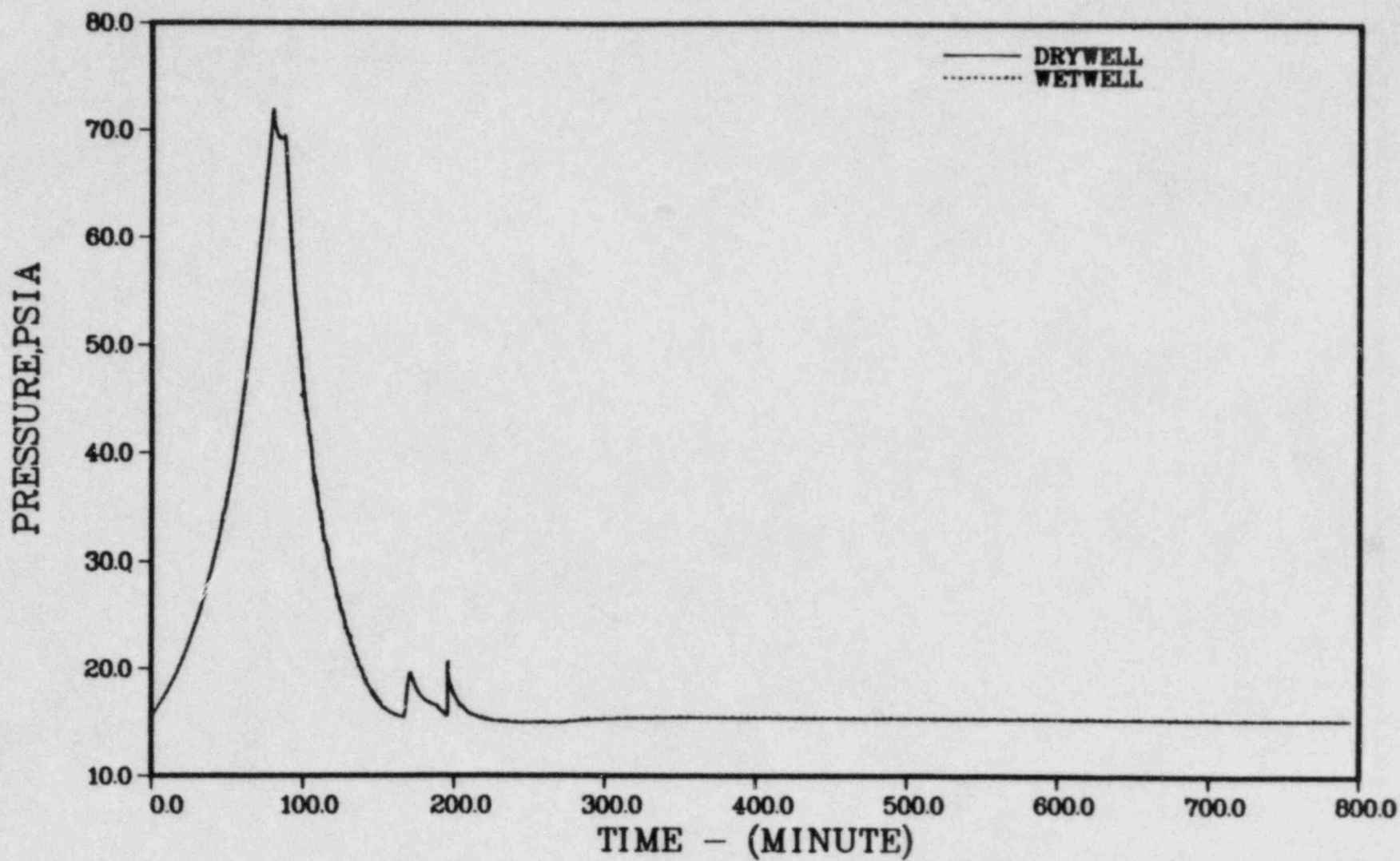


FIGURE 6.2 PRESSURES IN CONTAINMENT VOLUMES - SEQUENCE TC

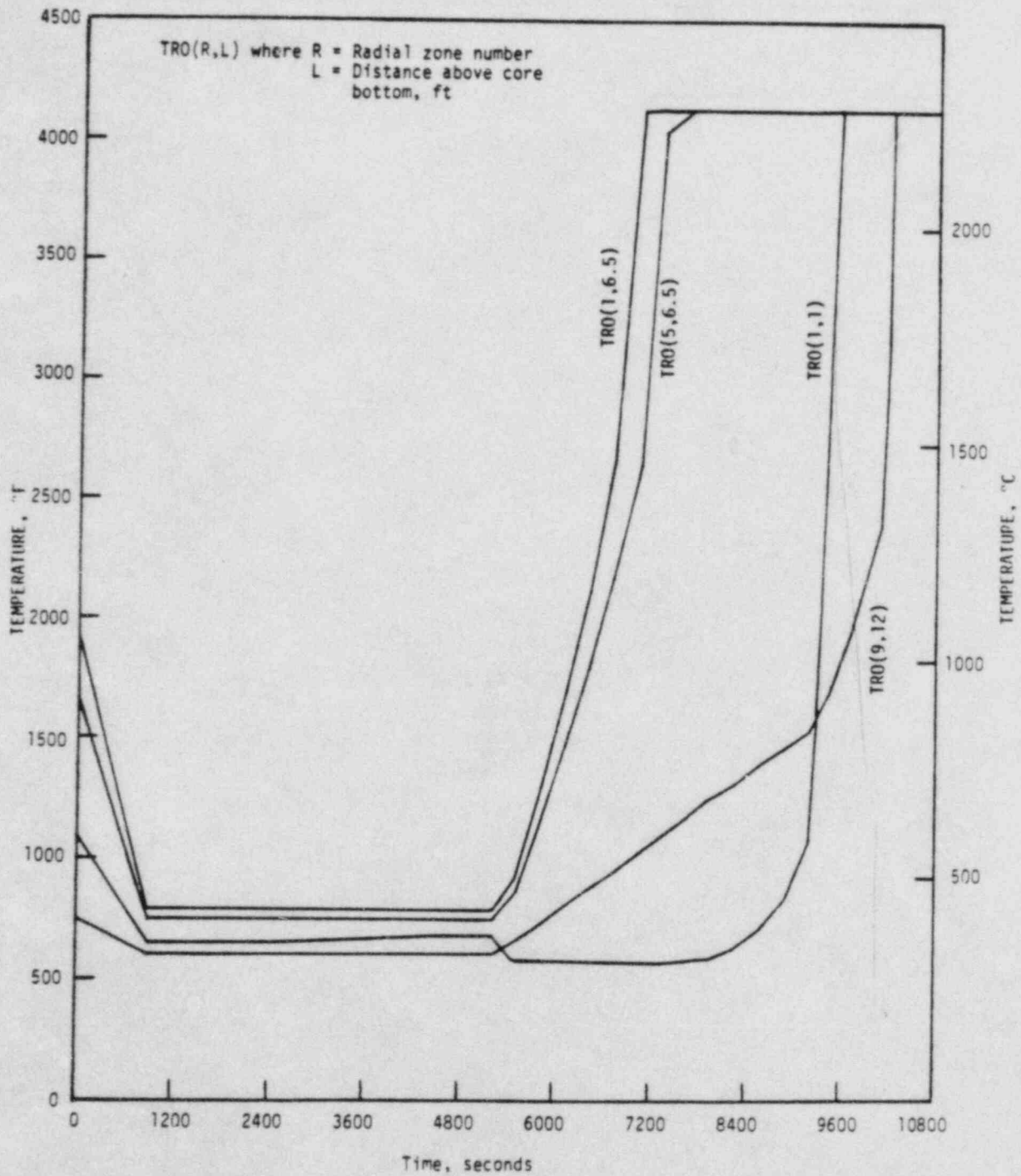


FIGURE 6.3 TEMPERATURES OF SELECTED FUEL REGIONS AS A FUNCTION OF TIME - SEQUENCE TC

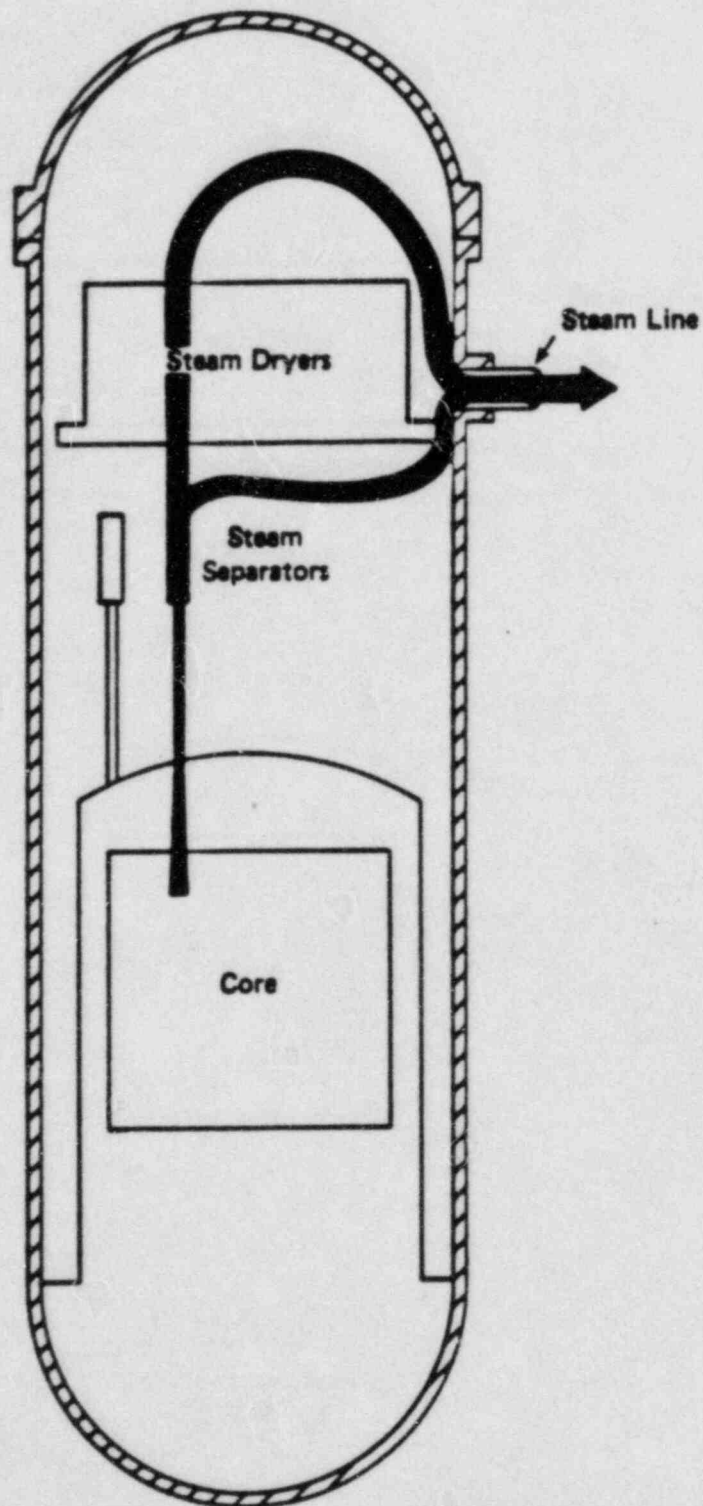


FIGURE 6.4 FLOWPATHS FOR FISSION PRODUCT TRANSPORT IN
RCS - SEQUENCES TC, TQUV, AND TPI

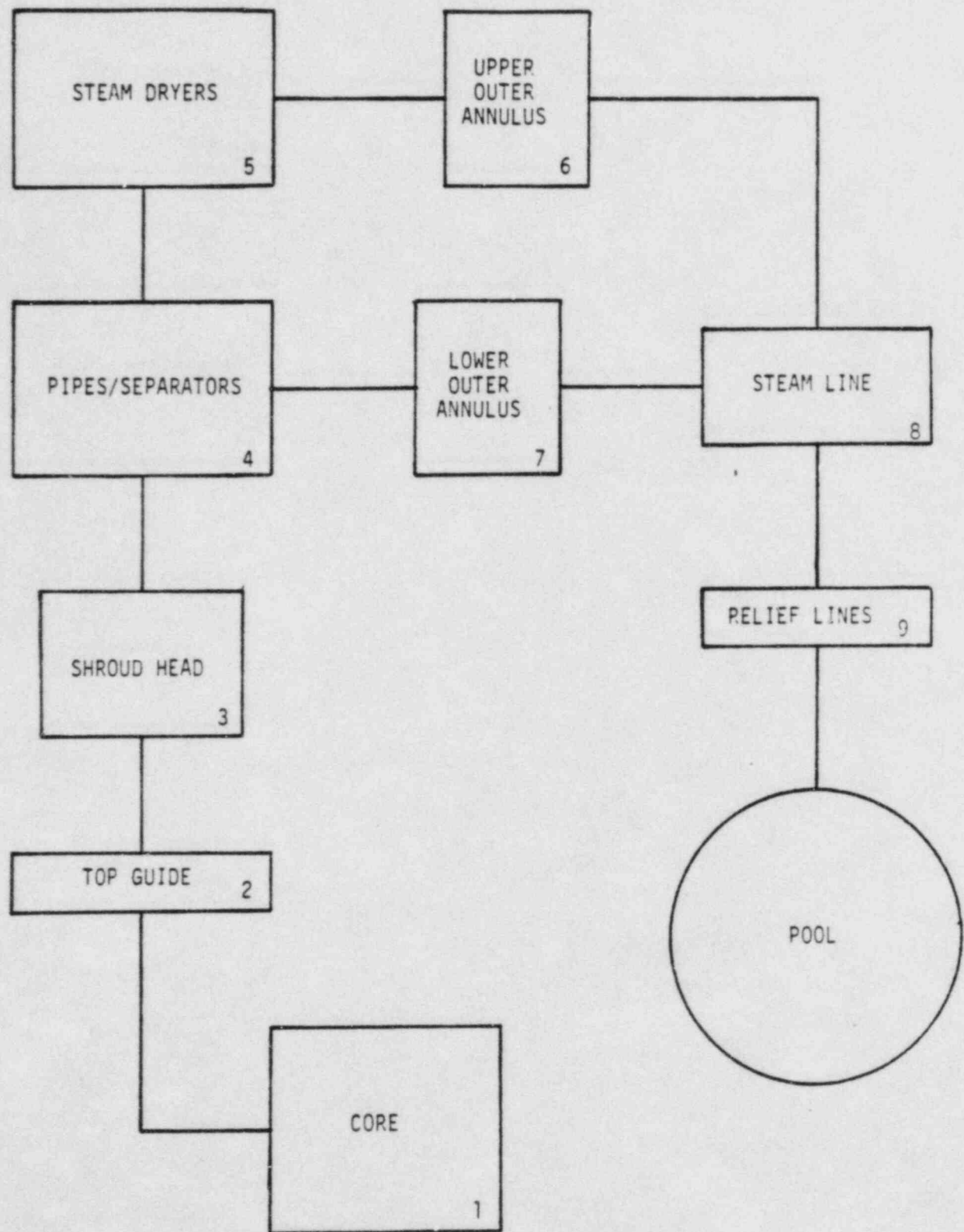


FIGURE 6.5 SCHEMATIC OF CONTROL VOLUMES FOR THE GRAND GULF SEQUENCES

and 6.7) in the reactor coolant system are therefore quite similar to those predicted for the same sequence in the Peach Bottom plant.

After leaving the vessel, fission products are carried down the steam line and relief line to the suppression pool. Fission products that escape the pool disperse within the primary containment volume before being released through the hole in containment to the environment. The flow path from the vessel to the environment is illustrated in Figure 6.8. After melt-through of the reactor vessel, fission products released during concrete attack flow from the cavity to the drywell and through the pool before passing into the containment and to the environment.

6.1.2 Sequence TPI

In this transient sequence a relief valve is assumed to stick open, resulting in blowdown of the reactor vessel to the suppression pool. The heat removal system for the suppression pool is also assumed to fail resulting in increasing pool temperature and containment pressure with time. At 1323 minutes, MARCH 2 predicts the containment to fail. Subsequently makeup flow to the vessel is lost, the core becomes uncovered and fuel degradation occurs. In Figures 6.9 and 6.10 temperatures and pressures in containment volumes are illustrated. Temperatures in selected fuel regions are also illustrated in Figure 6.11. Key events and containment conditions are tabulated in Table 6.2.

The flow paths in the TPI sequence are essentially the same as for the TC sequence. Gas temperatures and surface temperatures within subvolumes of the reactor coolant system as predicted by the MERGE code are illustrated in Figure 6.12 and 6.13.

6.1.3 Sequence TQUV

In the TQUV sequence, the various water supply systems capable of providing makeup to the vessel are all assumed to fail. At the time of core uncover the containment is intact. The MARCH 2 code predicts, however, that containment failure would occur during the melting phase

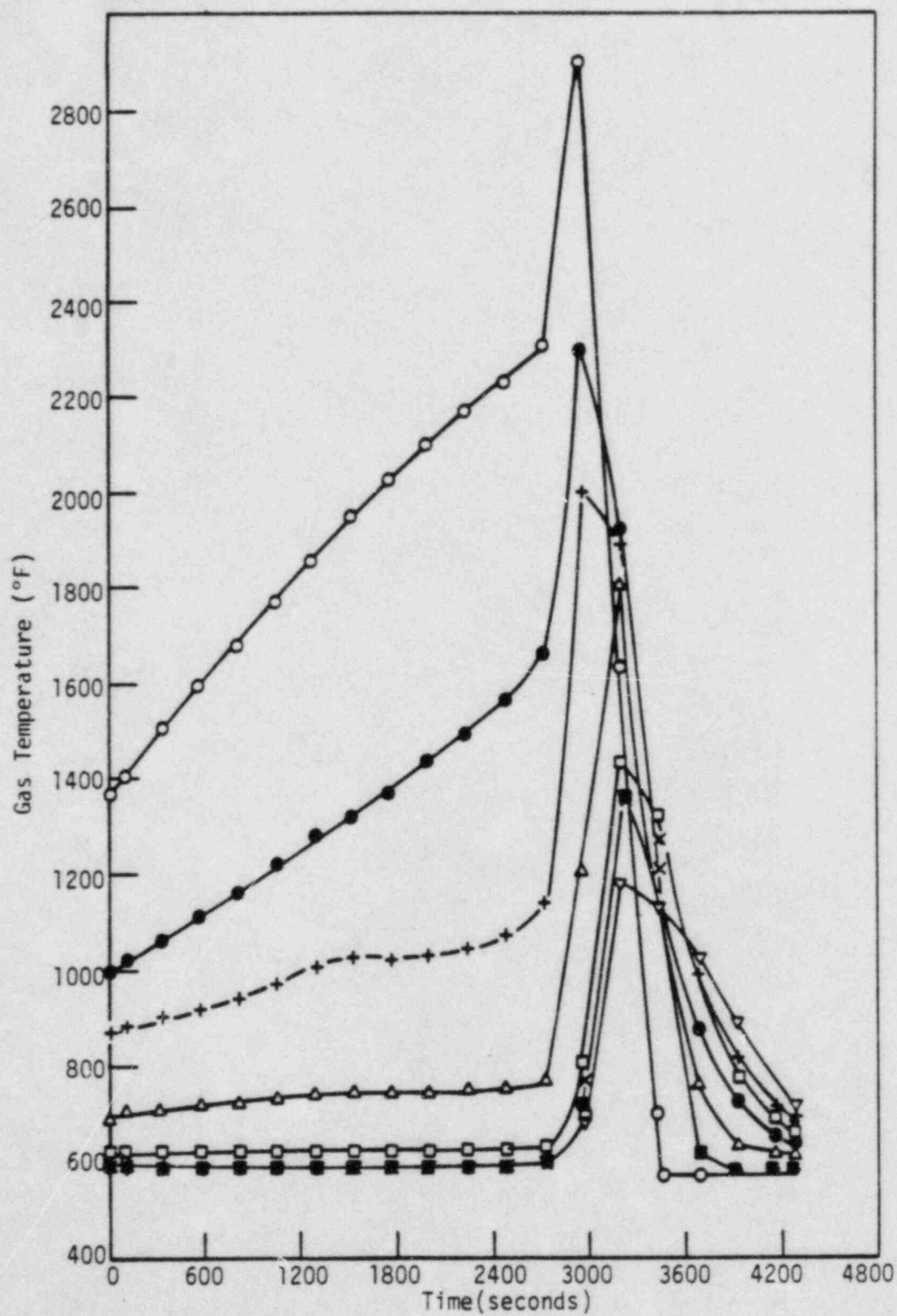


FIGURE 6.6 GAS TEMPERATURES IN RCS VOLUMES - SEQUENCE TC

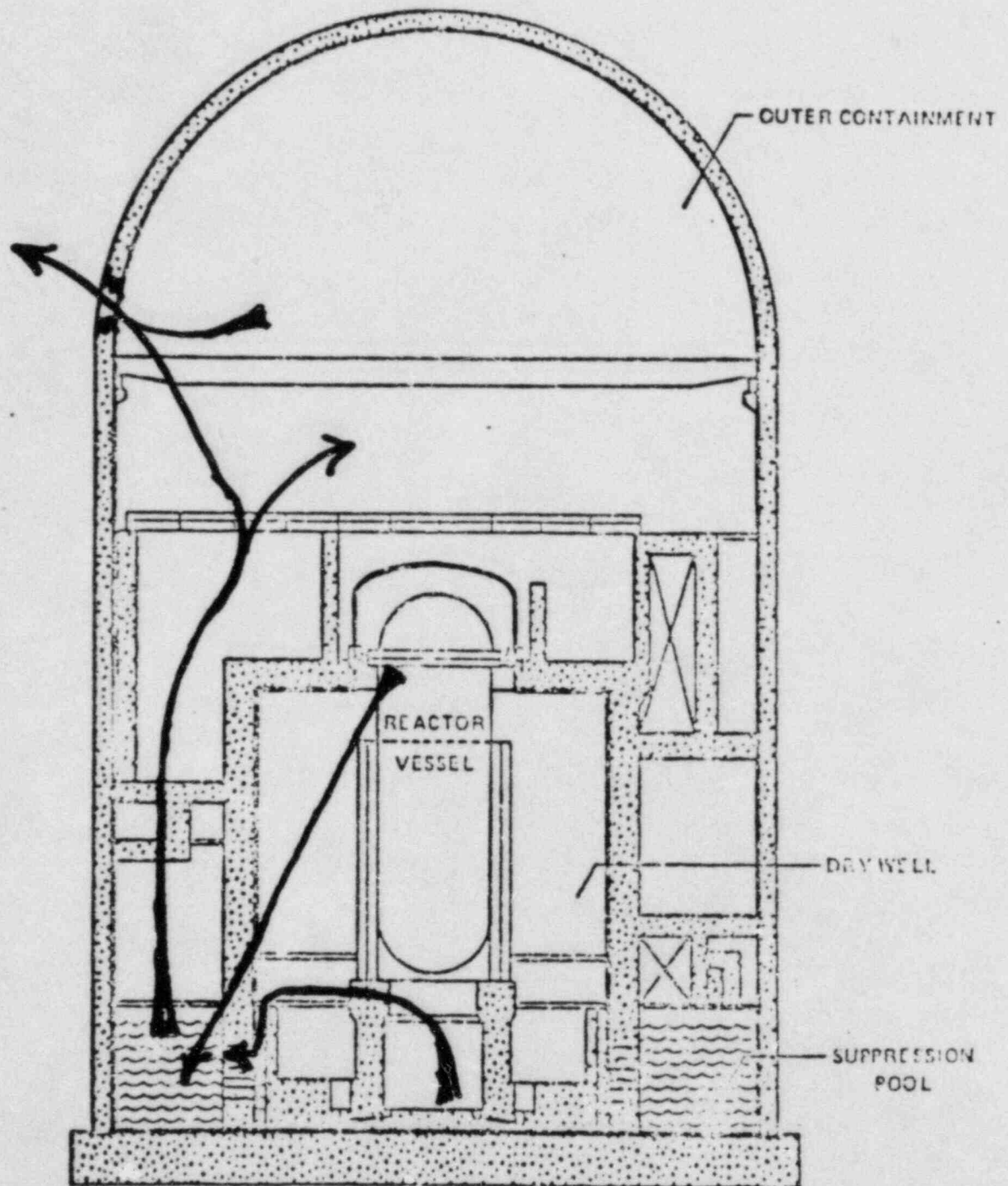


FIGURE 6.8 FLOWPATHS FROM THE VESSEL AND REACTOR CAVITY
TO THE ENVIRONMENT

GRAND GULF TPI

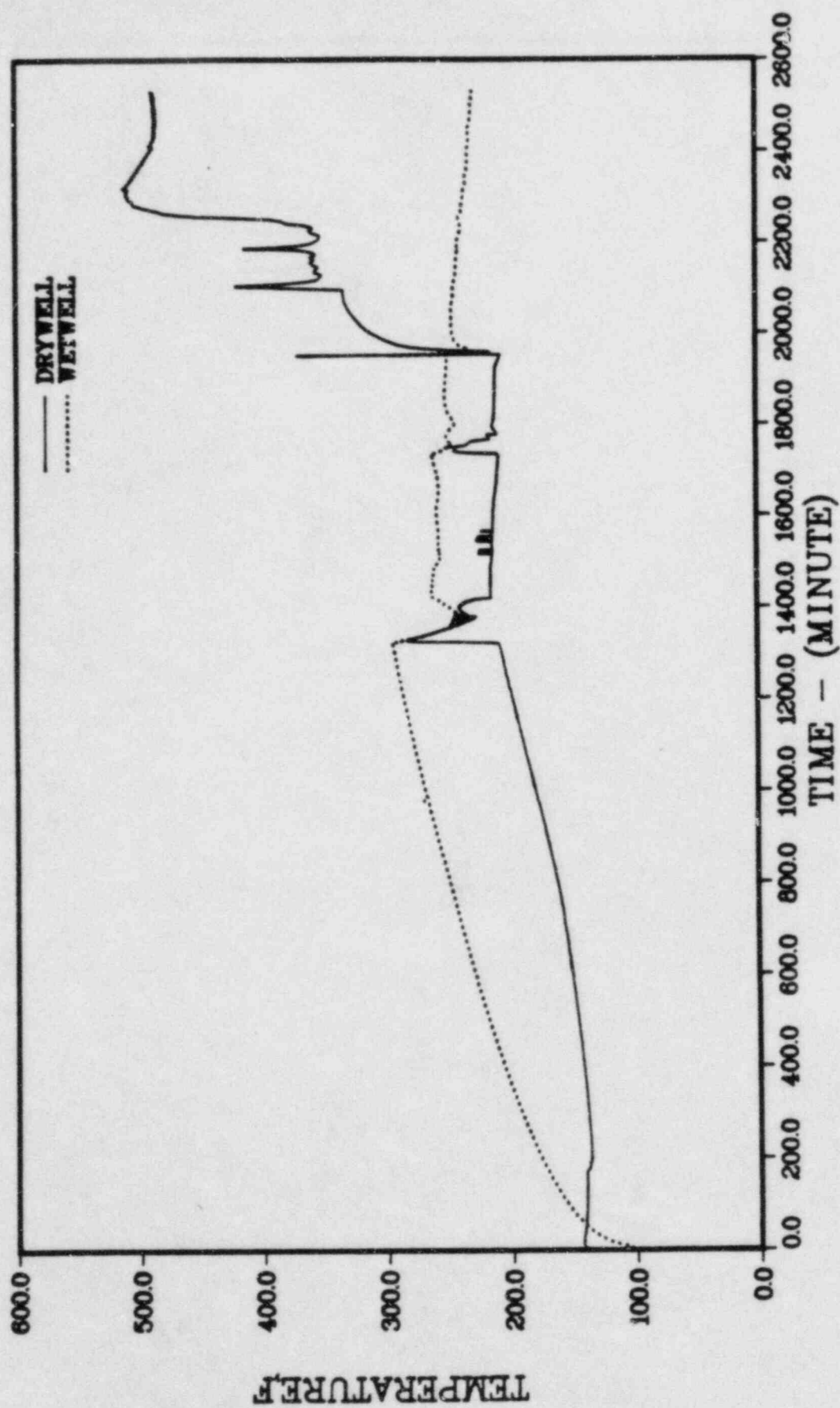


FIGURE 6.9 GAS TEMPERATURES IN CONTAINMENT VOLUMES - SEQUENCE TPI

GRAND GULF TPI

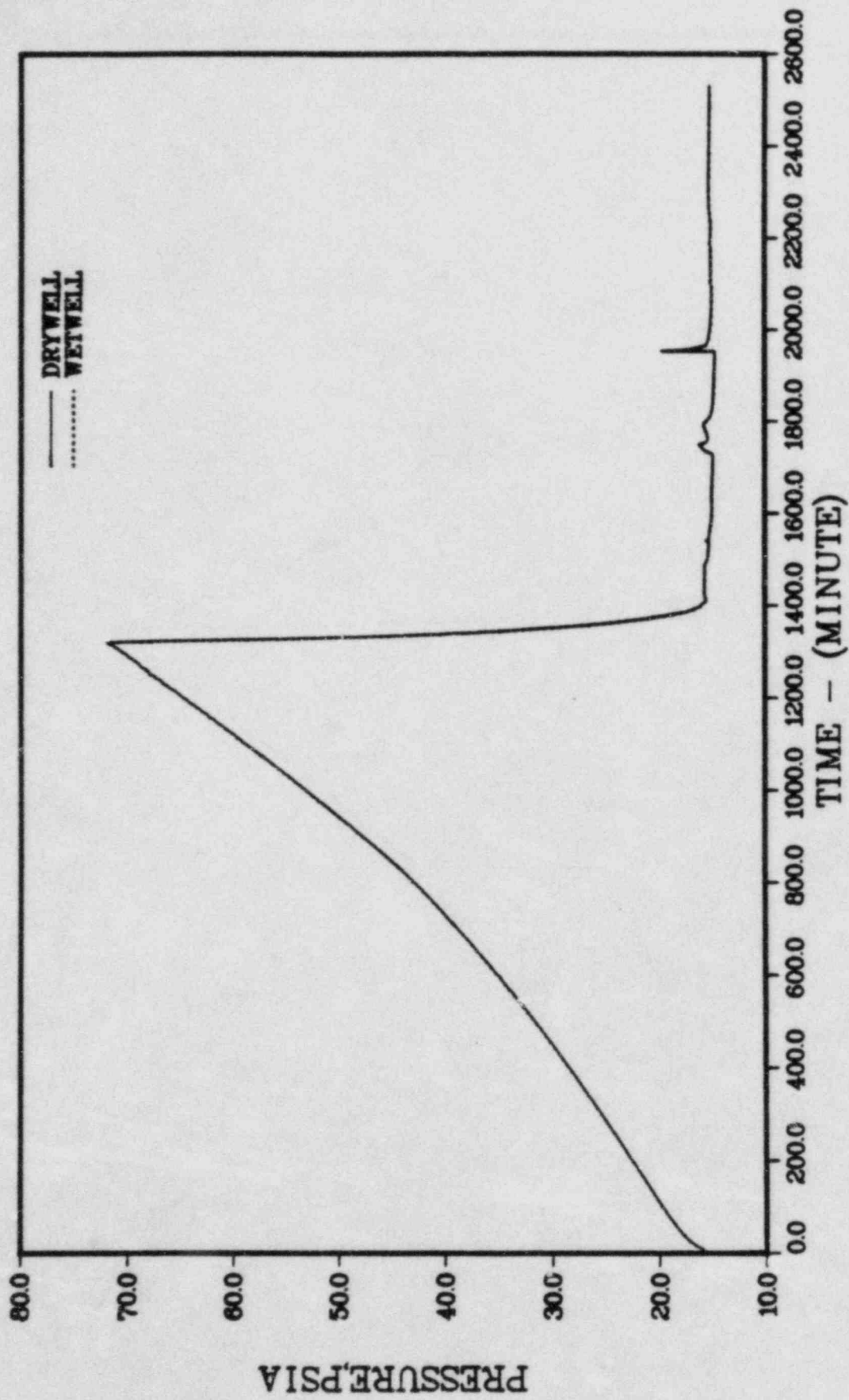


FIGURE 6.10 PRESSURES IN CONTAINMENT VOLUMES - SEQUENCE TPI

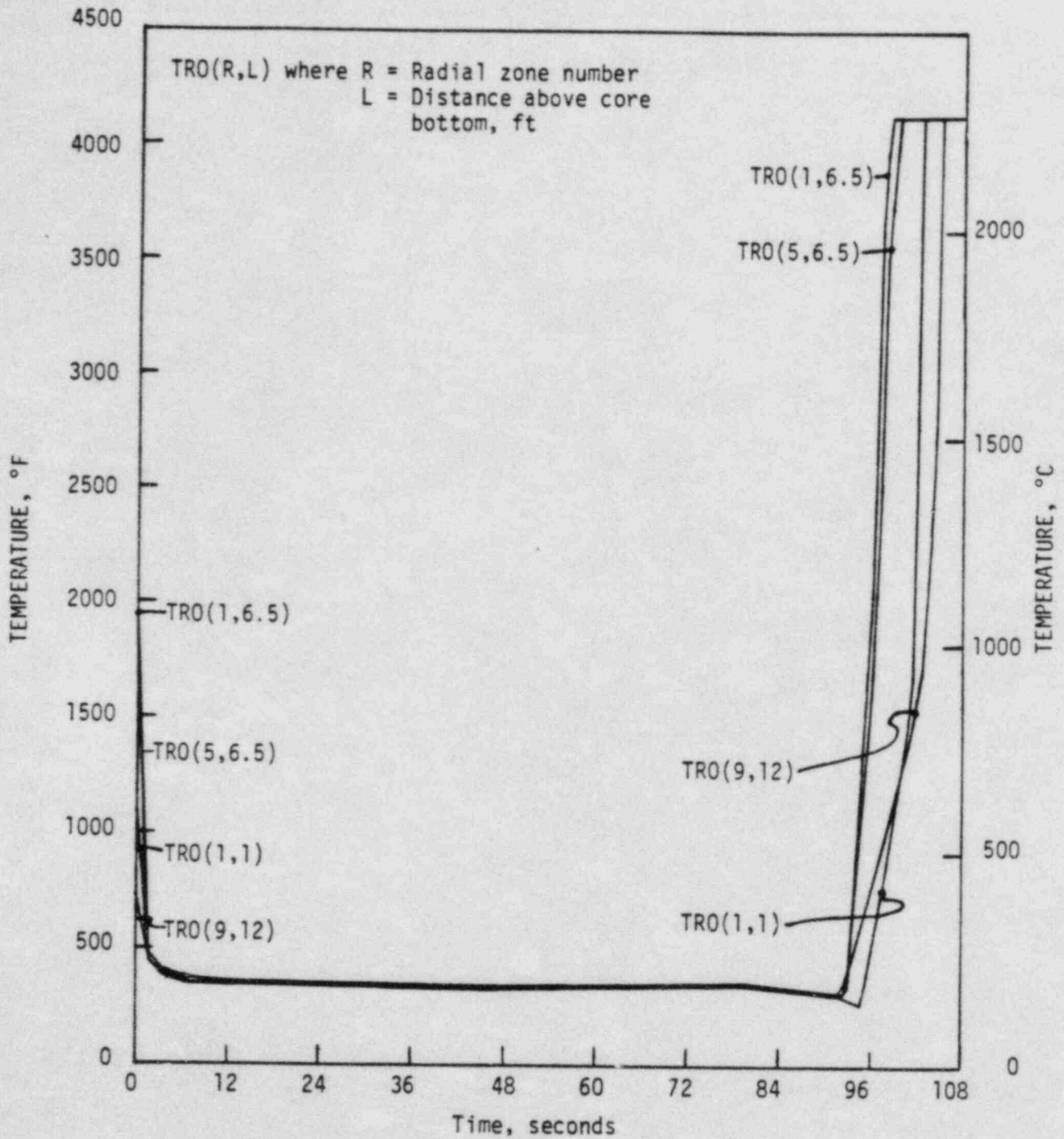


FIGURE 6.11 TEMPERATURES IN SELECTED FUEL REGIONS AS A FUNCTION OF TIME - SEQUENCE TPI

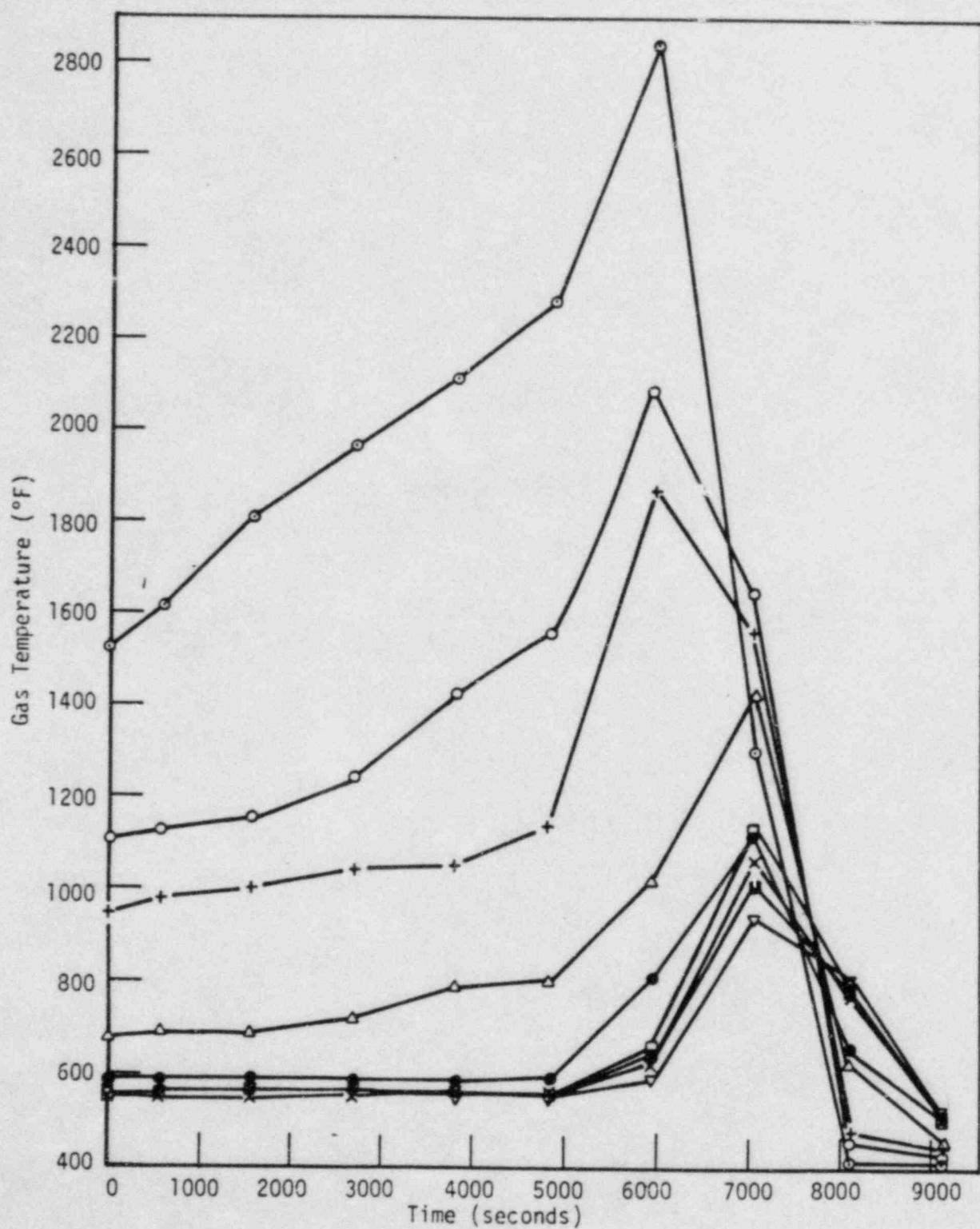


FIGURE 6.12 GAS TEMPERATURES IN RCS VOLUMES - SEQUENCE TPI

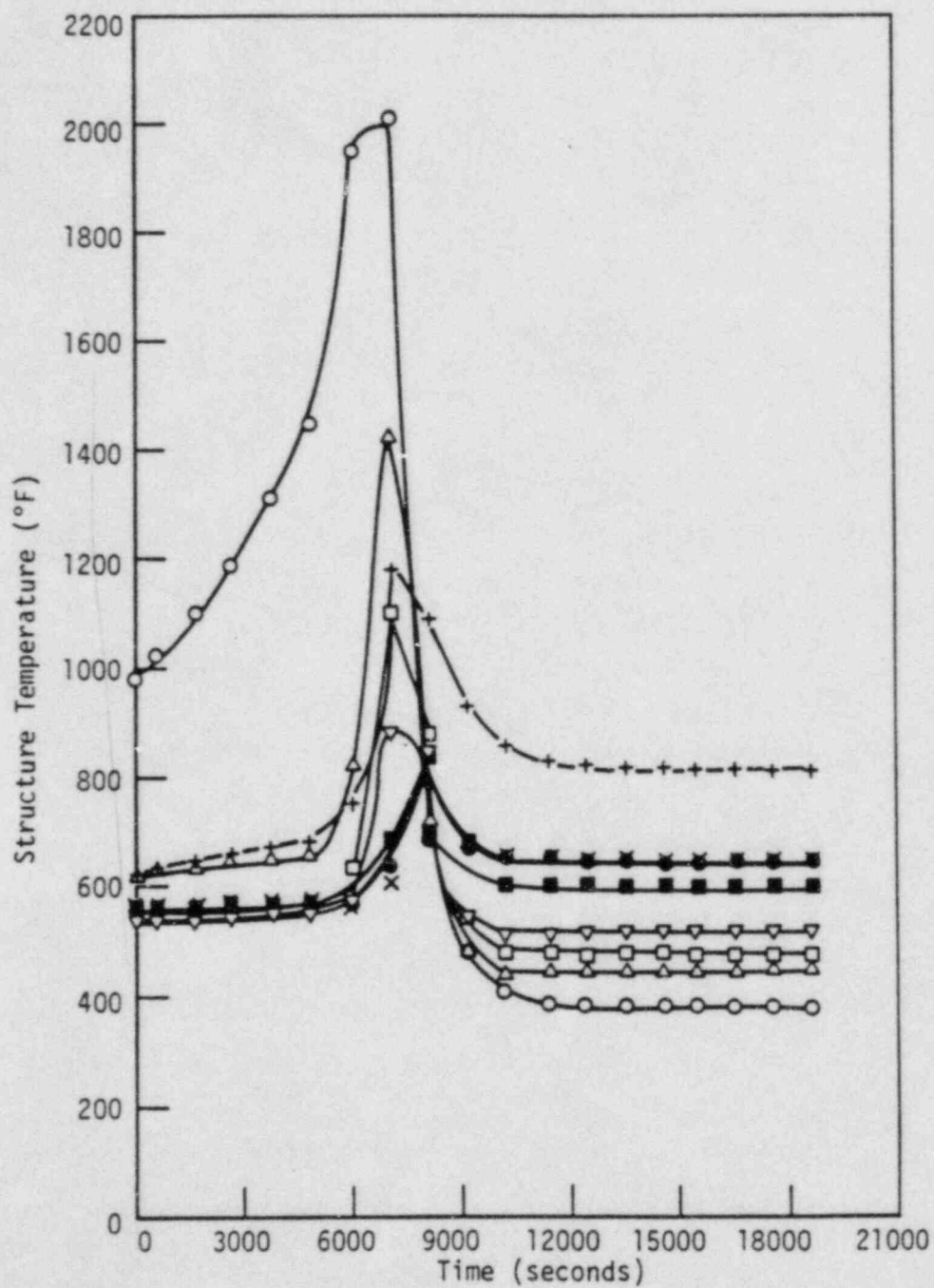


FIGURE 6.13 STRUCTURE TEMPERATURES IN RCS VOLUMES -
SEQUENCE TPI

as the result of hydrogen combustion. The conditions leading to hydrogen burning in this scenario involved a rapid discharge of hydrogen from the reactor vessel as a result of intentional depressurization consistent with emergency operating instructions when the level of water in the core reaches the 2-ft level. Temperatures and pressures in the containment volumes are illustrated in Figures 6.14 and 6.15. Key events and containment conditions are provided in Table 6.2.

Temperatures of selected fuel regions are illustrated in Figure 6.16. Gas temperatures and structure temperatures in subvolumes of the reactor coolant system are shown in Figures 6.17 and 6.18 as calculated by the MERGE code. Flow paths in the TQUV sequence are similar to those in the other two sequences as illustrated in Figure 6.8. Holdup and additional deposition of fission products would occur in the primary containment volume up to the time of failure.

6.2 Radionuclide Sources

6.2.1 Source Within Pressure Vessel

Inventory

The inventory of fission products used in the analysis of the Peach Bottom 2 reactor in Volume II of this report was based on ORIGEN 2(6.1) analyses. These analyses were performed by Oak Ridge National Laboratory for an actual core loading in the Browns Ferry Unit 1 plant. The bases for the calculations are described in the ORNL Station Blackout Study(6.2) and in Volume II of this report. In order to adapt the inventory to the Grand Gulf plant the inventories were normalized by the relative uranium loadings in the two cores. The Grand Gulf inventory is tabulated in Table 6.3.

GRAND GULF TQUV

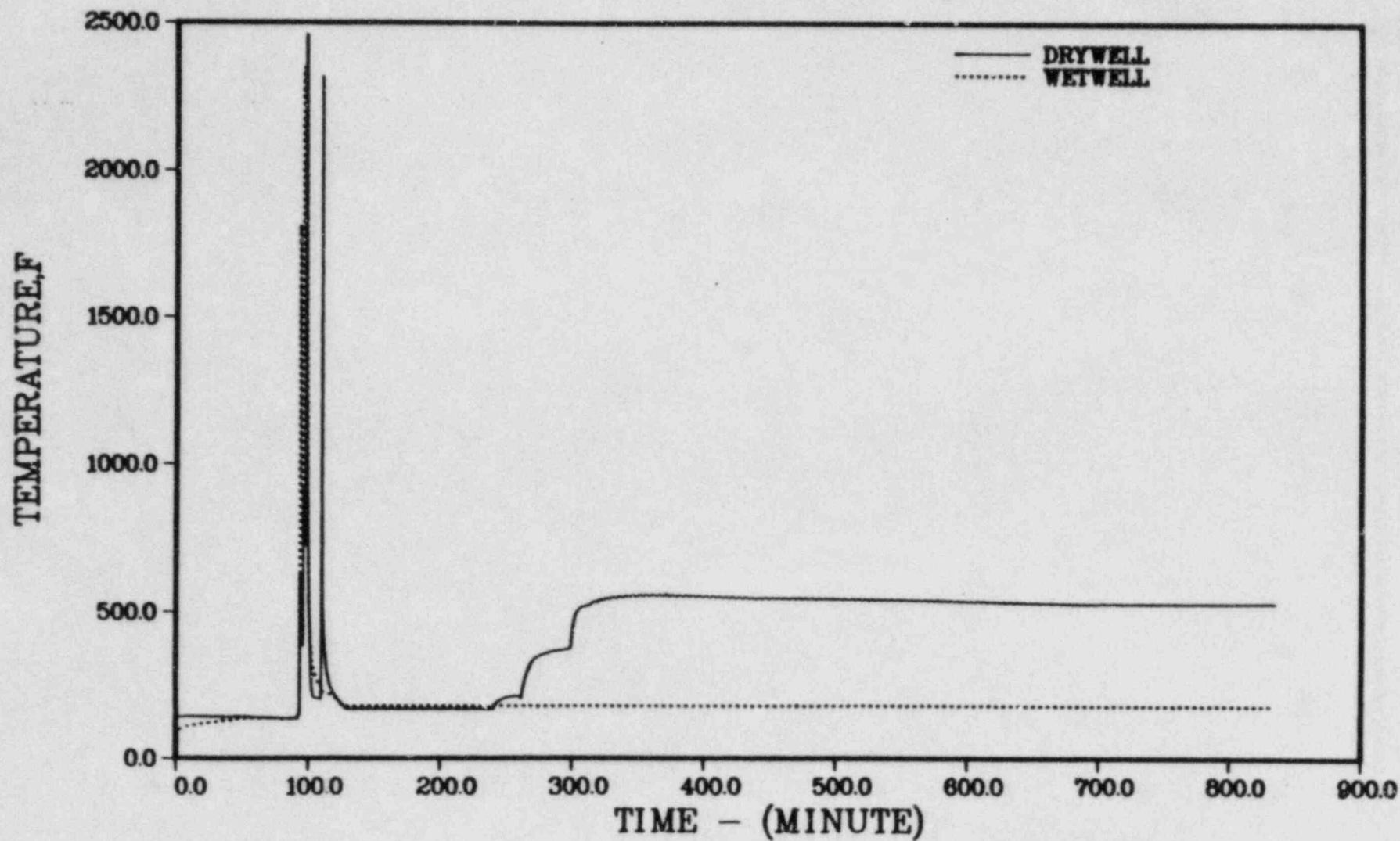


FIGURE 6.14 GAS TEMPERATURES IN CONTAINMENT VOLUMES - SEQUENCE TQUV

GRAND GULF TQUV

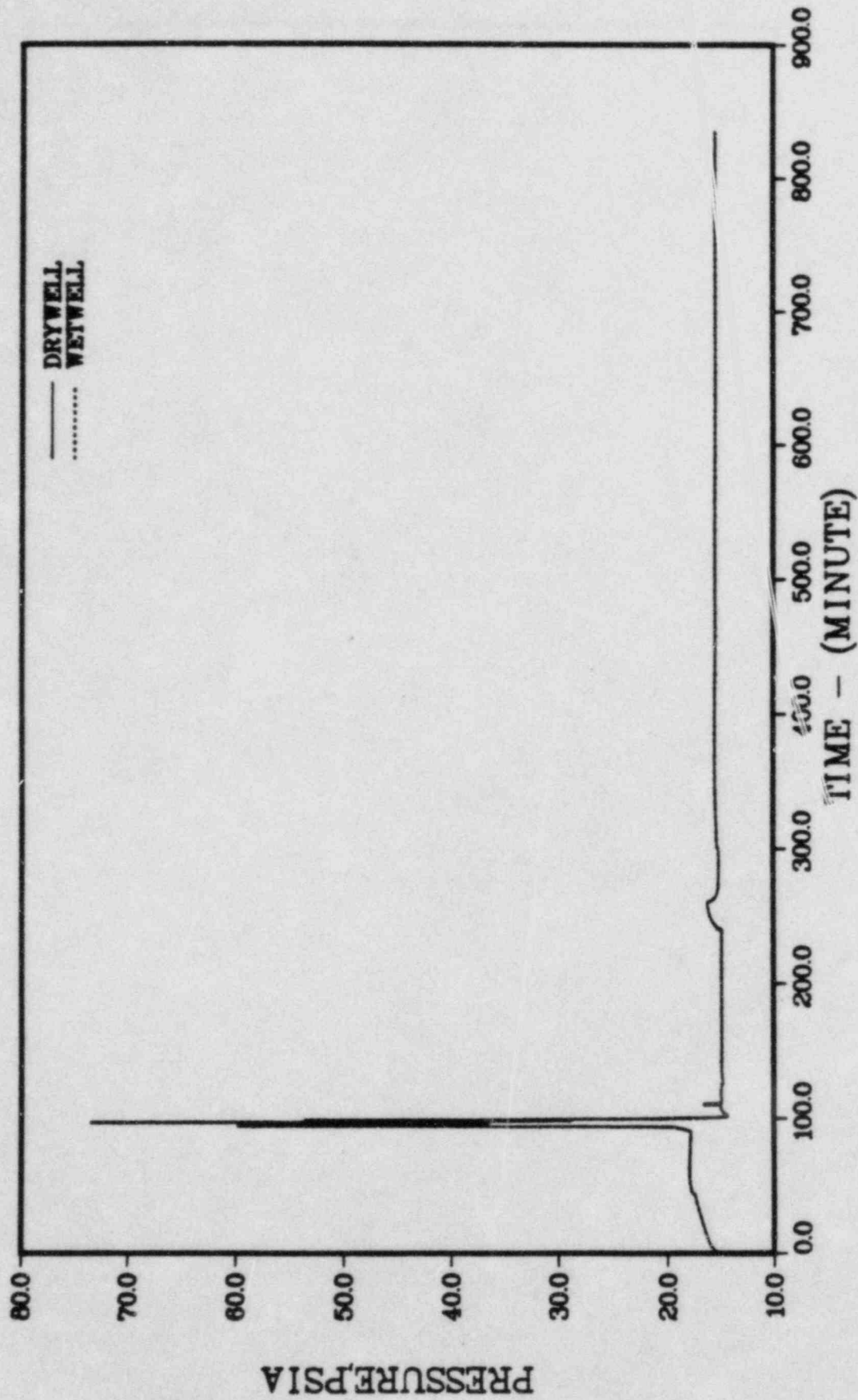


FIGURE 6.15 PRESSURES IN CONTAINMENT VOLUMES - SEQUENCE TQUV

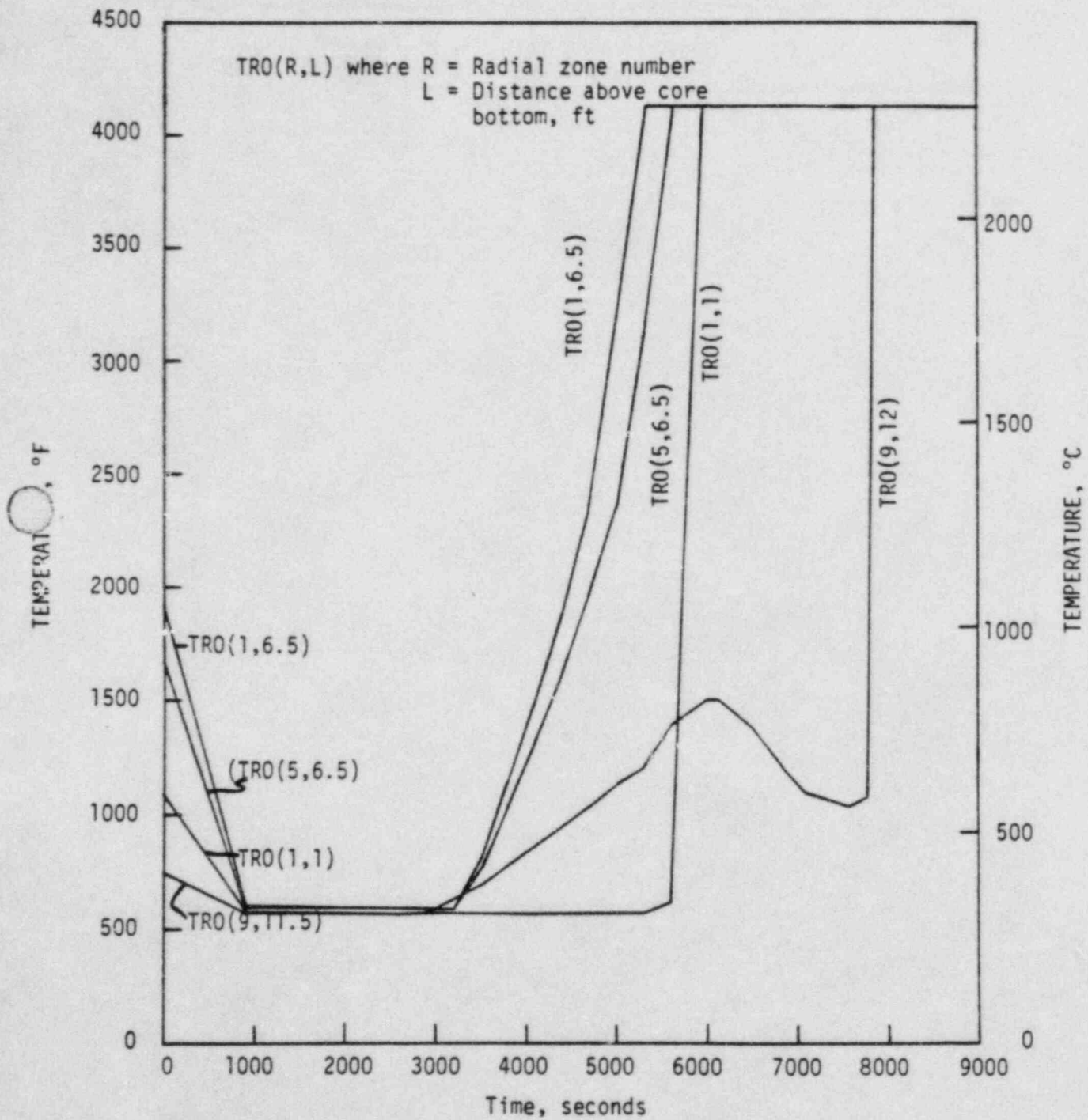


FIGURE 6.16 TEMPERATURES OF SELECTED FUEL REGIONS AS A FUNCTION OF TIME - SEQUENCE TQUV

FIGURE 6.17 GAS TEMPERATURES IN RCS VOLUMES - SEQUENCE TQV

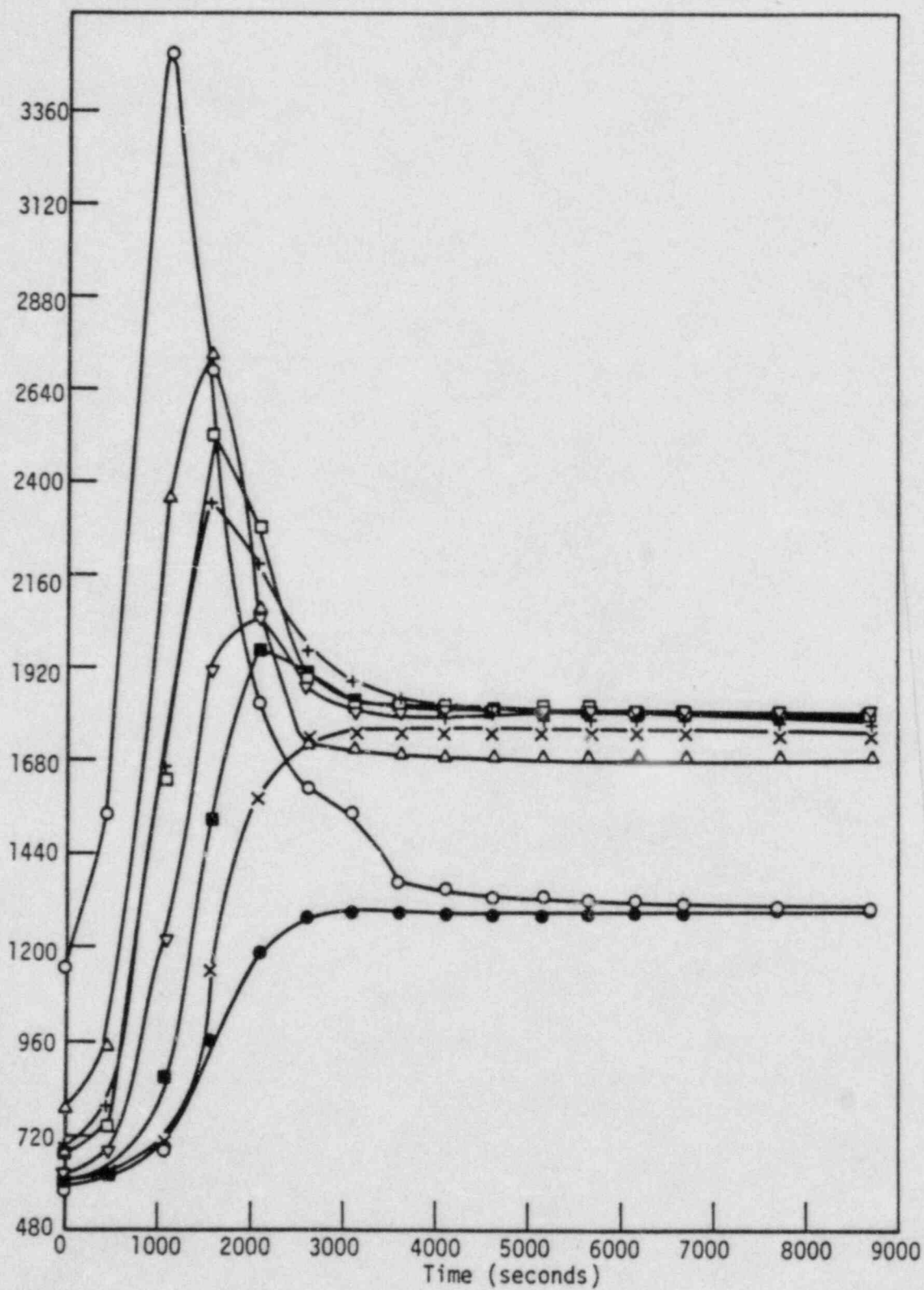


FIGURE 6.18 STRUCTURE TEMPERATURES IN RCS VOLUMES - SEQUENCE TQUV

Containment Parameters

Compartment 1: Drywell
Compartment 2: Primary Containment

Slab	Iron Thickness		Concrete Thickness		Heat Transfer Area	
	ft	cm	ft	m	ft ²	m ²
1. Drywell Floor	--	--	26.	7.92	3,402	316
2. Wetwell Floor	0.08	2.44	16.	4.88	5,900	548
3. Shield Wall	--	--	1.	0.305	9,603	892
4. Pedestal	--	--	3.	0.914	3,158	293

(Continued)

(Continued)

TABLE 6.1 (Continued)

Slab	Iron Thickness		Concrete Thickness		Heat Transfer Area	
	ft	cm	ft	m	ft ²	m ²
5. Wetwell Wall	0.14	4.27	--	--	80,490	7,478
6. Drywell Wall-Top	--	--	5.	1.524	23,920	2,222
7. Drywell Wall-Bottom	0.08	2.44	5.1	1.554	6,313	586
8. Miscellaneous Concrete	--	--	2.	0.610	16,880	1,568

Steel/Concrete Interface Coefficient: 100 Btu/hr/ft²/F (0.0568 W/cm²/C)

Initial Temperature Range of Slabs: 90-135 F (32.2-57.2 C)

Concrete Composition

Weight fraction CaCO ₃	0.8
Weight fraction Ca(OH) ₂	0.15
Weight fraction SiO ₂	0.01
Weight fraction Al ₂ O ₃	0.01
Weight fraction free H ₂ O	0.03
Gm rebar per gm concrete	0.135

Engineered Safety Systems

	Rated Flow		Pressure	
	GPM	ℓ/s	psia	MPa
ECC Pump				
High Head	7120	449.1	2000	13.8
Low Head	7500	473.1	550	3.8
Safety Injection	800	50.5	2000	13.8

Recirculation Spray Pump: 7450 gpm (469.9 ℓ/s)

Heat Exchanger

Capacity, Btu/hr	1.847 x 10 ⁸ (5.412 x 10 ⁷ W)
Primary flow, lb/min	61,090 (461.8 kg/s)
Secondary flow, lb/min	65,830 (497.7 kg/s)
Primary inlet, F	185 F (85 C)
Secondary inlet, F	90 F (32.2 C)

TABLE 6.1 (Continued)

ECC Storage and Injection Tanks

	RWST	
Weight of Water	$3. \times 10^6$ lb	1.36×10^6 kg
Initial Pressure	14.7 psia	0.1 MPa
Temperature	100 F	37.8 C
Fractional Value of RWST to Start ECC Recirculation:	0.43	

Calculated Model Input

Core Heatup Section

Number of radial zones:	9
Number of axial zones:	24
Meltdown model:	BOIL Model A

Core slumping starts when lowest node in region is molten.

Core collapse occurs when 75% of core has melted, or core support reaches melting temperature.

Zircaloy-water reaction: Urbanic-Heidrick reaction rate data, steam limited, continues for melted nodes, convective heat transfer in molten regions, reaction of Zircaloy with water in bottom head calculated.

TABLE 6.2 KEY EVENTS AND CONTAINMENT CONDITIONS PREDICTED BY MARCH

Subsequence	Time, min	Leak Rate ^(a) v/min	Drywell Pressure		Drywell Temp.		Wetwell Pressure		Wetwell Temp.		Remarks
			MPa	psia	°F	°C	MPa	psia	°F	°C	
TPIY	1323	0.2	0.50	72.1	209	98	0.50	72.1	294	146	Containment fails
	1525	0.25	0.11	15.3	214	101	0.11	15.3	256	124	Core uncovers
	1635	0.1	0.10	15.0	212	100	0.10	15.0	257	215	Start melt
	1720	0.03	0.10	14.9	209	98	0.10	14.9	260	217	Core slump
	1749	0.6	0.11	15.9	242	117	0.11	15.9	242	117	Head heatup
	1792	0.5	0.11	15.8	213	101	0.11	15.8	246	119	Vessel dry
	1953	0.	0.10	14.8	207	97	0.10	14.8	249	121	Head fail
	1953	1.6	0.10	19.7	338	170	0.14	19.7	298	148	Concrete attack
TQUVY	46.2	4.2×10^{-4}	0.12	17.7	143	62	0.12	17.7	134	57	Core uncovers
	82.6	4.2×10^{-4}	0.12	17.8	136	58	0.12	17.8	135	57	Start melt
	96.0	1.6	0.50	73.2	804	429	0.50	73.2	2310	1266	Containment fails
	97.4	1.7	0.25	36.4	848	453	0.25	36.4	1117	603	Core slump
	122.6	0.02	0.10	14.8	199	93	0.10	14.8	196	91	Vessel dry
	130.7		0.10	14.8	167	75	0.10	14.8	177	81	Head heatup
	240.1	0.27	0.10	15.1	174	79	0.10	15.1	181	83	Head fails
	240.2	0.29	0.10	15.1	174	79	0.10	15.1	182	83	Concrete attack
TCY	80.4	1.3	0.50	72.1	244	118	0.50	72.1	291	144	Containment fails
	87.9	1.5	0.48	69.5	297	147	0.48	69.5	298	148	Core uncovers
	117.8	1.5	0.21	29.9	250	121	0.21	29.9	250	121	Start melt
	166.7	0.36	0.11	15.5	214	101	0.11	15.5	237	114	Core slump
	170.4	1.5	0.13	19.5	239	115	0.13	19.5	254	123	Head heatup
	188.5	0.91	0.11	16.6	215	102	0.11	16.6	225	107	Vessel dry
	195.7	0.76	0.11	16.0	216	102	0.11	16.0	227	108	Head fail
	195.7	1.6	0.14	20.7	372	189	0.14	20.7	272	133	Concrete attack

TABLE 6.3 INVENTORIES OF RADIONUCLIDES AND STRUCTURAL MATERIALS

Fission Products		Actinides/Structural	
Element	Mass (kg)	Element	Mass (kg)
Kr	25.7	U	138,000
Rb	23.3	Pu	743
Sr	62.7		
Y	36.2	Cr	4,140
Zr	267	Mn	432
Mo	237	Fe	15,150
Tc	58.8	Ni	2,560
Ru	172	Zr	64,100
Rh	33.2	Sn	1,050
Pd	83.2	Gd	287
Te	34.9		
I	16.6		
Xe	387		
Cs	207		
Ba	105		
La	98.3		
Ce	208		
Pr	80.4		
Nd	271		
Sm	53.8		

References

- (6.1) Groff, A. G., "ORIGEN 2 -- A Revised and Updated Version of the Oak Ridge Isotope Generation and Depletion Code", ORNL-5621 (July, 1980).
- (6.2) Wichner, R. P., et al, "Station Blackout at Browns Ferry Unit One -- Iodine and Noble Gas Distribution and Release", NUREG/CR-2181 (August, 1982).

**REVIEW COMMENTS AND
ADDITIONAL RESULTS FOR
BMI -2104, VOLUME I**

PEER REVIEW MEETING

**U.S. Nuclear Regulatory Commission
Washington, D.C.**

MAY 24 & 25, 1983

Presentation Notes

RADIONUCLIDE RELEASE UNDER SPECIFIC LWR ACCIDENT CONDITIONS

OBJECTIVES

- (1) DEVELOP UPDATED RELEASE-FROM-PLANT FISSION PRODUCT SOURCE TERMS FOR FOUR TYPES OF NUCLEAR POWER PLANTS AND FOR ACCIDENT SEQUENCES GIVING A RANGE OF CONDITIONS. THE ESTIMATED SOURCE TERMS ARE TO BE BASED ON ANALYSES OF FISSION PRODUCT RELEASE FROM THE FUEL, TRANSPORT, AND DEPOSITION BY USING IMPROVED COMPUTATIONAL TOOLS IN A CONSISTENT STEP-BY-STEP MANNER.
- (2) DETERMINE THE EFFECTS ON FISSION PRODUCT RELEASES ASSOCIATED WITH MAJOR DIFFERENCES IN INPUT PARAMETERS ASSOCIATED WITH PLANT DESIGN AND ACCIDENT SEQUENCES.
- (3) PROVIDE IN-PLANT TIME AND LOCATION DEPENDENT DISTRIBUTIONS OF FISSION PRODUCT MASS.

PLANTS AND SEQUENCES FOR REPORT VOLUMES

BMI - 2104: VOLUME I - PWR, LARGE DRY CONTAINMENT
SLURRY (WITH MARCH 1.1)
SEQUENCES: AB, S₂D, V, TMLB'

VOLUME II - BWR, MARK I DESIGN
PEACH BOTTOM
SEQUENCES: AE, TC, TW

VOLUME III - BWR, MARK III DESIGN
GRAND GULF
SEQUENCES: TC, TQUV, TPI

VOLUME IV - PWR, ICE CONDENSER
SEQUOYAH
SEQUENCES: S₂H, S₂D, TMLB', TML

VOLUME V - PWR, LARGE DRY CONTAINMENT
SURRY (WITH MARCH 2.0)
SEQUENCES: AB, S₂D, V, TMLB'

VOLUME VI - PWR, LARGE DRY CONTAINMENT
ZION
SEQUENCES:

ACKNOWLEDGEMENTS

- WESTINGHOUSE
- STONE AND WEBSTER
- EPRI
- SANDIA
- ORNL

PEER REVIEW COMMENTS

- SUMMARY PREPARED BY NRC
- TOPICS
 - ACCIDENT SEQUENCES AND SYSTEM BEHAVIOR
 - FISSION PRODUCT RELEASE FROM FUEL
 - THERMAL HYDRAULICS
 - CHEMISTRY
 - PRIMARY SYSTEM: TRANSPORT, DEPOSITION
AND REENTRAINMENT OF AEROSOLS
 - CONTAINMENT: TRANSPORT, DEPOSITION
AND REENTRAINMENT OF AEROSOLS
 - CODE VALIDITY AND SENSITIVITY
 - REPORT STRUCTURE AND ORGANIZATION

MODIFICATIONS BEING MADE TO SURRY ANALYSES

<u>VOL. I</u>	<u>VOL. V</u>	<u>ISSUES:</u>
	X	1. USE MARCH 2.0 FOR ALL SEQUENCES
	X	2. USE REVISED UPPER PLENUM GEOMETRY WITH MERGE
	X	3. IMPROVED RELEASE RATES FROM FUEL
	X	4. EVALUATE IMPORTANCE OF INVENTORY DISTRIBUTION IN CORE ON RELEASE RATES
X	X	5. EVALUATE EFFECT OF DECAY HEATING OF DEPOSITS ON SUBSEQUENT DEPOSITION IN PRIMARY SYSTEM
	X	6. EVALUATE AND USE FINER NODALIZATION FOR PRIMARY SYSTEM (ESPECIALLY V SEQUENCE)
	X	7. USE CORRECT SURRY GEOMETRY AND MELT TEMPERATURES FROM MARCH, AND INCLUDE EFFECT OF CAVITY WATER IN CORE-CONCRETE RELEASE CALCULATIONS
X	X	8. INCLUDE EFFECT OF WATER CONDENSATION ONTO WALL IN CONTAINMENT DEPOSITION CALCULATIONS

MODIFICATIONS BEING MADE TO SURRY ANALYSES

<u>VOL. I</u>	<u>VOL. V</u>	<u>ISSUES:</u>
X	X	9. USE CORRECTED SPRAY FLOW RATES AND SPRAY REMOVAL EFFICIENCIES IN CONTAINMENT REMOVAL CALCULATIONS
X		10. CHECK SPRAY REMOVAL SENSITIVITY TO DROP SIZE
	X	11. INCLUDE DEPOSITION FROM FLOW BACK THROUGH PRIMARY SYSTEM IN CALCULATIONS FOR V SEQUENCE
	X	12. EVALUATE IMPORTANCE OF A COMPARTMENTALIZED CONTAINMENT AND USE IN CALCULATIONS
X		13. INCLUDE APPENDIX DESCRIBING TRAP-MELT CODE
		14. PRESSURE SPIKE SENSITIVITY STUDY FOR CONTAINMENT FAILURE ANALYSIS

ADDITIONAL RESULTS FOR VOLUME I (SURRY)

- TRAP-MELT² DESCRIPTION
- PRESSURE SPIKE SENSITIVITY
- TRANSPORT AND DEPOSITION IN
CONTAINMENT
 - DIFFUSIOPHORESIS, AB6
 - SPRAY REMOVAL, S₂D

SURRY TMLB' HOTDROP SENSITIVITY STUDY

OBJECTIVE

INVESTIGATE MAGNITUDE OF CONTAINMENT PRESSURE
LOADING AS FUNCTION OF MODELING ASSUMPTIONS.

SURRY TMLB' HOTDROP SENSITIVITY STUDY

APPROACH

PERFORM MARCH 2 CALCULATIONS OF CONTAINMENT PRESSURE
RESPONSE FOR:

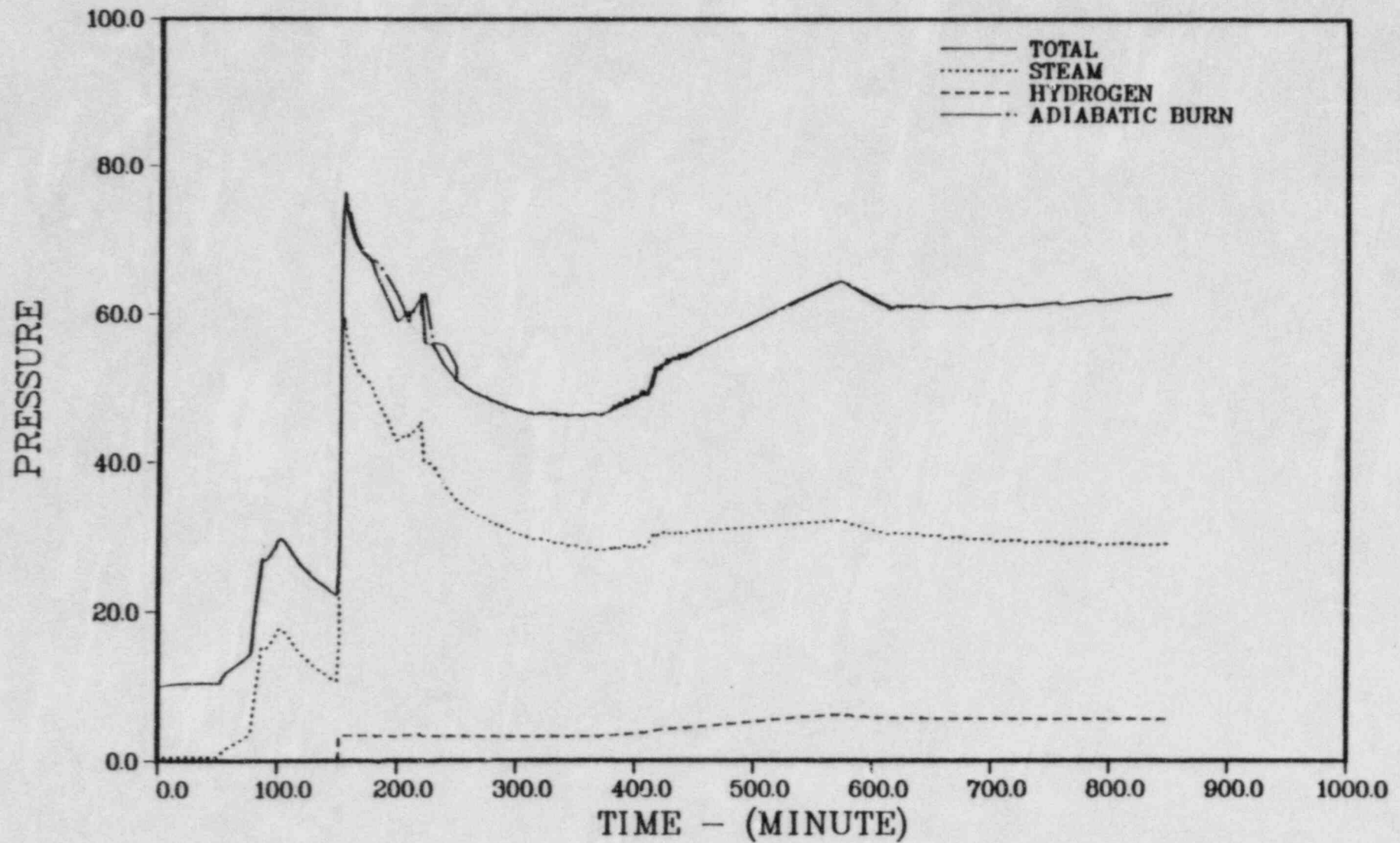
- (1) PARTICULATE HEAT TRANSFER FOR VARIOUS
ASSUMED PARTICLE SIZES
- (2) PARTICULATE HEAT TRANSFER FOLLOWED BY
DEBRIS BED AS CALCULATED BY LEVITATION
MODEL
- (3) PARTICULATE HEAT TRANSFER FOLLOWED BY
DEBRIS BED UPON PARTICLE SOLIDICATION
- (4) VARIATIONS OF IN-VESSEL MODELING ASSUMP-
TIONS

SURRY TMLB' HOTDROP SENSITIVITY STUDY

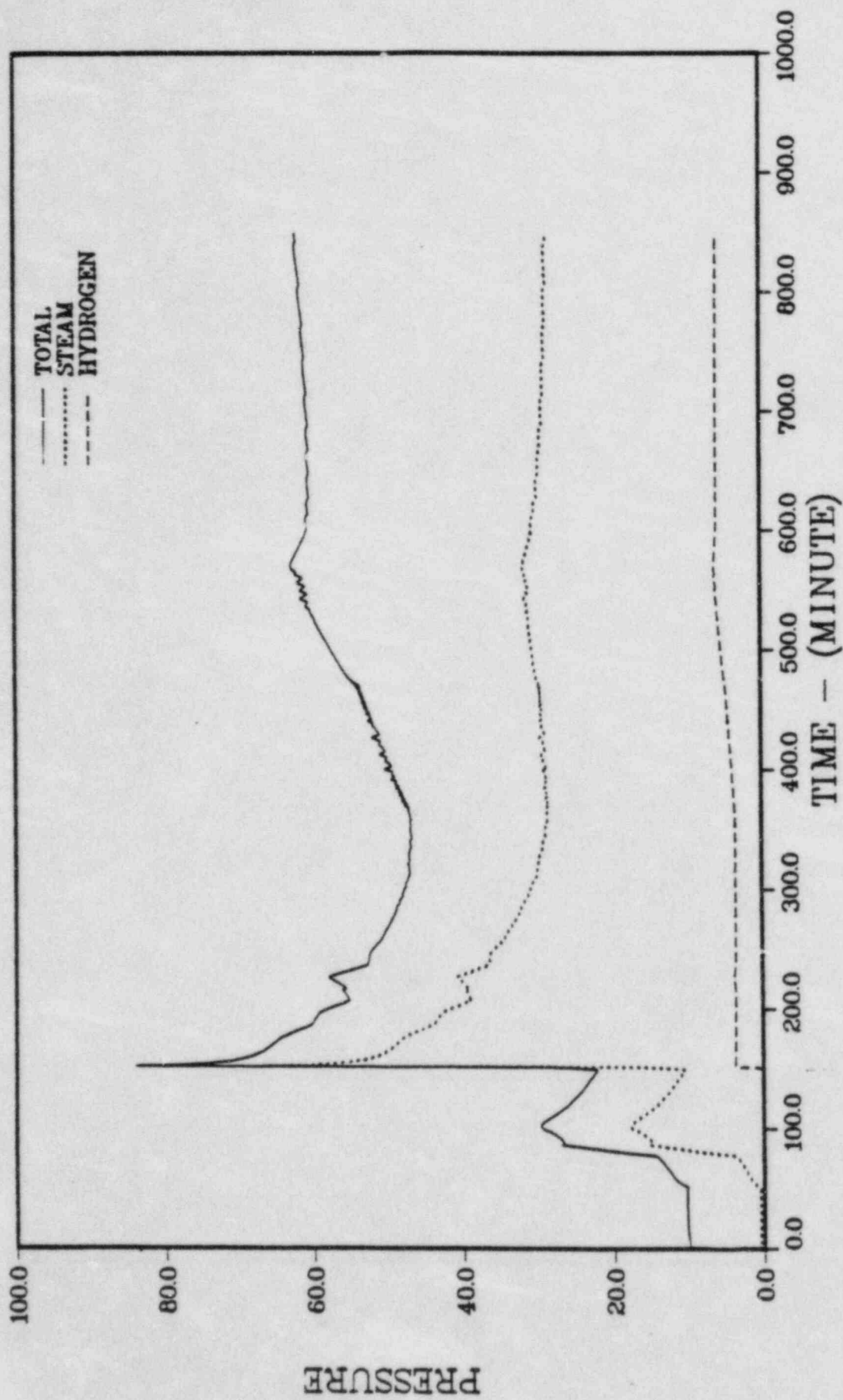
TIMING OF PRIMARY SYSTEM EVENTS FOR SURRY TMLB'

<u>EVENT</u>	<u>TIME, MIN</u>
STEAM GENERATOR DRY	68
CORE UNCOVER	99
START MELT	120
START CORE SLUMP	149
CORE COLLAPSE	151
HEAD FAIL	152

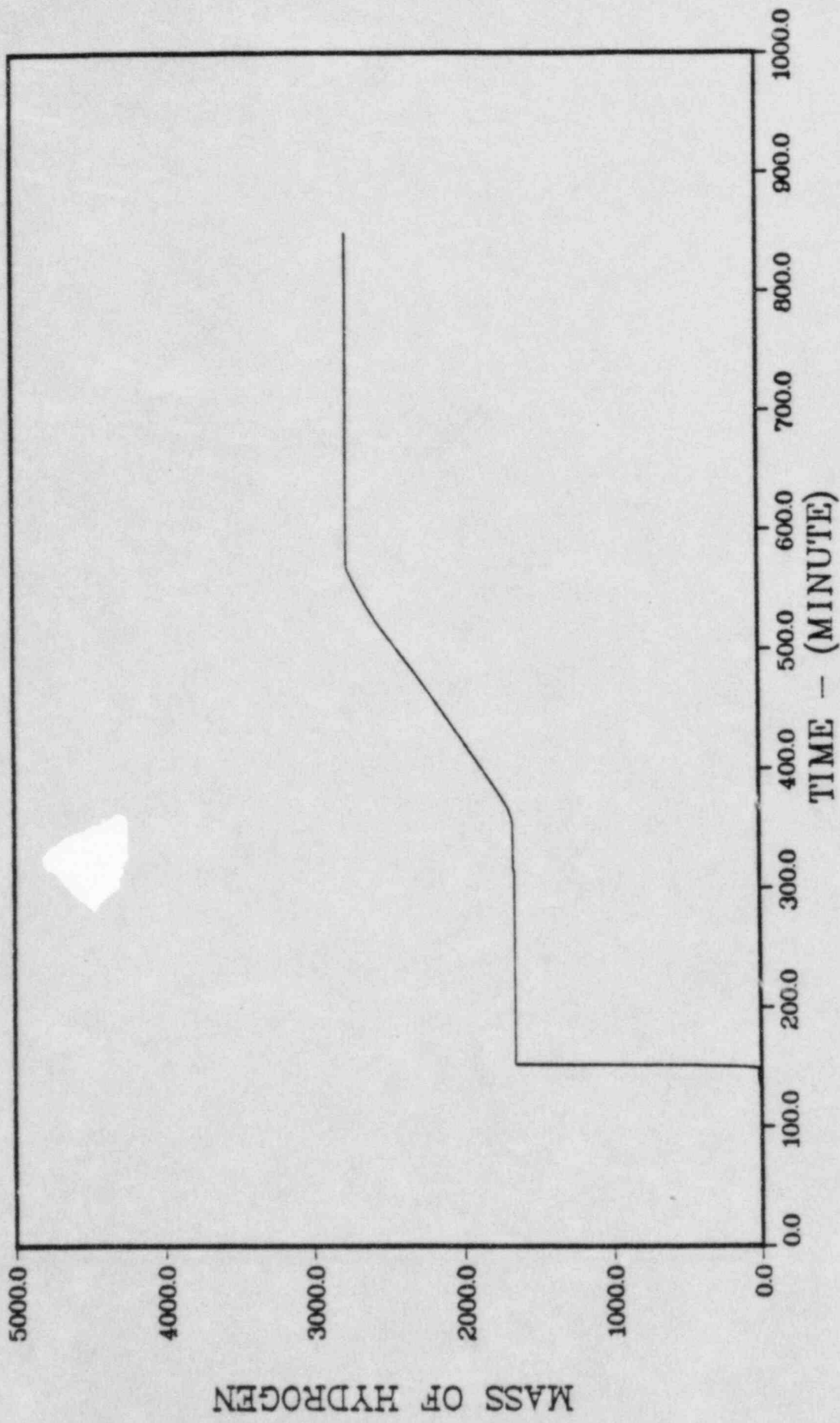
HOT1, PARTICLE, DP=1.0 IN.



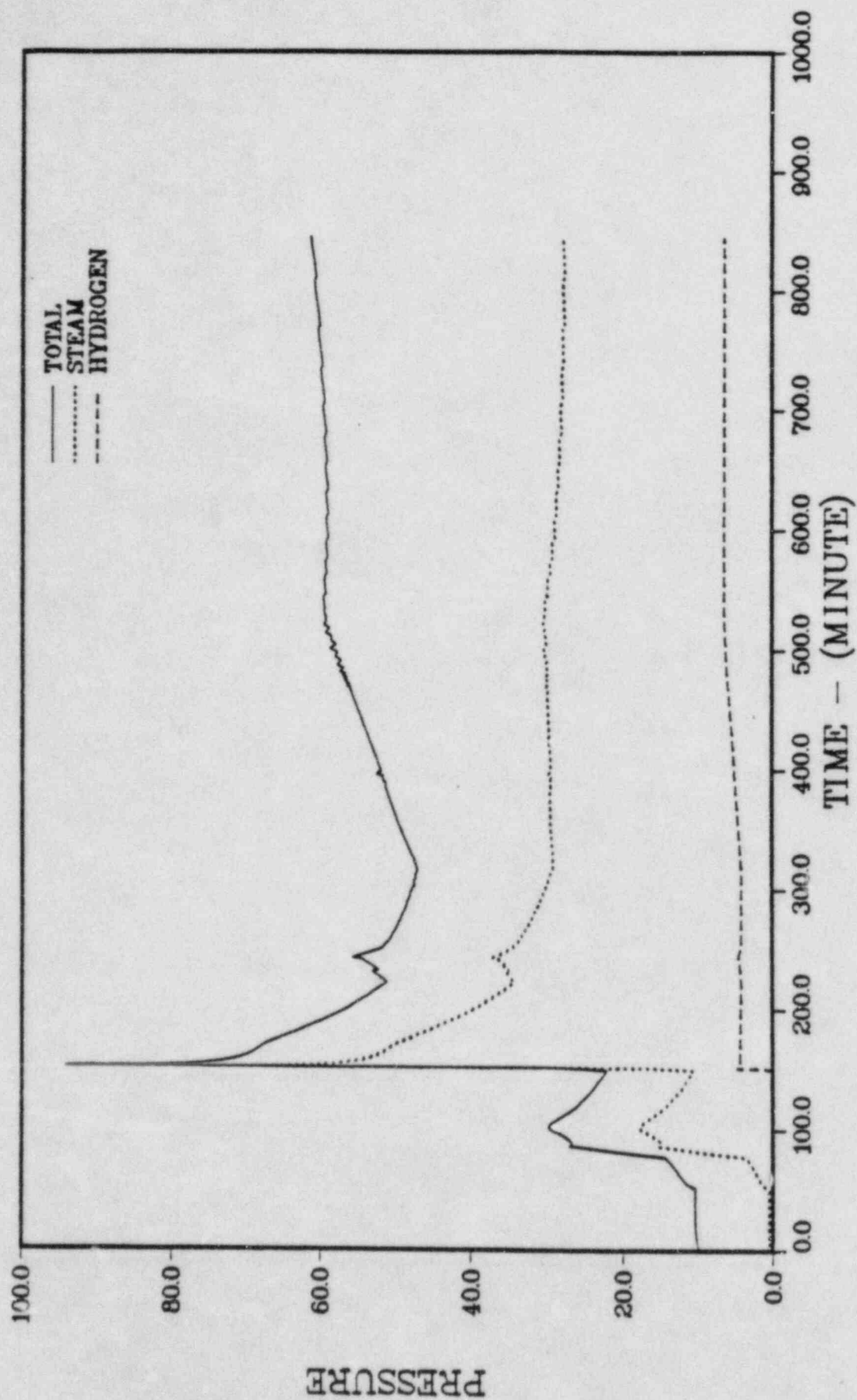
HOT2, PARTICLE, DP=0.2 IN.



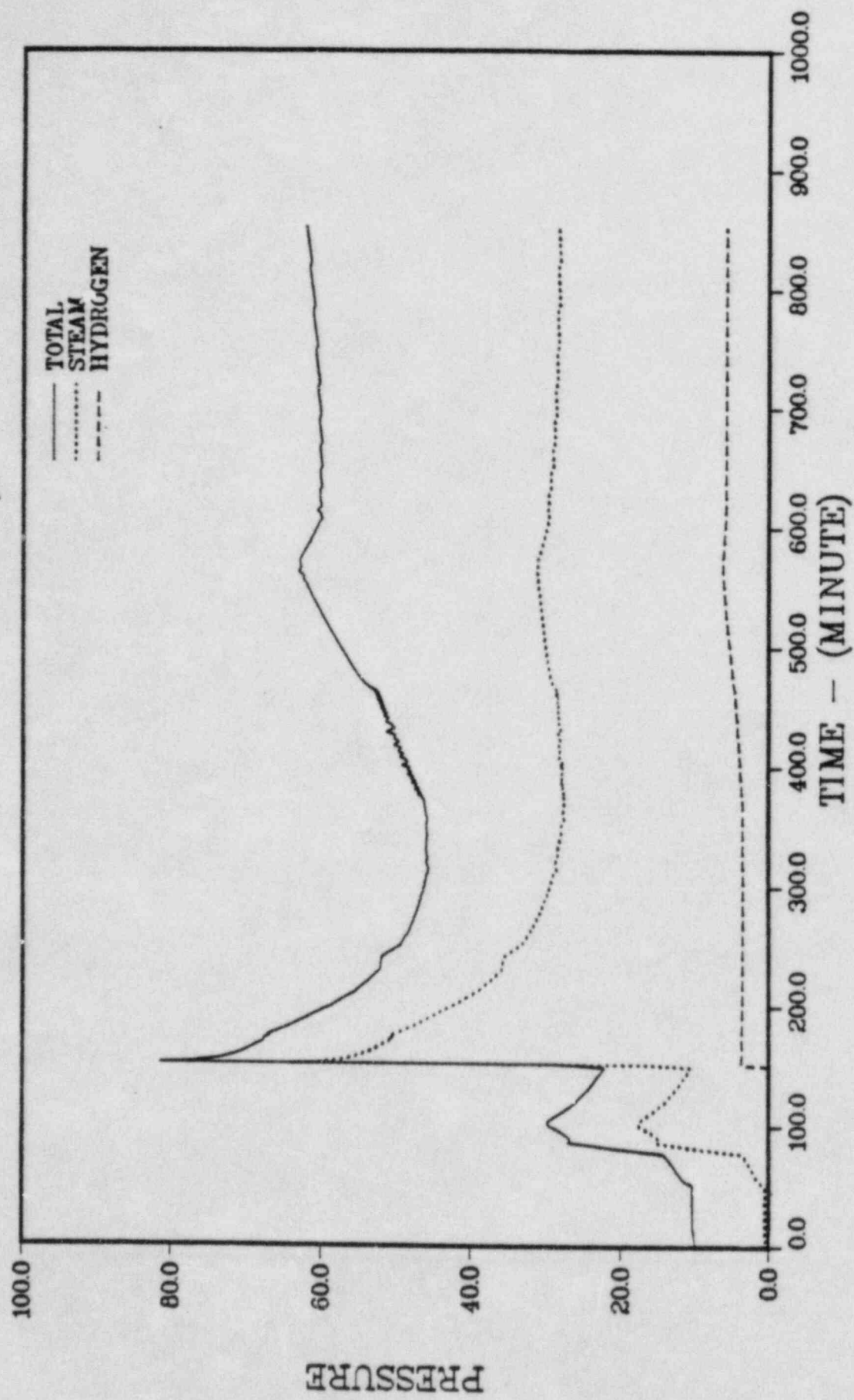
HOT2, PARTICLE, DP=0.2 IN.



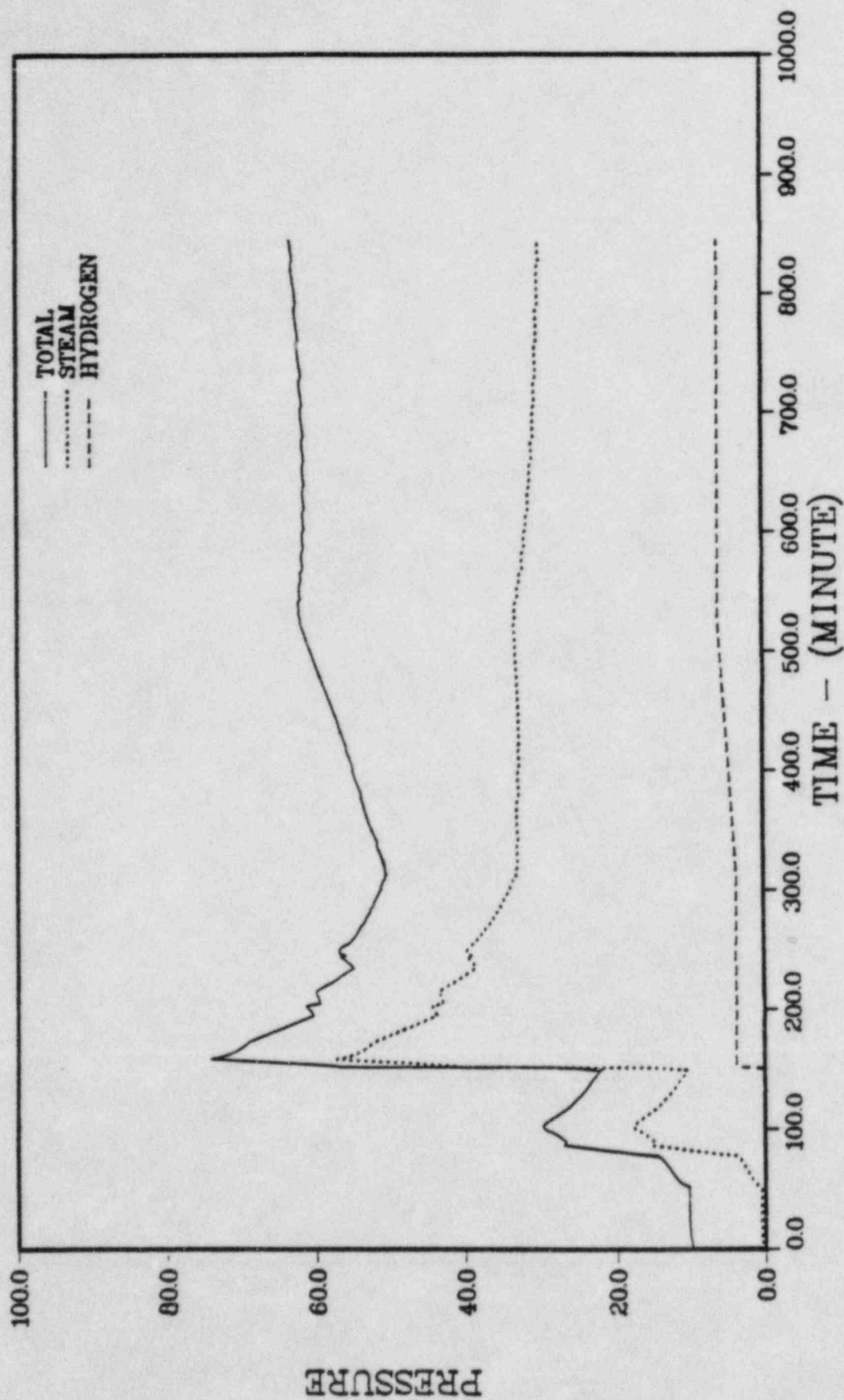
HOT3, PARTICLE, DP=0.04 IN.



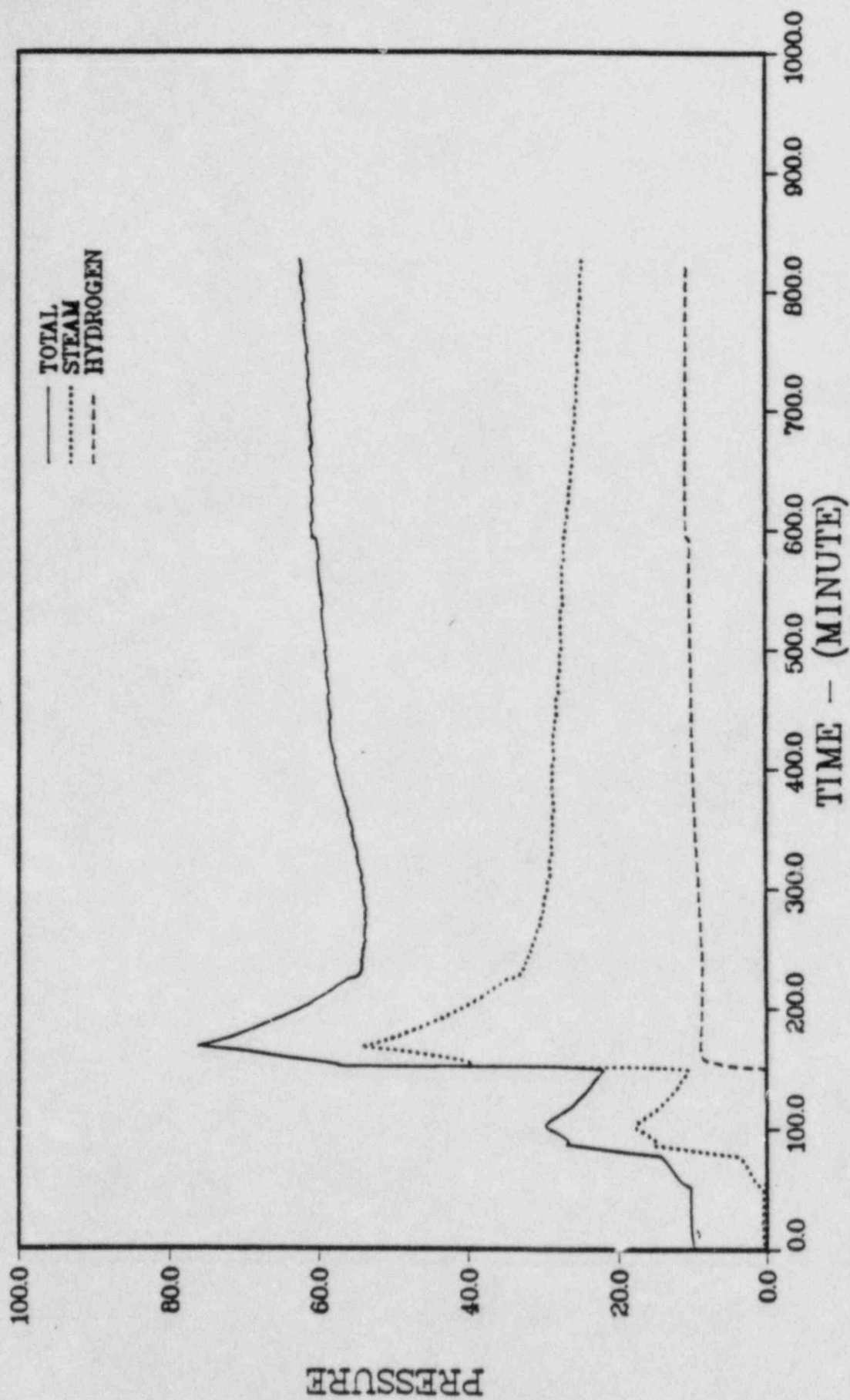
HOT5, BED (LEVITATION), DP=0.2 IN.



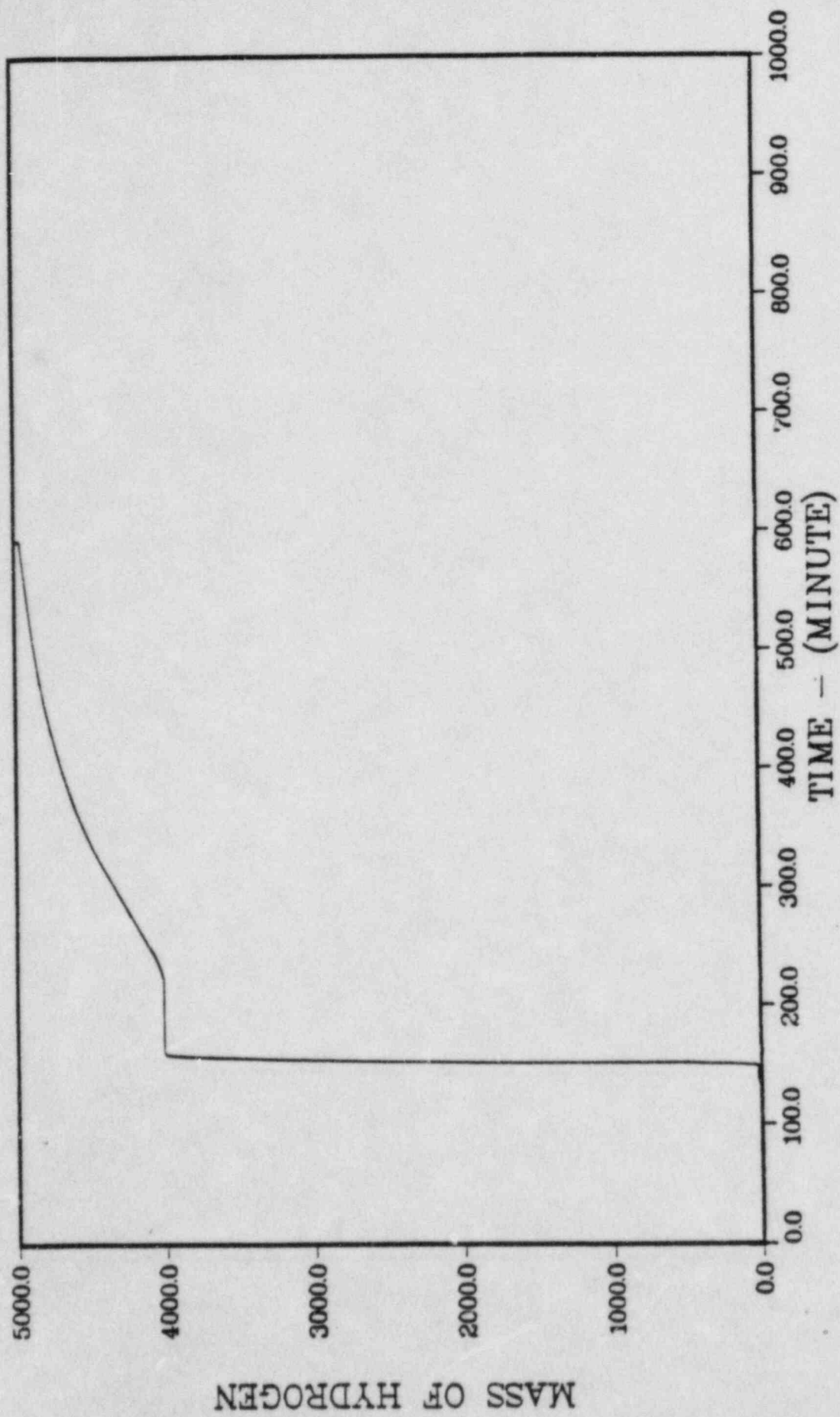
HOT9, BED (LEVITATION), DP=1.0 IN.



HOT7, BED (T=-3275), DP=0.2 IN.

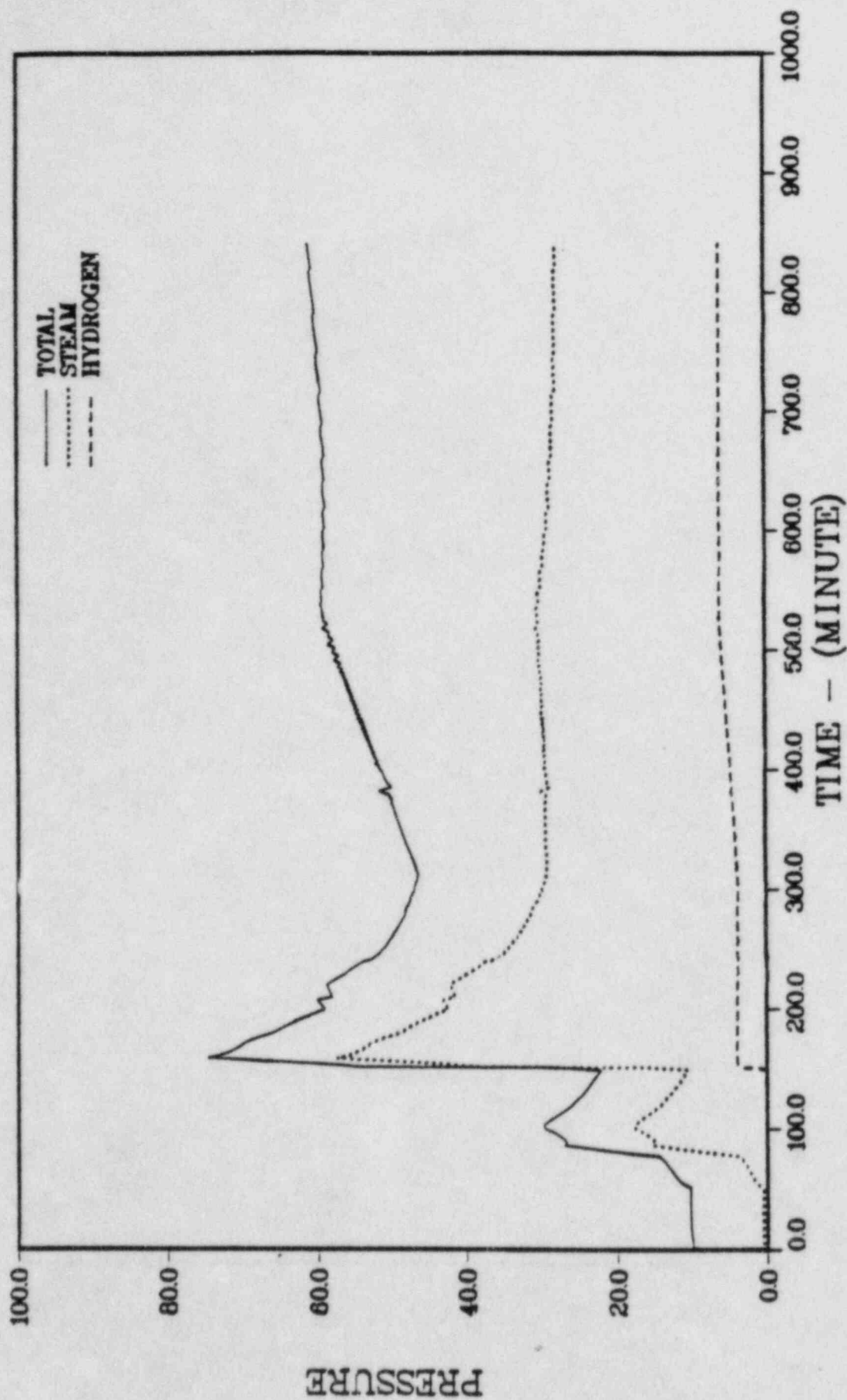


HOT7, BED (T=-3275), DP=0.2 IN.

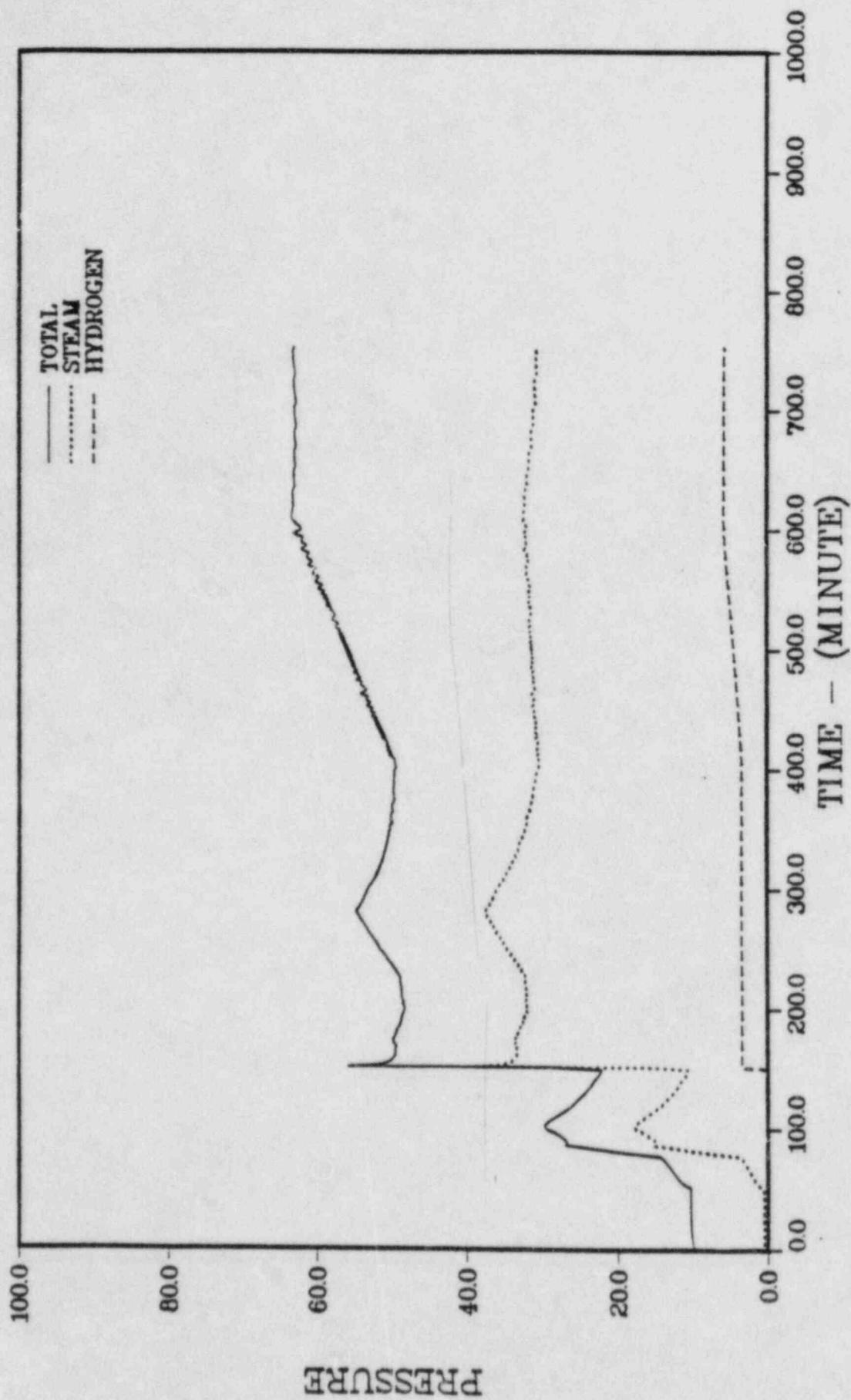


VOLUME NO. 1

HOT10, BED (LEVITATION), DP=1.0 IN.



HOT4, BED (T<3275), DP=0.2 IN.



SURRY TMLB' HOTDROP SENSITIVITY STUDY
SUMMARY OF RESULTS

Case	Key Parameters	Peak Containment Pressure, psia
Particulate Quench (HOT 1)	DP = 1.0	76
Particulate Quench (HOT 2)	DP = 0.2	84
Particulate Quench (HOT 3)	DP = 0.04	94
Particulate, Levitation Bed (HOT 5)	DP = 0.2	82
Particulate, Levitation Bed (HOT 9)	DP = 1.0	74
Particulate, Bed on Solidification (HOT 7)	DP = 0.2 TCORM = 3275	76
Particulate, Bed on Solidification (HOT 10)	DP = 1.0 TCORM = 3275	75
Particulate, Bed on Solidification, INTER (HOT 4)	DP = 0.2 TCORM = 3275	56
Particulate, Levitation Bed, Reduced In-Vessel M-W Reaction (HOT 8)	DP = 0.2	69
Particulate, Levitation Bed, Increased Vessel Strength (HOT 11)	DP = 0.2 1.6 x TS	82
Particulate, Levitation Bed, Increased Structural Material (HOT 12)	DP = 0.2 2 * WGRID	81
Particulate, Levitation Bed, Slump Model (HOT 13)	DP = 0.2 FDROP = 0.75	80
Particulate, Levitation Bed, Fuel Melting Point (HOT 14)	DP = 0.2 TMELT = 5280	82
Particulate, Levitation Bed, Meltdown Model (HOT 15)	DP = 0.2 MELMOD B	76
Particulate Quench, Increased Vessel Strength, Fuel Melting Point (HOT 00)	DP = 0.2 1.6 x TS TMELT = 5280	86

CONTAINMENT PRESSURE PREDICTIONS FOR ALTERNATE DESIGN

CASE	CONTAINMENT PRESSURE, PSIA
Particulate Quench, MARCH 1.1	110
Particulate Quench, MARCH 2	111
Debris Bed Without Steel- Water Reaction, MARCH 2	100
Debris Bed With Steel-Water Reaction, MARCH 2	129
Corium-Water Interaction Calculation Bypassed, MARCH 2	68

REMOVAL OF AEROSOL BY SPRAYING

$$\frac{dN}{dT} = -\epsilon \pi R^2 N (V_G - v_G) N$$

N = AEROSOL PARTICLE CONCENTRATION

R = RADIUS OF SPRAYING DROP

N = SPRAY DROP CONCENTRATION

T = TIME

V_G = SETTLING VELOCITY OF WATER DROP

v_G = SETTLING VELOCITY OF AEROSOL PARTICLES

$$\epsilon = \left[1 + \frac{0.75 \ln(2 \text{ STK})}{\text{STK} - 1.214} \right]^2 + \frac{1.5(R/r)^2}{(1 + R/r)^{0.33}}$$

WHERE:

$$\text{STK} = \frac{2(V_G - v_G) R^2 e_p}{9\mu R}$$



Battelle

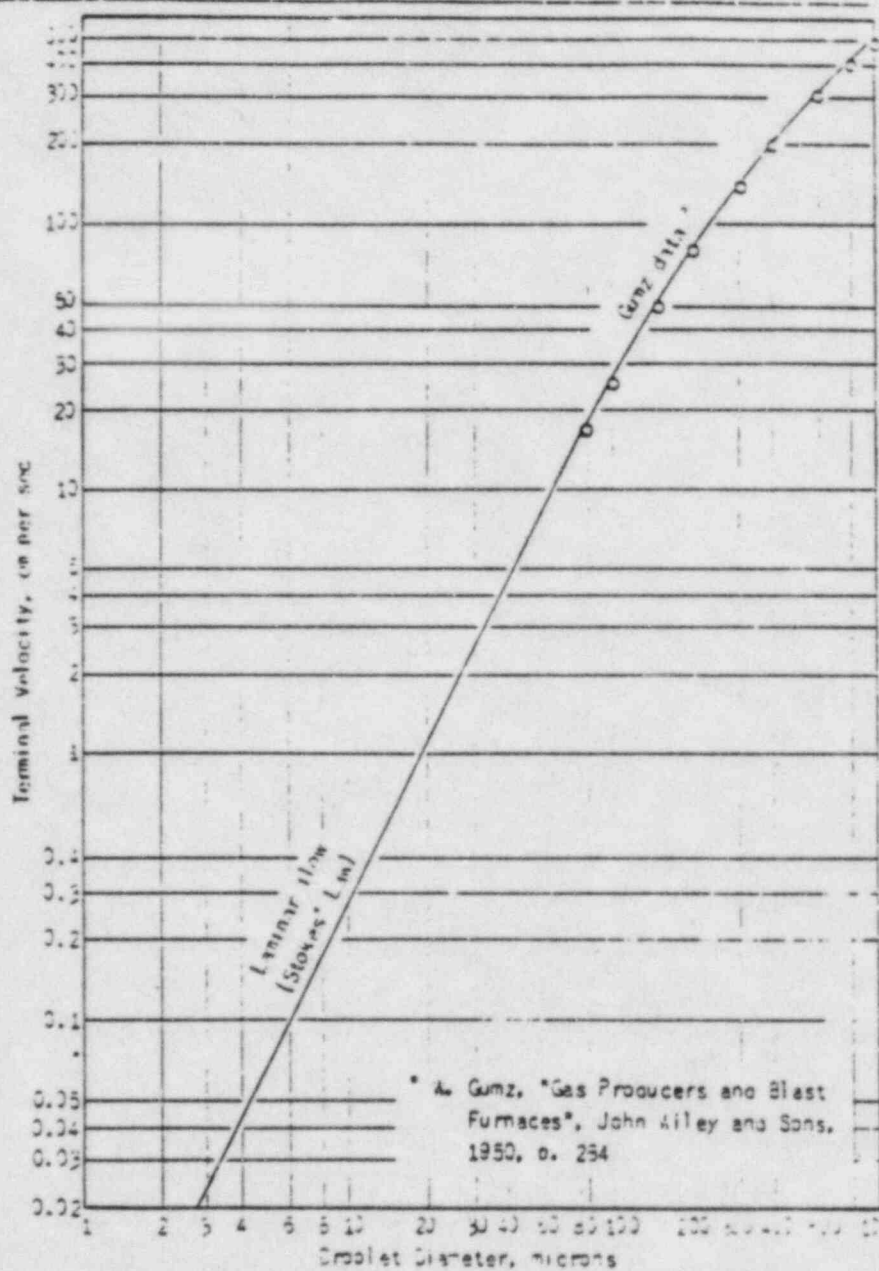
Columbus Laboratories

SENSITIVITY OF DROP SIZE

<u>DROP SIZE (μM)</u>	<u>ϵ</u>
1,000	1.5×10^{-6}
500	6×10^{-6}
100	1.5×10^{-4}
50	6×10^{-4}

PARTICLE DIAMETER: 1 μM

$$\lambda = \frac{3F_H \epsilon}{4R_W V_C}$$



TERMINAL VELOCITY OF WATER DROPLETS IN AIR AT 70°F

SPRAY FLOW RATES

CONTAINMENT INJECTION PUMP

3200 GPM (200 LPS)

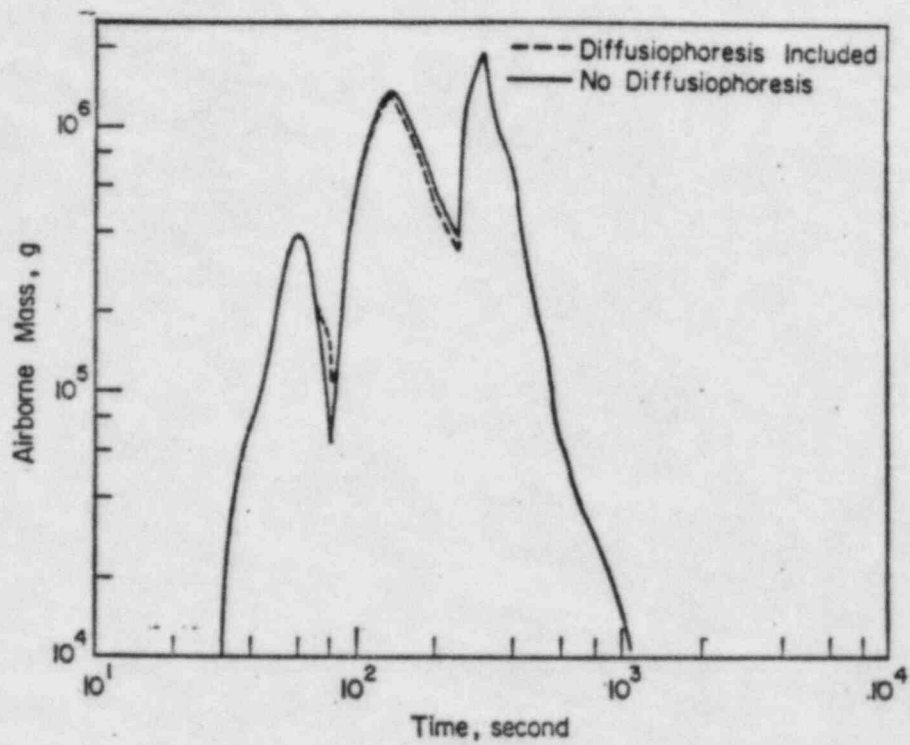
CONTAINMENT RECIRCULATION PUMP

3500 GPM (220 LPS)

- INJECTION SPRAY ON 20 MIN
- RECIRCULATION SPRAY ON 25 MIN
- INJECTION AND RECIRCULATION SPRAY OFF 80 MIN (8)
- INJECTION SPRAY OFF 130 MIN

SPRAYING

- (1) RE-EXAMINATION OF COLLISION
MECHANISMS
- (2) CORRECTION OF TERMINAL SETTLING
VELOCITY FOR LARGE DROPLETS
- (3) INCORPORATING OF BROWNIAN DIFFUSION
- (4) INCORPORATION OF TWO SEPARATE SPRAYING
FLOW RATES



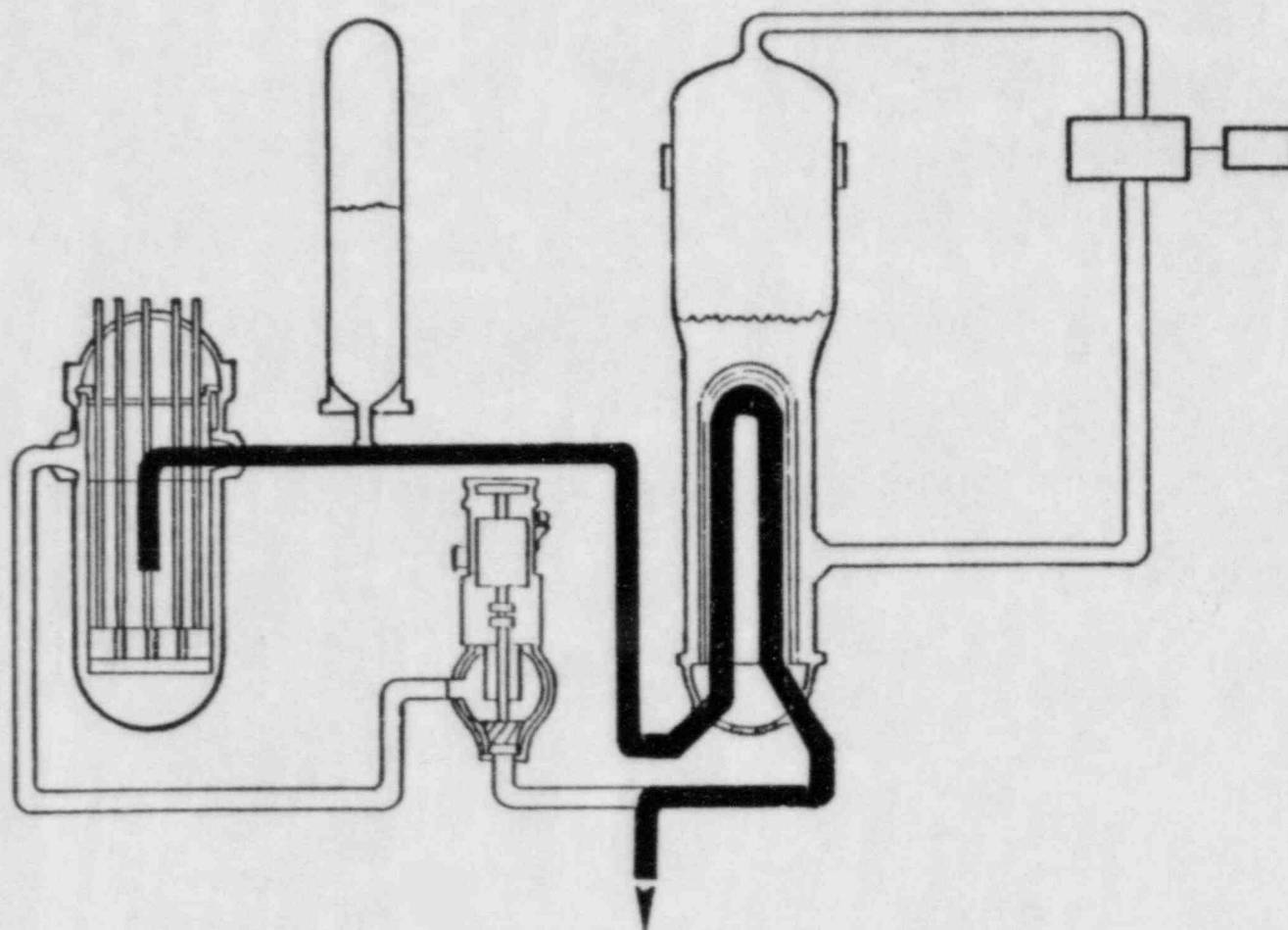
EFFECT OF FISSION PRODUCT HEATING ON STRUCTURE TEMPERATURES

ISSUES

- MERGE AND TRAP ANALYSES ARE PERFORMED INDEPENDENTLY--WHAT IS THE EFFECT OF FEEDBACK?
- IS THERE POTENTIAL FOR THE LONG TERM EVOLUTION OF FISSION PRODUCTS DEPOSITED IN THE RCS?

APPROACH

- PUT FISSION PRODUCT DECAY HEAT SOURCE TERM INTO MERGE ANALYSIS OF STRUCTURE TEMPERATURE.
- PERFORM MERGE-TRAP-MERGE-TRAP ITERATION TO EVALUATE EFFECT ON STRUCTURE TEMPERATURES AND FISSION PRODUCT RETENTION.



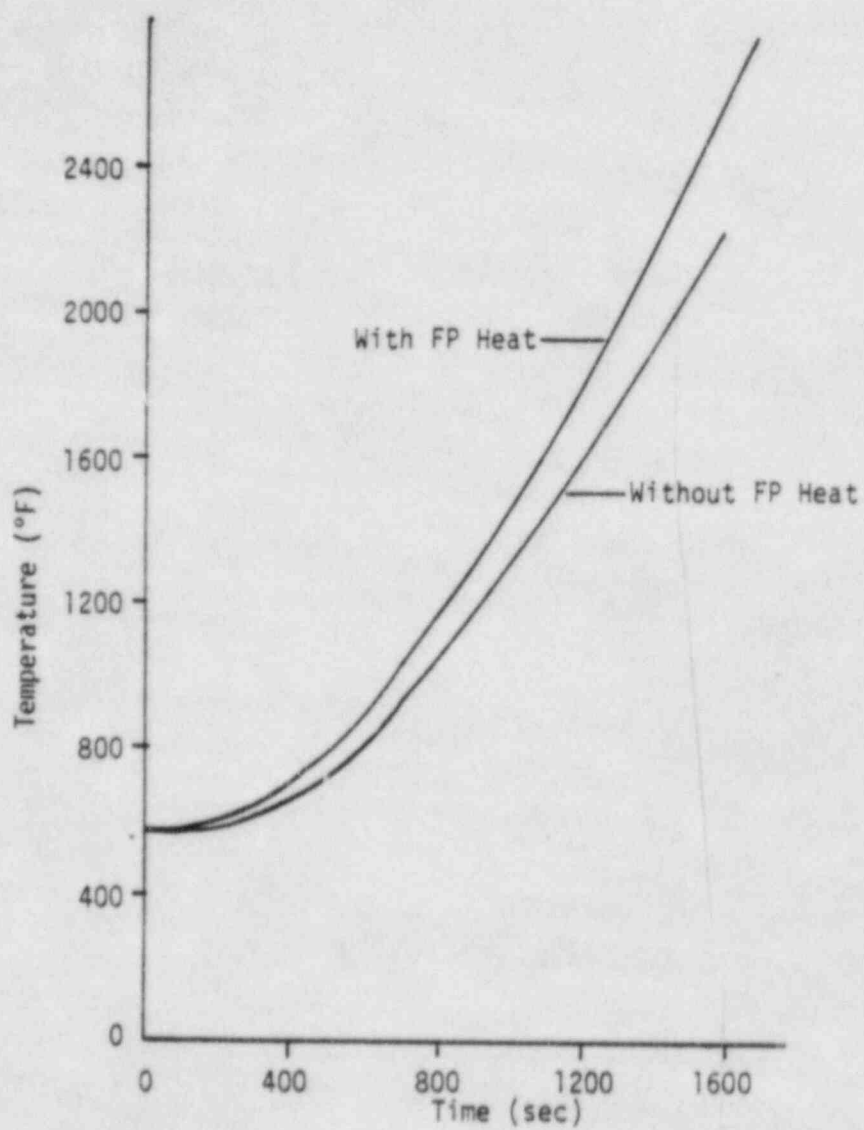
FLOW PATH FOR FISSION PRODUCT TRANSPORT IN SEQUENCE S₂D

FISSION PRODUCT DECAY HEAT
(ORIGEN)

TIME (MIN)	FRACTION IN GROUP				
	XE-KR	I	Cs	Te	BALANCE
0	.0796	.1300	.1440	.1530	.4930
30	.0332	.1600	.0752	.1450	.5820
60	.0383	.1890	.0617	.1060	.6050
120	.0370	.2000	.0394	.0722	.6510
300	.0322	.1850	.0210	.0406	.7210
1200	.0249	.1590	.0130	.0296	.7740

FRACTION OF INVENTORY DEPOSITED ON UPPER PLENUM STRUCTURES

TIME (MIN)	GROUP				
	XE-KR	I	Cs	Te	BALANCE
0	0	0	0	0	0
4.87	0.025	0.006	0.004	0.003	1.2×10^{-5}
9.75	0.054	0.039	0.034	0.110	2.9×10^{-4}
14.62	0.088	0	0.065	0.256	5.1×10^{-3}
19.50	0.080	0	0.106	0.448	1.4×10^{-2}
24.37	0.054	0	0.139	0.604	2.2×10^{-2}



UPPER PLENUM TEMPERATURES -- S₂D

EFFECTS OF DECAY HEATING ON PRIMARY SYSTEM RETENTION (S_2D)

- (1) NO EFFECT ON TOTAL AEROSOL DEPOSITION IN THE PRIMARY SYSTEM RESULTS WHEN DECAY HEATING OF SURFACES IS CONSIDERED.
- (2) THERE IS ENHANCED DEPOSITION OF HIGHER VOLATILITY MATERIALS (CsI , $CsOH$ AND Te) ON AEROSOL PARTICLES WHEN SURFACES ARE HEATED.
- (3) CHANGES IN DEPOSITION LOCATIONS OCCUR WHICH REFLECT CHANGES IN DEPOSITION MECHANISMS (DEPOSITION WITH AEROSOLS RATHER THAN DEPOSITION FROM VAPOR)
- (4) SOME REDUCTION IN TOTAL PRIMARY SYSTEM DEPOSITION OCCURS WHEN DECAY HEATING IS INCLUDED SUCH THAT THE RATIO OF DEPOSITION FOR THE CASE WITH DECAY HEATING TO THAT WITHOUT IS 0.84 FOR $CsOH$, 0.52 FOR CsI , AND 0.99 FOR Te .

APPENDIX D

Transcripts

1. 01/11/84 Peer Review - BCL Report on the Radionuclide Release Under Specific BWR Accident Conditions (38 pages)
2. 05/24/83 Peer Review Meeting - BMI-2104 Report (Draft) Radionuclide Release Under LWR Specific Accident Conditions, Volume II (944 pages)
- **3. 07/28/83 Peer Review - BCL Report on Radionuclide Release Under Specific BWR Accident Conditions Acc. No. 8309060590 (1102 pages)
4. 10/12/83 Peer Review of the BCL Report on Radionuclide Release Under Specific LWR Accident Conditions - Volume IV, V and VI (705 pages)
5. 01/26/84 BMI-2104 Report (Draft) Radionuclide Release Under LWR Specific Accident Conditions (1054 pages)

**Previously placed in the PDR.