ORIGINAL

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

In the matter of:

COMMISSION MEETING

Briefing by DOE on
R&D Results from
TMI-2 Cleanup

(Public Meeting)

Docket No.

Location: Washington, D. C.
Date: Tuesday, March 11, 1986

Pages: 1 - 79

ANN RILEY & ASSOCIATES
Court Reporters
1625 I St., N.W.
Suite 921
Washington, D.C. 20006
(202) 293-3950

D I S C L A I M E R

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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BRIEFING BY DOE ON R&D RESULTS FROM

TMI-2 CLEANUP

- - -

PUBLIC MEETING

- - -

Nuclear Regulatory Commission
Room 1130
1717 "H" Street, N.W.
Washington, D.C.

Tuesday, March 11, 1986

The Commission met in open session, pursuant to notice, at 2:05 o'clock p.m., NUNZIO J. PALLADINO, Chairman of the Commission, presiding.

COMMISSIONERS PRESENT:

NUNZIO J. PALLADINO, Chairman of the Commission
THOMAS M. ROBERTS, Member of the Commission
JAMES K. ASSELSTINE, Member of the Commission
FREDERICK M. BERNTHAL, Member of the Commission
LANDO W. ZECH, JR., Member of the Commission

STAFF AND PRESENTERS SEATED AT COMMISSION TABLE:

S. CHILK

T. ROTHSCHILD

J. VAUGHAN

D. McPHERSON

J. BROUGHTON

D. McGOFF

P R O C E E D I N G S

CHAIRMAN PALLADINO: Good afternoon, ladies and gentlemen. This afternoon the Commission will be briefed by the Department of Energy on results to date of research and development efforts involving the TMI-2 reactor.

Such data will be valuable in developing better means for accident prevention and mitigation and for reducing the uncertainties associated with requirements for plant design and operation.

More specifically, such date could have significant impact on NRC's source term assessment, emergency planning guidelines, equipment qualification for accident environments and related policies.

To present DOE's briefing Mr. Jim Vaughan, acting assistant secretary for nuclear energy, is here to provide a brief introduction. He will be followed by Don McPherson, TMI-2 accident evaluation program manager.

Also from DOE is Mr. Jim Broughton, project manager for EG&G Idaho and Mr. Dave McGoff, director of the office of light water safety and technology.

We very much appreciate having all of you here today to discuss DOE's TMI-2 program efforts and we welcome you. Before I turn the meeting over to Mr. Vaughan, I would like to ask that in addition to the technical aspects of DOE's R&D program you might address the availability of adequate funding to complete the R&D efforts in what you consider a satisfactory manner.

Now let me ask, do other commissioners have any opening remarks at this time?

(No response.)

CHAIRMAN PALLADINO: All right, then let me turn the meeting over to Mr. Jim Vaughan.

MR. VAUGHAN: Mr. Chairman and Commissioners, we are pleased to have this opportunity to appear before the Commission to describe the Department of Energy's TMI-2 accident evaluation program. We appreciate the support for this program that has been shown by the Commission in your recent letter, Mr. Chairman, to Secretary Herrington.

The Department of Energy is pleased with the efforts to date by all parties cooperating with General Public Utilities in the TMI-2 cleanup and the related accident evaluation program.

In response to your query, we do plan to continue adequate funding of this program while simultaneously continuing to meet our commitments to provide R&D support to the defueling and core shipping programs at TMI.

The $12 million dollar funding request in our fiscal year 1987 R&D budget and the eight million planned in fiscal year 1988 will complete our planned commitment for augmented funding of this TMI-2 program.

DOE plans to continue its presence at the Island through completion of core removal, estimated by the end of fiscal year 1987. The core examination efforts at the Idaho National Engineering Laboratory will continue through fiscal year 1988.

COMMISSIONER BERNTHAL: Jim, if I can interrupt for a second, you folks, I realize operate under a slightly different budget constraints and rules necessarily as direct members of the Executive Branch than we do here perhaps but if I went to Idaho Falls tomorrow and asked the engineers there whether they are going to be able to have available all of the funding that reasonably should be expected to gather the scientific date that clearly are there for the taking at TMI-2 and associated debris and what not, are you confident now that we have the funding that we are going to get all of the information and knowledge out of that event that we should be getting?

MR. VAUGHAN: I am not sure that if you ask each and every engineer working on the program that you get that answer--

COMMISSIONER BERNTHAL: Taking a rough average.

MR. VAUGHAN: I believe if you asked the management, they would tell you that there will be enough funds to do that. If as we get into the program with the plans that exist to evaluate it, it should turn out that there are identified some additional things that need to be done because you are finding as you go, our overall safety and licensing budget that continues from year-to-year and is somewhat centered in Idaho, should be available to accommodate that just as we are accommodating the post radiation exam of the loss of fluid test results in our continuing generic budget.

COMMISSIONER BERNTHAL: All right. I just want to re-emphasize and the Commission as a body has emphasized it in the letter, I know, but we just cannot afford, I think, to be cutting this area of fundamental knowledge. It could have been a better instrumented experiment but nevertheless, the experiment was carried in a way that was not very desirable but it is there now and if there is anything at all more that this Commission or I personally can do to drive that point home, I believe the Commission should do that and I will certainly help you do it.

It is just too important to let that knowledge fall by the wayside.

MR. VAUGHAN: We appreciate that offer of support. I can assure you that our objectives in completing it in a thorough and adequately technical and scientific manner are equal to yours.

COMMISSIONER BERNTHAL: Good.

MR. VAUGHAN: The plans for the shipment of the core debris from the site is an effort to which we have also paid particular attention. In this regard, I want to express my appreciation for the prompt review that the NRC staff has applied to the certification of the special shipping cask which has been developed by DOE for transportation of the TMI core debris to the Idaho National Engineering Laboratory where it will be examined as we just discussed.

I understand that all the issues regarding that certification have now been resolved with the staff and that a certificate of compliance is scheduled to be issued by NRC later this month. That is an important milestone to support the shipping campaign which is scheduled to be underway this June.

We share with industry and with the Commission the strong desire to evaluate, disseminate and apply the valuable safety and technology lessons being learned from the TMI-2 accident. Through this approach we can continue the efforts to assure rational regulation of reactor safety and emergency planning which can continue to protect public health and safety with balanced and technically sound approaches that are not an undue burden on the operators of nuclear power plants or on the ratepayers who are the very public being protected.

In addition to the severe accident analysis effort, valuable lessons are being learned for waste handling and disposal activities as well as decommissioning activities.

As you well know the TMI-2 accident confirmed that in spite of severe core damage, there are mechanisms to retain large proportions of the fission products and to prevent their release to the environment.

Data from our accident evaluation program should be of great value in both developing and confirming our understanding of severe accidents.

We expect this to occur by means of corroborating and extrapolating results from planned experiments such as those performed recently in the power burst facility and the loss-of-fluid test program and by providing a sufficiently clear understanding of this accident that it may be used to benchmark severe accident calculational tools and models.

From our perspective, the most important use to which the results can be put is in the regulatory arena. It is important to DOE that, based on these and the results from many other related programs now in progress, that the NRC be able to press ahead with regulatory changes that are possible now or in the near future while we continue to refine the date base as new data becomes available.

With respect to the execution of the TMI-2 accident evaluation program, I would like to specifically note that the cooperation with NRC under an agreement that includes our two agencies, General Public Utilities and the Electric Power Research Institute has been very good. The staffs have worked well together on a good solid technical basis.

Continuing participation by a group of Japanese utilities and industries is also valuable in evaluating and disseminating the data on an international basis. We appreciate particularly the help NRC has provided in formulating the TMI-2 core examination plan and in performing some of the fuel debris examination.

Further, it is worth noting at this time that the Department has recently concluded an arrangement with the Nuclear Energy Agency for several foreign countries to participate in the examination of T-2 debris and in be-chmarking their severe accident computer codes against the accident scenario which has been developed through this program.

Finally as a last comment, assuring that we keep the public well informed is also an important aspect of this effort and I am pleased, Mr. Chairman, that you, GPU officials and I were all able to participate in the public television report on TMI-2 which is being prepared by Penn State University for airing later this month. We think that is a very positive step.

This concludes my opening comments and perspective. Dr. McPherson has been in charge of our loss-of-fluid test examination program for a number of years and is also in charge of our TMI-2 severe accident program to help match those two efforts together and he has prepared a presentation for you largely using viewgraphs to help in understanding what has happened.

CHAIRMAN PALLADINO: May I ask you, what is the nature of the participation? Were these NEA countries?

MR. VAUGHAN: Yes.

CHAIRMAN PALLADINO: Are they providing funds or are they participating just in evaluating their codes?

MR. McGOFF: We expect that some of the NEA countries will perform analyses on TMI debris and share the results with us. We will provide samples and they will do the analyses.

CHAIRMAN PALLADINO: I see. All right.

MR. McGOFF: It will augment our program.

CHAIRMAN PALLADINO: thank you. Mr. McPherson.

MR. McPHERSON: Thank you, Mr. Chairman, and thank you, Mr. Vaughan.

[Slide.]

MR. McPHERSON: Jim Broughton will help me in my presentation by pointing out the features that need to be pointed out that I will refer to.

[Slide.]

MR. McPHERSON: These are all the same slides as you have in your handouts so that you can look at that, also. Let me go on to the outline now. I will be giving you a very straight forward simple presentation, giving you first the objectives of our program, the accident scenario and the end conditions that we now understand the reactor to be in.

I will describe the accident evaluation program that we have put together and have had help on from NRC, industry including GPU and B&W. Then I will end off by telling you the schedule of the work we have planned.

[Slide.]

MR. McPHERSON: To begin with, the program objectives are very simple. We simply want to understand what happened during that accident, no more than that to a degree, where we understand the consequences as they apply to the issues at hand today.

We would contribute the data from that study to the date base now being applied to the resolution of severe accident source term technical issues and we would also transfer all of that data we will be producing to the other government agencies and in particular, NRC, the nuclear industry and where possible to the public.

CHAIRMAN PALLADINO: How are the results of your R&D efforts provided to the NRC? Are they just in the form of a report?

MR. McPHERSON: That is correct, sir. In addition, you are represented on the accident evaluation assessment, our advisory committee, pardon me, and thereby receive those results first hand. We do take part in meetings together where the results are discussed.

We have an annual meeting where NRC staffers show up and participate. In general, however, we issue what are known as "GEND" reports where the "N" in the GEND refers to NRC and the "D" is DOE. So these reports are reviewed by all sides. The "G" is GPU and the "E" is EPRI.

CHAIRMAN PALLADINO: All right. Thank you.

MR. McPHERSON: As the program evolves, you may participate in different ways but that is the way that we have been operating to date.

[Slide.]

MR. McPHERSON: I would like to first discuss the accident scenario.

CHAIRMAN PALLADINO: Just one other follow-up, how about the nuclear industry? Do they get the information through reports primarily?

MR. McPHERSON: Yes, sir.

CHAIRMAN PALLADINO: All right.

MR. McPHERSON: Again though, they are represented on the advisory committee.

CHAIRMAN PALLADINO: All right.

MR. McPHERSON: The accident scenario that I will be presenting is as interpreted by the known conditions of the core, from the SCDAP analysis which we have been doing where

SCDAP is the NRC code which stands for Severe Core Damage Analysis Program and the other information comes from the on-line instrumentation as it is being interpreted and re-interpreted from the time it was originally recorded back at the time of the accident.

That is turning out to be a very significant source of new data for us.

[Slide.]

MR. McPHERSON: Let me begin then with the known core conditions. I will start at the top on this slide and we will go down from the top.

The leadscrews have been found to have been at maximum temperatures of 755 K at the top to as high as 1255 K at the bottom of the upper plenum just above the core.

The other leadscrews which are not shown in this diagram have lower temperatures going out to the periphery. Clearly, they have all been at extremely high temperatures.

Just below the upper plenum, we see a 30 percent void in the core and at the top of the upper plenum, there are localized regions of oxidized and molten stainless steel. I will show you photographs of these subsequently.

At the top of the existing core now, there is a debris which contains prior molten fuel. Therefore, it has reached 3100 K and there is fully oxidized zircaloy. There is some unrestructured fuel to be found.

Below that, there is a hard layer of about 1.60 to 1.75 meters thick.

CHAIRMAN PALLADINO: Excuse me. I tend to think in Fahrenheit. Is 3100 K above 5,000 degree Fahrenheit?

MR. McPHERSON: Yes, sir, it is.

CHAIRMAN PALLADINO: Thank you.

MR. McPHERSON: I apologize. All of our temperatures are going to be reported in Kelvin but perhaps I could give you some assistance as we go along.

CHAIRMAN PALLADINO: I notice later you are going to give us Mega Pascals per unit area and I am going to have to get that translated to PSI.

MR. McPHERSON: We will manage with that.

COMMISSIONER BERNTHAL: Just multiply by nine fifths, Joe, and you will be okay.

MR. McPHERSON: As I say, there is some unrestructured fuel but in the main, it is in the form of cinders and previously molten oxides.

Then there is the hard layer which is above the unknown portion in the core and we will be talking a little bit about that later, what we think is in there.

Below is the core support assembly which to all observations has undergone no damage that we can see. In particular, the bolts around the assembly holding the whole thing together appear completely undamaged.

Then below that core support assembly is from ten to 20-percent of the original core laying in the lower plenum. There are thermocouples coming up through the bottom of the lower plenum which have had their junctions reformed at that point indicating that they have seen extremely high temperatures. Clearly they have if the core is down there or part of the core is down there.

Before moving on, let me say that we will first look at the bottom of the upper plenum. We will be looking up at that and then we will look down at the top of the debris bed on top of the core.

I would like to recall that the upper plenum has been removed. Consequently, the standing fuel bundles which were in the periphery of the bundle have now fallen over on top of that debris and create a further debris bed of rather jackstraw appearance.

So when we look down, we will be seeing that rather than the original debris that was seen.

We are then going to sneak down a television camera to the lower plenum where we will see the debris in the lower plenum from various views and I will show you what those views are before showing the photographs and then look up through holes in the lower plate, the flow distributor, the very bottom plate and look at some debris up inside the core support structure, the assembly there. We will see what is to be seen down there.

COMMISSIONER ASSELSTINE: Don, do you have an estimate for how much of the core actually melted in terms of the fuel itself?

CHAIRMAN PALLADINO: In terms of fuel?

COMMISSIONER ASSELSTINE: Yes.

MR. McPHERSON: There is a variety of ways of answering that question, Commissioner Asselstine, and let me first say that we know for certain that there has been some molten UO-2 meaning we have hit those top temperatures but there is a mixture of UO-2 and zirconium dioxide and a mixture of those two in solution which could be anywhere which means that the temperatures which they reached could be anywhere from about 2000 K up to the 3100 K.

So if your question is how much of the core was molten, then my estimate personally from what I have seen is 70-percent but that is my own personal estimate having looked at what I have seen. GPU has not said that nor has EG&G.

CHAIRMAN PALLADINO: I am sorry, do you mean 70-percent fuel?

MR. McPHERSON: Of the entire core.

CHAIRMAN PALLADINO: Of the entire core.

MR. McPHERSON: Yes.

CHAIRMAN PALLADINO: Do I conclude that means 70-percent of the fuel?

MR. McPHERSON: Yes, sir. I don't mean that 70-percent reached 3100 K, a smaller percentage, perhaps and let me just guess, five to ten percent of the fuel reached that temperature.

We have some confusion in this question of amount of melting because of the various temperatures at which the different metals and oxides melt. We begin by the control rod materials melting below 1500 K and failing at about 1500 K so that they become liquid and are candling down before anything else is.

Then the zirconium starts to melt at about 1720 K and then the -- I am sorry, the stainless steel does at 1720, then the zirconium beta phase melts at 1950 K, the alpha phase melts at 2150 K and both of those zirconia are capable then of dissolving UO-2. So you have a new mix coming into play and as the temperature goes up to 2650, the zircaloy forms a monotectic which is capable of absorbing all of the UO-2 in the core if it were all molten, if the zircaloy were all molten.

But it is oxidizing meanwhile and then you get up to the question of when does the zirconium dioxide melt and that comes in at 2950 and then we have, of course, the UO-2 melting at 3150.

Sc with that maze of different materials melting at different points it is a difficult question to answer very directly.

COMMISSIONER ASSELSTINE: Thank you.

[Slide.]

MR. McPHERSON: In the next slide we have a color legend indicating the amount of damage that has been observed in the lower surface of the upper plenum.

You will see a very asymmetric design or pattern of this damage. You will see that there are a few areas of extreme deformation and then some areas, the pink areas, a foamy surface of stainless steel. That means that it has been oxidized by steam so a high temperature of steam has passed over those areas.

Next, there is a damaged area in yellow but which is not foamy. This has been damaged then by high temperature gas but with not much oxygen in it. So it is probably not steam and it is probably high temperature hydrogen.

There are slightly damaged areas and then areas not affected at all. So they have not seen temperatures above 1700 in those undamaged areas.

This implies a geometry of core damage and of flow of coolant or steam or hydrogen out of those damaged areas which is very asymmetrical and this leads us to believe that there is an interesting structure within the damaged area below which needs to be understood.

That will be one of the objectives of our program to determine why we have that damage pattern.

[Slide.]

MR. McPHERSON: My next two sides are in fact photographs of that same structure we have just been discussing.

CHAIRMAN PALLADINO: You say this is very asymmetric and yet I can see a certain amount of symmetry relative to the loop outlets. I will agree that it is not perfectly symmetric but it is split right down the middle it seems like.

MR. McPHERSON: Yes. I was referring in a way to the fact that what you would expect under these conditions is the hottest area to be in the center and the cooler areas toward the periphery and here we see the hottest areas of skewed around. If you look at the white, they are just in very isolated locations.

CHAIRMAN PALLADINO: Yes, I see.

MR. McPHERSON: The pink area is skewed around to the right on the right and then sort of spotty on the left. There is an implication that there were certain flow streamings of the high temperature hydrogen, for example, coming up here.

CHAIRMAN PALLADINO: All right.

MR. McPHERSON: It is no doubt related to the way in which the core relocated and a crust formed and allowed the gases to flow through it.

If we now look up at the actual photographs of this area we see rods of zircaloy and control rod guide tubes.

CHAIRMAN PALLADINO: Are we looking down on the upper grid?

MR. McPHERSON: We are looking up on it.

CHAIRMAN PALLADINO: Oh, we are looking up.

MR. McPHERSON: From within the void and looking up on the upper grid.

MR. VAUGHAN: A camera in the void looking upward.

CHAIRMAN PALLADINO: All right.

MR. McPHERSON: So many of these rods, of course, have been destroyed and in one way or another fallen off and there is a highly oxidized zircaloy rod on the right that once was a fuel rod and you see no fuel exists inside. It has clearly fallen out one way or the other.

[Slide.]

MR. McPHERSON: In the next viewgraph, we see some photographs of lugs. These are thick steel slabs which are part of the upper plenum which lower down between each fuel element to position it and these lugs, you will see here in this case, have been melted away with not much oxidation because there is not much foaming or going to the next photo, they have been foamed away or oxidized and as a result produce this foamy structure.

[Slide.]

MR. McPHERSON: In the following photograph, we see a lug which has been ablated by the flow of high temperature high velocity gas. Very likely hydrogen has passed by and carried away the melted steel as it was passing by.

[Slide.]

MR. McPHERSON: Now I am going to divert our discussion a little bit at this point, because it is pertinent to point out that we have in the LOFT -- from the last LOFT experiment, have a fuel bundle that was damaged almost to the same degree, and if you look at the -- if you recall what we just saw with those rods hanging down, burnt off, broken off, and some of the debris that you saw, this next photograph is a picture of the slot, looking into the very top of the fuel bundle, which was put through a severe fuel damage accident in the final experiment in LOFT.

The debris that you see sitting on this little ledge right at the top of the fuel has been identified as foamed stainless steel, silver nuggets which came out of the control rod materials which were inside that bundle, and in one case -- you won't see it here -- a fuel pellet has been observed.

Control rods can be seen looking into this, and perhaps you'll see them a little on the next photograph.

[Slide.]

And they have been equally damaged, very similar to what we have seen in the TMI case.

CHAIRMAN PALLADINO: Now what am I looking at here?

MR. McPHERSON: You're looking through a horizontal slot at the very top of a fuel bundle, and hanging down inside, there are control rods which you can see the light surface there that Jim is pointing out.

CHAIRMAN PALLADINO: Oh, I see.

MR. McPHERSON: Some of those are eaten away, burned away, fallen off. It's the very same structure, essentially, as we have seen at the top of the core in TMI.

Now in the case of the LOFT test, no materials came out the bottom, as you recall, there were materials that fell or flowed out through the bottom, from the bottom of the core in TMI. This means that we have damaged the LOFT bundle to some intermediary point through the evolution of the TMI accident and then frozen it there. And I am very pleased to say that OECD LOFT Board has just decided to fund the examination of that bundle, so we will be cutting it up and examining it, and have data two or three years down the line from now which will be directly applicable and appropriate to interpolation of the data between TMI and your PBF program.

CHAIRMAN PALLADINO: What is it? A fuel element from LOFT that they're going to --

MR. McPHERSON: That's correct, sir, yes.

COMMISSIONER BERNTHAL: Where is the funding for this coming from besides OECD?

MR. McPHERSON: Well, OECD itself does not provide any funding. The program was formed under their auspices. The funding comes from ten countries which have signed up, signed an agreement to participate in this program. In the

U.S., these consist of DOE, the NRC, and EPRI, and at this time we are having discussions with the NRC on what the share of the U.S. contribution will be.

MR. VAUGHAN: You will remember, Mr. Chairman, of course, that the significance of this is that the LOFT bundle was highly instrumented on purpose to try to repeat the conditions, whereas the TMI-2 situation, of course, was not.

MR. McPHERSON: This is that highly instrumented test that you were looking for, Mr. Chairman, in the last meeting on TMI, when you were referring in the last meeting with GPU that there should have been more -- a better instrumented, and while we have an experiment which is very similar, but which was instrumented.

I'll go on now to one last look down at the top of the core.

[Slide.]

And you'll see this --

CHAIRMAN PALLADINO: Now are we looking on the top of the core?

MR. McPHERSON: Back to TMI.

CHAIRMAN PALLADINO: And not on the grid.

MR. McPHERSON: No. We're looking -- no, we've turned our sights downwards. You'll see some lights lighting up this jackstrawed configuration of rod stubs lying on top of the earlier debris that we say.

COMMISSIONER ASSELSTINE: This is after the upper plenum has been removed?

MR. McPHERSON: Yes, sir, that's correct.

CHAIRMAN PALLADINO: What are those dark spots again?

MR. McPHERSON: Those are dirt. The ones on the right in the pattern of three, those are simply dirt on the camera lens. The two dark spots in the light are simply the lights. The light below is shadowing them.

There's a canister on the left into which the damaged fuel is being placed. There is an end fitting above the left light. It's a square arrangement there. And for those of you looking at our dirty laundry, why we have a chem wipe lying on top of the core there.

CHAIRMAN PALLADINO: A what?

MR. McPHERSON: A chem wipe.

COMMISSIONER BERNTHAL: It's amazing that made it through the accident.

[Laughter.]

[Slide.]

MR. McPHERSON: I haven't told you about all the screwdrivers and nuts and bolts in there.

We'll go under the lower head debris now. Before showing you the photographs, it's useful to look at a rather complicated diagram which will help me explain where we're going to be seeing photographs in the next slides.

To begin with, there is a flange right around this diagram containing holes through which cameras, lighting, and sample-grabbers were lowered.

CHAIRMAN PALLADINO: I'm sorry. I missed that. You say that's a -- is that an annulus?

MR. McPHERSON: Yes.

CHAIRMAN PALLADINO: You said a flange.

MR. McPHERSON: I'm sorry. It's a flange, and there are holes in that flange.

CHAIRMAN PALLADINO: Oh, I see.

MR. McPHERSON: This is actually the flange that separates the downcomer from the upper plenum, the hot from cold leg areas. And these cameras, lighting, and sample-grabbers were lowered down through those tiny holes in that flange.

The shaded area in your handout is the area which was first observed up until June of '85, and that's the darker blue. And then the lighter blue areas or those areas in your handout which are circumscribed by a very heavy line are the areas which have been viewed subsequently up to December of '85.

The grid that's overlaid within the circle simply shows the pattern of fuel bundles, and the dark spots on many of the squares in that grid are the locations of instrument guide tubes which come up through the upper plenum. There are 52 of these, so there is considerable information to be gained from the instruments and information to be learned from the interaction of the fuel which fell through into the lower plenum and interacted with those.

CHAIRMAN PALLADINO: Was there water in the lower plenum, do you expect, when that dropped in?

MR. McPHERSON: Yes, sir. Yes. I will show you later what information we have to lead us to that conclusion.

Now there is a red line on the photograph and a lighter line in your handout which indicates the boundary that we understand the debris forms at this time in the lower plenum -- that is, beyond that boundary, there's simply a clean surface of lower plenum or the inner liner of the --

CHAIRMAN PALLADINO: Now which line is it again?

MR. McPHERSON: In your handout, it's the thinner line with some dots in it and with some dashes in it. The dashes indicate an area of uncertainty that we haven't seen. The small dots, which Jim is pointing to -- it's a red line on the photograph -- is a cliff of this debris material from four to twelve inches high.

CHAIRMAN PALLADINO: Now you're saying, it was clean outside this -- I'll call it circle; it isn't a circle, but --

MR. McPHERSON: Yes, sir, that's correct.

CHAIRMAN PALLADINO: But what are these dark --

MR. McPHERSON: The dark? The dashed grey --

CHAIRMAN PALLADINO: The grey spots on our handouts. Some of those are outside the circle.

MR. McPHERSON: Those are the areas we have been able to visually see, to see with our cameras.

COMMISSIONER ASSELSTINE: Those are just the areas that you looked at.

MR. McPHERSON: Yes, up until June. And the other areas in the larger area, we have looked at up to December.

Now before you turn your page, we are going to see photographs first of an instrument penetration at the 2-L level, the 2-L point, that instrument penetration.

CHAIRMAN PALLADINO: 2-L? Oh, I see.

MR. McPHERSON: And then we're going to look along Row 13 and see three of these instruments which are outside the boundary of the debris, followed by one that is encompassed by the debris.

Now we'll go on to those photographs.

[Slide.]

CHAIRMAN PALLADINO: Now are we looking down, or are we looking up? We're looking down?

MR. McPHERSON: We're looking downwards, yes. And the first one on your handout is the one at the top of the page.

We are looking down, then, at the debris coming up to the curvature of the lower plenum.

CHAIRMAN PALLADINO: Is this in the 13th row area?

MR. McPHERSON: Yes. That's the 2-L row.

CHAIRMAN PALLADINO: 2-L?

MR. McPHERSON: Yes.

CHAIRMAN PALLADINO: Oh, that's not 13.

MR. McPHERSON: The first one is 2-L. The subsequent ones are all 13's.

But this was to show you first an example of the horizontal layering of the debris. And I will say something about dimensions here first.

The instrument guide tube rising up to the left, at the left corner, has a 4.5-inch diameter with the penetration nozzle below it, 1.75-inch, just to give you an idea of the sizes of the debris.

The nature of that debris we have found to date is, it's prior molten. It is a ceramic; it is brittle, porous, and it is homogeneous. Generally these are of the same nature as the debris seen -- that has been taken as a sample out of the upper part of the core, with one exception, that that debris is non-homogeneous

CHAIRMAN PALLADINO: Is what?

MR. McPHERSON: It's heterogeneous.

COMMISSIONER BERNTHAL: It's ceramic, meaning its zirc oxide primarily.

MR. McPHERSON: Zirc oxide, UO-2.

COMMISSIONER BERNTHAL: What else?

MR. McPHERSON: And UO-2.

There are also some indications of nickel, chrome, and ferrous oxides, meaning some steel is involved that has been melted down here, and that steel could have come from the grids or the upper structures.

There is about a 20 percent retention of iodine and cesium, which is surprising to us in that these are highly volatile, and one would have expected them to have been driven off, but they've been retained, 20 percent. It was 30 percent in the debris taken from the core.

COMMISSIONER BERNTHAL: Is that retention also homogeneous retention throughout the rubble material?

MR. McPHERSON: In the lower plenum, yes. Everything is quite homogeneous down there.

COMMISSIONER BERNTHAL: Have you got any suggestions for mechanism there?

MR. McPHERSON: I defer to my expert here. Any suggestions for a mechanism, Jim?

MR. BROUGHTON: No, at this point in time, we don't have any real suggestion. We were surprised, quite surprised, that the retention was that high in materials that have been to in excess of 2800 Kelvin.

COMMISSIONER BERNTHAL: It really has to be almost a high-temperature absorption or something, doesn't it?

MR. BROUGHTON: One of the suggestions is that it might be a silicate, cesium silicate, formed as the materials flowed through the core support assembly. Cesium silicates are relatively involatile.

COMMISSIONER BERNTHAL: Cesium is easier to understand, but the iodine is --

MR. BROUGHTON: The iodine, we don't understand yet. That's one of the measurement objectives, is to find out what chemical form it is and why it was retained.

COMMISSIONER BERNTHAL: I guess unless the cesium -- unless it was carried in cesium iodide somehow and the silicate forms, and the iodine is left homogeneously, then, throughout the material.

MR. BROUGHTON: But that's not consistent with the percentages. We're seeing approximately 20 percent cesium and approximately 20 percent iodine. Remember that the ratios of cesium to iodine are approximately 1 in 8 or 1 in 10.

CHAIRMAN PALLADINO: Cesium to iodine?

MR. BROUGHTON: Cesium to iodine. There is eight to ten times more cesium than iodine.

CHAIRMAN PALLADINO: Oh, I see.

MR. BROUGHTON: So 20 percent cesium and 20 percent iodine still gives you that same ratio of 1 in 8 or 1 in 10. So it's not consistent that one would have --

COMMISSIONER BERNTHAL: Sorry. I'm missing something here.

CHAIRMAN PALLADINO: I missed it too.

COMMISSIONER BERNTHAL: It's 1 to 1 atom percent, or what are you talking about here?

MR. BROUGHTON: No. In a normal reactor in a normal core, the ratio is one atom of iodine to eight atoms of cesium.

COMMISSIONER BERNTHAL: But you're saying it's 1 to 1 here.

MR. BROUGHTON: No. I'm saying that the percent retention is about the same, 20 percent.

COMMISSIONER BERNTHAL: Oh, I see. I see, okay.

CHAIRMAN PALLADINO: So they keep the ratio.

MR. BROUGHTON: The ratio stays approximately the same. So what the bottom line is, we don't at this point in time really understand why the high volatiles are retained to this extent.

MR. McPHERSON: One other point that you might want to pursue with Jim is we have also noted that the noble metals, the retention of the noble metals down here, which you would expect to find closer to 100 percent, is less than 10 percent.

CHAIRMAN PALLADINO: What do you mean, noble metal?

MR. McPHERSON: The antimony, ruthenium and molybdenum. We have not found those metals outside the containment vessel, however, so we expect -- again, theorize -- that they have gone with other metals, have relocated themselves, associated with the steel, for example.

[Slide.]

I will move on now to the next photograph, which goes around to that row 13 and shows the wall of debris. That is simply looking in from the top of that diagram we were looking at before, where we saw a cliff of the debris material. That cliff is visible in this photograph.

[Slide.]

And we just turn a little to the right by looking at the next photograph, and we can see a penetration here which indicates, our experts say, that the weld of the penetration through the reactor vessel is in excellent shape. It looks like a new weld, as far as the experts are concerned.

COMMISSIONER BERNTHAL: This is now 86-72-3, No. 6?

MR. McPHERSON: That's correct, yes.

CHAIRMAN PALLADINO: Where is the weld?

COMMISSIONER BERNTHAL: If you can tell that's an excellent weld, you have better eyesight than I do.

MR. McPHERSON: That's what I said, too.

CHAIRMAN PALLADINO: What is that thing that seems to be going up to the right?

MR. McPHERSON: That is the penetration nozzle of an instrument.

CHAIRMAN PALLADINO: I see.

MR. McPHERSON: And it is the weld that we are concerned with there where that interfaces with the vessel.

[Slide.]

The next photograph indicates the wall having essentially encompassed an instrument penetration tube.

CHAIRMAN PALLADINO: Can I ask you a question? The penetration, you say, is about an inch and three quarters? And what is the 4-inch part above it?

MR. McPHERSON: That is a guide tube through which the instruments are allowed to move. It doesn't have any particular importance to us except to indicate that there has been no damage to those that we can see. Even this one which has been wrapped around by the debris does not appear to be damaged.

CHAIRMAN PALLADINO: The guide tube.

MR. McPHERSON: Yes, sir, the guide tube and the --

CHAIRMAN PALLADINO: How about that lower tube? I can't tell whether it is damaged or just wrapped around the debris.

MR. McPHERSON: Yes. Our information from the experts is they cannot see any damage. Of course, we have got to remove that debris and look in behind eventually, but from the visible side there is no damage.

[Slide]

We move now to a photograph which simply shows a size of one of the larger pieces of debris. There is a light cord and light handle shown on the lower left of that photograph. The handle is about four inches long, and the idea here is to show that larger piece of debris must be about 6-1/2 inches long by 4 inches wide, perhaps, something which --

CHAIRMAN PALLADINO: How can you tell it's a single piece?

MR. McPHERSON: Well, it looks a single piece, I guess, is all I could say. Any other evidence that it's a single piece, Jim?

MR. VAUGHAN: I think what you are seeing is the lighting highlights on the irregular surface on the second piece, kind of like a chunk of a rock.

MR. McPHERSON: They do move the light around so that while they are looking at it they get an idea.

[Slide.]

In the next photograph we are now looking up at the diffuser plate, the one through which the flow passes normally up into the core, and you will see some debris hanging down out of this hole. We have seen several holes like this with debris hanging from them. We have put the camera up into at least two holes, and we see some debris hanging up on that plate, and we are also able to see holes above in the next plate above and see no damage to those holes.

Now, the access we have had is very limited, so this is not a generalization, but anything we have seen does not show damage.

[Slide.]

I am going to go through what we believe to be the evolution of the accident following a pressure history. In any kind of experiment or accident where temperatures and pressures are changing, a pressure history is a very meaningful way to follow that. We see a lot of things showing up and see events take place by the changes in the gradient of the pressure, and this in megaPascals we see, and as you were pointing out, Mr. Chairman, if one multiplies by 145, you get it in megaPascals into psi, or better still, the 15 megaPascals is roughly 2200 psi, the operating pressure of the reactor when the accident was initiated, and the 5 is down around 700, 750 psi. So we are wandering around between 750 and 2300.

During the first hundred minutes of the accident, as you know, the PORV was stuck open and we were continually losing inventory from the primary coolant system. The HPIS, the high pressure injection system, was from time to time turned on and throttled into different degrees, so there was a tiny flow in but a very significant flow out of the primary system from the PORV.

At 100 minutes, because of the continuing loss of inventory, the pumps began to vibrate to the point where it was decided they had to be shut down, and of course, at that time the inventory was that low that when it settled out, the water separated from the steam, the core was already beginning to uncover. Now we see the pressure continuing to drop because now it is relieved by steam flowing out of the PORV and you can relieve a higher volume flow rate with steam rather than two-phase water and steam, so the pressure drops more quickly.

At about 110 minutes, the fuel failures began, and the crew began to pick up indications of released fission products. When we get down to the 130-minute point, a block valve was closed. At that point, of course, it stopped up again, and because steam is still being generated in the core, the pressure began to rise.

We were into significant zircalloy oxidation at that point, and at about 160 minutes, that was exacerbated as the zircalloy reached higher temperatures up at the point where it starts to really burn. The temperature rise increases dramatically at that point. As Jim has pointed out, I'm sure it's burning up. And at a point right where Jim will indicate there, the B pump was turned on.

Now, it was turned on for five minutes, but there was only water in that pump sufficient to provide a few seconds of flow. As that flow passed up through the core, considerable amount of vapor was generated, and that caused the higher rise rate in pressure. But since there was just a flash of water passing through, the rise rate dropped again, and you see it peaked out up at the top and returned to the same rise rate as we had way back before the zircalloy started to burn.

At the very top pressure point, the block valve was reopened, and of course, that dropped the pressure and it continued to drop and the HPIS was brought on, which even dropped it further because that is cold water dropping into hot steam. It condenses the steam and the pressure drops more quickly.

Down at the bottom of that slope, the block valve was closed -- Jim has got it. The block valve was closed, so you see the pressure rise again at the same earlier rate. Then we believe the core relocated to the lower plenum. In other words, a slurry of the core mixture flowed down from within the core into the lower plenum through the holes in that core support structure that we saw earlier.

That, of course, generated steam, which caused the pressure to rise by approximately 1.5 megaPascals, 200 to 250 psi. And then that died away again because the slurry of molten fuel would by then have been surrounded in a vapor layer, which does not generate much steam. It is just a vapor layer sitting quietly in the bottom of the lower plenum and slowly cooling off.

In fact, as I will point out later, that cool-off period occurred over a period of many tens of hours.

CHAIRMAN PALLADINO: Did you say earlier there was water in the bottom plenum?

MR. McPHERSON: Yes, sir.

CHAIRMAN PALLADINO: How far up?

MR. McPHERSON: At the time this relocated, we believe the core was essentially covered. The core material was covered.

CHAIRMAN PALLADINO: When?

MR. McPHERSON: At 227 minutes. It is not marked on there, but where the arrow points to core relocation, that, i fact, is the 227-minute mark.

COMMISSIONER ASSELSTINE: So the melting really occurred between 7 and 8 o'clock.

CHAIRMAN PALLADINO: Between what?

COMMISSIONER ASSELSTINE: Between 7 and 8 o'clock.

MR. McPHERSON: That melting, yes, sir.

COMMISSIONER BERNTHAL: That occurred at that point, though, because you had a large mass that could not be effectively cooled even though the vessel was full, essentially.

MR. McPHERSON: That is correct. I will come back to that.

This is sort of the end of what we know. Now I will get into what we think happened through that sequence again. I know you have heard some of this before from GPU, and I apologize for repeating, but I know it is helpful to have these things repeated.

COMMISSIONER BERNTHAL: I guess Commissioner Asselstine has heard some of this for about the six hundredth time, but it is quite all right.

MR. McPHERSON: He clearly enjoys it, I can see.

COMMISSIONER ASSELSTINE: There are new interesting wrinkles every time.

CHAIRMAN PALLADINO: Some of us need refreshers anyhow.

COMMISSIONER BERNTHAL: We do learn more, though, as we go along.

COMMISSIONER ASSELSTINE: That's right.

MR. McPHERSON: One last piece of evidence is shown in this next slide.

[Slide.]

There is a grid overview here, but in fact what we are showing is the temperatures which are actually measured in the lower plenum. Within that shaded area, we have found that all of the thermocouples which came up through the instrument penetration nozzles have rejunctioned, that is, formed a new hot junction down where they were melted, or saw high temperatures. In fact, around about 2200 K, a thermocouple will typically rejunction. These thermocouples do. And all of these rejunctions are inside that area and they all show these temperatures which are very high -- and incidentally, they showed them at a time beyond the 227-minute point.

CHAIRMAN PALLADINO: Did I hear you right? Did you say that it forms a new junction at 2200?

MR. McPHERSON: Yes, sir.

CHAIRMAN PALLADINO: Well, these temperatures seem lower than 2200.

MR. McPHERSON: Yes, sir.

CHAIRMAN PALLADINO: So what are they telling us?

MR. McPHERSON: What we are telling us is that the fuel flowed down into the lower plenum and caused new junctions to form down there, and subsequent to that reformation, these are temperatures which they then read.

MR. VAUGHAN: That means it is functioning again.

MR. McPHERSON: They are refunctioning.

COMMISSIONER BERNTHAL: Was that unexpected at all? I guess I asked the same question of INEL. I can't remember what they told me. These things really can melt and then cool back down and give accurate temperature readings after reforming?

MR. McPHERSON: Yes, sir.

COMMISSIONER BERNTHAL: Was that unexpected?

MR. McPHERSON: No.

COMMISSIONER BERNTHAL: It was not unexpected.

MR. McPHERSON: I can't say at the time of the accident whether -- I don't think they were expecting anything of this nature. But in all of the severe fuel damage work that we have been doing in PBF, for example, and in the LOFT program, rejunctioning is a standard practice.

CHAIRMAN PALLADINO: You used the word "accurate." Are they accurate? You didn't have any calibration, did you?

MR. McPHERSON: They are relatively accurate. Do you have a comment on that, Jim?

MR. BROUGHTON: We found in the PBF test that the new junctions formed during the high temperature portion of the tests, then when the tests are terminated and the bundles are reflooded, the new junctions will measure very closely the temperature of the water that comes in and saturation temperature. And it is nearly as accurate as a calibrated thermocouple.

CHAIRMAN PALLADINO: We are not going to melt cores to get good thermal couples. Okay. Go on.

[Slide.]

MR. McPHERSON: We will move now to what we understand as the scenario. We will start at the 174 minute point, and that is because the pumps were turned on at 175. THe idea here is this was just before the pump was turned on.

At this point, we believe the coolant level was at about two feet above the bottom of the core.

CHAIRMAN PALLADINO: I'm sorry. What point in time are we looking at?

MR. McPHERSON: 174 minutes. It is in the heading.

The liquid level at that point in the core is about two feet. We are quite certain of that because the self powered neutron detectors of which there are hundreds in this core, but at any given layer, there are 52, any given level, and at the lowest level, those self powered neutron detectors had not alarmed. We know those alarm -- there are a couple of alarm points, which we have discovered since the accident and gone back and have been able to interpret the accident on that basis.

Based upon that information, I will just briefly say that we know that this level was covered at the one foot, one and a half foot level. We assume then that the level was approximately two feet.

Below that, we still have intact fuel rod stubs. Of course, at the top of the core, we have highly oxidized rod like geometry and intermediate to that, we have had the melting going on of the control rod materials, then the zircaloy, and then the liquifaction of the UO2 from the zircaloy which has all been falling down to the liquid level, forming a solidified crust at that liquid level, and building up a rather solid mass of a mix of the core materials.

Once again, our SPND's and our intermediate and source range detectors corroborate this fuel movement. This comes from looking back at the data that was recorded at the time.

[Slide.]

MR. McPHERSON: We move to the point when the pump was turned on. Of course, the highly oxidized zirc is immediately shattered by the water passing up through it. Starting at the top, we have still some oxidized rod stubs right at the top. We have a debris bed now of oxidized and previously molten fuel rod materials which have fallen down on top of that building crust that started near the bottom.

Within that, is relocated and partially solidified core material, which will continue now to heat up, even though it is covered with water.

We have performed calculations to confirm that such a mass cannot be cooled by surrounding water.

CHAIRMAN PALLADINO: It apparently wasn't porous so that the water could get up in between?

MR. McPHERSON: Not sufficiently porous. If it were, it would be that hot that above the frost point, it would be blocked by a vapor that would form quickly.

COMMISSIONER ASSELSTINE: The water just couldn't get in it?

MR. McPHERSON: That's right; yes.

As that heated up, of course, it grew in magnitude as far as the liquified portion was concerned and either melted itself through the crust or dissolved itself through any UO2 that was in that lower part of the crust. That will only be known after we obtain samples from that area.

[Slide.]

MR. McPHERSON: Moving on, we have what we believe to be the end state conditions. Beginning at the top then, we still have the oxidized rod stubs, the core void region, the debris bed, the crust surrounding in there, the volume which once was liquid and which has eaten itself into the lower plenum. The state of the core support assembly, however, is unknown. While it is shown as perhaps somewhat broken up there, we have no evidence that has been broken up. As I mentioned, everything we have seen indicates no damage.

COMMISSIONER BERNTHAL: But that's a fascinating point in itself, because there are two key elements here that prevented this thing, I guess, from being catastrophic. One is the fact that you kept water just above one or more of these plates, I guess. I don't know what the technical term is.

CHAIRMAN PALLADINO: Where was the lowest point of water?

MR. McPHERSON: About two feet.

COMMISSIONER BERNTHAL: It was two feet from the bottom of the core. For reasons that weren't clear, I guess, even to INEL, maybe they are by now, even though the melting point of that steel in the plate is lower than the 5,000 degrees of some of the core material, stop me if I am wrong here, by whatever the heat transfer mechanism was, obviously it was pretty good, you still managed to ooze that molten material through the plate without very much damage. That is a rather surprising thing.

MR. McPHERSON: Yes. Just to give you a little more information on that, recall that pressure rise that we saw at the 227 minute point, that was about 250 psi, let us say, and took place over an 18 second period. That would suggest that this relocation, the flow out down through these holes occurred in about that time, 18 seconds.

COMMISSIONER ASSELSTINE: Because it dribbled down through and then there was enough water there, it cooled by the time it hit the bottom?

MR. McPHERSON: Well, cooled enough that it formed a cold outer surface, let's say, like pipes in a lava flow, and probably formed some solid plates which we saw down below and when we looked in the lower plenum, were pushed along as it oozed out.

COMMISSIONER BERNTHAL: It also broke up so that you could get more cooling.

MR. McPHERSON: Yes, get more coolant to it.

COMMISSIONER BERNTHAL: It ran it through a sieve, in a crude sense.

MR. McPHERSON: Yes, which would suggest that under this circumstance and in any future accident, any hypothesized accident, given there is water, given there is a sieve like core support assembly, this kind of thing would normally happen, as I said, we see no damage to the inner liner of the plenum, which is stainless steel, of the lower plenum, and those temperatures we showed you, they were very close to the melting point of stainless steel.

There is some corroborating evidence now, recently produced from the self powered neutron detectors and from the source range detectors outside the reactor, which have been interpreted to indicate the flow of the core material down to the lower plenum at this time, 227 minute point.

COMMISSIONER BERNTHAL: The message, and you can call it encouraging if you like, and I guess that is not a very good term to use about the whole incident, but the message that is somewhat extraordinary, at least to me, is how much a saving grace is, even a small amount of water that remains in the bottom of the vessel. There wasn't an awful lot left. We had to achieve the purpose of apparently maintaining those steel support structures barely intact and breaking up the molten material as it ran through those support structures. It is really a very key event in the progression of the accident.

COMMISSIONER ASSELSTINE: Was that due to turning on the pump, providing the water in there?

MR. McPHERSON: No.

COMMISSIONER ASSELSTINE: That was the water that was in there?

MR. McPHERSON: Yes. That pump that was turned on only supplied a very small amount. In fact, that is what broke up the upper core to give us the mess we saw later. It is supplying HPIS and feed water.

COMMISSIONER BERNTHAL: I was under the impression that stuff that was oozing through the stainless structure there, that was considerably above the melting point of stainless steel. I believe that is what I was told.

MR. McPHERSON: Yes. I believe it was, too. I was referring to the temperatures that were measured in, once it got down there and the hot junctions performed a virtual junction down there.

MR. VAUGHAN: But the water cooling was sufficient to keep it from eroding or melting the stainless steel, which shows the whole thing happened in a flash.

COMMISSIONER ASSELSTINE: The water was really due to the HPI flow, something turned on HPI?

MR. McPHERSON: Yes.

COMMISSIONER ASSELSTINE: If they hadn't turned on HPI, I take it then you would have had the molten blob that hit the bottom?

MR. McPHERSON: Yes. Then it is questionable what would happen, but certainly it is a new ball game there.

COMMISSIONER ASSELSTINE: Exposing the blocked valve and turning on HPI.

MR. VAUGHAN: More precisely to Commissioner Asselstine's question, do we know that turning on the high pressure injection is what put all the water in the bottom or was some of it there any way?

MR. McPHERSON: I see.

MR. VAUGHAN: I think that is the point he is asking. I'm not sure that the HPI flow made up the total amount that was in the bottom. I think it did not.

COMMISSIONER ASSELSTINE: Yes.

MR. McPHERSON: Mr. Vaughan is correct. There was water to begin with and there always was water down there. The HPIS was on and off and we still don't know the real history of it.

MR. BROUGHTON: I would like to add there is evidence that the HPIS was throttled back from its nominal flow, and what is significant here is with water in the lower plenum, a significant fraction of the core relocated into the lower plenum, formed a coval configuration and the throttle flow from the HPIS maintained that material cool until force cooling was re-established at about 15.5 hours. I think that is a very significant thing here.

[Slide.]

MR. McPHERSON: I will just give you a summary of the estimated radioisotope distribution in the reactor. It's a rather busy slide. I think after we look at it a bit, things will follow.

The six locations that we are going to cover in the plant are indicated on the left. The different radioisotopes are indicated in the table. To begin with, the fuel and core debris within the vessel still contains a significant amount of krypton, that is calculated in the intact fuel rods, so that should be there. All other krypton did escape.

However, this cesium and iodine in the 30 percent ranges, higher than expected, as we implied before. There has been no tellurium measured. Strontium, 115 percent. What that is indicating is it seems to have concentrated up there in the core debris, whereas ruthenium and cerium -- while cerium is 100 percent, as you expect, ruthenium is low, and we mentioned that earlier.

Going into the vessel internals, the only thing that really shows up there is tellurium at two percent of its original inventory. There again, we expect the tellurium to bind up with metals, it normally is absorbed onto stainless steel, for example. Primary coolant system, while we see the cesium and iodine, that is shown up in the primary coolant and not much else.

In the reactor and auxiliary buildings, the sumps, again, the cesium and iodine show up strongly. They are very soluble and you would expect to find them in the water. Some tellurium and strontium were found there. In the rest of the reactor and auxiliary buildings and in the reactor building atmosphere, there is very little fission products to be found.

CHAIRMAN PALLADINO: What form was the iodine for it to be in the auxiliary building sumps? It wouldn't have been gaseous.

MR. McPHERSON: No. Cesium dioxide, the form now doesn't indicate how it was released, of course.

MR. BROUGHTON: The indirect evidence is that the iodine was transported as an iodide, probably cesium iodide, but there is no direct evidence for us to confirm that. We are continuing to evaluate just to try to build a stronger case to show that in fact it was cesium iodide, but it does appear to have been transported as an iodide.

COMMISSIONER BERNTHAL: Let me see if I understand. When you say 27, 33 for fuel and core debris, 45, 41 for the reactor and auxiliary building, et cetera, that means those reflect the 8 to 1 fission product ratio, as well?

MR. BROUGHTON: Yes.

COMMISSIONER BERNTHAL: So clearly, it didn't all get transported as cesium iodine.

MR. BROUGHTON: The cesium would not have been, no. Cesium hydroxide is very soluble in water and tends to go with the water.

COMMISSIONER BERNTHAL: I also understand, and I guess I keep thinking this should add up to 100. Where did the tellurium go?

MR. BROUGHTON: The tellurium, in the measurements reflected in this table, tellurium was not measured to any appreciable amount, and it is primarily due to at the time we made these measurements, we had not yet developed a technique to measure or separate the tellurium from the cesium, which tends to mask the tellurium in the sample. We are redoing those measurements now. We have done some measurements on the lower plenum debris which indicate that antimony is not retained to a significant amount in the lower plenum, in the debris we see there.

We believe that tellurium and the antimony have preferentially separated and segregated with metallic pressures which we have not yet found or examined.

COMMISSIONER BERNTHAL: The ruthenium?

MR. BROUGHTON: The ruthenium, there is evidence from George Parker's work at Oak Ridge that ruthenium also will preferentially separate with metallic structures. Again, we are finding that tellurium has been removed from these high temperature debris and is probably what those metallic structures -- or where we will find the tellurium and the antimony.

CHAIRMAN PALLADINO: All right. Are you ready to go on?

COMMISSIONER ASSELSTINE: I take it, in terms of the cesium iodide, you have not obtained a lot of information to let you know for sure one way or the other?

MR. BROUGHTON: The direct evidence is no longer available.

COMMISSIONER ASSELSTINE: Okay. All right.

[Slide.]

MR. McPHERSON: Okay. We will move on now to the conclusions that we've taken from the accident scenario. We believe we have a viable and consistent scenario for the accident. We now know sufficient that a scenario will provide a challenging benchmark for severe accident analysis codes and methodologies.

TMI-2 results indicate that small-scale severe accident tests such as those at PBF, ACRR, NRU, which they're performing in Canada, and the LOFT experiments most recently can be extrapolated to large plants.

CHAIRMAN PALLADINO: All aspects of it?

MR. McPHERSON: No, sir. I think the crux of the data that one develops in these small-scale experiments is very useful in developing in the codes and understanding the phenomena that we are seeing in TMI, and they will undoubtedly help us to get that whole picture put together in the end.

COMMISSIONER ASSELSTINE: What's the basis for that judgment? Was it both the correlation between these and the last LOFT results?

MR. McPHERSON: Oh, much more than that, Commissioner Asselstine.

I think the PBF results have been most helpful in getting the picture together, what to expect, how fission products interact with one another, what happens in candling. The whole scenario has been developed in small-scale in PBF, and that's helped us all from that point on.

Finally, a point that I think both you and Commissioner Bernthal were making, the relocation of the molten core into the lower plenum results in a coolable debris for accidents such as occurred at TMI-2 with the lower plenum full of water.

COMMISSIONER ASSELSTINE: On your second bullet there, do you think that you now have that benchmark in place, or is still something that you have got to develop?

MR. McPHERSON: We're still developing it, but we're getting close, and I will come back to that in a second to tell you where we are in it.

[Slide.]

This is perhaps a little on the side, but we have been doing an instrumentation and electrical program which is essentially finished, and I knew you wanted to know the results of all of our R&D, so I've listed them on this one graph, the results of that program.

Most of the instrumentation which failed did fail within 24 hours, and it was due generally to moisture intrusion. There was no functional damage caused by the hydrogen burn which occurred.

CHAIRMAN PALLADINO: These are instruments in the containment?

MR. McPHERSON: Yes, sir.

The use of radiation-sensitive transistors in some instruments does cause functional failure. Off-shelf components are less reliable, and recommendations are being developed for standards to apply in containment instrumentation.

CHAIRMAN PALLADINO: What do you mean, they are less reliable? You mean they failed sooner than 24 hours?

MR. McPHERSON: Yes, sir. Well, they fail sooner than others, let's say. Those which met different standards

-- let us say, military standards, for example, military specs -- lasted much longer.

There is a report out on that which is in the Staff's hands, so more details are with you.

COMMISSIONER ASSELSTINE: Which instruments or components were designed to, say, military specifications as opposed to a commercial off-the-shelf?

MR. McPHERSON: I can't give you any information on that.

COMMISSIONER ASSELSTINE: Okay. But I take it, there were some in the plant.

MR. McPHERSON: Yes.

COMMISSIONER ASSELSTINE: Okay.

MR. McPHERSON: In-core thermocouples always give useful information, as you've brought out here, in spite of the virtual junction formation above the 2200, and we have developed a circuit diagnostic system for normal maintenance which is now being put to use in some commercial plants at this very time for maintenance, on-the-job maintenance of the circuitry.

COMMISSIONER ASSELSTINE: Are those results being fed back in through EPRI or otherwise into the utility EQ programs?

MR. McPHERSON: I believe they are, sir, yes.

[Slide.]

Now I'm going to change the subject slightly. To meet the program objectives that I mentioned right in the beginning, I am going to just list the basic information required, and from that, show you or give you a list of the kinds of things we're doing in the future program.

We need to know the system configuration and the operator actions that were taken at the time, the plant initial and boundary conditions, the peak temperatures, material interactions and extent of material oxidation. We need to know the relocation, the structure, and the composition of the core materials.

[Slide.]

The effect of control and burnable poison rods, damage to control support assembly, the instrument structures and to the reactor vessel lower head, and we need to know the retained fission products and chemical form.

How are we going to find out that information?

[Slide.]

We go on now to the mechanisms that we have to obtain that data. We have visual and we have acoustic inspections. I will show you some photographs relevant to those in a second.

We will be acquiring core bores, drilling down and taking drill cores of the core. We will be defueling, of course. We are defueling. We have defueled about 8 percent of the total core at this time; GPU has, I should say.

COMMISSIONER ASSELSTINE: Is that mostly the loose stuff on the top?

MR. McPHERSON: Yes, sir.

[Slide.]

The other mechanisms we have are the physical, chemical, and radiochemical examinations of the core samples, and perhaps I shouldn't take your time to enumerate them, but you can see them laid out there, various core components right through, and finally the basement sludge and concrete drill core bores taken from down below in the sump.

CHAIRMAN PALLADINO: With regard to core defueling, there are parts of it, if I remember, you said you really don't know the conditions, and you're going to have to have a chopping tool possibly?

MR. McPHERSON: Yes. I'll be showing you the core bore, the drill machine we have coming up now, and there are many tools that GPU has developed, which I think they mentioned at their last meeting with you.

And, of course, finally we will be evaluating and qualifying the online instrumentation, and we are continuing to do that.

[Slide.]

The next slide is just to give you an indication of a summary of the prioritized sample acquisition and examination tasks we have. I have no intention r' chrough them all for you, but you can see, we're going to be looking at everything that deals with those different topics I've just mentioned.

CHAIRMAN PALLADINO: Will you be able to get information from all the samples that you have planned?

MR. McPHERSON: At this point, it still looks as if we can.

CHAIRMAN PALLADINO: With the funds available.

MR. McPHERSON: Well, the funds are available, and it's just a question of being able to locate those samples. At times, they are difficult. GPU is not having an easy time getting at some of the particular fuel bundles and control rod materials that we would like, but we're working together with them to try to do that. If we miss something, we pick out something else to go for, and so far it's working out.

COMMISSIONER BERNTHAL: Is there a constant and thorough, complete communication and interaction between you and GPU on methodology, procedures, exactly how best to get at the data? This is a little bit like a postmortem here, and you don't want to -- you want to go at it in a way that I trust the scientific community now reaches consensus on. I hope that's the way it's working.

MR. McPHERSON: Yes. We are using the assistance of the scientific community to assist us in selecting this program. But as far as the work goes, we are very closely coordinating our interests with the work that is ongoing at the Island. And this is why Mr. Vaughan brought to your attention our continued presence on the Island. That is very -- it's essential to continue to work together so closely to get the samples that we need. GPU is certainly very much in support of our program, and therefore trying their best to get the samples we want.

We have visits by Jim Broughton here every other week, I think, to discuss how things are going, and or course we have -- we're on the phone continually with him.

COMMISSIONER BERNTHAL: Well, that's good. I see some GPU people here, and I can't stress too much, I think, that the public interest in this thing really transcends the narrow interest or the narrower interest of the utility in this case, and I am sure they're very sensitive to that and hope that they work very closely with you and others.

MR. McGOFF: We've already received substantial support from GPU in terms of laying out the scientific program.

COMMISSIONER BERNTHAL: Yes, I trust that's the answer.

MR. VAUGHAN: And likewise, we're doing it in a manner which doesn't delay the defueling in an untimely manner either, because it's obviously important to continue to get the core defueled on schedule and get the fuel away. So it's a give-and-take, but it's been a good give-and-take.

CHAIRMAN PALLADINO: Earlier you mentioned a steering group. Could you tell us a little bit about the steering group, how many people, the spectrum of talent, how often they meet, what they give guidance on, for what it's worth.

MR. McPHERSON: Yes, sir. We have had actually three different names for groups that have been in place.

CHAIRMAN PALLADINO: How many names?

MR. McPHERSON: Three different groups have been in place as the program has evolved -- the Technical Evaluation Group. I've forgotten the name of the second one.

MR. BROUGHTON: The Industry Review Group.

MR. McPHERSON: Industry Review Group. And now we have an Accident Evaluation and Review Group. This has evolved with the form -- as we have formulated our program.

The people involved, though, the representatives, the people represent industry, always EPRI, IDCOR, B&W, GPU, and universities, the NRC and DOE.

CHAIRMAN PALLADINO: I was trying to connect this to the question that was raised about getting scientific input on making sure that you are taking advantage, maximum advantage of the opportunity that we have here.

Do you have independent scientists, or is that --

MR. McGOFF: The Chairman of the Review Group is Dr. Todreos. He's brought with him a group from the scientific community and the laboratories to review the program and to make sure that we're doing the right thing.

CHAIRMAN PALLADINO: Well, I don't want to dwell on it.

MR. BROUGHTON: And I would like to add one other thing, Mr. Chairman.

We also bring together groups of specialists when we have significant results. Last March, we had the first evidence of fuel melting in our examinations of the debris from the upper plenum, and we brought together a group of well-respected metallurgists with a great deal of experience in UO-2 fuel, light water reactor safety research to review those results and to see if they concurred with the conclusions we had obtained at Idaho in our evaluations, and we will continue to do that as other technical results come about that warrant such a review.

MR. McPHERSON: If we can move on, if there are no further questions, I have some photographs here to back up what I was saying earlier.

[Slide.]

A photograph of the core bore hardware, which has been tested in Idaho. It was designed by the oil industry and is typical of the technology used in drilling for oil, and it uses drill bits which will go through concrete and steel and any other substance whose nature we think we understand in the core.

It is a very sturdy piece of equipment. It has been well tested and is about to be set up over the core at TMI to start drilling those samples we mentioned.

The way in which it functions is shown in the next slide, and I won't dwell on it but just to say we can drill right down through as far as we need to.

[Slide.]

COMMISSIONER ASSELSTINE: And no further.

MR. McPHERSON: No further. It is physically limited. We have some strong constraints from GPU. They will not go into the lower plenum and touch that lower plenum material at this point.

MR. McGOFF: They won't allow us to bring more drill bit into the containment than would reach a certain depth.

COMMISSIONER BERNTHAL: I can understand that.

[SLIDE.]

MR. McPHERSON: We will be doing an acoustic topography measurement to help us understand the topography of the crust.

[Slide.]

That takes us on to how we put this whole thing together. I don't want to dwell on this one either. I have told you that we are continuing to look at the end state of the reactor system and the on-line data, and we are doing independent severe accident -- using the results from independent severe accident research, all feeding into an analysis group, an evaluation group which is putting this whole picture together using codes, developing the necessary models, and in the long run, we, of course, hope to have a comprehensive TMI accident scenario.

As this is proceeding -- and now we are getting to a qeustion that the Chairman raised earlier -- we are getting to the point where we are able to formulate the TMI standard problem.

[Slide]

By that I mean we are able to define the initial and end conditions, the uncertainty in the various data that we have measured, and we are able thus to provide that information to different code users to attempt to understand, to benchmark their codes against this accident, and thus compare the behavior of the codes, get more insight into the accident. And you can see there would be some feedback to understanding the accident, as well as the most important thing, arriving at an independent consensus by the various participants.

We are nearing the point where we will be able to perform the standard problem, or benchmark problem is a better way to put it since standard problems are normally well-designed experiments that you apply to codes.

COMMISSIONER BERNTHAL: I was going to say I hope this is a rather unique problem, not a standard one.

MR. McPHERSON: Yes. We are using the word "standard" only because it is standardized and we have a methodology for getting people together.

MR. VAUGHAN: It is a reference problem.

CHAIRMAN PALLADINO: What are you going to do, develop codes and methodoligies that would predict what you found?

MR. McPHERSON: Yes, sir.

MR. VAUGHAN: And can be then used to predict other scenarios based on having been correlated to the factual evidence.

CHAIRMAN PALLADINO: Good.

MR. McPHERSON: Of course, we have many codes and they are proliferating now around the world, and many countries are interested in taking part in this. Mr. Vaughan alluded to this earlier. We have invited the OECD, the CSNI of the OECD -- do you know those initials all right? -- to sponsor the meeting of all interested countries to get together to define the standard problem with us. We then will be able to all work from the same data base and go home to our different countries and do these calculations, come back and discuss the results.

I can't emphasize more the importance of having an independent assessment of both the accident and their codes so that they together can come up with a consensus of how good their codes are and how much we understand this accident, what phenomena need to be studied further.

The first meeting of that group will take place in Idaho at the end of April this year, and we expect then to have the standard problem available for them, the defined problem, let us say, the initial boundary conditions of the accident, available to them by September of this year.

I am sure it will go on for one to two years because we are only going to be getting more and more data over the next two years from this program, as we will see at the end when we get to the schedule. I would hope, then, that there would be feedback from the data that we develop in our program to the severe accident standard problem participants.

We have had initial indication of strong support for this program and are anticipating probably eight countries will be represented and be running this problem.

Incidentally, they will also be asking for different samples from the core to analyze those in their hot shop, in their hot cells in their own countries, and dividing and sharing the data that they obtain, with us and each other.

[Slide.]

My next Vu-graph shows the research methodology. I won't spend long on it, but I have an important point to make. You are well aware of the approach we take of separate effects models going through to reactor system models and applying that to technical issues and eventually an acceptable reactor system model. Of course, the research that feeds that stepwise methodology starts with separate effects experiments, reactor system simulations, and all feeds into the end result.

TMI, you see, as indicated in the lower part of this Vu-graph, that oval indicates how TMI fits both into the separate effects programs, the reactor systems and directly into the technical issues.

Now, I thought it important to point out that this isn't the whole story. I don't believe that we will get that end arrow, that end balloon with all of the data that we have provided so far in your severe fuel damage program, nor from TMI. There are bound to be some voids in our knowledge, and unfortunately, we have no facility, no significant reactor facility in this country remaining operable now. PBF and LOFT are shut down. You have ACRR, but that is a very small facility.

I want to emphasize that we must keep our connections up with our international friends. There are still reactors in this world capable of doing experiments of the nature that will get us to that end point, and we must maintain our good relations with those other countries.

I think the standard problem is one way in which we do it. Clearly, we win in many ways. One, we have facilities to gain additional data from, but we have an independent approach which can't be faulted by, let's say, the intervenors if the question comes up as to parochial funding. If the world is together on the conclusions we come up with, I think that lends strong weight to the results.

COMMISSIONER ASSELSTINE: But what you are saying is now in terms of research facilities, we are totally dependent upon facilities overseas.

MR. McPHERSON: Aside from Canada, which is not quite overseas, but yes.

COMMISSIONER ASSELSTINE: Outside the U.S.

COMMISSIONER BERNTHAL: I'm tempted to say tell it to OMB.

CHAIRMAN PALLADINO: It is an unfortunate situation, but I guess we are not here to solve that.

MR. McPHERSON: No.

CHAIRMAN PALLADINO: I would like to see if we can adjourn by 4 o'clock.

MR. McPHERSON: We are at that point, yes.

[Slide.]

The program schedule is laid out here, and I don't need to go through each item. It is only to show you that in the mid-'87 to end of '88 calendar years, we will be really reaping the benefits of this program.

CHAIRMAN PALLADINO: Will you be doing testing in 1987, sample testing?

MR. McPHERSON: Sample examination, yes, that's correct.

CHAIRMAN PALLADINO: And in 1988 also?

MR. McPHERSON: And in '88.

CHAIRMAN PALLADINO: Then does your funding cease? Is there nothing after '88?

MR. McGOFF: On the TMI program, yes, sir. We probably will carry on some additional on the TMI-3 under the base program, as Dr. Vaughan mentioned earlier.

CHAIRMAN PALLADINO: The base program. Whose --

MR. VAUGHAN: Our base safety and licensing R&D program.

CHAIRMAN PALLADINO: And you will carry that on beyond '88?

MR. VAUGHAN: If it looks like there is more to learn, yes.

CHAIRMAN PALLADINO: I thought even your base program was going out of existence.

MR. VAUGHAN: We were not planning to take it out of existence.

CHAIRMAN PALLADINO: Good. I'm glad to hear that.

MR. VAUGHAN: It is not as broadly funded as yours is, Mr. Chairman, but it is about an $11 million effort for basic R&D licensing effort.

CHAIRMAN PALLADINO: When I read in the trade press, I get the impression that everything you are doing is related to military.

MR. VAUGHAN: I think that is an overstatement by the trade press in what you are reading. I know NRC doesn't have those problems, but we occasionally do.

[Laughter.]

[Slide.]

MR. McPHERSON: I probably should conclude at this point by a simple statement. The TMI accident has enhanced our understanding of severe accidents and source term phenomena. The accident will provide an important, unique benchmark of severe accident codes and methodologies, and the accident provides a unique research opportunity: a severe core damage accident in a full-scale plant.

CHAIRMAN PALLADINO: Thank you. Let me ask you one question. I forget which slide brought it to mind. I guess I'm pretty sure not everything in the containment was environmentally qualified for the conditions it met. Apparently there were some off-the-shelf items.

Did they survive well enough to do their functions? Do you have any conclusions on that? You know, we are spending a lot of money on equipment qualification to make sure that it can function under the environment that we might expect, and I was really interested whether you got any clue from the experience at TMI on those items, terminal blocks, anything else that might be involved.

MR. McPHERSON: My comment is limited to my reading of that one report I referred to and would indicate that by 24 hours, there were a lot of instruments not functioning adequately, and therefore, I would support any program which would qualify instruments to operate in this conditions.

CHAIRMAN PALLADINO: I want to examine "not functioning adequately" just a moment. Had some of the equipment performed the function it was designed to perform or were you still expecting it to function during the course of the accident so you can have more information?

MR. McPHERSON: I think it is best I defer this, if you would like to ask someone from GPU to respond to that.

CHAIRMAN PALLADINO: Maybe you ought to give me the reference for the report and I might spend a little time looking at the report.

COMMISSIONER ASSELSTINE: I think that is a good idea. I think it would be useful to look at the report.My

CHAIRMAN PALLADINO: Maybe after the meeting.

MR. McPHERSON: I will call your assistant with it.

CHAIRMAN PALLADINO: Good.

Well, I found that a very useful and interesting presentation. I don't know if there are other questions or comments commissioners want to raise at the present time.

COMMISSIONER BERNTHAL: I have a quick question or two. It is probably too early to tell, but would you be so bold today as to characterize the quality, I guess, and perhaps quantity of the source term information that might derive from further analysis here? Would you say it is likely that this would be rather definitive or simply assist in our understanding? How would you characterize it at this point?

MR. McPHERSON: My reading of what I have learned from my one year on this project and talking to the experts is that it will qualify the data that we are producing from our more definitive experiments. It will support but in some cases surprise us. As Jim Broughton mentioned, in a big system things don't happen the way they do in a nice, well-coordinated and characterized experiment.

The existence of a variety of metals, a variety of atmospheres may certainly alter the source term or the fission product behavior, and those are the things that we will learn from the TMI accident.

COMMISSIONER BERNTHAL: It sounds like it is too early to tell.

One other question. I think it is fair to say this was a core melt accident. There has been an inclination not to call it that, but it is quite clear now that it was. Is it fair to say, then, that the step beyond where we are right now, that is, if we have had a fairly definitive, complete core melt accident within vessel, then I presume that it was this saving element of two feet of the core remaining underwater and perhaps the bottom structures remaining underwater as well that then formed the boundary between that and the next step of core on the floor, as some of our staff are wont to call it.

Is that a fair characterization of where we are in the assessment of the accident itself now?

MR. McPHERSON: I think that is a fair assessment, though whether the core would be on the floor or in less water, I don't think we can say.

COMMISSIONER BERNTHAL: Well, less or none. None probably is the more important question.

MR. VAUGHAN: I don't think we have the data to say that even if there had not been any water there, whether we would have breached the vessel.

COMMISSIONER BERNTHAL: No, you don't have the data and you never will, but one hopes --

MR. VAUGHAN: I hope we never get that data.

MR. McGOFF: I would take that lesson that only a small amount of water is sufficient for the progression, and then use that lesson in future reactor design to make sure we always have an amount of water --

COMMISSIONER BERNTHAL: Well, I guess what I am asking is, and let me put it this way, is there any reason to believe -- you know, you guys are the nuclear engineers, I'm not -- that if that small water inventory had not been there, that you would not then have had a continued progression, or is there reason to believe from what you have seen that the usual scenario that one imagines may not have obtained here?

Is it too early to say, or you don't know, or --

MR. McPHERSON: Too early to say.

MR. VAUGHAN: I think it's too early to say. I think we haven't done that analysis nor really looked well enough at the conditions of the structure in the bottom. Remember we are doing this with very remote, thin, TV cameras. It is too early to tell.

COMMISSIONER BERNTHAL: Is that thing accurate? I have been looking at that for two hours now. Is that supposed to be an accurate scale reproduction of how you see things at this point?

MR. BROUGHTON: It is a scale model of the vessel and approximately where the debris currently resides within the vessel.

COMMISSIONER BERNTHAL: It is a lot of debris. That is a lot more than I had actually pictured in my own mind.

CHAIRMAN PALLADINO: Let me ask a question not quite related to the subject but still somewhat related. Will DOE's reduced funding affect in any way the TMI-2 cleanup, at least so far as your activities or support are concerned?

MR. VAUGHAN: With respect to the TMI-2 program, the DOE funding is not reduced below what it was projected to be back in fiscal year 1986 when we augmented the funding for the fact that things had been delayed, so we anticipate in working with GPU that it will not affect the cleanup program.

To further amplify your question, some of the reductions in the advanced reactor development programs that you have been reading about in the trade press and budget documents primarily relate to having to use limited funds to meet some of our commitments for nuclear energy sources or military and defense programs such as SDI, but we are continuing to maintain fairly level funding for our light-water reactor programs, which include these and the other advanced light-water reactor programs that we are doing in conjunction with EPRI, that ought to lead, hopefully, to the certification of some of the advanced light-water designs that are being done by U.S. vendors in conjunction with Japanese vendors, or with some of the mid-sized advance light-water reactors in which a number of utilities have shown interest in terms of adding reactors to their utility system in smaller blocks than the 1000-megawatt reactors.

So those efforts are fairly level funded in our budget.

CHAIRMAN PALLADINO: I am glad to hear that you are maintaining the basic program in those areas.

Are there other questions that commissioners want to raise?

COMMISSIONER ASSELSTINE: Just a comment. I thought this was a very interesting presentation, and Jim, I think the points that you made earlier about the extent to which the core was contained with virtually no addition of cooling water for that long period of time is quite remarkable. It's a very interesting presentation.

COMMISSIONER ZECH: I would like to say too I thought it was an excellent presentation. Of course, you are involved in something that is not only fascinating but has a tremendous potential in many areas. I hope that when you wind up and as you go along, you will try to focus a bit on some of what you might call the significant findings.

I agree with Commissioner Asselstine. I think the fact that the core vessel itself, the reactor vessel itself obviously stayed intact and withstood a very significant temperature and pressure and so forth is what I would consider very significant and should be highlighted in some way from your research.

Also any other surprises. In other words, was there anything that we learned that really was new and perhaps could be considered something that would be in the form of something that you were rather surprised to find out? Any of the metals, any of the materials that reacted perhaps in that harsh environment differently than you might have thought.

And certainly lessons learned should be something that you should be thinking about all the time, it seems to me, and obviously you are, but certainly one of the lessons clearly, I think, is to keep the core covered.

COMMISSIONER BERNTHAL: A little bit of water goes a long way.

COMMISSIONER ZECH: Yes.

COMMISSIONER ASSELSTINE: The more the better.

COMMISSIONER ZECH: The more the better. But it really is, and perhaps there is something other that is less obvious than that, but lessons learned, I think, so that we can apply them to future operations to help our plants operate in a safe and reliable manner also might be something.

The only reason I emphasize this is because you are head down into all the technical details of it. I appreciate that and that is very important, but as you go along, you may come across some of these things that are important to take a little bit of note of at the time so that when we have finished all this, we will at least be able to boil it down to some valuable findings that we can use to make sure that this accident will benefit the public.

So those are the things I hope you will be focusing on because I think there is an awful lot to be learned here, and obviously we are learning a lot, and the GPU folks are learning a lot and I recognize they are actually doing the work, but I know you are working closely with them and with our staff, too, but I think we should try to focus on what we can learn. Although those are all fascinating things to you, I think from an operational and a safety standpoint, we should really try to make sure we pull out the lessons, and I would commend your effort to that as well as your continuing effort to get the most from your research.

MR. VAUGHAN: Certainly, Commissioner Zech, no lesson is more important than the basic one of if you can do a better job of keeping the whole core covered and not having any voids, then you never have the accident in the first place. My review and, I hope, your staff's review of some of these advanced light-water reactor designs that I mentioned just a few minutes ago show to me that a great deal more attention has been paid to that and that we would have had several orders of magnitude or margin of keeping the core covered in the first place than we had in the TMI-2 situation and may never have even had the event, which is the best lesson of all.

COMMISSIONER ASSELSTINE: Jim, I think that is a very good point there. You are absolutely right. There are some features in some of those advanced designs that clearly would provide substantial additional margins of protection to avoid getting into the accident situation to start with. That is a good lesson to be drawn from it.

CHAIRMAN PALLADINO: Thank you very much, gentlemen. That was a very useful session and we appreciated your coming.

MR. VAUGHAN: We appreciate your taking the time to spend two hours out of your valuable day to go through it because it is important to all of us.

CHAIRMAN PALLADINO: It is these kind of sessions that help give value to our day.

Thank you.

[Whereupon, at 4:07 p.m., the meeting was concluded.]

CERTIFICATE OF OFFICIAL REPORTER

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

Name of Proceeding: Briefing by DOE on R&D Results from TMI-2 Cleanup (Public Meeting)

Docket No.:

Place: Washington, D. C.

Date: Tuesday, March 11, 1986

were held as herein appears and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission.

(Signature) ______________________

(Typed Name of Reporter) Marilynn M. Nations

Ann Riley & Associates, Ltd.

SCHEDULING NOTES

TITLE: BRIEFING BY DOE ON R&D RESULTS FROM TMI-2 CLEANUP

SCHEDULED: 2:00 P.M., TUESDAY, MARCH 11, 1986 (OPEN)

DURATION: APPROX 1-1/2 HRS

AGENDA: JIM VAUGHAN
ACTING ASSISTANT SECRETARY FOR NUCLEAR ENERGY
U.S. DEPARTMENT OF ENERGY

- INTRODUCTION

DON MCPHERSON
TMI-2 ACCIDENT EVALUATION PROGRAM MANAGER
LIGHT WATER REACTOR SAFETY AND TECHNOLOGY OFFICE
U.S. DEPARTMENT OF ENERGY

- PROGRAM OBJECTIVES
- ACCIDENT SCENARIO AND END CONDITIONS
- ACCIDENT EVALUATION PROGRAM
- SCHEDULE

DAVE MCGOFF, DIRECTOR
OFFICE OF LWR SAFETY AND TECHNOLOGY
U.S. DEPARTMENT OF ENERGY

JIM BROUGHTON, MANAGER
TMI ACCIDENT EVALUATION PROGRAM
EG&G IDAHO, INC.

TMI-2 Accident Evaluation Program

Presented by:
Dr. G.D. McPherson
U.S. Department of Energy
March 11, 1986

P225-ALA86002-4A

Outline

- Program objectives
- Accident scenario and end conditions
- Accident evaluation program
- Schedule

Program Objectives

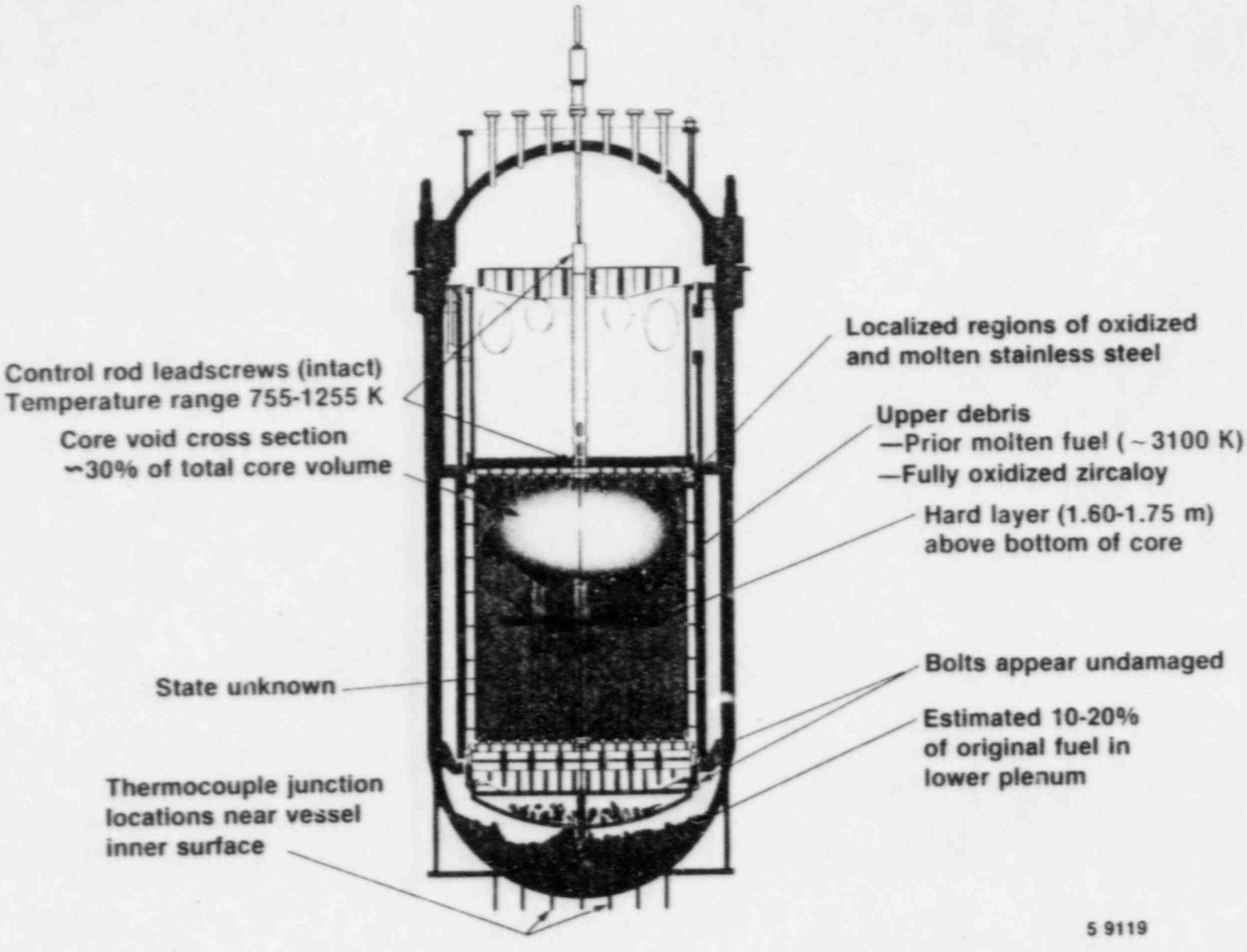
- Understand what happened during accident
- Apply understanding to resolution of severe accident source term technical issues
- Transfer results of program to government, nuclear industry, and public

P225-ALA86002-28

Accident Scenario

- Known conditions of core
- SCDAP analysis
- On-line instrumentation data

Known Core Conditions



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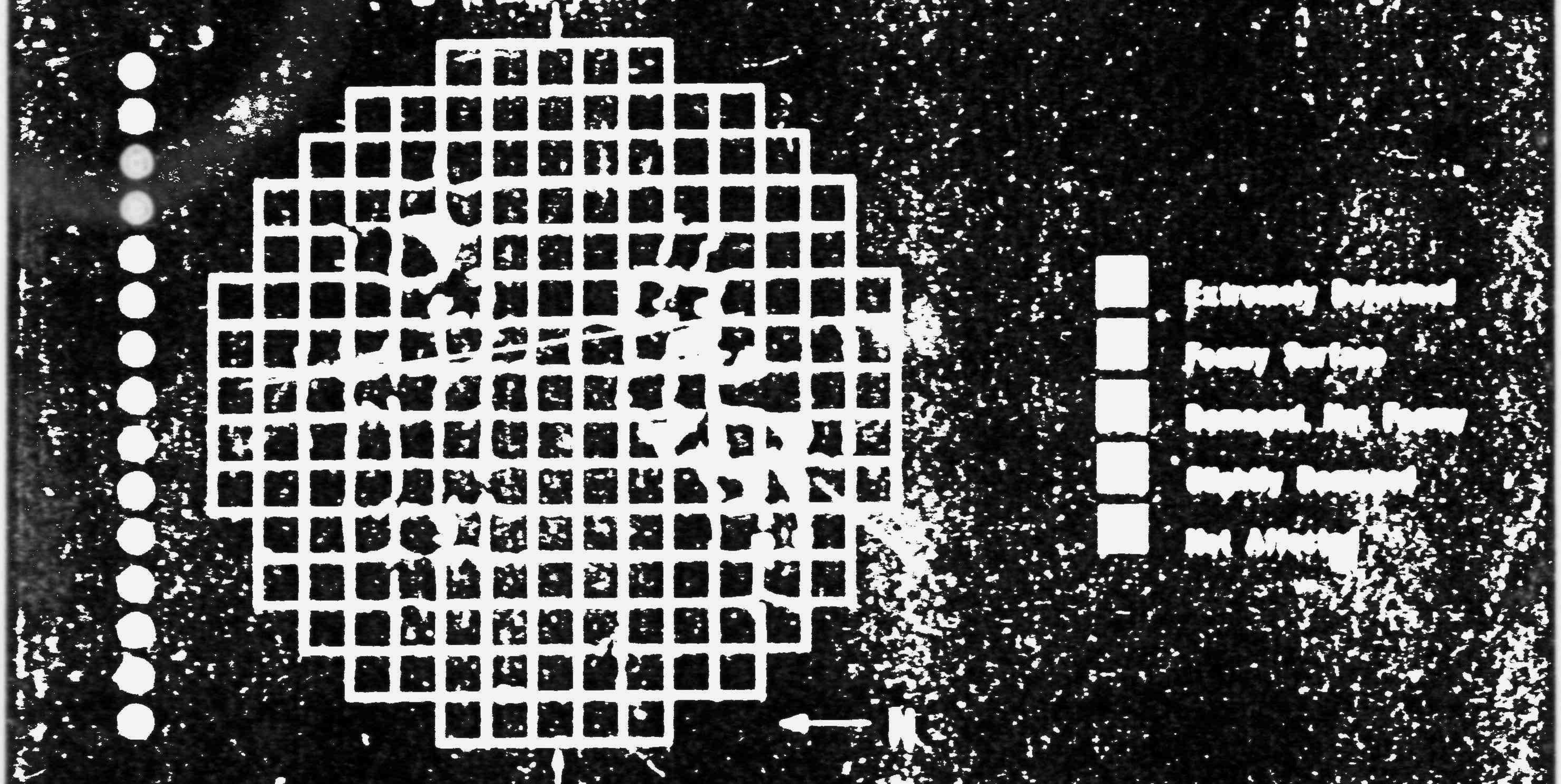
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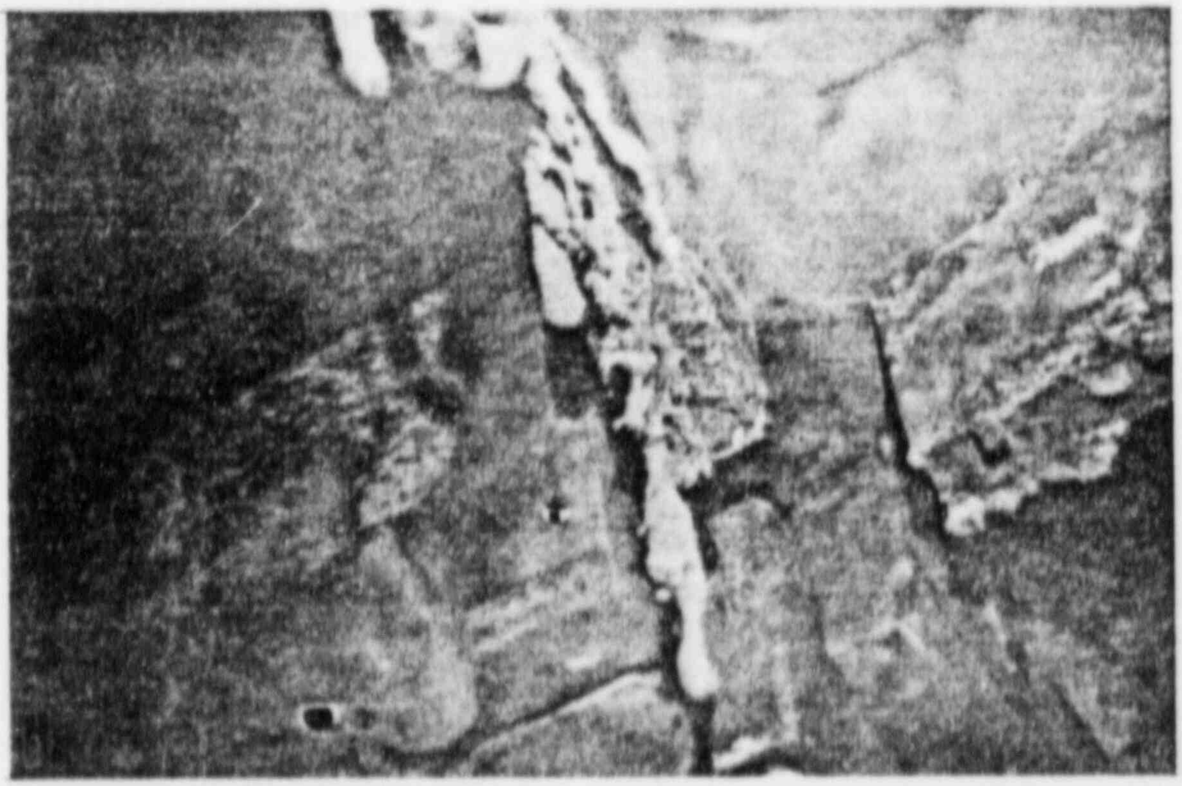
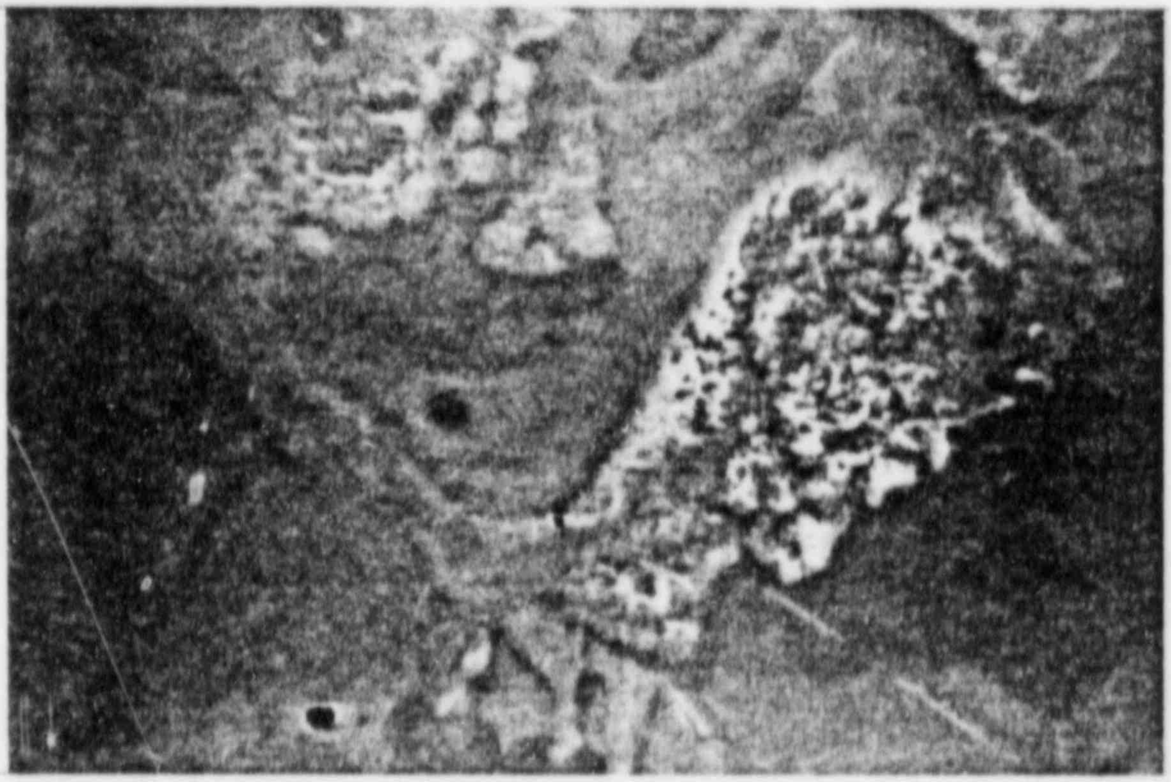
Foamy Surface
Deformed, Not Foamy
Slightly Deformed
Not Affected
N

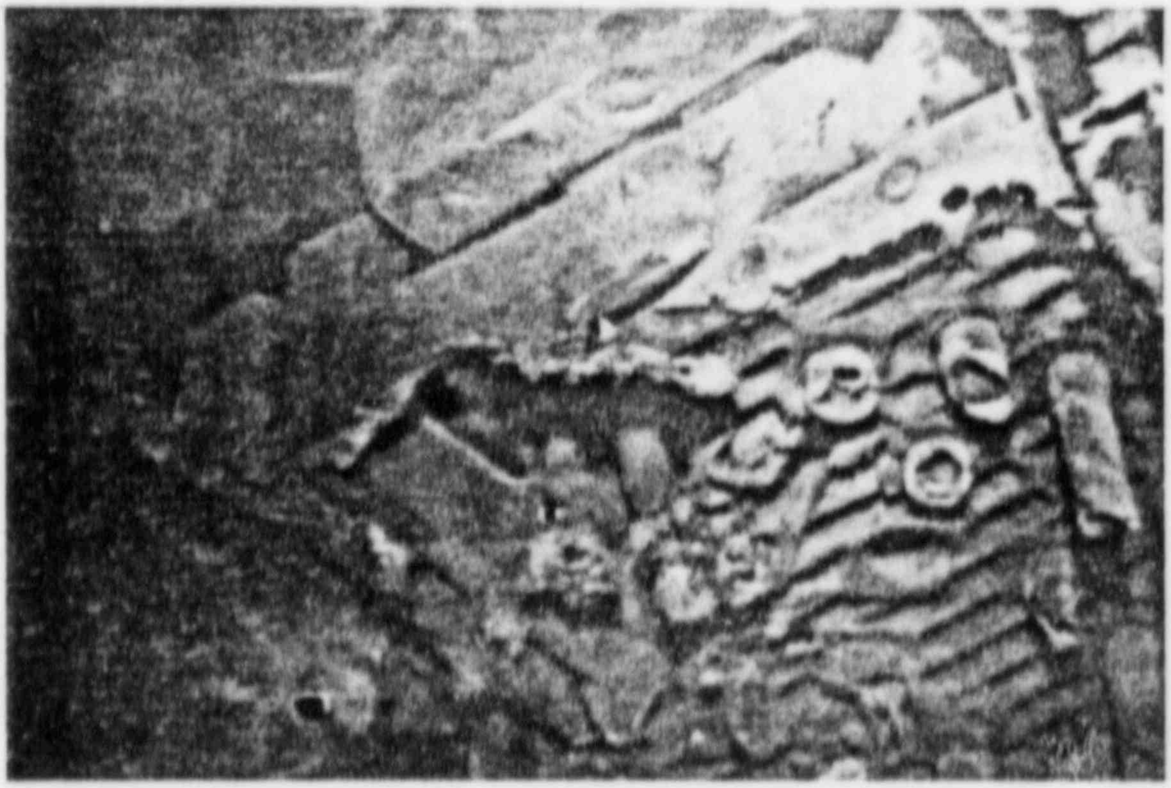
86-72-5, #12 Upper grid structure



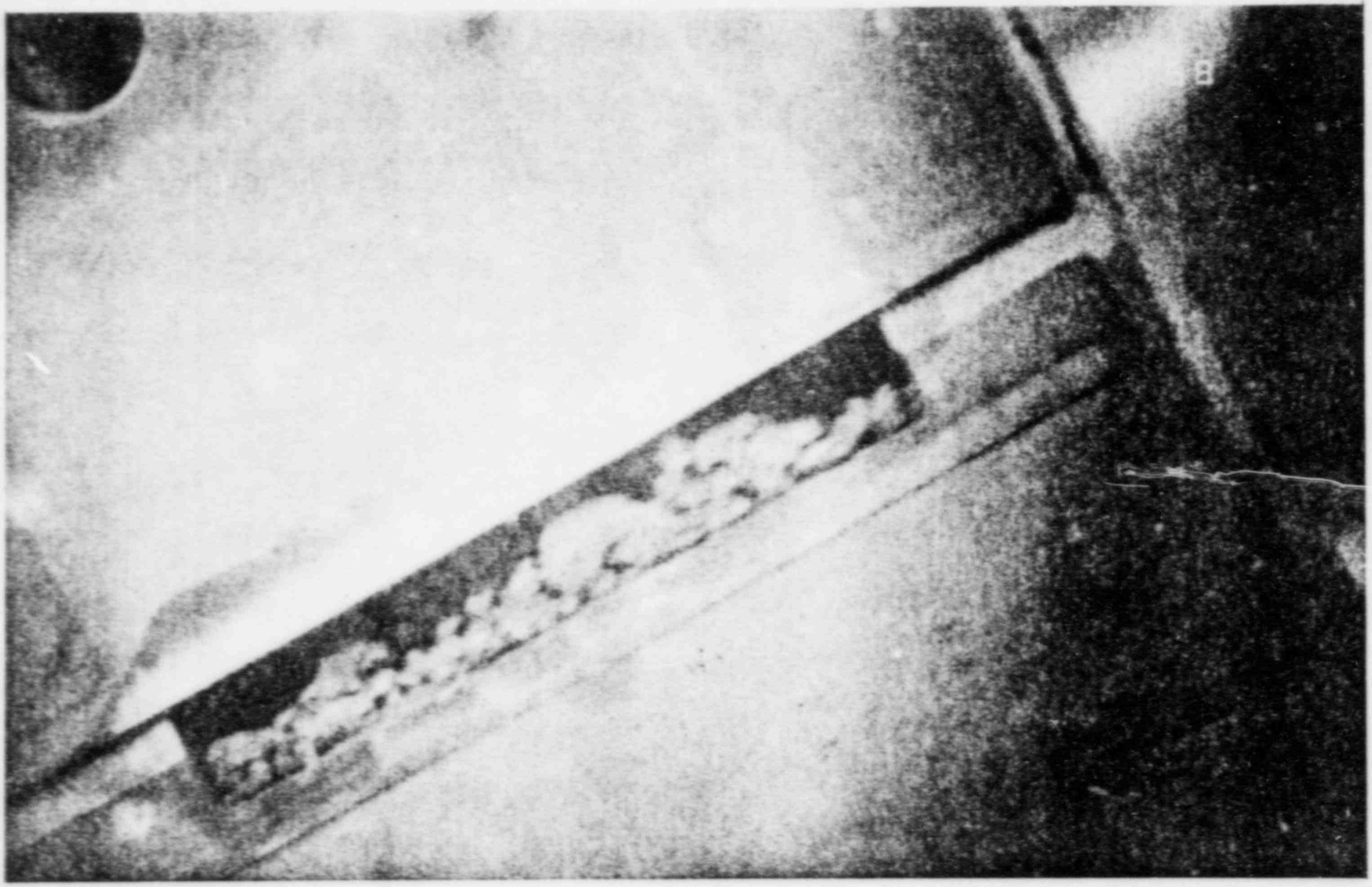
86-72-6, #1 Melting of upper grid structure



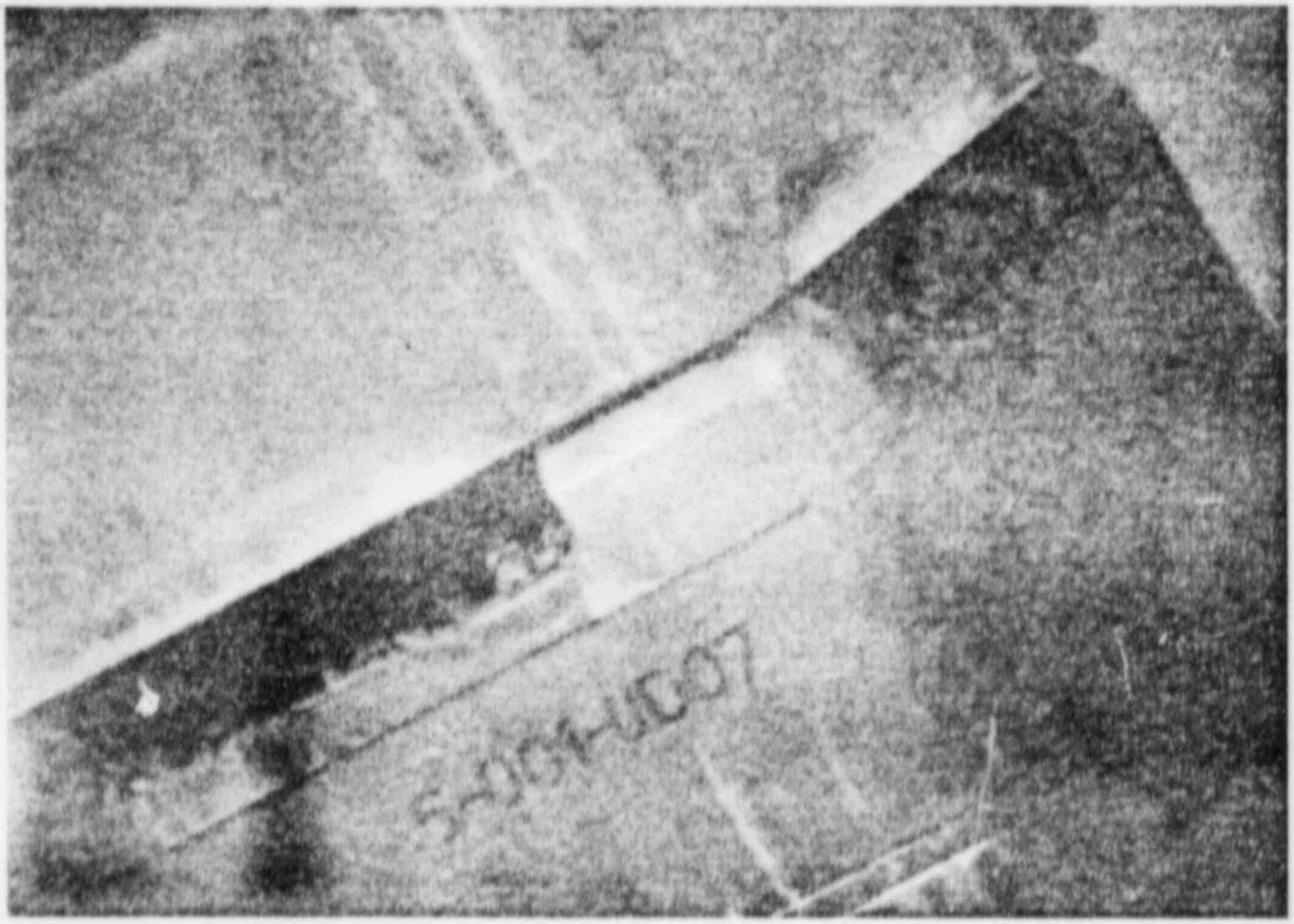
86-72-5, #10 Foaming of upper grid structure



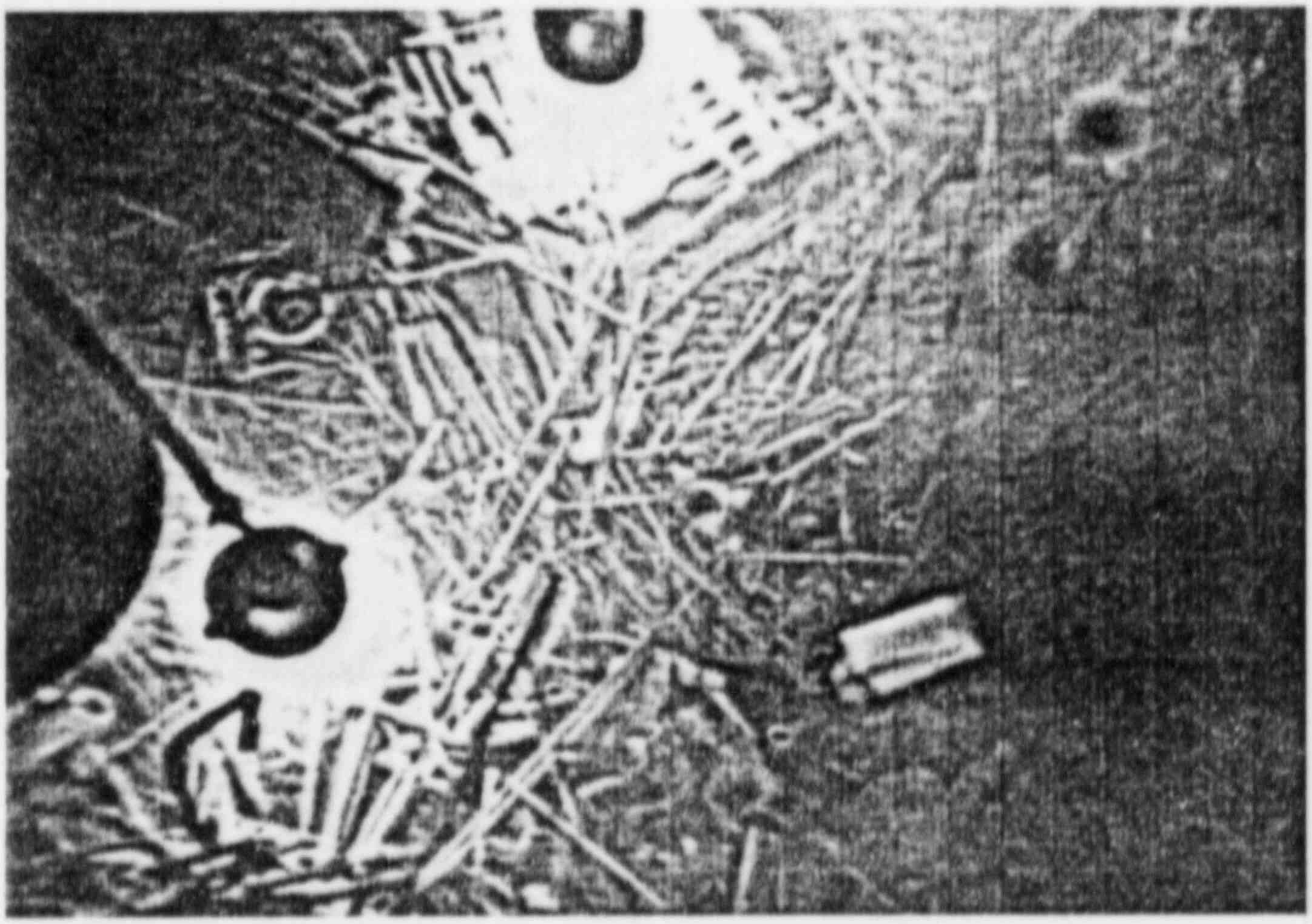
86-72-5, #11 Ablation of upper grid structure



86-34-1-34 LOFT FP-2 Bundle

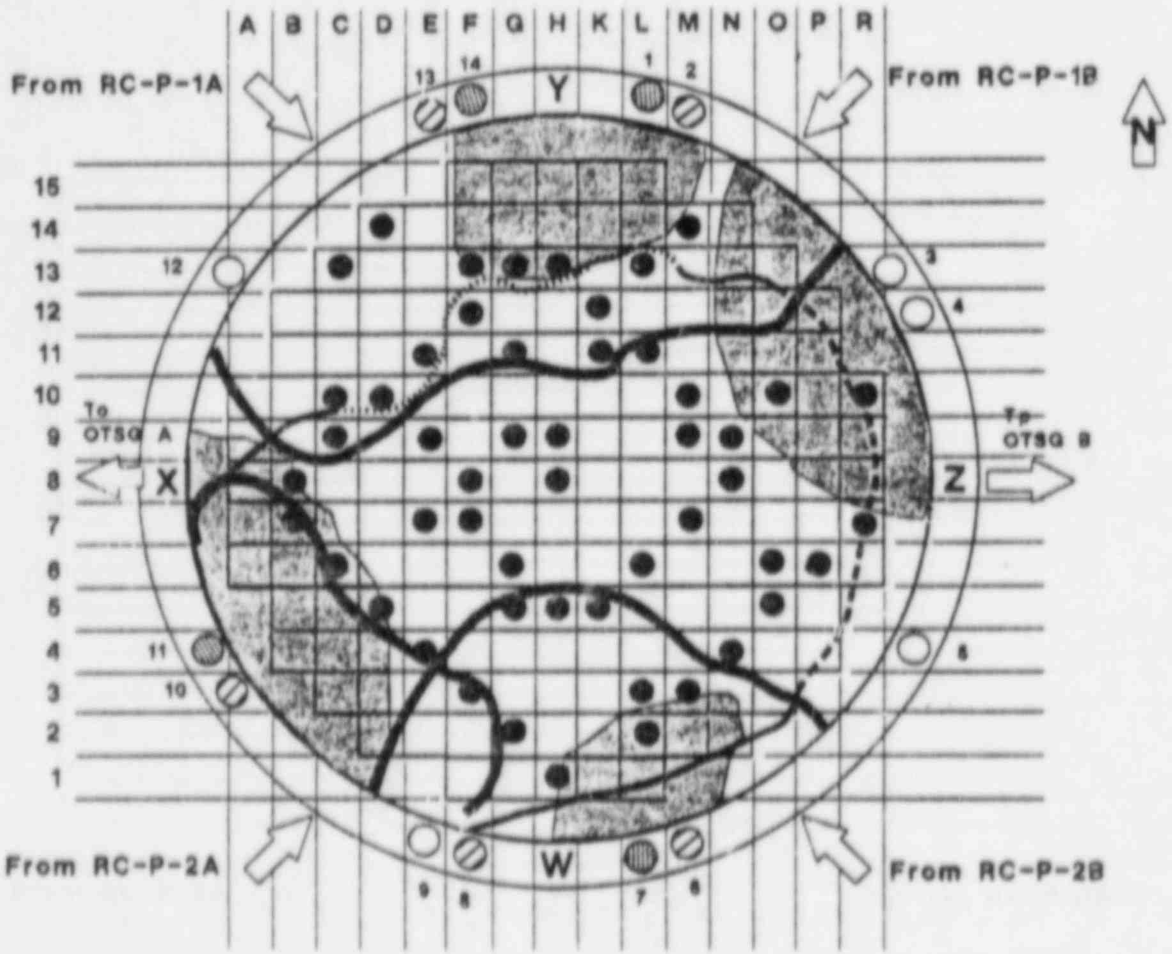


LOFT FP-2: 86-34-1-34



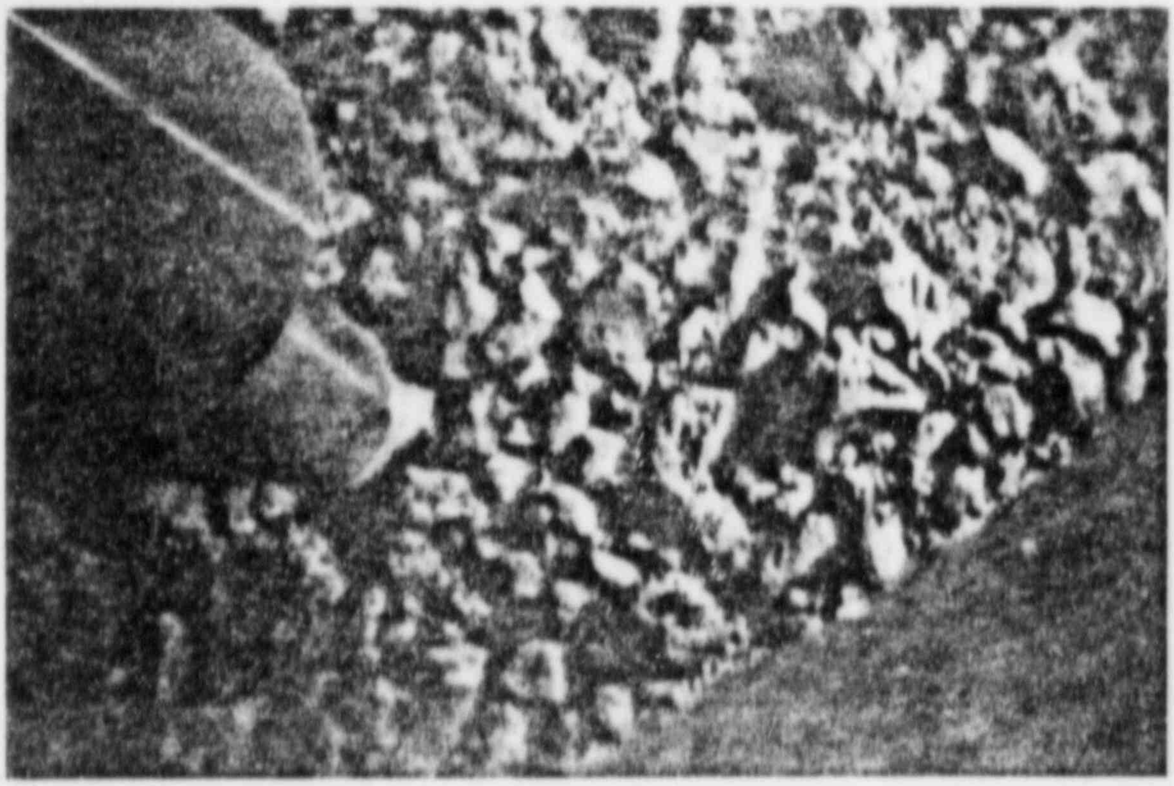
86-72-6, #3 Upper core debris bed

Lower Head Debris

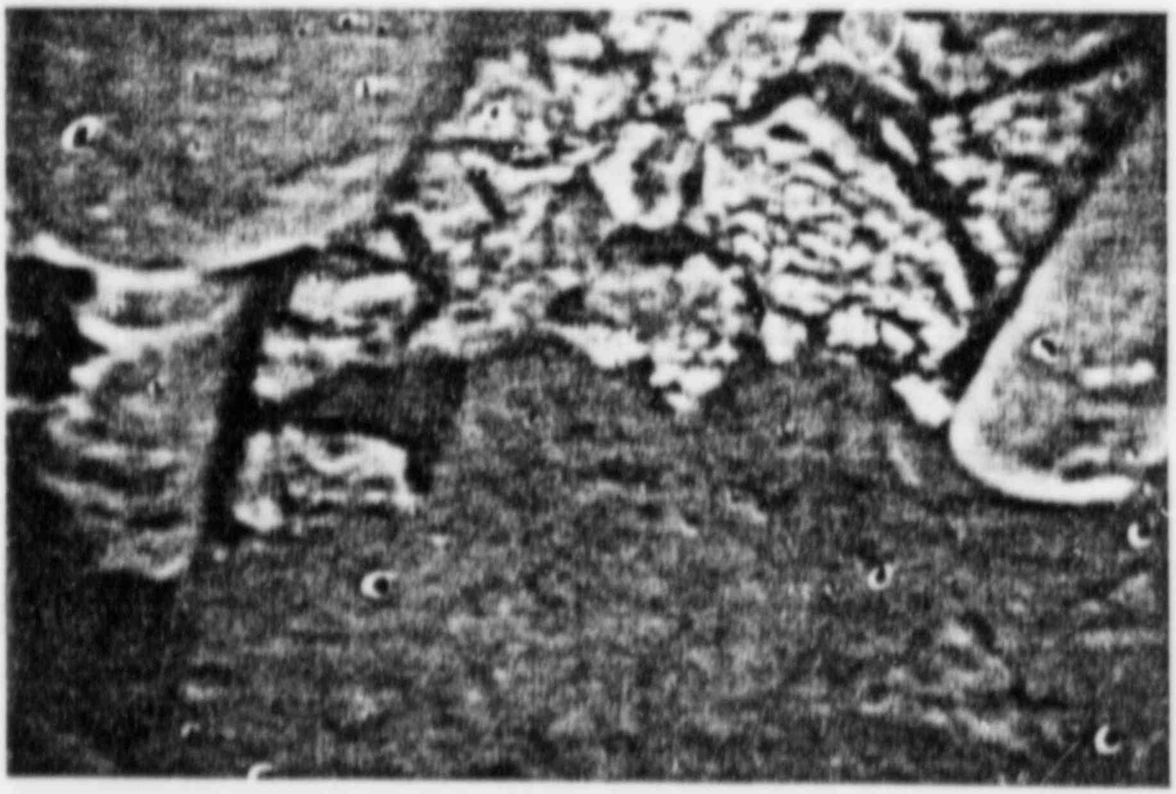


- In-core instrument guide tubes
- Surveillance capsule access holes (3-7/8") (used for manipulator)
- Vent valve access holes (3-1/8") (used for cameras and lights)
- Not used in December 1985 exam
- Area initially examined
- Bounds of present examination
- Boundary of deep debris bed (estimated depth at center - almost 34")
- Extrapolated
- Steep "cliff-like" structure ~4-12" high

CV6 3041



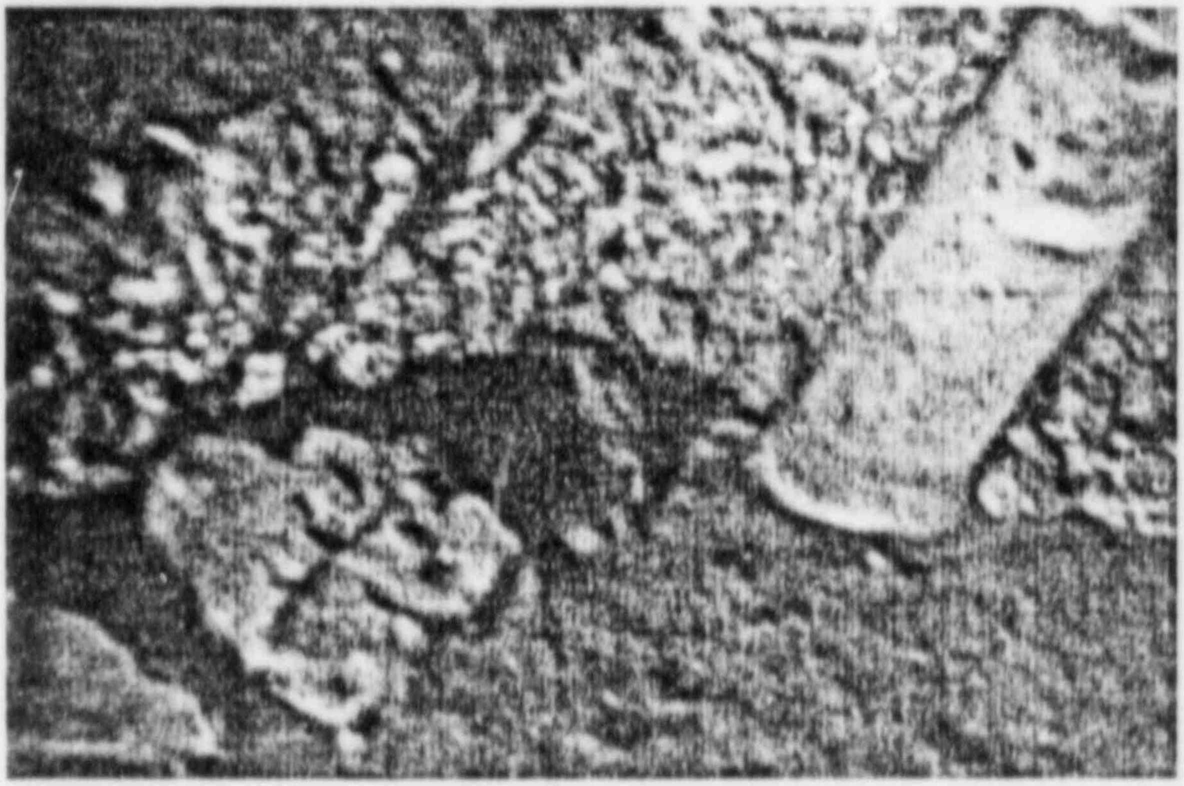
86-72-6, #2 Lower plenum debris: w-axis view



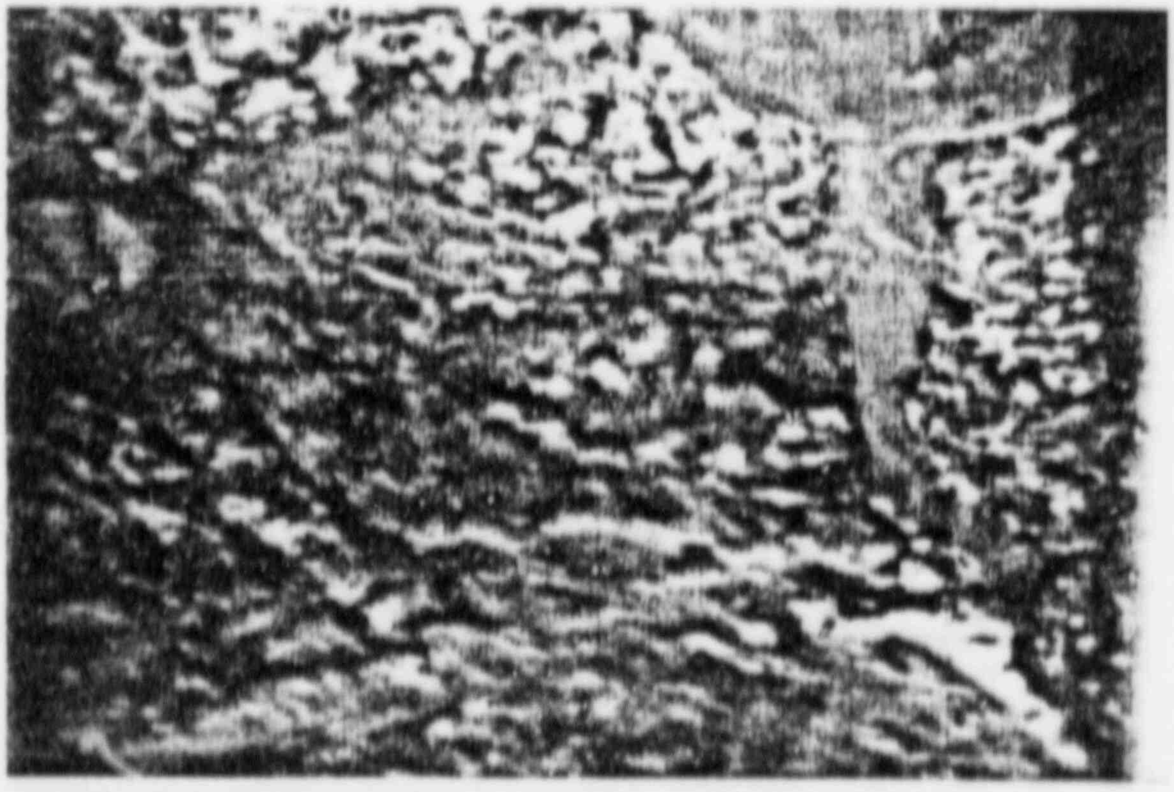
86-72-3, #9 Lower plenum debris, y-axis: "wall" of debris and vessel penetration

86-72-3, #7 Lower plenum debris, y-axis: nozzle on right of 86-72-3, #9

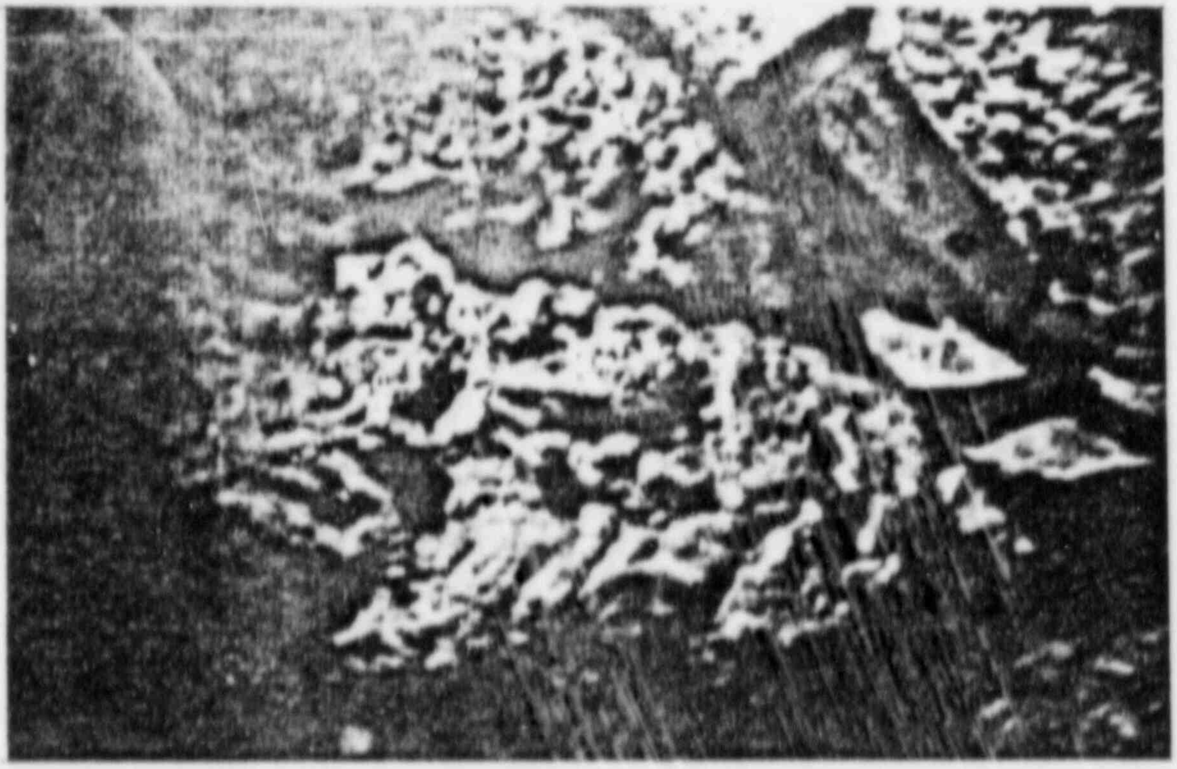
86-72-3, #8 Lower plenum debris, y-axis: guide tube and nozzle on left of 86-72-3, #9



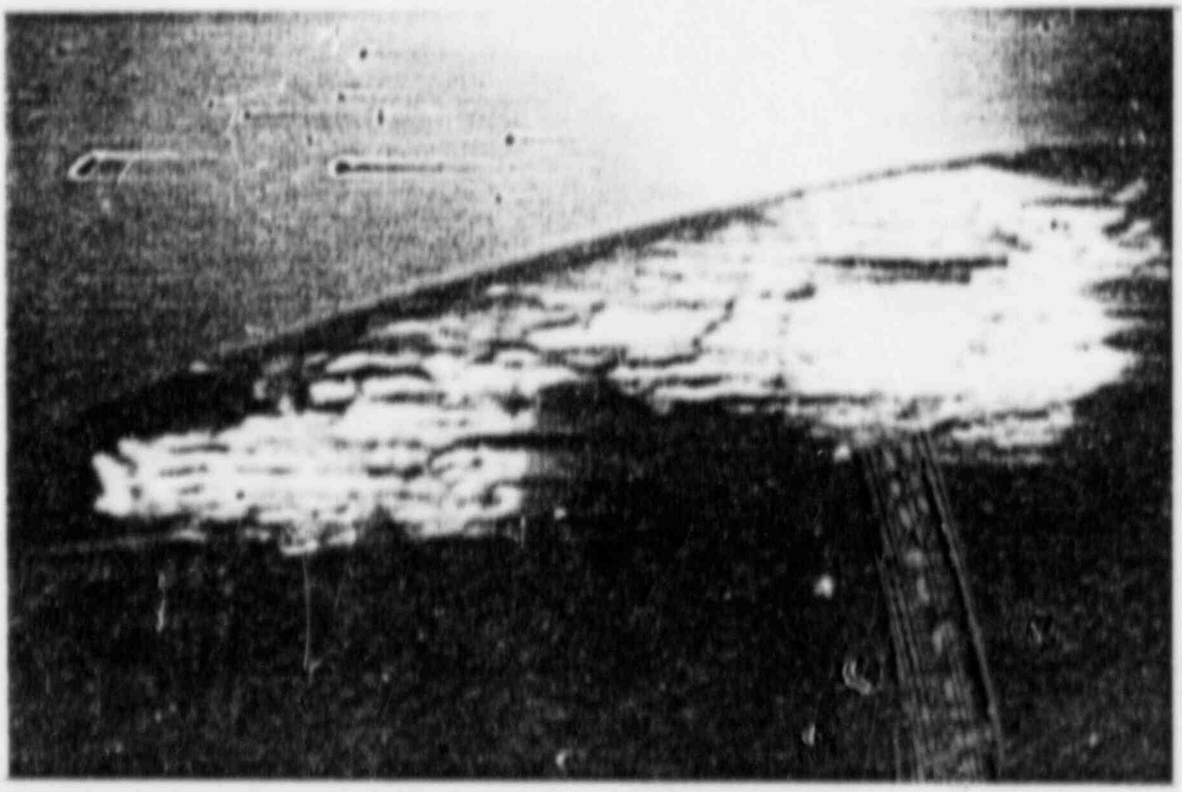
86-72-3, #6 Lower plenum debris, w-axis: penetration weld and debris near "wall"



86-72-3, #3 Lower plenum debris, w-axis: debris covering penetration

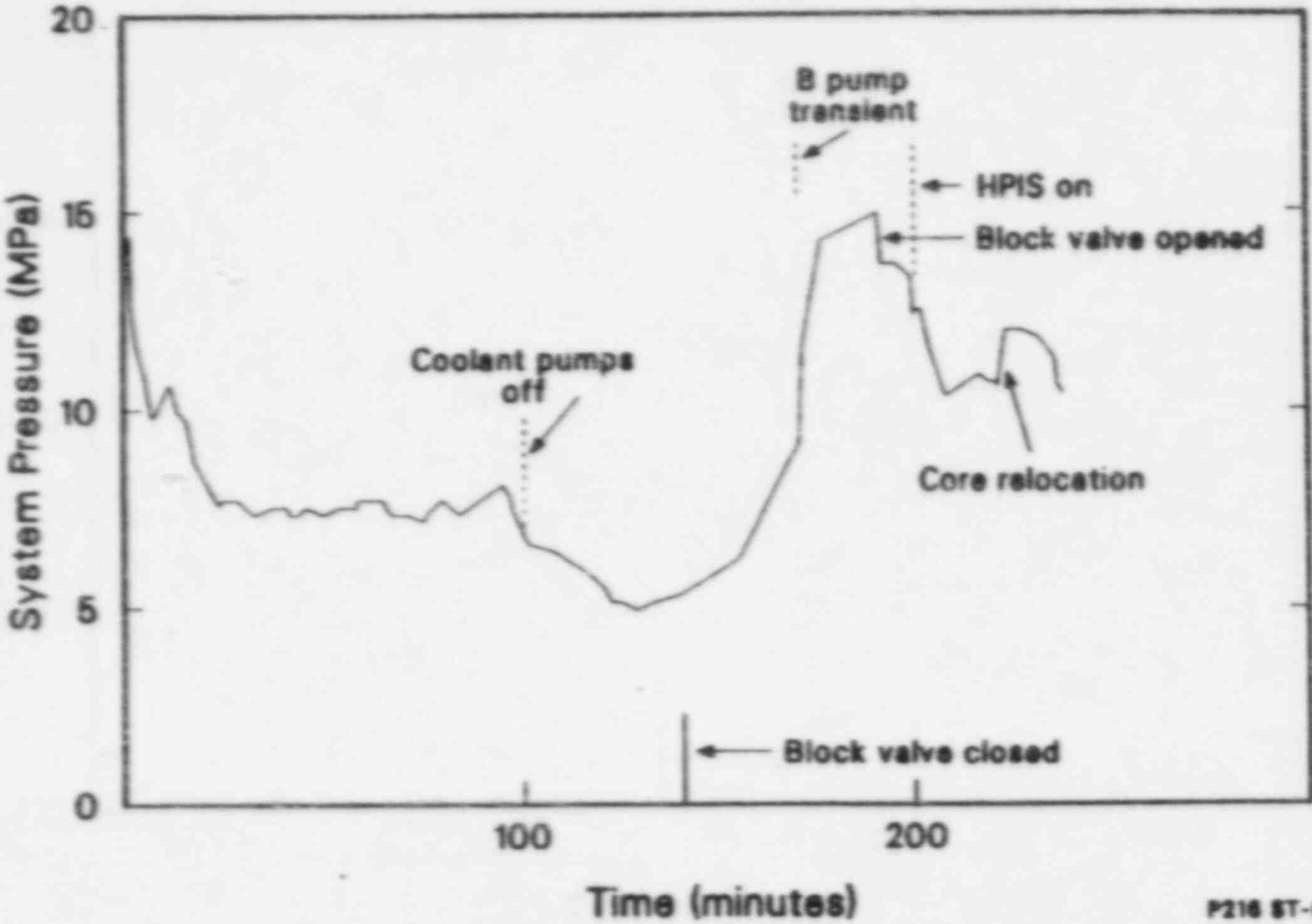


86-72-3, #2 Lower plenum debris, w-axis: debris, light, light core and housing



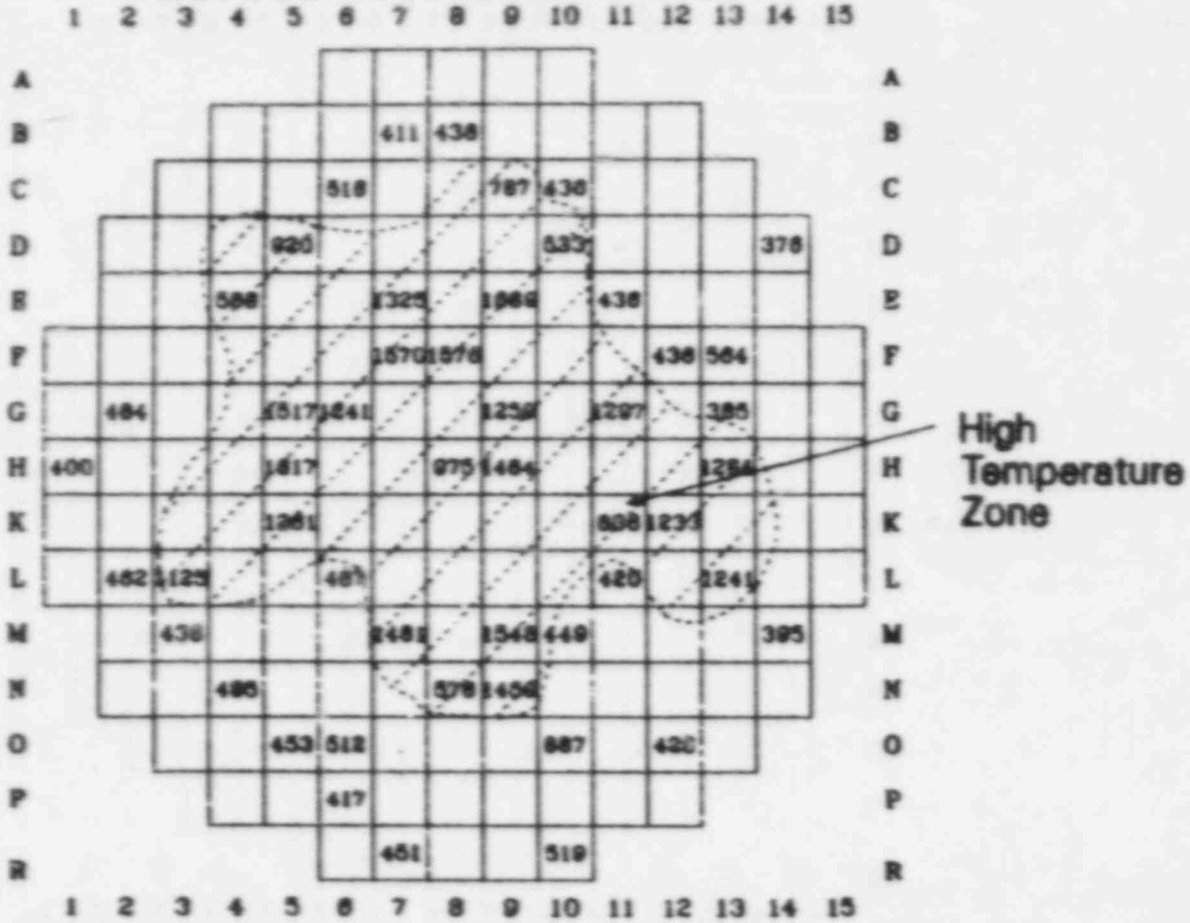
86-72-3, #11 Lower plenum debris, w-axis: bottom diffuser plate with debris in 6" hole

Measured Reactor System Pressure History



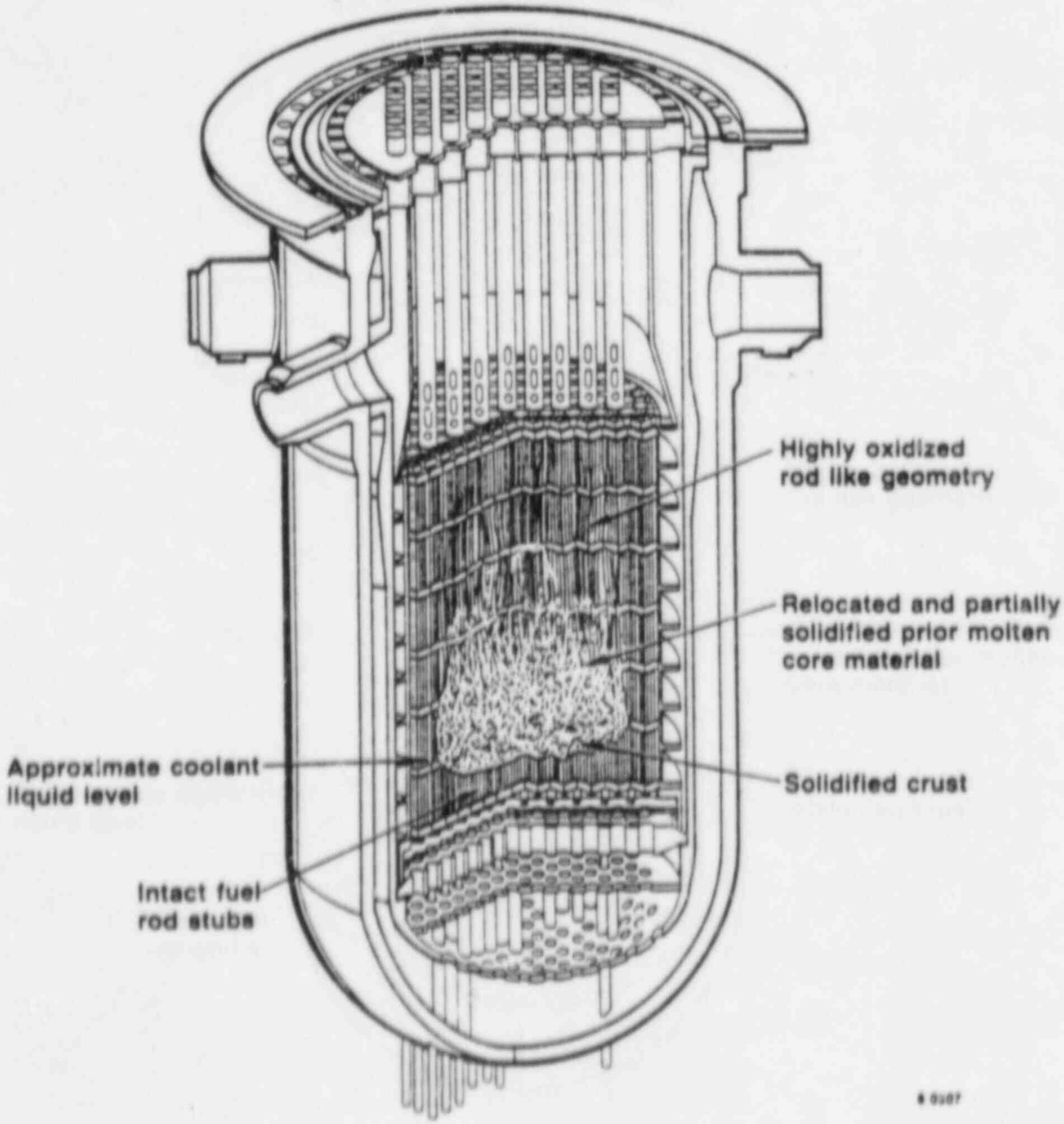
P216 ST-0149-04

Incore Temperatures from Thermocouple Measurements Between 240-330 Minutes

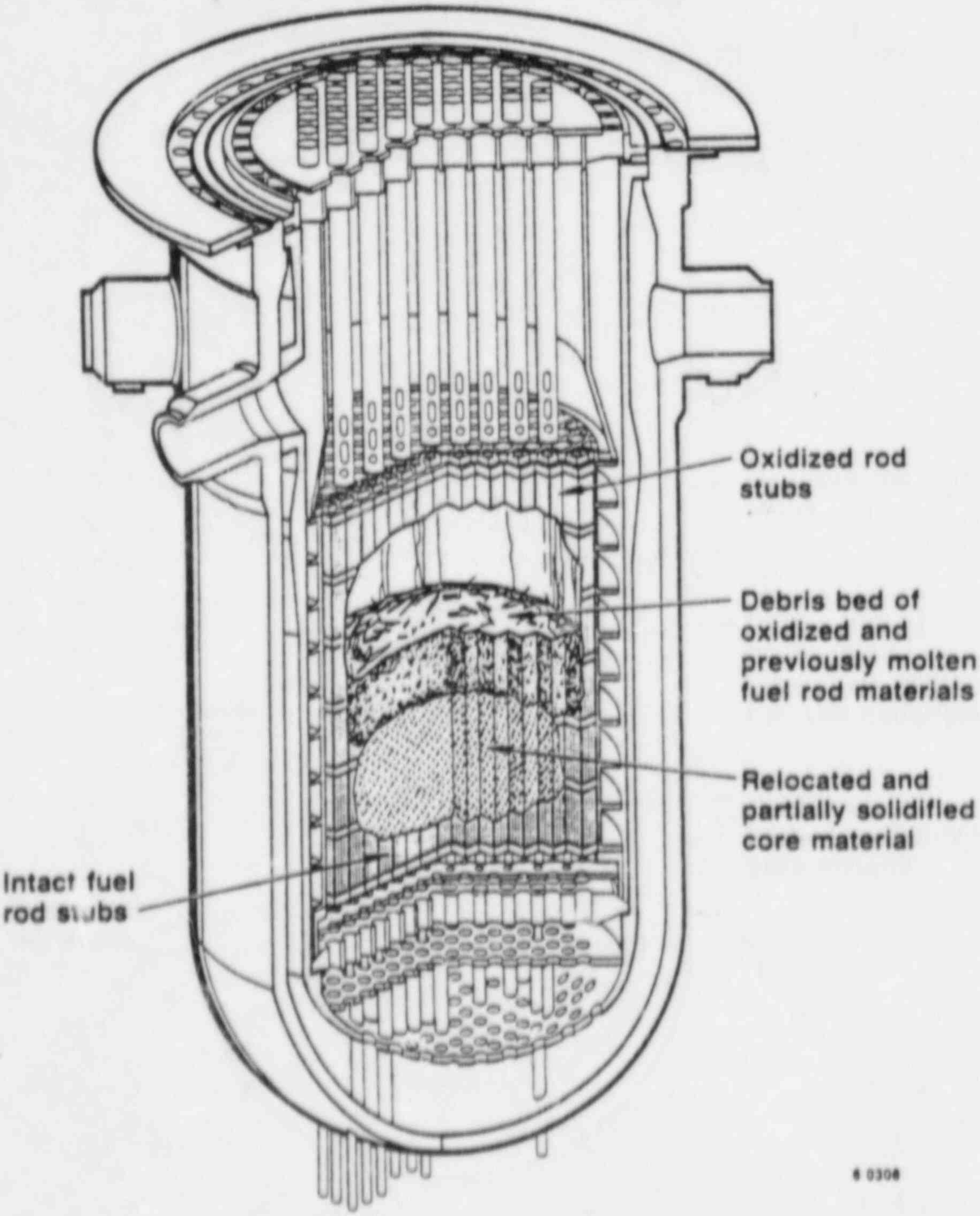


P226 ST-0162-06

Core Condition Just Prior to 'B' Pump Transient (174 Minutes)



Core Condition Just After 'B' Pump Transient (175-180 Minutes)



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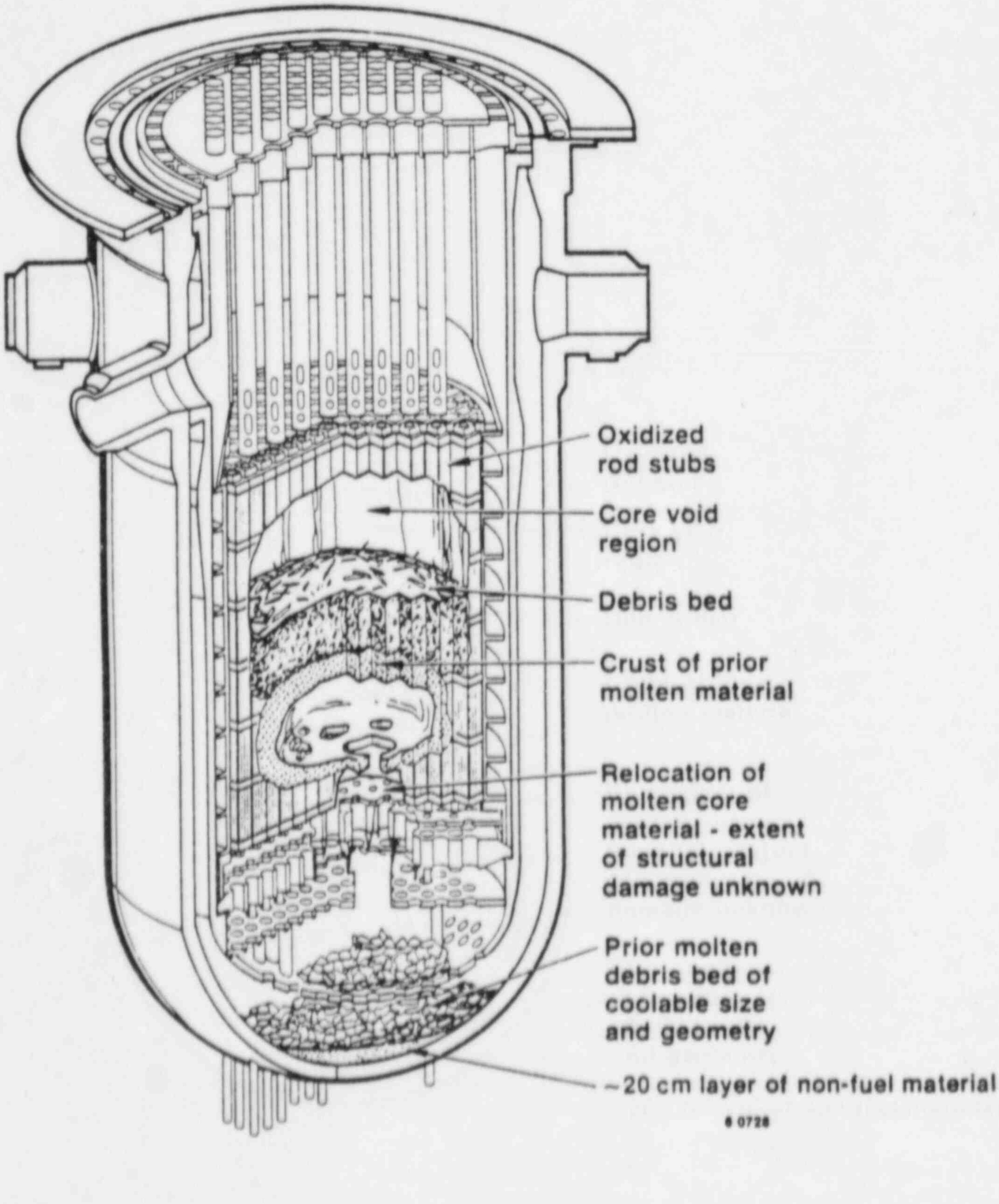
Estimated End State Core Conditions



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Summary of Estimated Radioisotope Distribution in the TMI-2 Reactor

Plant Location	Kr	Cs	I	Te	Sr	Ru	Ce
	Estimated Percentage of Inventory at Time of Accident						
1. Fuel and core debris within the vessel	13[a]	27	33	nm	115	61	~100
2. Vessel internals and primary system piping	nm	~ 1	1	2	<1	<<1	<<1
3. Primary system coolant	<1	~10	~ 8	<<1	~ 1	<<1	nm
4. Reactor and auxiliary building sumps and tanks	nm	45	41	4	~ 2	<1	nm
5. Reactor and auxiliary building surfaces	nm	<1	<1	<1	<1	nm	nm
6. Reactor building atmosphere	54	<<1	<<1	nm	<<1	nm	nm
TOTAL	67	83	82	--	115	61	~100

nm = not measured

(a) calculated for apparently intact fuel rods only

P225 ST-0152-04

Radionuclides Released to Environment as a Result of TMI-2 Accident[a]

Radio-nuclide	Half-life	Quantity in Core at Time of Shutdown (curies)	Estimated Quantity Released (curies)	Estimated Fraction of Total Release
^{88}Kr	2.8 hours	6.92×10^7	3.75×10^5	0.15
^{133}Xe	5.2 days	1.42×10^8	1.58×10^6	0.63
^{133m}Xe	2.2 days	2.11×10^7	2.25×10^5	0.09
^{135}Xe	9.1 hours	3.31×10^7	3.0×10^5	0.12
^{135m}Xe	15.3 min	2.60×10^7	2.5×10^4	0.01
^{131}I	8.0 days	6.55×10^7	15	(b)

[a] Rogovin report, V.II, part 2, page 334

[b] On an estimated fractional basis of total nuclides released, ^{131}I was very small (about 15 curies as opposed to about 2.5 million curies of noble gases)

P225-ALA86002-11

Conclusions from Accident Scenario

- A viable and consistent scenario for accident has been developed
- Scenario will provide a challenging benchmark for severe accident analysis codes and methodologies
- TMI-2 results indicate that small-scale severe accident tests can be extrapolated to large plants
- Relocation of a molten core into lower plenum results in coolable debris for accidents such as occurred at TMI-2 with lower plenum full of water

P226-ALA86002-12

Results of Instrumentation and Electrical Program

- Most failures within 24 hours due to moisture intrusion
- No functional damage due to hydrogen burn
- Use of radiation-sensitive transistors in some instruments caused functional failure
- Off-shelf components less reliable; recommendations being developed
- In-core thermocouples always give useful information, in spite of virtual junction formation above 2200 K
- Develop circuit diagnostic system for normal maintenance

P225-ALA86002-31B

Basic Information
Required from TMI-2 Research

- System configuration and operator actions
- Plant initial and boundary conditions
- Peak temperatures, materials interactions, and extent of material oxidation
- Relocation, structure, and composition of core materials

Basic Information Required from TMI-2 Research (continued)

- Effect of control and burnable poison rods
- Damage to core support assembly, instrument structures to the RV lower head
- Retained fission products and chemical form

Mechanisms for Obtaining Data

- Visual and acoustic inspections
- Acquisition of core bores
- Core defueling operations

Mechanisms for Obtaining Data (continued)

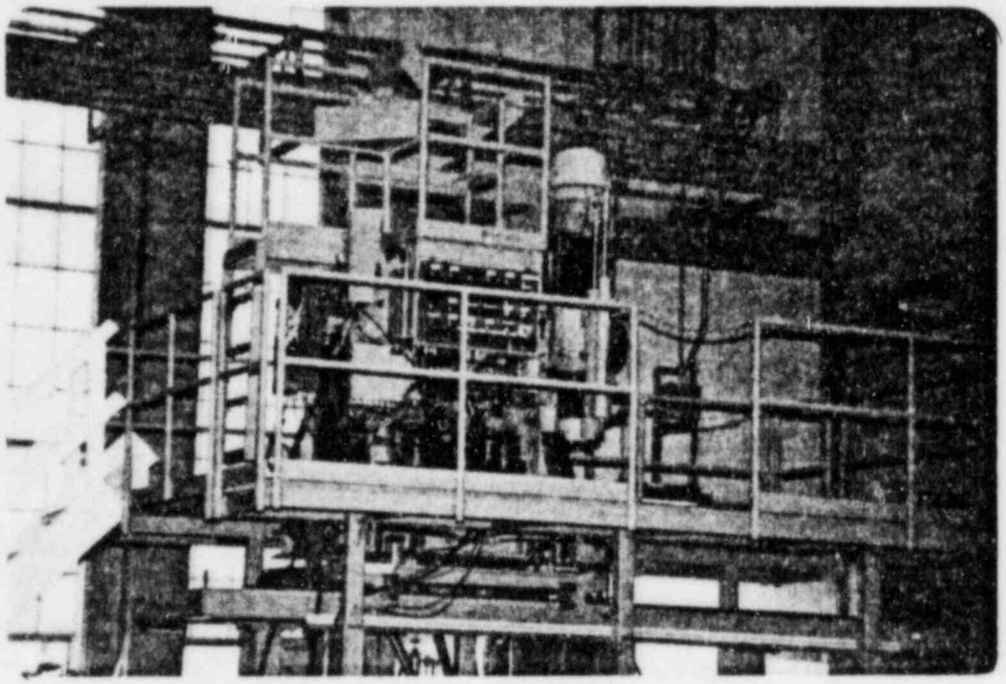
- Physical, chemical, and radiochemical examinations of core samples
  - Fuel rod segments, core debris, and core bores
  - Fuel bundle, structural components-end boxes, spiders, and springs
  - CSA, instrument structures, and lower head
  - RCS surface samples and sludge
  - Basement sludge and concrete drill-core bores
- Evaluation and qualification of on-line instrumentation

P225-ALA86002-16

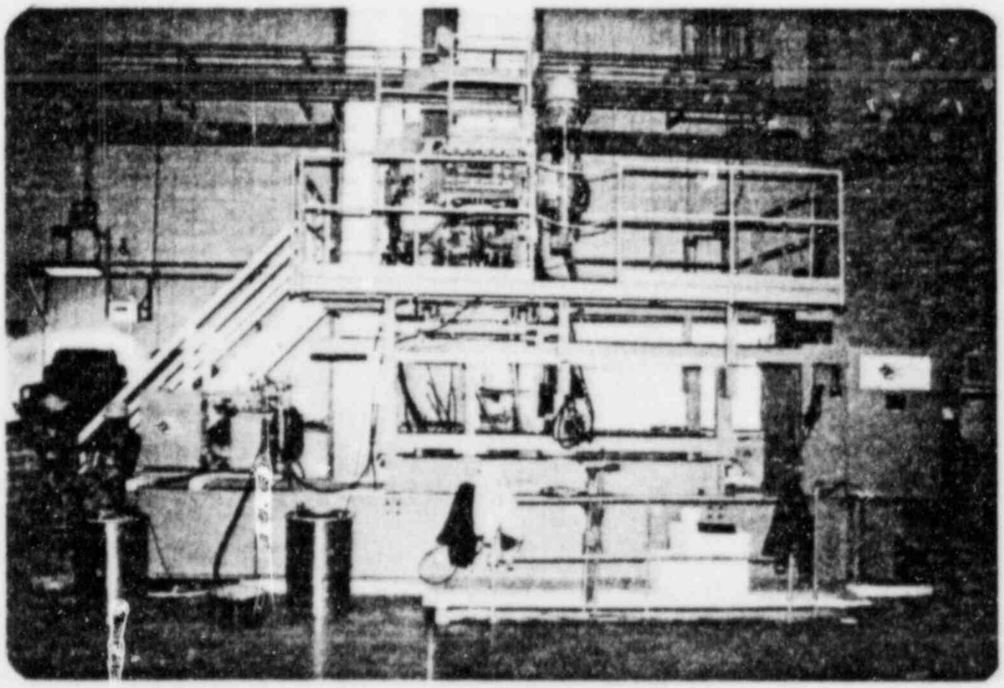
Summary of Prioritized Sample Acquisition and Examination Tasks

1. Central core bore to lower core support plate and visual examination
2. Central core bore to lower head and visual examination
3. Large volume sample from upper debris
4. Topography of the crust below debris bed
5. Mid-radius core bores to lower plenum (3 bores)
6. Local large volume samples of debris from core support assembly region
7. Local large volume samples of debris resting in bottom of reactor vessel
8. Two intact, part length fuel assemblies from control rod and poison rod locations
9. Outer radius core bore to lower core support plate
10. Basement sludge samples
11. Concrete samples from containment basement walls
12. Primary cooling system surface and sediment samples from A and B loop steam generators, pressurizer, hot leg RTD thermowells, and steam generator manway and handhole covers
13. Samples of interaction zone between core materials and lower core support assembly
14. Samples of interaction zone between instrument guide tube structures and core material
15. Samples of interaction zone between reactor vessel lower head surface and lower core debris materials
16. Samples of interaction zone between core former wall and core
17. Fission product retention surfaces in upper plenum
18. Upper plenum leadscrews
19. Upper end boxes, control rod spiders, and spring from top of core
20. Fuel rod segments from debris bed

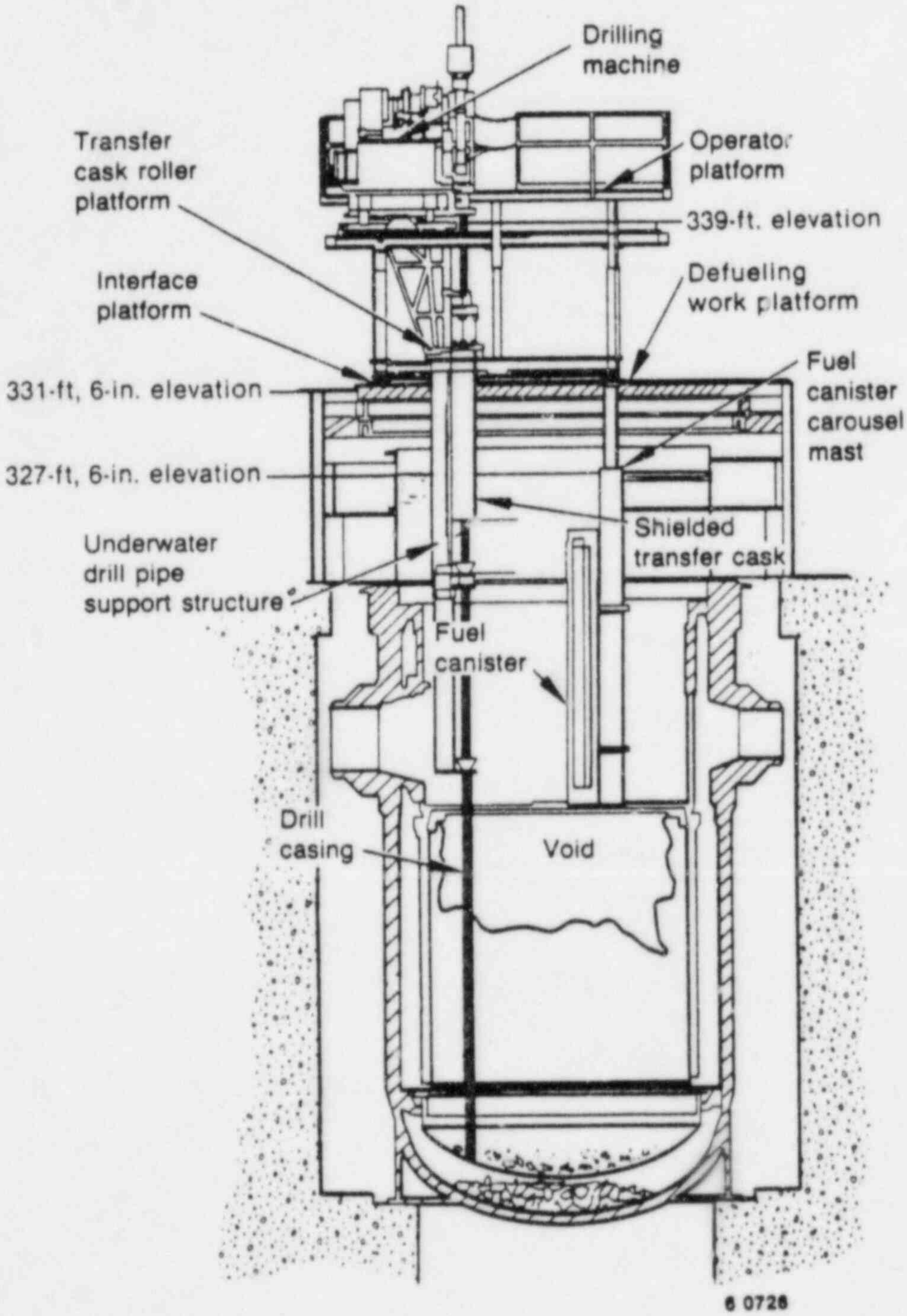
P225-ALA86002-17A



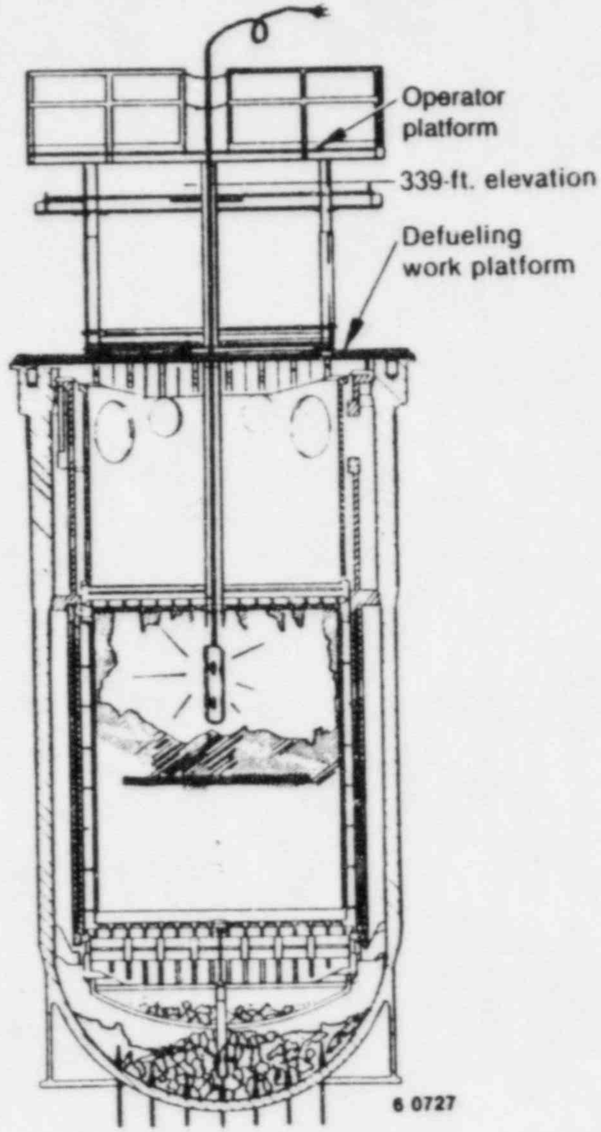
Core Bore Hardware



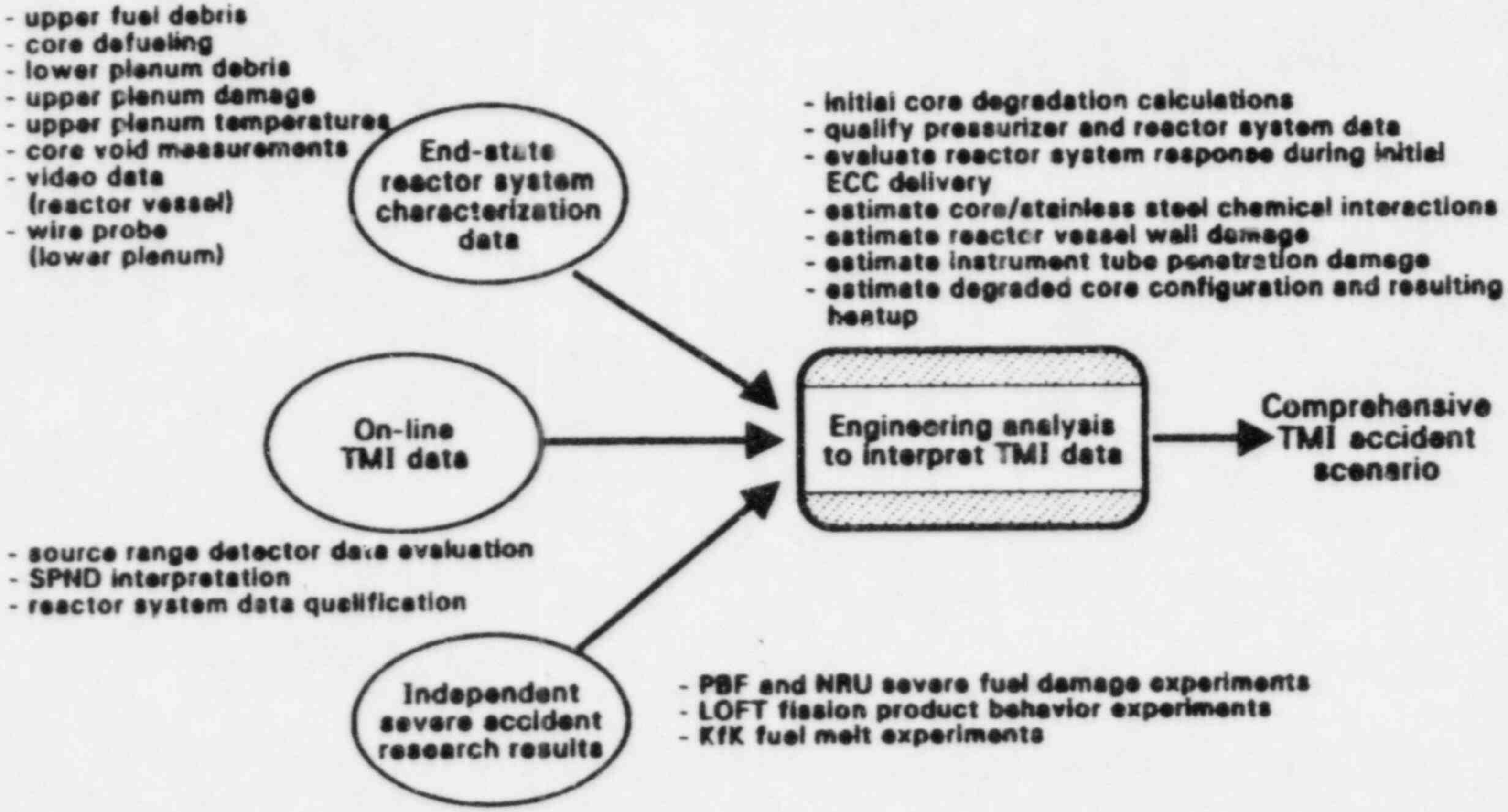
Core Boring Machine



Acoustic Topography



Development of Accident Scenario



P225-ALA86002-1A

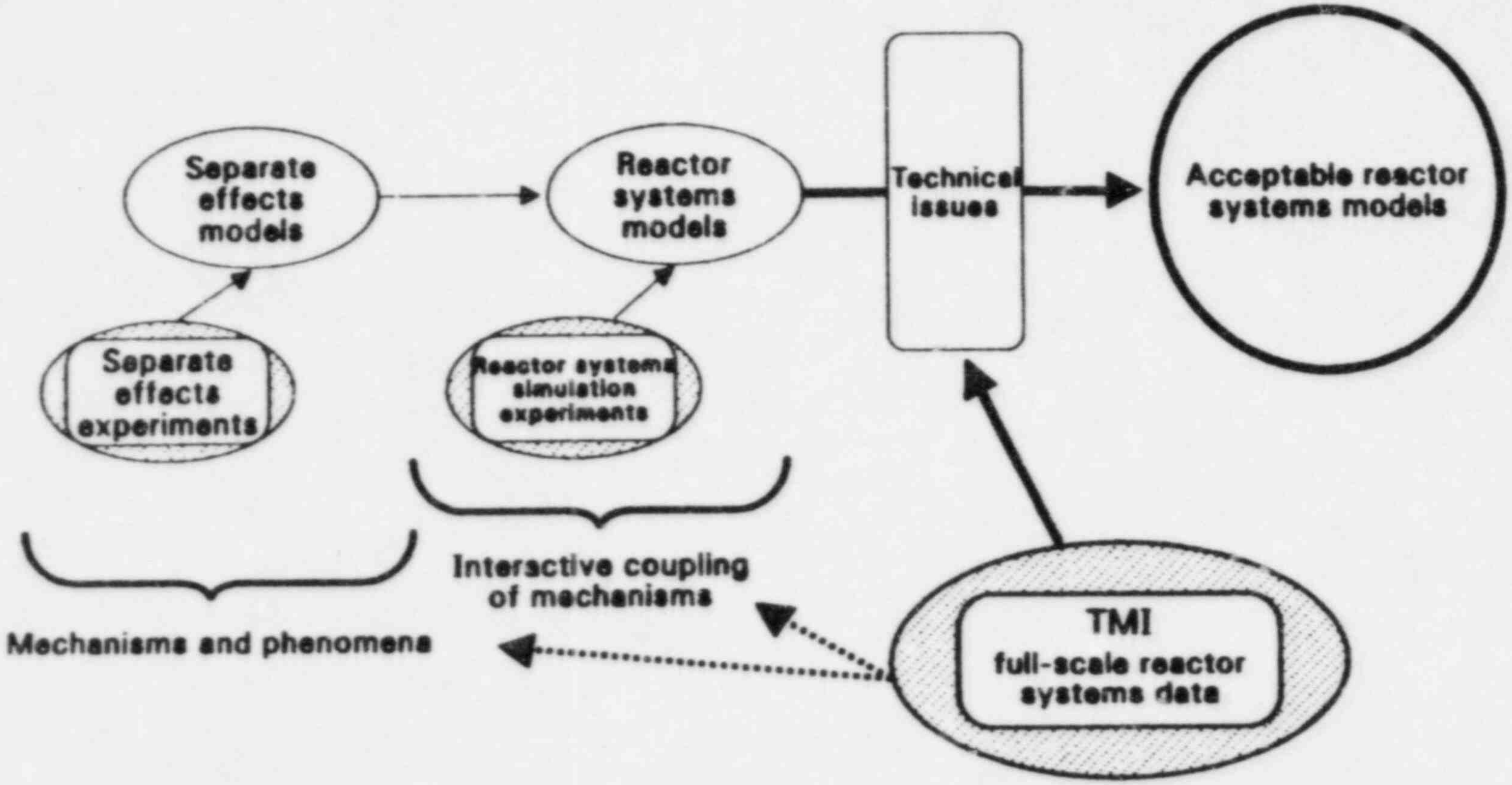
TMI Standard Problem

- Provide a full-scale severe accident benchmark for best-estimate severe accident analysis codes and methodologies

- Compare alternate severe accident analysis techniques and methods

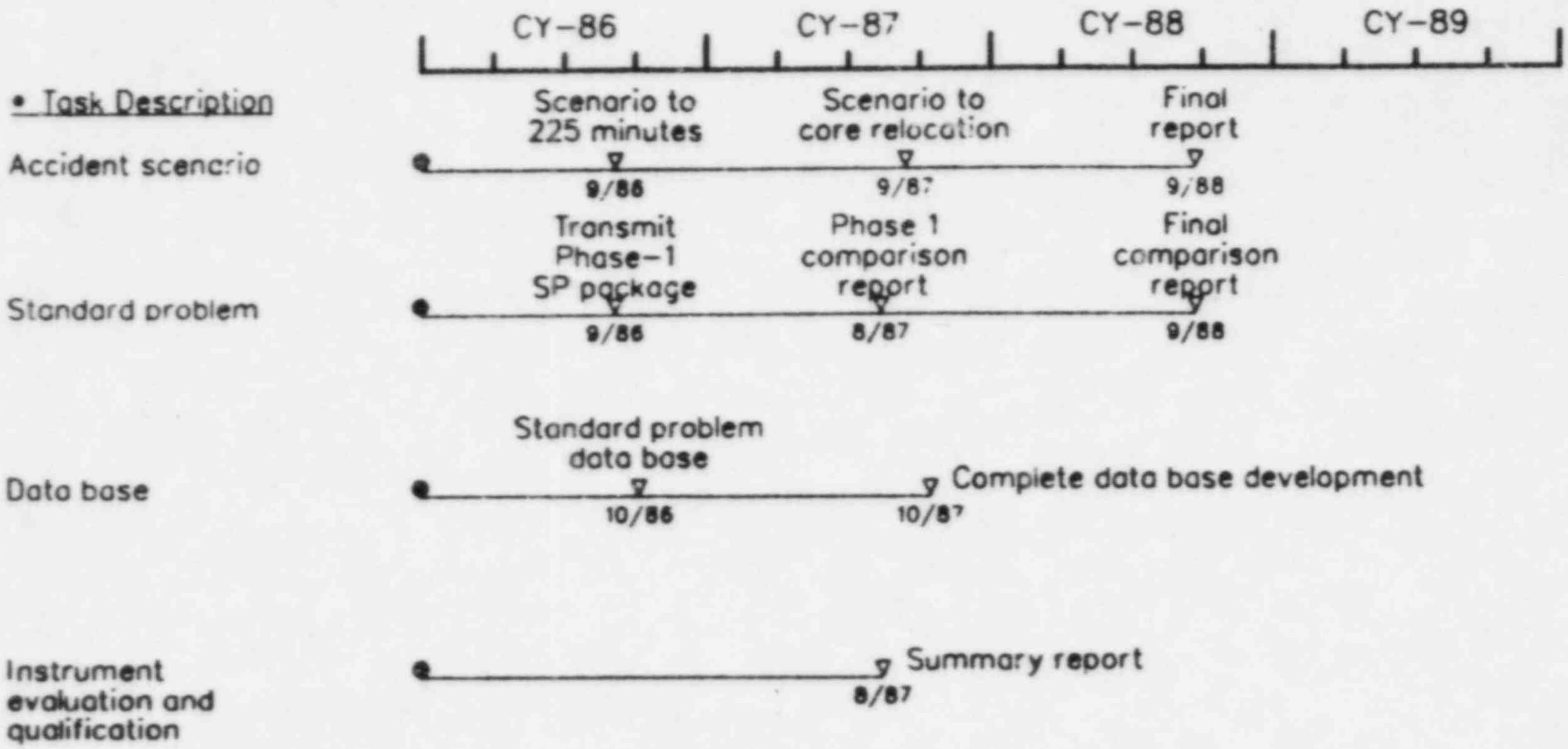
P226-ALA86002-20

Research Methodology



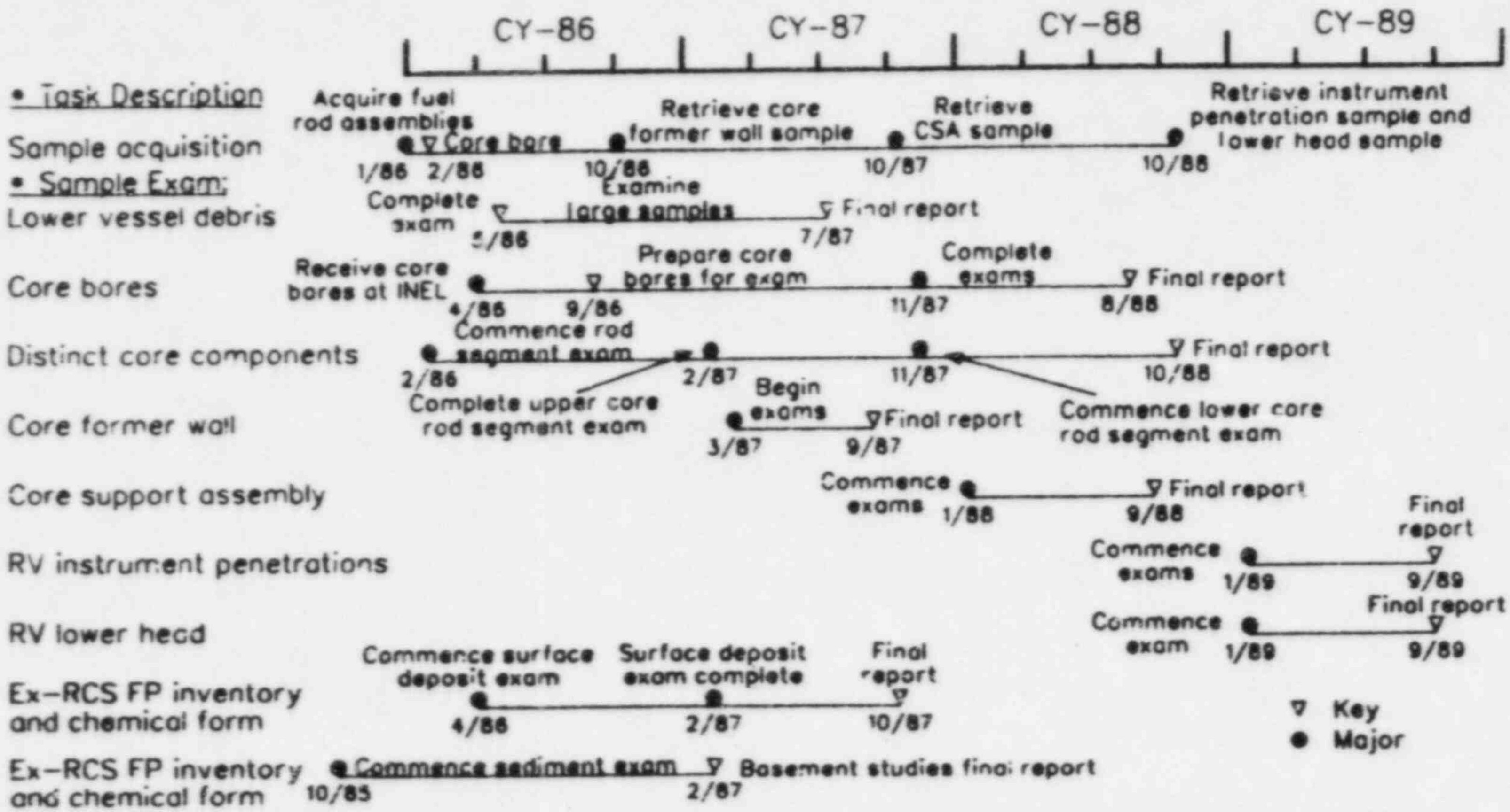
P225-ALA86002-2

TMI-2 Accident Evaluation Program



P225-ALA86002-30

TMI-2 Accident Evaluation Program (cont'd)



P225-ALA86002-29

Conclusions

- TMI-2 accident has enhanced our understanding of severe accidents and source term phenomena
- TMI-2 accident will provide an important and unique benchmark of severe accident codes and methodologies
- TMI-2 accident provides an unique research opportunity: a severe core damage accident in a full-scale plant

P226-ALA86002-24

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Meeting Date: 3/11/86 Open X Closed ___

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