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1 UNITED STATES OF AMERICA

2 NUCLEAR REGULATORY COMMISSION

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4 ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

5 492ND ACRS MEETING

6 + + + + +

7 FRIDAY

8 MAY 3, 2002

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10 ROCKVILLE, MARYLAND

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12 The Advisory Committee on Reactor

13 Safeguards met at the Nuclear Regulatory Commission,

14 Two White Flint North, Room T2B3, 11545 Rockville

15 Pike, at 8:30 a.m., Dr. George E. Apostolakis,

16 Chairman, presiding.

17 PRESENT:

18 DR. GEORGE E. APOSTOLAKIS, Chairman

19 DR. MARIO V. BONACA, Vice Chairman

20 DR. F. PETER FORD, Member

21 DR. THOMAS S. KRESS, Member at Large

22 DR. GRAHAM M. LEITCH, Member

23 DR. DANA A. POWERS, Member

24 DR. VICTOR H. RANSOM, Member

25 DR. STEPHEN L. ROSEN, Member

1 PRESENT: (CONT.)

2 DR. WILLIAM J. SHACK, Member

3 DR. JOHN D. SIEBER, Member

4 DR. GRAHAM B. WALLIS, Member

5

6

7 ACRS STAFF:

8 DR. SHER BAHADUR, Associate Director

9 DR. JOHN T. LARKINS, Executive Director

10 JENNIE GALLO, ACRS Staff

11 MEDHAT EL-ZEFTAWY, ACRS Staff

12 HOWARD J. LARSON, Special Assistant

13

14 ALSO PRESENT:

15 ALAN MAILLIAT, IRSN

16 MICHEL SCHWARZ, IRSN/DRS-CADARACHE

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I-N-D-E-X

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

2 (8:30 a.m.)

3 CHAIRMAN APOSTOLAKIS: The meeting will
4 now come to order. This is the second day of the
5 492nd meeting of the Advisory Committee on Reactor
6 Safeguards.

7 During today's meeting the committee will
8 consider the following: PHEBUS-FP, PHEBUS-2K, and
9 PHEBUS-LOCA International Projects, Future ACRS
10 activities, report of the planning and procedures
11 subcommittee; reconciliation of ACRS comments and
12 recommendations; proposed ACRS reports.

13 This meeting is being conducted in
14 accordance with the provisions of the Federal Advisory
15 Committee Act. Mr. Sam Duraiswamy is the Designated
16 Federal Official for the initial portion of the
17 meeting.

18 We have received no written comments or
19 requests for time to make oral statements from members
20 of the public regarding today's sessions. A
21 transcript of a portion of the meeting is being kept,
22 and it is requested that the speakers use one of the
23 microphones, identify themselves, and speak with
24 sufficient clarity and volume so that they can be
25 readily heard.

1 The first item on the agenda is the PHEBUS
2 International Projects, and Dr. Powers will guide us
3 through this.
4 DR. POWERS: Thanks, George. Members, we
5 are going to discuss the PHEBUS Program. This is an
6 experimental program intended to provide some
7 validation for the computer codes we use in
8 connection with the analysis of severe accidents.
9 And it is going to be a pleasure of mine
10 to introduce a couple of my heros in the area of
11 severe accident analysis, Michel Schwartz and Alan
12 Mailliat.
13 As a bit of an introduction, Michel I know
14 is a good man. He spent two years at Sandia, and so
15 he has been properly trained.
16 DR. SIEBER: But he was young and --
17 DR. POWERS: And impressionable. Alan is
18 a devotee of the study of severe reactor accidents and
19 practically gave his life for this particular thing.
20 In fact, working hard late one night in his
21 laboratory, when he left, he had a car accident, and
22 was in the hospital for six months.
23 So you know that he is a dedicated
24 individual. Today you are going to hear about his
25 progress in the PHEBUS program. PHEBUS is an amazing

1 cooperative research program, in which they are trying
2 to simulate the physics and chemistry of a severe
3 accident beginning with fuel degradation, fission
4 product transport, fission product behavior in the
5 containment.
6 A few of us at this table have tried to
7 simulate various snippets of the overall accident
8 sequences that you have in a severe accident, and we
9 all know how difficult that is, and these guys are
10 trying to do the whole thing.
11 So you can imagine how difficult it is.
12 Just to make it a little more challenging, they do it
13 as part of an international cooperative effort. So
14 about every six months, they get all the advice and
15 help from a large contingent of people coming to look
16 over their shoulders.
17 And I have never once seen them lose their
18 temper at any of those meetings.
19 DR. WALLIS: Let's see if we can try it
20 today.
21 DR. POWERS: But one of the things that we
22 want to explore with them outside of the formal
23 meeting was in fact how they have handled that
24 international cooperative effort, because I think they
25 have even set the standard on the proper way to set up

1 an international cooperative research program.

2 With that bit of introduction, I will

3 invite Alan and Michel to begin their presentations.

4 DR. SCHWARZ: Thank you for the

5 introduction, Mr. Chairman, and good morning, ladies

6 and gentlemen. So this is the line of my

7 presentation, and I am going to talk about the

8 objective of this international program, and describe

9 the specificity and the measurement systems, and give

10 a view on the test matrix, describe the cooperation in

11 international efforts around this program.

12 CHAIRMAN APOSTOLAKIS: Why don't we give

13 him the mobile microphone so he can stand up. This is

14 very awkward. Can you also tell us why you call it

15 PHEBUS?

16 DR. POWERS: I don't know.

17 (Laughter.)

18 CHAIRMAN APOSTOLAKIS: No, there was a

19 Greek god in mythology somewhere named PHEBUS, and

20 that's why I am curious.

21 DR. POWERS: It has nothing to do with

22 Greek.

23 CHAIRMAN APOSTOLAKIS: It is just a random

24 coincidence.

25 DR. POWERS: That's right.

1 DR. SCHWARZ: Can you hear me?

2 CHAIRMAN APOSTOLAKIS: Yes.

3 DR. SCHWARZ: Okay. There is a few years
4 involved of testing involved in this program, and the
5 most important part of my talk will be related to my
6 achievements and lessons from the first tests, and
7 then a few words of conclusions.

8 So the objective of the PHEBUS program is
9 through this phenomena, and involved severe accidents
10 in light water reactors, and not all the phenomena,
11 and this phenomena involved is a Core-1 progression of
12 liquid hydrogen and fission projects, and radioactive
13 products from the core, were transported into the
14 primary sections.

15 The behavior of fission products inside
16 containment, with a special focus on the iodine
17 behavior. As you know, iodine is arriving in the
18 bottom of the containment. There is some very complex
19 hydrogen chemical reactions, which is a transforming
20 part of the iodized into iodine, which can evaporate
21 from the system. And they react with the paints and
22 form organic iodides.

23 The objective is to react in time to
24 measure the concentration of the fission products
25 inside the containment in order to be more of a better

1 way to assess what could be dangerous to the
2 environment through the gauges, or in France, for
3 instance, where the so-called procedure U5 which is
4 calling for a different venting, and outside is the
5 containment in order to preserve or prevent the
6 containment from failing.
7 This program has involved using some
8 integral tests using core materials, and the
9 prototypical physical chemical conditions because the
10 key here is the relativity of the fission products and
11 chemistry. Since then, there has been a lot of
12 scientific tests in order to investigate, for
13 instance, the release from the fuel.
14 And in your country it was a breach test,
15 and in France, a vector test, to calculate, to
16 measure, to investigate the position of the fission
17 products via a source into the containment -- excuse
18 me, into the insides of the primary circuit, and
19 inside of the containment.
20 There have been a lot of experiments
21 investigating the reactions and production of -- in
22 the sump, and the avenue here was to travel into their
23 experiments in order to compliment these scientific
24 tests to see whether they were adequately presented to
25 you, because most of these tests were performed using

1 simulated fission products.

2 And also the Commission engaged us to
3 investigate whether we had risks in the present
4 phenomena, and you will see that the answer is yes
5 from the first observations of the program.

6 This program is providing a huge database
7 which is used later to validate the code systems like
8 MELCOR in your country, and ASTEC, ICARE, which is
9 devoted to describe the core mode progression, ATHLET
10 CD in Germany, and SCDAP in your country. Next slide,
11 please.

12 The PHEBUS facility was built in the late
13 '70s, and in fact this part, which was built in the
14 late '70s, it involves pool tank and this is a
15 prototype of nuclear reactors at 1,400 megawatt. At
16 your center of the core there is a test section which
17 comprises the fuel which is tested.

18 And the first program which was initiated
19 in PHEBUS was the so-called PHEBUS LOCA, loss of
20 coolant accident, and there was a pressurized leak in
21 order to reproduce from the laboratory conditions to
22 do these kinds of tests. Then after the PHEBUS LOCA,
23 more experiments were performed in this program.

24 There is another program called the PHEBUS
25 fuel damage program in the early '80s, and still using

1 the reactor; and then at the end of the '80s, a
2 measure of growth of the reactor, and even then, was
3 a bit which contains still 200 or 300 cubic meters,
4 which execute for the fission product program.
5 The building was reinforced with a lot of
6 concrete in order to comply with the new system of
7 defense regarding the special damage of earthquake,
8 and a cooling tower has been added in order to be able
9 to prepare the core of the reactors for damage.
10 So it was a very large program for
11 upgrading this reactor, it lasts about 3 years, and in
12 '93, they performed the first tests as a program of
13 PTO. Next slide, please.
14 This is a view of the PHEBUS core, so it
15 is 16 by 60 centimeters, over 80 centimeters, high,
16 and this picture was taken just during the loading of
17 the core, and at the center, you can see the test
18 cell, which is right at the center of the core.
19 The core providing the nutrients to heat
20 up the test fuel, which is inside this test site.
21 This is a skeleton view of the PHEBUS-FP, you
22 recognize the reactor, the PHEBUS reactor, and the
23 core here at the test site.
24 At the center of the test site is
25 introduced a test section, and you can see here on the

1 left side. It is comprised of 21 fuel rods, and with
2 a single engine cadmium control rod right at the
3 center of the bundle.
4 This is one of the high bundles which is
5 surrounded by thermal insulation inside the pressure
6 tube. For the week real periods, the reactor at 99
7 point, in order to build the French, excuse me, to
8 build the short life fission products inside the fuel.
9 For instance, iodine 141.
10 I should mention that these fuels are
11 coming from the Berchem Belgium reactors and are one
12 meter high. The amount of fuel inside this bundle is
13 about -- is a little bit more than 10 kilograms. So
14 you have roughly speaking a scaling factor of one over
15 5,000; as compared to a 180 kilometer pressurized
16 water reactor.
17 DR. KRESS: What was the band total of the
18 BR3?
19 DR. SCHWARZ: I will show that in the test
20 matrix. There was a moderate one, about 20 gigawatts.
21 After the separation for a leak, the reactor is
22 SCRAM'ed and the bundle is dried.
23 And we are listening to the whole accident
24 in the PHEBUS. You are just -- You are looking at the
25 thermal hydraulics part of the accident, and we are

1 just injecting steam at the bottom of this bundle, and
2 increases the power stepwise in order to reproduce the
3 temperature feed, will activate the sealant in the
4 fuel.
5 The fission products which are released
6 during the melting of the rods are concerned with,
7 kind of LOCA with the primary circuit of reactors, and
8 you can see here huge room of steam generator, and the
9 same studying factors.
10 And the object of this huge room, the
11 fission products are transferred inside a vessel of 10
12 cubic meters with a sump, and with cooling structures
13 inside this vessel. This vessel is intended to
14 simulate the containment of the reactor. Ten cubic
15 meters means about also a scaling factor of one over
16 5,000.
17 You cannot scale down both the volume and
18 the surface or what has been chosen as an option as to
19 heat up the wall, the outer wall of the vessel or to
20 prevent any steam condensation inside the vessel and
21 the position of aerosols. And we have introduced the
22 school structure, which are of the scale of the room
23 of the containment, and which are partially paint in
24 order to reproduce chemistry that we like to simulate
25 in this vessel.

1 I forgot to mention that these are low
2 pressure tests. The pressure is 2 bars, at point 2
3 meters pascal, and this line is heated to 700 degrees
4 C, and the rest of the circuit is at 150 degrees C.
5 There is no steam condensation under these conditions,
6 and so we are investigating the positions by similar
7 forces, and condensation of these fission products
8 which are under performed. Next slide, please.
9 DR. RANSOM: Are you going to discuss some
10 of the other scaling factors, like height, diameter,
11 mike scale?
12 DR. SCHWARZ: That was not my intention,
13 because there were a lot of considerations during
14 that, and there has been some intent to do some
15 scaling studies, and I think Diner has contributed to
16 that.
17 As I said, there are some scaling factors
18 compared to the mass of fuel, mass of silver and
19 cadmium material, controllable material and inside.
20 The scaling factors as I say are kept the same for the
21 steam generator parts mainly, for the vellum and for
22 the cooling hairs.
23 However, there are also some -- I should
24 say sound effect. For instance, we have instruments
25 made of thermal compress, and we have to measure

1 something, you know, made of radium, so we are using
2 the radium inside the circuit, which is not typical,
3 you know, and so we have made some studies to see the
4 effect of this radium in the chemistry.
5 Regarding the scaling factors, I should
6 say that the height in the containment vessel is not
7 correct. We have a source setting faster than your
8 situation, and so the idea here is not to have a
9 correct -- I mean, a correct study of all of the
10 phenomena.
11 These are a correct range of magnitudes
12 for most of the important parameters, and then rely on
13 curves, of course, to transfer to the direct
14 situation.
15 DR. RANSOM: Fuel elements are actual
16 diameter?
17 DR. SCHWARZ: Excuse me?
18 DR. RANSOM: The fuel elements are actual
19 diameter?
20 DR. SCHWARZ: Absolutely, yes. These fuel
21 elements are typical of light water reactor elements,
22 except that they are only one meter high, as compared
23 to four meters of a normal reactor.
24 This is a view of the inside of this 300
25 cubic meter caisson, so you can see that this is a

very -- I mean, there are lots of instrumentations and materials inside this caisson.

The reactor, the fuels reactor is just behind this wall, and the fission products are right here. It is difficult to see, but in the circuit which is right here, and you can see here the video tube of the stage monitor, and then here, this is the vessel, a 10 cubic meter vessel simulating the containment.

There is a lot of auxiliary equipments and measurements. Okay. We have to measure something, of course, in such experiments, quite difficult, we have about 250 sensors taking on-line measurements I should say, and classical measurements.

We are measuring, of course, reactor powers, temperatures, pressures, size of bundles, some insulation around the bundles, we are measuring pressures, steam flow rate, fluid composition, hydrogen, content, humidity in the containment data, and the Ph in the sump.

And we are also using the mass spectrometers, you know, that you measure to identify fission products which are released by the fuel, and also assess the flow rate of the fission products on the -- the mass of fission products deposited on the

1 different parts of the circuit of the containments.

2 We are using mass spectrometers of the

3 matter of the steam generators on the leaking, and the

4 atmosphere, the cool surfaces inside the containment

5 within the sump.

6 We are measuring aerosol density using

7 photometers, both in the circuit and in the

8 containment. We are using special instruments to

9 measure the size of the aerosols, called impactors,

10 which are located at different points in the circuit

11 and the containment.

12 We have developed special instruments to

13 measure the iodine forms, the so-called Maypacks,

14 which are specific tests, with different stages of

15 filters to trap articles, to trap iodine, molecular

16 iodine, and to trap organic iodine.

17 One of these Maypack is used sequentially

18 during the test and uses demi-scanned during the test,

19 and we are using about 7 to 7 over Maypacks, which are

20 used sequentially; one after the event, and the test,

21 and which are post-test demi-scanned.

22 In addition, we have filters located at

23 different arrangement of the steam generators, in

24 sizes, taking some space from the containment

25 atmospheres. So we have typically, sample, a few

1 tenths of seconds, the gas circulating inside the
2 circuit, or simply the gas in the containment
3 atmosphere.
4 And then after the test, these filters are
5 demi-scanned. All of these measurements are computed
6 by extensive non-destructive examinations of the
7 bundle after the test, taking X-ray radiograms,
8 tomograms.
9 We have also developed the capacity to do
10 some delineation tomograms, which is very useful to
11 assess what is still in the bundle after the test, and
12 what is the location of these fission products.
13 We are taking then the fuel to the hotlegs
14 to do some destructive examination, typically using
15 micro pods, and making measuring points of the columns
16 or column, and we are sending some samples which have
17 been taken of the filters to various European labs, in
18 France, but also Germany, in England, the U.K., to do
19 some radiochemical analysis measuring solubility also,
20 even some image --
21 DR. KRESS: Can you control the pH of your
22 circ, or do you know --
23 DR. SCHWARZ: Yes. We see that in the
24 test matrix again, and that we are buffering the
25 sample to have as constant as possible pH during the

1 experiments. Next slide, please.

2 DR. RANSOM: Are you measuring hydrogen

3 concentrations?

4 DR. SCHWARZ: We have one sir, right here.

5 This is a typical -- this is a FPT1 solvent test

6 similarly, and so again a few powers, we are playing

7 around with the power and the reactor power and the

8 steam flow injectors that's a bundle of the power. In

9 order to reproduce temperature rate, temperature

10 plateaus, and to calibrate per section. And then we

11 are increasing the reactor power in order to increase

12 the temperature inside the bundle, and as you can see,

13 we have first, the oxidation under way, the cladding,

14 oxidation by steam, and production of hydrogens, and

15 then here, steam production of hydrogens,

16 concentration of hydrogen in the circuit.

17 After that we are stabilizing the power in

18 order to check our instrumentation, and then we are

19 ramping again the figure's got power, in order to

20 reach hot temperature, and to reach this kind of

21 degradation that you can see on the right side of the

22 chart.

23 So this is a pre-trial level of FPT1, and

24 these are phase colors, coding the density, as you can

25 see the melting pool is located at the bottom of the

1 bundle, and some cavity above and still some partly
2 degraded fuel parts etc. You can see the kind of
3 tomograms we are getting after the tests. We are
4 getting about 400 tomograms.
5 These are not nice pictures. We are using
6 a digital camera, and we are assessing the mass
7 distribution of, the axial distribution of material
8 after the test, and this is very important to compare
9 that with the predictions of the code. Next slide,
10 please.
11 Well, this is an example of the kind of
12 measurement we are doing in the containment at mess
13 lab, this is the iodine 141 concentration, as function
14 of time, and this is during the degradation phase, and
15 you can see here that we have a decay of the iodine
16 141, not due to radiated decay, but due to the fact
17 that we are all of us in the position well before we
18 SCRAM the test.
19 And you can see these nice curves giving
20 the time determined decay of the position of the
21 aerosols inside the containment, and these are used in
22 order to convert the check markers also. Next slide.
23 This is also an example of the kind of
24 data that we are obtaining regarding fission products.
25 This you recognize as the circuit, and the containment

1 metal. There are three elements in here coming from
2 the control room. This is for iodine, but also for
3 about 20 elements, 20 isotopes, we can get, we can
4 close the mass balance actually, and these are some
5 data regarding the amount of fission products or
6 structure materials which flew out of the steam
7 generator and since has been deposited in the steam,
8 in the room of the steam generator and so on, with
9 some uncertainties.
10 Generally speaking there is a precision
11 regarding those measurements of fission products which
12 are 80 meters, which is about 20 percent, plus or
13 minus 20 percent, it is another 30 percent, plus or
14 minus 30 percent for visible elements, and you have to
15 use mass spectrometry in order to assess the amount
16 of, for instance of reactor heights. Next slide,
17 please.
18 DR. KRESS: Are those supposed to add up
19 to a hundred percent?
20 DR. SCHWARZ: Excuse me?
21 VICE CHAIRMAN BONACA: Well, some are
22 flows and some are --
23 DR. SCHWARZ: Okay. Excuse me. Some are
24 flows, you know, getting out of the bundle, flowing in
25 the inside of the steam generator and so on. Those

1 are depositions, and depositions that are in the
2 hotleg of the steam generator, and inside the, on the
3 wall of the containment inside the coolant structure,
4 and the sump and so on.
5 And you cannot hardly see in this slide,
6 but you have quite two different members in the sump,
7 for instance, the iodine and sump, and cesium for
8 instance, cesium is not deposited in the rod that is
9 measured in the solutions of the water; whereas, for
10 iodine, it is just the reverse situation, and
11 releasing iodine and giving a lot of information.
12 This is a typical time frame for such a
13 test, and we are starting about four hours before the
14 test to discuss the test objectives, and test
15 protocols, and making some preliminary exploratory
16 calculations.
17 This is defining the experimental circuit
18 and the test device, and making some pre-test
19 calculations and we will see that in the international
20 framework.
21 Preparing the test conduct, this is quite
22 plain, and I should say that for each of these
23 experiments were other group meetings, and that means
24 supervisory or committee meeting in order to see the
25 test conducted, and the specific case on how the test

1 will be conducted.

2 And since we are melting about two

3 kilograms of fuel inside the nuclear reactors, you can

4 imagine that we have a lot of questions, and these

5 predictions were not as good for each test, we have to

6 take the lessons from the previous test, and take that

7 into account, and take that into preparation as a

8 proven test.

9 A lot of work then is devoted to assemble

10 the circuit inside the caisson, making sure during

11 test to see that the fission is working quite well,

12 because

13 you cannot miss the test.

14 And the experiment itself, is five hours,

15 it is typical duration for the fuel degradation part,

16 and then we are investigating the fission product

17 behavior in the containment during five days.

18 And then after that there is a lot of time

19 consuming work, and I should say first of all

20 removing, covering the sampling instrument using

21 remote handling system, and choosing the iodine, this

22 is very busy for about four months after the test.

23 And then we have to decontaminate the

24 circuit, we have about 20,000 curies in this caisson

25 after the test, dismantling first using remote

operation and then manually the circuits tooling the caisson. And this is typically the critical path between two tests, and it takes about 2 years to clean up everything inside the caisson, to be able to view the new circuit, so that makes it about 3 years between tests.

A lot of work is then devoted to evaluating data, especially the fission products data, left to analyze are about 100,000 gamma spectra, and some of them are with very high concentrates, and so we have to use a special decontamination techniques to evaluate or to get the information on the reaction products.

Then we have, we are performing the examination of the fuel and the, analysis, chemical analysis of the samplings, it takes a lot of time. Then we have to make some coolant system studies about these data coming from the gamma spectra, spectra analysis, and the chemical analyses, and then we are issuing a final report about 5 years after the test.

And so it is about 8 years from the idea of making the test, and defining the objectives, and to issuing the final report. Next slide, please.

While this slide is not very good, it sets data taken very recently, this is in order to give you

1 an idea of the environment inside this caisson of 300
2 cubic meters, two workers inside the caisson,
3 dismantling the FPT-2 circuit, this test was performed
4 in October of 2000, and so we are using tight suits
5 and mask, and the time they can stay inside the
6 caisson using this type of suit is about 40 minutes.
7 So that gives you an idea of the
8 conditions, the difficult conditions, to clean up the
9 inside of this caisson, and to feed the new circuit.
10 Next slide, please.
11 This is a test matrix for five tests, four
12 of them have already been performed, this is FPT-O,
13 and FPT-1, and FPT-2 007 cadmium control rod. The
14 first test was performed in '93, and it was using
15 fresh fuel, which has been trace irradiated for a week
16 in the reactors.
17 This test was performed under storage
18 conditions, which means that during the flooding
19 oxidation went away, we are not in the pure hydrogen,
20 but was a mixture of hydrogen and steel, and a maximum
21 concentration of hydrogen was 50 percent there.
22 And there was a containment of acidic sump
23 in order to promote the release of, revitalization of
24 iodine, that wasn't in place in these conditions.
25 And we repeated this test about 2-1/2

1 years after that in FPT-1, using this time irradiated
2 fuel of 23 GWd, and the last test was FPT-2, where as
3 I said was performed in October of 2000, and this time
4 under a steam poor environment, and that means that we
5 have fewer hydrogens for about 80 minutes during the
6 test, and very acidic additives.
7 And this time we used alkaline sump and to
8 sometimes hot, and that means that we are commuting
9 evaporation from the sample of the environment.
10 FPT-4 was a special test performed in '99,
11 and that means about one year before FPT-2, and we did
12 not use any circuit, in fact, in this test. This test,
13 had the DB is bad, typically if the DB is bad, if the
14 level is bad we're having some element over the
15 purity. And the object of the test was to investigate
16 the products and also oxidize. From this kind of
17 configuration where we have very specific areas we
18 perform the test up to about 3 kilograms, between 2
19 and 3 kilograms of fuel, too.
20 We used fuel coming from an EDF plant,
21 Granville, it was a quite irradiated fuel Gwd, with
22 some oxidized cladding performance inside of that.
23 And we have filters on the top part of the entire test
24 package, and so we did not contaminate the circuit
25 during these tests.

1 And we are just as I showed you in the
2 previous slide cleaning up, dismantling and cleaning
3 up the FPT-2 circuits, and constructing the FPT-3
4 circuits. The test is planned for early 2004, and we
5 will use a B4C control rod instead of a samarium
6 control rod, because it may have an effect on the core
7 melt progression, and also the fission product
8 chemistry that we have not foreseen in some advanced
9 hot water reactors in France.
10 As you know, we are using reactors, and
11 water reactors. Next slide, please.
12 This is the International framework, you
13 see we have a steering committee, and we are
14 representing to customers, I should say, the IRSN, the
15 operating commission, your country, of course, and
16 Canada, UPEC from Japan. I think there was a flag of
17 South Korea, and the Swiss also in this program.
18 The steering committee is supported by the
19 scientific analysis working group, which meets twice
20 a year, and we have about 80 experts from 43
21 organizations that constitute this working group.
22 And these working groups are discussing
23 the objective of the tests and giving the pre-
24 calculations, discussing the test protocol, reviewing
25 the data, and discussing interpretation.

1 And in the groups the interpretations are
2 discussed more in detail in circles, and there are
3 three interpretation circles. One is for the bundle
4 interpretation and another one is for the containment
5 chemistry, and the last one is for the circuit and
6 containment aerosol interpretation. Next slide,
7 please.
8 We are -- as I said, PHEBUS is a series of
9 different tests, and I am making a lot of
10 measurements, but of course specifically to draw
11 precise measurements to see specific effects.
12 So I should say that through this there
13 are a lot of separate effect tests, and I just mention
14 two here, two programs here. There is the PHEBUS-RTF,
15 RTF meaning for Radiating Test Facility in the AECL -
16 Whiteshell.
17 This test facility, as you know, is shut
18 down now, but our Canadian experts perform a series of
19 tests in order to investigate more precisely the
20 iodine behavior inside the sump, or inside the
21 containment, and reproduces conditions we had in the
22 different PHEBUS-FP, and the presence of silver, the
23 pH, which is varying from one test to another, and
24 dose rate, and this was very useful in order to
25 investigate the critiques of the reaction between

1 silver and iodine.

2 And you can see here the comparison

3 between ion code and some experimental measurements on

4 the concentration of ions inside the containment.

5 VICE CHAIRMAN BONACA: How do they

6 introduce the dose to these?

7 DR. SCHWARZ: Next slide please.

8 VICE CHAIRMAN BONACA: I'm sorry, what we

9 are looking at here, that's charts A and B?

10 DR. SCHWARZ: Excuse me? A I think are

11 exponents. This is asterisk, so this is our

12 calculations, and I think B--

13 DR. POWERS: Ok.

14 VICE CHAIRMAN BONACA: And this is how

15 iodine is in solution in the liquid?

16 DR. SCHWARZ: Yes.

17 DR. POWERS: If you want to see a real

18 good comparison look at what MELCOR predicted.

19 DR. KRESS: He did, you know that's --

20 DR. SCHWARZ: This is another example of

21 separate effector program and this is a so-called

22 SISYPHE experiments. SISYPHE is a one-on-one scale

23 mock-up of a PHEBUS containment, which is used in

24 order to perform some tests, there is lots of

25 instrumentation inside, and a lot of measurements, lot

1 of simulators, to see the complex flow patterns inside
2 this containment.
3 And also to investigate mass concerns
4 between the sump water here and the containment. We
5 are inserting the iodine here via oxygen in fact, and
6 so we are introducing sulfite in order to exhaust all
7 oxygen inside the sump, and then we let the sump water
8 to be reoxygenated, and there is this kind of oxygen
9 concentration in the water over a section of time.
10 So the purities and also the concentration
11 which at the end of the experiment, which is not an
12 equilibrium as yet, gives information between the
13 different mechanisms, we have diffusion here and also
14 convection, obvection, still which is being evaporated
15 from the sump.
16 Just to give you examples of what we are
17 making around PHEBUS in order to get more data to
18 interpret properly the data coming out from the
19 integral tests.
20 And you can see that there is a very
21 advanced stage of degradation in each case. First,
22 the FTPO and FPT1, the situation is the same. The
23 final report has been issued, and this is the size of
24 the final report, 1,600 pages.
25 This puts the data in an informatic

format, which is very nice to be comparing predictions, and interpretation of both tests are being finalized inside the circles that I described earlier.

DR. POWERS: I just can't resist to pull out the numbers, and the tomography on the left of this slide. This is the most fantastic tomography I have ever seen that they have there.

There is incredible high resolution of these tomographic slices. It is incredibly dense tomography, to the point that you practically don't have to do PIE on the test bundle. It was a major innovation compared to what we have in the PDF tests.

DR. SCHWARZ: This is one tomograph here of 400.

DR. POWERS: And they give us a week. I mean, it is fantastic.

DR. FORD: Are these neutron radiographs?

DR. SCHWARZ: These are x-ray radiographs and we are radiating the test sections.

DR. KRESS: That FPT4 was -- it started out as a debris bed?

DR. SCHWARZ: Absolutely.

DR. KRESS: Is it? How high was it?

DR. POWERS: About a half-meter, I think.

1 DR. KRESS: So it is about like what he
2 shows on the --
3 DR. POWERS: Right.
4 DR. SCHWARZ: The scaling is not the same
5 on this slide, and this one. This is one meter, one
6 meter high, and about 7 centimeters wide. FPT4
7 preliminary report, I think some of the members are
8 reviewing the report during the time being, and FPT4,
9 we have issued a preliminary report, and we are
10 getting other critical analyzes which are located
11 above that, and we are expecting to release a final
12 report in the middle of next year.
13 In FPT2, a final report is expected in the
14 middle of 2004.
15 DR. KRESS: In FPT2, where and how did you
16 introduce the boric acid?
17 DR. SCHWARZ: Well, as I mentioned, we are
18 injecting steam, and this steam was mixed with boric
19 acid.
20 DR. KRESS: I see.
21 DR. SCHWARZ: On top of the reactor and
22 mixed with boric acid, and I think the concentration
23 was about 1 ppm, and this is injected inside the line,
24 which vaporizes over time. Next slide, please.
25 So, main lessons. Regarding core melt-

1 down, and we have our first lessons coming from the H2
2 production kinetics from FPTO, and in fact were
3 underestimated in production of hydrogen by a factor
4 of two.
5 I should say that this is the total. I
6 mean, the amount, the total amount of hydrogen
7 produced during the test was calculated quite well I
8 should say, calculated by most codes. But this large
9 production during the cladding oxidation was not very
10 well calculated by codes.
11 And the reason that this occurs, we have
12 the cladding dislocation criteria, which is estimated
13 with conditions regarding temperatures and
14 reactiveness which provides relocation of the
15 cladding, so stopping the oxidation reactions, and so
16 the production of hydrogen.
17 And in fact the lessons we learned from
18 these tests FPT0 and FPT1, is that under steam rich
19 conditions -- the cladding are staying in place for a
20 very long time, and so this explains why we have such
21 a large production of hydrogen.
22 The defining codes, I don't know if it's
23 been modified in the appropriate way, because it is
24 something that is very difficult. I am not sure we
25 have a complete understanding of the physics on the

1 dislocation of cladding yet, but at least we have some
2 correlation which has been adjusted and this is the
3 case of an accident in the main core.
4 DR. KRESS: Can you have 125 grams of
5 hydrogen roughly in FPT-0?
6 DR. SCHWARZ: Yes.
7 DR. KRESS: How much hydrogen is available
8 in the clad?
9 DR. SCHWARZ: This represents about 75
10 percent of the event that we expect and I am not
11 saying that on these slides is that once cladding
12 dislocation has been adjusted the curves are
13 calculating correctly this strong production on the
14 cladding oxidation. But if you will remember the
15 slides that I presented in the FPT1 test and
16 variations, later on, during the fuel relocation we
17 have several peak of production of hydrogen, and this
18 is not well calculated by curves.
19 DR. KRESS: The take-off of hydrogen when
20 you get to igniting the clad, about what temperature
21 does that correspond to in the test?
22 DR. SCHWARZ: I would say roughly speaking
23 reaching 1600 K.
24 DR. KRESS: For the cladding.
25 DR. SCHWARZ: And I'm sure as as high as

2600 K during FPT-O. And just some information regarding FPT-2, remember that we are under steam-poor conditions, and in this case curves are doing quite good jobs in the prediction of hydrogen production under steam-poor conditions, which is about twice less regarding the kinetics.

The first test in FPT-O and FPT-1 is quite well reproduced, and again in this FPT-2 test, the total mass of hydrogen is a little bit higher than in FPT-O and FPT-1. We had some interesting discussions between us about that.

DR. WALLIS: These temperatures, how uniform is the temperature in this assembly?

DR. SCHWARZ: Well, the oxidation -- well, I should say it is a rather steep oxidation distribution, and so the cladding oxidation start about a little bit above the mid-plane and then as you know progress upwards and downwards, but not more than, I would say 26 meters.

I might mention that we have a cosine distribution, and most of the heat which is produced inside the fuel is lost to the surrounding stretching and few amount of heat is taken by the steam.

So that explains why as the oxidation reaction starts a little bit above the mid-plane and

1 progresses a bit above and below. As was mentioned,
2 we have about 75 percent of the bundle which is
3 oxidized during the test, and later on when we are
4 relocating fuel we are igniting the reaction of the
5 bottom of the bundle. Next slide, please.
6 Okay. This is regarding the fuel
7 relocation and there were some surprises here also.
8 FPT-O in fact before the test from the precalculations
9 which have been performed it was inferred that we are
10 to go very high in the PHEBUS core power in order to
11 produce the degradation 1 to 12 we need a kilogram of
12 fuel, and in fact we were surprised to get this type
13 of degradation at the much lower power, and one reason
14 for that is that the fuel started to relocate at a
15 lower temperature, about 2400 K.
16 And whereas we expected 2800 K, and even
17 more in some codes. And from the measurements that we
18 performed in this test, viscotive measurements, the
19 explanation is that during the oxidation there has
20 been a small quantity, but enough, of zirconium not
21 totally oxidized, which reacted with the fuel, and
22 this reaction is in fact t-- the interaction is
23 permitted by the fact that there is some process of
24 high oxide observed from oxide inside and out.
25 And this as you know is varying as a

1 liquefaction temperature of the fuel. And I should
2 say that is not at the time being correcting metals in
3 codes, which are using the prescribed temperature in
4 order to reproduce this phenomena. There is a lot of
5 work with Germany, for instance, and others on dynamic
6 codes in order to try to reproduce this liquefaction
7 process.
8 DR. KRESS: When you are undergoing a
9 severe accident in some fuel which is the temperature
10 at which it wants to relocate, is it generally under
11 steam core conditions?
12 DR. SCHWARZ: Well, some of them, yes. If
13 you think of TMI-2 , for instance, when you are
14 sometimes refueling the core with water and you have
15 a steam rich environment.
16 DR. KRESS: I was thinking of the large
17 break and low pressure. You'd get an interior density
18 at poor conditions wouldn't you?
19 DR. SCHWARZ: Yes, you are right, and this
20 is the reason why we perform this FPT-2 under steam
21 cooled conditions, but in other instances, a small
22 break for instance, you may have steam rich
23 conditions. I did not mention that in PHEBUS we were
24 not intending to simulate accident extensively.
25 Otherwise, we would have to have many

1 tests, more than five, and so we are trying to fix
2 very well known boundary conditions under which we
3 perform the test.
4 But I just wanted to mention that under
5 FPT-2 under steam poor conditions, this temperature
6 was about 200 K higher, and this is interpreted as a
7 fact that depending on the strengths of the reactions
8 between the -- excitation reaction between the
9 cladding and the steam we have different movement.
10 Having time to reproduce these reactions, we can
11 oxidize almost a whole cladding and having less
12 interaction between the remaining not totally oxidized
13 cladding which has also a lower temperature in FPT-2,
14 it seem that steam starvation is in fact driving the
15 temperature as a process.
16 So, I just wanted to point out that
17 because this is very important for those of us who are
18 making analysis of the hydration processes, and trying
19 to simulate that in codes. Next slide.
20 Next is the fission products, and lessons
21 about fission products. We should say that given the
22 state of degradation we're obtaining in PHEBUS you can
23 easily imagine that we are releasing a lot of fission
24 products. And I should say that there is a fractional
25 release of fission products and actinidies we're

1 measuring from the first PHEBUS test, are consistent
2 with what we would expect based on the basis of the
3 separate effect test, of excess volume. We are
4 releasing a very very little amount of volume in this
5 test, under steam cooled conditions as well as in the
6 steam rich conditions, and typically if one to two
7 percent of ORNL/VERCORS test measure as much as 50
8 percent of released volume.
9 And we are making some interpretation
10 about that, and we think that this is because there
11 are some contents of volume which are formed,
12 zirconium, iron oxides, which are very less volatile
13 from the metal volume, and we are making some
14 calculations which indicates that this is in fact the
15 case.
16 So, this probably due to the fact that
17 there are some items coming from the temperature
18 control rod which are not represented, and this is a
19 separate effect test, which a few amounts are making
20 a big difference.
21 DR. KRESS: Did you have any anomalies
22 with respect to the actiniae release, or did you
23 actually measure it?
24 DR. SCHWARZ: Excuse me?
25 DR. KRESS: After releasing the actiniae,

1 did it release --

2 DR. SCHWARZ: I don't remember -- we have

3 some details. I don't want to give you numbers but I

4 can check for you if you like.

5 DR. KRESS: It always behaves funny in

6 accrued tests, and sometimes you get a lot of it

7 released, and sometimes hardly any of it, and you

8 haven't figured out why.

9 DR. POWERS: My recollection is that --

10 well, first of all, the actinide was not a focus of

11 the measurement effort. And second that it makes the

12 same -- it is not a big inventory in these experiment

13 packages.

14 And I don't recall anything unusual about

15 it. We didn't get this on/off kind of release from

16 it.

17 DR. KRESS: I finally concluded that it

18 did the same thing that the tellurium did. It got

19 tied up by the clad at times, and so it depends on

20 what you do to the clad.

21 DR. POWERS: It could very well, assuming

22 there's an opportunity for it to do that, but these

23 experiments would tend to get much higher releases of

24 tellurium than the did in the Oak Ridge test.

25 And that has to do with the fast that

1 we're degrading the clad, and it is running down and
2 exposing the fuel directly to the steam action.
3 DR. KRESS: And in this business, it's low
4 release from a molten pool doesn't surprise me at all.
5 DR. POWERS: No, it does not surprise me.
6 DR. KRESS: That is what I expected.
7 DR. SCHWARZ: And so this is what I was
8 saying, and so as soon as we from the molten pool we
9 have a strong decrease of the release, when you expect
10 advancement from the volitisation products because we
11 have released a lot, but this is also the case for the
12 low volitisation products, and we are making -- this
13 is not yet the case, but we are making some analysis
14 using thermodynamic codes, thermochemistry codes.
15 You know, it is a question of
16 thermochemistry effects mixed with the liquid fuel and
17 there is a mass transfer inside the pool and above the
18 pool. And regarding transport there are some
19 surprises also. We were expecting cesium behaving as
20 a cesium hydroxide fission and this was not the case,
21 and in fact the cesium is less volatile. It is coming
22 with less volatility than what was expected, and we
23 think that this is due to the fact the cesium is
24 released or transported outside of the bundle as many
25 beads of cesium, because we have large release of many

1 beads also during the test.

2 And I just wanted to point out the
3 complexity of the cesium, and here this is FPT-1, this
4 is on-line measurements as a position of cesium, just
5 as in the matter of the steam generator before SCRAM.

6 And you can see here that after SCRAM we
7 have a decrease, a large reorganization of itself, the
8 cesium deposited in the steam generator, which is
9 later deposited inside the hotlegs in a steam
10 generator.

11 So we have some -- I would say that this
12 cesium is a case of cesium on-line spectrometry. It
13 is telling you that all the cesium is behaving like
14 that. I did not mention that we are taking samples
15 out of FPT-1, out of the FPT-1 test, and we are
16 sending that in to the hotlegs and we are making some
17 test measurements of this.

18 And these are the temperature plateaus
19 which during the test sees more DTT I guess. And this
20 is the release of fission from different plateaus. It
21 is under investigation, but clearly we are at
22 different species of cesium coming out at different
23 temperatures, and this is a leading indication on the
24 complex chemistry of the cesium at the position on the
25 wall of the sump units.

1 DR. WALLIS: How do you scrub the reactor?

2 DR. SCHWARZ: There is a PHEBUS core just

3 scrubbing the control rod. In fact, scrubbing the

4 core, stopping the reaction here and so we are not

5 emitting any more cesium, and so the vapor pressure is

6 changed inside the steam coming out of the manhole,

7 and this explains the suspension effect.

8 Regarding transport, reposition in the

9 steam generator is estimated by codes by a factor of

10 three, and this is not yet explained. You can see

11 here the deposition measurements of the steam

12 generator's wall for cesium, I guess, and for iodine,

13 and so you see a change in slope here.

14 This is typical of condensation. Iodine

15 arriving in the steam generator as vapor, which is

16 being condensed on both the wall and the other sumps,

17 and then here is the position that is theorizes. In

18 fact the curve predicts quite well the iodine here,

19 and so the amount of deposition, and there is a

20 thermal size effect is really not producing the

21 curves. This is under investigation.

22 And in fact, we have a huge hydrogen

23 temperature gradient since the steam is arriving at

24 700 degrees C, and as a rule, steam generators are

25 1150 degrees C. And so it seems there must be some

1 work in this part, which tends to indicate that we
2 have to be more precise in describing the profile of
3 concentrations inside this large hydrothermal
4 gradient.
5 As you may expect, we are getting out of
6 these bundles multi-continental rod sumps, and we see
7 here the composition, and the main part is silver,
8 coming from the degradation of the control rod. There
9 is some uranium and we spoke about that, coming from
10 the degradation of the instrumentation and from the
11 cladding, and from the control rods as you may expect.
12 And of course you can see also some system collapse
13 which is typical of FTP-1. Thanks to the end
14 captures, we are measuring the size of the aerosol,
15 and the variance in diameter is typically 3, with a
16 standard deviation of 2 inside the cold leg, and it is
17 a little bit larger in the containment, about 4 to 5.
18 DR. KRESS: Is the silver-cadmium control
19 rod in there?
20 DR. SCHWARZ: Yes. In the first test,
21 there is FPT-1, FPT-2.
22 DR. KRESS: Did that release its aerosols
23 other than the fission products?
24 DR. SCHWARZ: Yes. It starts earlier, but
25 this is continuously in use during the whole test.

1 DR. KRESS: I see.

2 DR. SCHWARZ: Of course, this is an over-
3 all consideration, and you can see that, depending on
4 the time we are sumping the composition is varying.
5 In the beginning there is more content in uranium than
6 at the end. But it is always about this amount of
7 silver even in the last phase of the test, and this is
8 important.

9 DR. KRESS: Okay.

10 DR. SHACK: Are they really in this kind
11 of performance, or --

12 DR. POWERS: No.

13 DR. SCHWARZ: In fact, there is a lot of
14 difficulties introduced in trying to get the chemical
15 species under which the fission products and released.
16 In fact, we have indirect measurements, so we are at
17 least, I'm sure at which the different species
18 commence, for instance. We are using these sequence
19 measurements, but we don't have direct measurements,
20 and this is something which is going to be very, very
21 difficult, because we have emissions, I should say, of
22 materials.

23 Regarding silver, there is no new metal
24 inside the sump unit, and part of this is where it
25 becomes oxidized in the containment to answer that

1 question.

2 DR. WALLIS: These this percent by weight

3 are they?

4 DR. SCHWARZ: Yes.

5 DR. WALLIS: By weight.

6 DR. SHACK: Did you notice, for example,

7 a big effect in the ignition temperature between the

8 first -- the FPT-0 test and the one test where you had

9 essentially no irradiation in the clad in the first

10 one, and then you had a 23 gigawatt blaze?

11 DR. SCHWARZ: It was perfect. I think the

12 big surprise came regarding iodine behavior. It is

13 difficult to explain. Okay. First of all, the first

14 surprise -- this is FPT-2 in fact, and so you sees the

15 nice hydrogen production, this is a 80 minute steam

16 starvation period.

17 Hydrogen produces in the late phases in

18 the test and in the relocation of the material due to

19 the heat up of the lower part of the bundle, and these

20 points here are the measurements of the concentration

21 in the iodine in the size of the containment.

22 And I should say that before the test we

23 were expecting that iodine was arriving in the

24 containment in condensed form as opposed to the other

25 sumps, and this also settled down to the bottom of the

1 containment. If you remember the sump combines the
2 whole cross-section so we have more test procedure.
3 The day after the test washing phase of the bundle is
4 done for containment, in order to collect all of the
5 aerosols inside the sump.
6 And we were expecting that after this
7 washing phase that we would have production of iodine
8 inside the containment. In fact, this picture was
9 totally wrong. In fact, all ready during the
10 radiation part we have a lot of iodine. Well, when I
11 say a lot, it is a lot as compared to zero. And then
12 this iodine is in fact decreasing rapidly, and this is
13 under investigation. As I said, this is a big
14 surprise.
15 DR. KRESS: In FPT-2, you have a sump with
16 a high pH?
17 DR. SCHWARZ: Yes, and this -- well, the
18 high pH is explained in the main term, just for
19 causing in the short term, a few hours.
20 DR. KRESS: Oh, that is short term?
21 DR. SCHWARZ: Yes, that is short term. We
22 see that typically 5 hours here. So we have probably
23 10 hours on this diagram here. I should mention that
24 in FPT-0 we were informed from the measurement that
25 during the end part of the test and we have about 40

1 percent of the iodine arriving at the back, which was
2 in a gaseous form.
3 It was less than FPT-1, and I should say
4 the same amount of latitude as in FPT-1 and FPT-2.
5 There are two assumptions to explain that. There is
6 a difference between FPT-0 and FPT-1 tends to indicate
7 that we are not in a chemical equilibrium. I should
8 say that at the present time from the output of the
9 bundle to the containment is on the order of a few
10 seconds, and everything is getting from typically 1400
11 K to 300 K in the containment.
12 You may think that in FPT-0 there is only
13 trace iodine, a few milligrams of iodine, it was an
14 irradiated fuel so you have typically a gram of
15 iodine. So you would expect some time, but not enough
16 to reach complete equilibrium during the transport in
17 the sump unit.
18 And in order to check this assumption, we
19 are going to launch an out of time test, and then we
20 are going to mix different elements, and mix that in
21 a furnace, and then have short term trial in a sump
22 unit and some measurements in order to see whether
23 this assumption is correct or not.
24 And see whether this assumption is correct
25 or not, and see whether this is due to the presence of

1 silver, for instance, or not.

2 DR. KRESS: FPT-2 was a steam poor test?

3 DR. SCHWARZ: Yes.

4 DR. KRESS: And could that iodine be a

5 hydrogen iodine in that case? If you have got a lot

6 of hydrogen and --

7 DR. SCHWARZ: In fact, if you look at the

8 calculations of the thermal chemistry codes, it tells

9 you that you may have some HI during the steam-rich

10 phase, and, how do you say, oxidation conditions, and

11 you don't expect any diffuse fuel under reducing

12 conditions.

13 DR. KRESS: I thought it was just the

14 opposite.

15 DR. POWERS: Well, you need to recognize

16 that the steam poor conditions prevail for about 18

17 minutes in that test, just during the escalation

18 phase, and then when steam rich--

19 DR. KRESS: Well, during the escalation

20 phase, you have probably got a lot of hydrogen

21 generating.

22 DR. POWERS: Well, yes.

23 DR. KRESS: And that is when you are

24 releasing the iodine, and you have got a good

25 opportunity for cesium iodine if it got released that

1 way to convert to HI, I think, and it is less gaseous,
2 and that may be -- I don't know if that is what you
3 are seeing in that early phase or not.
4 DR. POWERS: It is probably a little hard
5 to tell right now from the FPT-2, but what you do get
6 with the existing equilibrium codes that they will
7 tell you, yes, there is a certain fraction of it is
8 iodine just from the -- in the circuit temperatures
9 and the natural chemical equilibrium.
10 And once they scramble the reactor, you
11 start getting the vaporization of gaseous iodine and
12 species off the surfaces. And at this kind of level,
13 you are really working in traces of trace here. This
14 is typically around 3 percent.
15 It is not a wholesale conversion, but it
16 is enough to create maybe some iodine in the initial
17 conditions in the containment, and then you start
18 seeing these things that we never anticipated, because
19 we are just not very smart.
20 But that is the whole point, is the
21 chemistry in these severe accidents is so complicated
22 that if you try to anticipate everything the computer
23 codes just get outlandishly complicated, and here with
24 mixing all the right chemicals together, and they tell
25 us what chemistry you need to focus on and where, we

1 learn quickly.

2 DR. KRESS: I was trying to reconcile this

3 1465 source term with --

4 DR. POWERS: Well, the authors of the 1465

5 are pretty perspicacious and they anticipated a

6 certain amount of gaseous iodine at a time when there

7 was a religious fervor about everything that was using

8 iodides.

9 You have to give the authors of 1465 a lot

10 of credit for guts.

11 DR. SCHWARZ: Okay. So non-chemical

12 equilibrium is one possible explanation, and another

13 one is relativization of the condense iodine once it

14 arrives in these containments, or oxidation or

15 oxidizing conditions.

16 But again it is a matter of debate between

17 the generalists. Next slide. Of relevance, and which

18 was not expected at all, and this is the Russian phase

19 I mentioned earlier, and so we are collecting the

20 iodine inside the sump, and then you measure by means

21 of the mass spectrometer, looking at the sump. Decay

22 of the iodine concentration in the sump of the fuel

23 rods, which is not due to the radiative decay of

24 iodine-151, this has been attributed to the fact that

25 silver is reacting with iodine, and we have deposition

1 of silver iodide in the bottom of the sump.

2 And this has been verified in the RTF test

3 we mentioned earlier. But you have to in France, at

4 least, check about all our chemists. We have spent

5 years writing many equations, chemistry equations of

6 the sump, and FPT-1 is telling us that nothing is

7 getting out of the sump, simply because iodine is

8 trapped by the silver, and we were very disappointed.

9 Another instance, and this is FPT-1 here,

10 are coming directly from the Maypack. I mentioned

11 specific features earlier which very often

12 discriminate between the different forms of iodine,

13 and after the Russian phase in FPT-1, the measure

14 decreased of the iodine -- radical iodine

15 concentration, in red here, during that time.

16 Whereas the iodine -- organic agent

17 concentration is increasing, and after ten hours we

18 have mainly only organic iodide inside the

19 containment, and no longer radical iodine, and this is

20 for FPT-1, the picture is different for FPT-2, and

21 this is again very interesting for interpretation.

22 So just to conclude on the iodine, there

23 are very important lessons here, and we are launching

24 and re-orienting some of the separate effects tests in

25 order to investigate these. I mentioned we are also

1 going to launch a new program, which is devoted to and
2 listed as a production of organic iodides.
3 And there has also been some tests in
4 Tucson at PSI in order to measure the stability of
5 these iodides and beta and gamma radiation.
6 DR. ROSEN: Before you leave that slide it
7 seems to me that it is a very important conclusion
8 that the silver is trapping the iodine in the sump
9 from a dose perspective.
10 Now, some plants, and that means that you
11 need to get the silver from same place, and you can
12 see clearly that it comes from the control rods, and
13 plants whose control rods are made of silver in the
14 cadmium, which is fairly typical.
15 But there are some plants that use hafnium
16 for the control rods, or at least there was a move
17 towards hafnium.
18 DR. POWERS: There was a move toward it,
19 but hydrogen absorption was slowing and people backed
20 off the big time.
21 DR. ROSEN: Did all people back away from
22 hafnium?
23 DR. POWERS: Yes. And I long time ago
24 learned never to say all things about our reactors,
25 but I believe there is enthusiasm for hafnium rods in

1 the Navy.

2 DR. ROSEN: Yes, clearly in the Navy, but

3 also there was a time it was being suggested to us in

4 the utilities to move towards hafnium. We didn't do

5 it, but here is another reason why we shouldn't,

6 unless hafnium behaves like silver. I don't know.

7 DR. POWERS: It won't, but there are lots

8 of disadvantages in severe accidents to having silver

9 and cadmium rods around. I don't think that any of

10 those disadvantages are so great that you would stop

11 using them, but it is not a panacea.

12 DR. ROSEN: And you are saying that the

13 silver in the cadmium rods should not be used, because

14 I am drawing the opposite conclusion.

15 DR. POWERS: Well, you have not looked at

16 what they did in the core degradation and things like

17 that for it.

18 DR. ROSEN: But having the silver there

19 certainly helps attract the iodides is what these

20 results show.

21 DR. POWERS: Well, there is lots of ways

22 to trap iodine.

23 DR. SCHWARZ: To complete what you said,

24 in fact, silver is trapping efficiently iodine inside

25 the sump under accident conditions. It is not the

1 case in alkaline conditions, but in this case iodine
2 is hydrolyzed, and so there is nothing to worry about.
3 And one of the conclusions is that even if
4 you fail to to inject soda, for instance, silver has
5 some good points regarding -- which is trapping this
6 here
7 DR. KRESS: The ratio of the control rod
8 and the material to fuel material, was it prototypical
9 of the PWR, the amount that you had in there?
10 DR. SCHWARZ: No. I am speaking just of
11 this. You have a large excess of silver as compared
12 to iodine. This was very important because we are
13 reevaluating our source term. Our source term is
14 something that is used to design emergency plants, and
15 this is the so-called FP in France, which is assuming
16 realistic accident sequences were you have the spray.
17 So you are releasing into the iodine some fission
18 products after a while, it is delayed release.
19 And the fact that we have organic iodide
20 in the late term, and the organic iodine is not at all
21 trapped by the filters in the inside of the
22 containment. For the 900 megawatt unit the conclusion
23 came that there was no big margin, as compared to the
24 assumptions made previously when designing emergency
25 plants.

1 But the situation may be worse for the
2 1400 or the 1450 megawatt that we have in France,
3 because there is almost no silver in these reactors.
4 So we are learning a lot of information from the next
5 test, FPT-3, for our reactors. Next slide, please.
6 Well, this is the end of our presentation,
7 and so it seems to me that it was a good idea to send
8 out some invitations, we have to keep on working on
9 this, especially in the field of iodine chemistry.
10 I think we are producing quite an
11 interesting database, and there are a lot of
12 benchmarking activities around PHEBUS, an online
13 reservoir, I should say, and there are a lot of
14 activities in the circles around this data.
15 As I mentioned, we are reorienting and
16 launching new separate effect test programs in order
17 to more deeply investigate, especially in the PHEBUS
18 iodine.
19 Thank you.
20 CHAIRMAN APOSTOLAKIS: I was wondering,
21 Dana, in 1150, these things were handled using expert
22 opinion.
23 DR. POWERS: Yes, they were.
24 CHAIRMAN APOSTOLAKIS: Did we learn
25 something about the validity of these assessments by

1 going back and comparing with the actual results, or
2 we don't have sufficient information to say something
3 else?
4 DR. POWERS: Well, there is a lot of
5 things to derive from that, and what we learned is
6 that probably we were a little over-optimistic in 1150
7 about our ability to predict the degradation and
8 relocation of fuel.
9 CHAIRMAN APOSTOLAKIS: These are the
10 ranges that were there--
11 DR. POWERS: Yes, even in the range. I
12 mean, I can find experts that override, but in general
13 people were a little over-optimistic about what they
14 can do there. We are a little pollyannaish about the
15 complexities in the chemistry.
16 For instance, release fractions in some of
17 the elements were pretty big ranges, and you can find
18 things like that. Now, I don't know if there has been
19 any disciplined effort to do that, but what's making
20 it interesting right now, is the impact that it has
21 had among the remodeled accident analysis codes that
22 we have now.
23 Remember, 1150 spurred a new generation
24 of codes that weren't available then, and because they
25 are sort of a benchmark to give us an idea, one of the

1 tests being used is an international standard problem
2 and 47 groups will submit contributions to that
3 international standard problem.
4 And I think 17 different computer codes
5 are being used, and five of them are the full suite,
6 from beginning to the end, and the rest are specific
7 phenomenal logical codes.
8 And it is so illuminating, and there are
9 just a lot more. Fission product release has always
10 been treated as a temperature driven phenomena only.
11 And one of the things that we have learned
12 is movement, and relocation of material and the gas
13 composition is every bit as important as temperature
14 in dictating the release of fission products.
15 And we look at this containment phenomena,
16 which has always been the step-child of source terms,
17 and you finding iodine trapped in the sump sure enough
18 by the silver, but on the other hand, you have lots of
19 iodine in the containment because of things going
20 wrong in the whirls and in paints, and things like
21 that.
22 It is a little more complicated than you
23 would like to say, but it is focusing more attention
24 on the things in a way you could never be if you just
25 did it in the abstract.

1 CHAIRMAN APOSTOLAKIS: The reason why I am
2 asking is that there is very little information out
3 there on how credible experts can be, and there are
4 very few opportunities to actually go back and see how
5 well the experts performed.
6 That doesn't necessarily mean that they
7 would perform the same way in the future, but at least
8 it gives you some insights, and so I was wondering
9 whether that would be something worthwhile in doing?
10 DR. ROSEN: Well, the problem is obviously
11 more complex than even that, because you would find
12 something out about the experts in this particular --
13 these particular experts on this particular problem.
14 You might not find out anything about
15 experts in general though.
16 CHAIRMAN APOSTOLAKIS: That's very true,
17 but on the other hand, it was a major study. I mean,
18 they did go out of their way to find --
19 DR. POWERS: There is no question that you
20 would find experts that probably got including the
21 range of phenomena. The means probably deviate a lot,
22 but --
23 CHAIRMAN APOSTOLAKIS: It would be
24 suspicious, probably.
25 DR. POWERS: Yeah, it would be.

1 DR. KRESS: The experts did a remarkable
2 job of actually addressing the unanticipated results.
3 CHAIRMAN APOSTOLAKIS: The intent was --
4 DR. KRESS: They discuss things that
5 obviously are being validated.
6 CHAIRMAN APOSTOLAKIS: But that would be part of
7 the study; to say the good things and the bad things.
8 Anything else?
9 DR. ROSEN: One thing that would be of
10 interest is how do these results compare to the loft
11 test. You know, the last loft test? Did you hear
12 anything about --
13 DR. POWERS: There's nothing in the loft
14 test.
15 DR. KRESS: There's nothing to compare
16 with.
17 VICE CHAIRMAN BONACA: Yes, you would --
18 DR. KRESS: It's not a fission product
19 test.
20 DR. POWERS: We'd be burning huge amount
21 of fuel and then wasting the results of fission
22 product release.
23 DR. FORD: OK, I have indicated that
24 myself, and the interesting thing was the effect of
25 silver in the sump. Can we guess what would happen at

1 BWR?

2 DR. KRESS: Yes, you would expect the B4C

3 to have a big effect, because it reacts and produces

4 organic iodine. Now, the question is can the B4C and

5 the iodine get together, and I think that is what this

6 test is going to show.

7 DR. FORD: So you would predict,

8 therefore, that the source term, the iodine would be

9 worse in BWRs than in Ps?

10 VICE CHAIRMAN BONACA: Yes, you can get a

11 lot of organic iodine, which doesn't settle down. It

12 will react with walls, but it is so volatile that it

13 is likely to be released. So that is the big issue

14 there, is what happens to the iodine.

15 It also affects the chemistry of the

16 cesium, the cesium borates. So I don't know what

17 happens to it.

18 CHAIRMAN APOSTOLAKIS: I have long since

19 learned to say we will see.

20 DR. KRESS: Well, a lot depends on where

21 the -- on what happens to the B4C and where it goes,

22 because it is reactive with a lot of things, and it

23 can get tied up with waters, and the question is:

24 does that oversee it?

25 DR. LEITCH: Professor, that is a good

1 question about hydrogen. I guess if I am interpreting
2 this data correctly, it would seem to suggest that our
3 predictions of hydrogen generated following core melt
4 may be half of what it actually is, or what these
5 tests would suggest.
6 And I am wondering as we move to risk-
7 informed regulation as we are considering changing
8 combustible gas pools, and if we take that fact into
9 account.
10 In other words, here it says that the
11 codes have been --
12 DR. WALLIS: It is just that the total
13 comes out the same.
14 DR. LEITCH: So is that at a different
15 rate?
16 DR. WALLIS: It is the rate which is off
17 by a factor of two, and where 75 percent is another.
18 DR. SCHWARZ: That could be important for
19 recent radiation measures, you know, using the
20 combiners, for instance. But as I said, the total
21 amount was well predicted by codes. This is the
22 kinetic rate of production, which was not totally
23 correct during the cladding oxidation that went away.
24 MR. LEE: This is Richard Lee from
25 Research. In the PHEBUS results, the FPT-0 and FPT-1,

1 the MELCOR quota is factored in in release version
2 124, and we factor in all information that we have
3 learned for it so far under steamless conditions, and
4 so all the oxygen --
5 Actually, when we adjusted the core
6 degradation ordering and so forth, all the MELCOR
7 predictions now, when compared back to some of the
8 organization experiments done in the U.S., all those
9 predictions have improved tremendously. So all the
10 information has been factored in.
11 STAFF: Dana, do you know if there was
12 -- in the unmarked code there was a hydrogen model,
13 especially for steam-rich conditions. Is that the one
14 that got translated into MELCOR?
15 DR. POWERS: The kinetic equations for
16 oxidation are -- let's see. The kinetic pull in one
17 temperature region, and was switched to. One should
18 get the solution of fuel and particularly when be
19 switched to mass-transport unit model. That is one of
20 the results of the PHEBUS thing; is that we really
21 didn't know how to handle that once you got liquid
22 running and bringing down the rods.
23 And PHEBUS said, and, yes, you have to
24 handle that, because it was a significant amount of
25 hydrogen generation. What I would propose, Mr.

1 Chairman, is that we take a break, and then switch to
2 the plans for the future.
3 DR. SCHWARZ: I have one comment because
4 I have to go to another meeting and I will be coming
5 back.
6 CHAIRMAN APOSTOLAKIS: Do you find that
7 you go to a lot of meetings?
8 DR. SCHWARZ: I continuously go to
9 meetings.
10 CHAIRMAN APOSTOLAKIS: That's all that I
11 do. They pay me for that.
12 DR. SCHWARZ: I think you raised a very
13 good point about the 1150 and we are concerned about
14 the same thing, and as you know the expert
15 illustration had been done before most of the research
16 on severe accidents is completed, and so we have
17 learned a lot, and have an initiative for research and
18 to see the difference between the expert illustration
19 and the scientifics.
20 CHAIRMAN APOSTOLAKIS: That would be very
21 good.
22 DR. SCHWARZ: As much as we can, there is
23 a big difference. We will undertake the study for the
24 rest of the plants.
25 CHAIRMAN APOSTOLAKIS: Well, it is one

1 thing to redo the analysis, and another thing to go
2 back and try to evaluate the quality of the expert
3 judgment, and that is more of an expert judgment, and
4 the first part is more of the engineering and science
5 part.
6 But I think, for example, what Dr. Kress
7 said is very important here, that the initial
8 inclination would be to find the negative things, but
9 there may be some good things that the experts
10 anticipated, and the experiment is validated. So it
11 will take some creative approach I would say.
12 But that is excellent. That is really a
13 good idea what you are doing. Okay. Let's recess
14 until 10:20 and then we will come back to these
15 issues.
16 (Whereupon , the proceedings in the above-
17 entitled matter went off the record at 10:04 a.m. and
18 went back on the record at 10:20 a.m.)
19 CHAIRMAN APOSTOLAKIS: We are back and we
20 will continue with our presentation of PHEBUS. Dr.
21 Powers.
22 DR. POWERS: What we are seeing is a bit
23 about the entirety of the PHEBUS program, and what you
24 have seen is that they have conducted 4 out of 5 of
25 the planned tests, and they rescinded an effective

1 experimental facility and an effective team for
2 conducting the experiments of this type. We have
3 learned a lot about how to conduct tests of this type.
4 The issue comes are there opportunities to
5 go beyond the fission -- the VFP program into other
6 areas that would be of interest for reactors under
7 stressful or accident conditions.
8 And our second talk will deal with some
9 follow-on's that are possible from the PHEBUS program,
10 and I will introduce Alan Mailliat to present that
11 material.
12 DR. MAILLIAT: Thank you, Dana. Good
13 morning, everybody. Well, my mission is to try to
14 give you an insiders view of the IRSN Future Programs,
15 and to clearly give you the reason why from the safety
16 context of Europe and the reason why there is a safety
17 context, and try to give you the highlights of the
18 high burnup LOCA program, and several accidents
19 programs. Next slide, please.
20 So far, here is the situation for a severe
21 case that we are now facing an evolution of the
22 market. That means that we are less and less
23 commissioning the construction of nuclear power
24 plants, and that means we are a better organization
25 and so far necessity of an efficiency of that, that's

1 what it is.

2 Therefore, we are seeing the evolution of

3 the reactors. We have a lot of change here, but this

4 has been I would say in the last 20 years. Next

5 slide, please.

6 DR. WALLIS: Mailliat, it looks like a

7 medieval castle.

8 DR. MAILLIAT: I beg your pardon?

9 DR. WALLIS: It looks like a medieval

10 castle.

11 DR. MAILLIAT: Yes.

12 DR. WALLIS: I'm sorry, the picture. The

13 picture. I'm sorry.

14 DR. MAILLIAT: Therefore, thank you

15 everything that we had, and we had rather wide

16 margins, because according to our evaluator, our

17 assistant evaluator designed these margins, and for

18 the moment we have to consider the use.

19 But mainly, unless they ask for a product

20 adjustment to necessitate the safety due to error -,

21 and plant incorporation, and furthermore, we see

22 increase in tendencies of the reactors to use best

23 estimate codes with modernistic computer conditions.

24 Therefore probabilistic safety studies and

25 we are appreciative that we need to refine and to

1 reduce some datas on the consequence of some specific
2 accident -- for example, air ingress and core
3 quenching. And the basically the IS equation now is
4 are the codes always correct? And I don't know why,
5 and are IS accident estimate always correct? And
6 basically IS is saying that we need to extend the
7 database, first, and not only but certainly appreciate
8 which is the totals of the database, and what is that,
9 for safety applications. Next slide, please.
10 So what we need to do is to basically
11 update and upgrade existing codes to such a business
12 you need first to set off an optimized number of
13 small-scale or semi-integral, out-of-pile, or in-pile
14 experiments, you need to have requested for our
15 computer code continuations.
16 But that is not enough. You need a few
17 integral in-pile experiments, because it is the only
18 way when you are talking what you got from PHEBUS is
19 a clear demonstration which you need in-pile programs,
20 which give you an area of reactor applicability, and
21 much simulation completeness. And we heard some
22 examples previously, and furthermore you need to
23 integrate an experiment to be able to quantify the
24 things mentioned previously.
25 So for coming to such a context, IS has

1 decided to prepare two programs. The first one is
2 related to a LOCA, and APRP-Irradie is the French term
3 for a LOCA, and PHEBUS 2000 for severe accidents.
4 Next slide, please.
5 But first I will chat a bit about new
6 information regarding LOCA. Now basically they tried
7 to list the pending issues, and here is the reason
8 why, and then we try to give new information here
9 regarding the LOCA key point which flying -- phase of
10 the design. Next slide, please.
11 The budget process for which we need
12 information is fuel relocation. There is a LOCA that
13 in the clear event evidence of fuel stock is decreased
14 burst of the rod. The restoration was made maybe 20
15 years ago, and we did not include the consequence of
16 such a process in any computer code with a LOCA
17 accident present.
18 And the designation when the fuel melt
19 take place and are there any delays due to fuel-clad
20 bonding? What is the filling ratio, because if we
21 have fuel inside the balloon we have additional power
22 and how much will depend on the filling ratio.
23 And what is the fragment size and what is
24 the corresponding conductivity to put in the code to
25 mobilize the transfer in the balloon.

1 Next slide, please.

2 There is another cut here of a view of

3 these different situations and this is a fresh fuel

4 rod, and here is the same with 35 gigawatt, and you

5 see fuel debris inside the rod.

6 And this is not a new process, and there

7 is nothing new there because even in the USNRC, in

8 1981, you had such evidence. And at this time I would

9 say that the discussion was mentioned, and the process

10 was mentioned, but the discussion didn't go further.

11 Next slide, please.

12 Some pending questions which are in terms

13 of criteria regarding the peak clad temperature and

14 the evident clad react. What is the effect on peak

15 clad temperature, the effect on final oxidation ratio,

16 and consequences for quenching, and post-quenching

17 embrittlement. What is the impact of hydrogen uptake

18 and consequence once more for quenching.

19 As you know, in the burst area you will

20 change the internal oxidation and you will change the

21 internal hydrogen uptake, and that will impact on the

22 capability of the fuel rod to be allowed to support

23 quenching. We see all the pending questions.

24 Next slide, please.

25 And here we have performed some estimation

1 of fuel relocation. You see the calculation performed
2 one year ago by our colleague and friend Grandjean,
3 Hache, and Rongier, which was provided to one of the
4 sessions of the Identification and Ranking Process in
5 USNRC one year ago.
6 And you can see that we have two kinds of
7 calculations. This one is for the fuel relocation,
8 and this is a normal transient and we stopped the
9 calculations and we changed the fuel relocation and we
10 put fuel melt in the balloon corresponding to the
11 observation made in the FR-2 result in Germany, and
12 you get this temperature calculation.
13 And I would say you have roughly, I would
14 say, 200 or 300 degrees in addition. And in this
15 case, we have relocations. We have clear evidence of
16 consequences. Obviously this is just simulation
17 performed by IPSN. We won't know exactly will be the
18 right and furthermore this calculation was performed
19 without taking into account any recladding. And in
20 this case thermal hydraulics for this case is exactly
21 the same as this one. It means that the calculation
22 of quenching is the same.
23 DR. WALLIS: But that is a low temperature
24 where your curves separate there at 800 degrees.
25 DR. MAILLIAT: Yes.

1 DR. WALLIS: The new curve and the old
2 curve. That is quite a low temperature isn't it? No,
3 800. You have two curves, where the dash curve and
4 the old curve meet.
5 DR. MAILLIAT: Yes.
6 DR. WALLIS: That is a low temperature
7 isn't it?
8 DR. MAILLIAT: It's okay.
9 DR. WALLIS: It's okay?
10 DR. MAILLIAT: The temperature for the
11 burst I would say between 800 and 600 at the second
12 peak. Now if fuel relocation takes place at this time,
13 according to the time where fuel relocation takes
14 place and you will have an addition of power, the
15 train has been changed. If you have a late fuel
16 addition it will not be the same for the maximum
17 temperature and for the oxidation.
18 Next slide.
19 And now we will check what would be the
20 consequence in terms of a quench drop. Our first
21 question, What is the maximum flow blockage ratio that
22 leaves coolable an irradiated rods bundle? Here is an
23 image we got from the previous LOCA test, and in order
24 to have the right idea of the fuel cage you need to
25 oxidate fuel because there is strong interaction

1 between fuel rods. And in such a picture you have
2 just the cladding because in the PHEBUS LOCA test we
3 have only -
4 And furthermore now keep in mind that such
5 pictures and put fuel there and fill with fuel. And
6 the question is which is maximum flow blockage ratio
7 that leaves coolable fuel rods. I would say 20 or 25
8 years ago we had some programs, FEBA, SEFLEX and we
9 got the value of 90 percent of coolability, but the
10 result we got with any contact between the heating
11 element and the clad because by this time we had fresh
12 fuel simulations.
13 Now fill this base with fuel, and are
14 there any new values here and we have no information.
15 Therefore, mild quenching, which is the impact of
16 failure during quenching .
17 There is another point which is so
18 important is the quenching was not considered 25 years
19 ago is breakage of the fuel rods due to the guides.
20 And a program made in Germany made out that such
21 situation could be not so pleasant I would say.
22 There is one point I will save for the
23 pending questions, and now the main point that we
24 follow is a long time cooling, which is residual
25 ductility of cladding after the quenching. Now we

1 have reflooding, you may have such
2 -- if you have any movement due to discharging the
3 core, how much you can withstand such situations, and
4 this is described as long time cooling.
5 Therefore, according to all literature,
6 pending issues IPSN --
7 CHAIRMAN APOSTOLAKIS: What does it stand
8 for?
9 DR. MAILLIAT: It's for Institute for
10 Radioproduction and Nuclear Safety.
11 CHAIRMAN APOSTOLAKIS: What are the French
12 words? Institute --
13 DR. MAILLIAT: (French phrase.)
14 CHAIRMAN APOSTOLAKIS: Thank you.
15 DR. MAILLIAT: Therefore you have radio in
16 addition to protection.
17 CHAIRMAN APOSTOLAKIS: Okay.
18 DR. MAILLIAT: Okay. We have merged two
19 institutes. Therefore, what we are planning to do is
20 to have our safeguard APRP program, which include
21 first several programs. Some of them are still
22 underway, and this one is underway and this one is
23 underway, and this one is underway.
24 We intend to use the in-pile specific
25 experiments. First, we intend to use a single test

1 OECD program to evaluate the basic process, which is
2 fuel relocation. You have one rod and a test protocol
3 will be defined in such a way that we can learn the
4 consequence of fuel relocation.
5 One fuel relocation will take place. And
6 then as I mentioned, in addition to single rod test we
7 will do bundle tests. And then the second step is
8 code developments.
9 So the main aspects of the program will be
10 the nature of the fuel, UO2, MOX, and burnup. The
11 fuel-clad thermomechanical coupling, we intend to use
12 the actual fuel rods in actual conditions, because
13 reactor information about the fuel rods we have
14 information about the cladding we need to check it
15 with is a consequence of the burnup of an actual fuel
16 rod.
17 And the thermal azimuthal gradients are
18 the main factors affecting cladding strain and
19 blockage ratio, but we intend to explore
20 thermohydraulic aspects in terms of consequence for
21 data, and as you can see, we intend to study at least
22 quenching, coolability of blocked arrays.
23 Next slide, please.
24 So now the question is we know what we
25 have to learn, and the question is how to produce the

1 light water, and the further question is rational and
2 how do we define the LOCA test.
3 In-pile experiments are a necessary
4 requirement, because this is a unique way to maintain
5 the heat generation in the right place. If you have
6 fuel relocations, you need to rise the power
7 generation where there is the fuel.
8 For the heat generation is not a
9 necessity for itself. In fact, if you have heat
10 generation as the right place, you will not have the
11 right condition to produce ECR and PCT, oxidation,
12 uptake is an integral part of the fuel clad ratio of
13 the value. And once if you can produce the heat,
14 even if you produce the fuel ration to produce the
15 steam access inside the bundle. If not, your data
16 will be not correct.
17 Furthermore, internal reflooding, you have
18 to appreciate I will say the actual situation. A
19 famous LOCA test we had maybe five years ago and then
20 quenching is not a flow. Quenching is not just
21 putting water and the water increasing. Quenching is
22 first quenching and then drying and then requenching,
23 and on the same fuel rod, you may have quenching on
24 one side, and dry on the other side.
25 So it means that the stresses which will

1 be separated by your system will depend on the actual
2 orientation of the various fuel rod and so on. And
3 furthermore, you need to lengthen the flow because if
4 you have just enough for the first quench the water
5 could dry after the first quench but in this one you
6 need more.
7 Next slide.
8 Another point which was mentioned, I would
9 say is we have absolutely no idea for the consequence
10 of a blowdown. There is a blowdown here inside the
11 fuel pellet, and then the transient center of the
12 pellet will decrease and the size will increase. So
13 for a pellet will suffer temperature transient from I
14 would say 1500 degrees down to 1,000 for the center,
15 and I would say for the outside from 300 up to 1,000.
16 Thermal stresses may induce pellet fragmentation.
17 And there is no information regarding how
18 much the induced thermal stresses may product
19 additional rim and pellet fragmentation. Suppress
20 clad-fuel bonding, and this is an important point for
21 fuel relocation.
22 And I would say much -- I will say flow
23 paths will induce from the upper plenum of the fuel
24 down to the lowest point. And this transient may be
25 associated to -- will produce FP releases from the

1 intergranular inventory.

2 Therefore to correctly, then we -- because

3 to have this kind of a transient to a flat profile,

4 there is no other way but to have extract a lot of

5 power before the transients, and then you have nothing

6 after as a blowdown, and there is no other way to have

7 an in-pile system with the pressurization. Next

8 slide, please.

9 DR. WALLIS: Well, while I am listening to

10 you, I am saying why do we -- this sounds like

11 something that we should have heard in 1965 or

12 something like that. Why has it taken so long, or are

13 we not revisiting some of the old problems here? Of

14 course, we can talk about that later.

15 DR. MAILLIAT: Okay. But now we have high

16 burnup fuel.

17 DR. WALLIS: Yes.

18 DR. MAILLIAT: Next, bundle experiments.

19 It is crucial to get the correct azimuthal temperature

20 field around the tested fuel rod, because the size

21 will depend on the thermal profile around the rod.

22 If you have a cold point, you will see a

23 small balloon. If you have roughly azimuthal

24 temperature field you will get a huge balloon. I will

25 show you such information. Therefore, temperature

1 field correctness is crucial to produce realistic
2 balloon, and radial interactions between adjacent fuel
3 rods impact the balloon size and balloon size and
4 shape impact the amount of relocated material.
5 So if you need to have right balloon, do
6 not use single rod test. And if you see the balloon
7 size and shape impact the amount of relocated
8 material, and what we are looking at. This is our
9 main study. Therefore, if you miss the balloon size,
10 you may miss our objective.
11 But here are all the single burst results
12 we had, and the area of the balloon -- single rod
13 tests is not. And we feel that's for such kind of
14 tests there is a good probability of a cold point.
15 These tests tend to have a small -- a tendency to have
16 a small burst of strain, or a strain of bursts.
17 Sorry.
18 For a more significant situation, and
19 good deal of symmetry, as it tends to produce too
20 large strain, you can get the right one but the
21 tendency is to produce too large strain. And as you
22 see here each is a typical bundle value.
23 It means that if you attempt to study a
24 balloon, to produce a balloon that is one single rod
25 test, you need to be very prudent.

1 Next slide.

2 The second reason for the bundle
3 experiments are to represent the axial stresses, and
4 they represent the effect of the control rod, and to
5 get a realistic value of the flow blockage, and to get
6 the realistic complex flow behavior, and quench front
7 progressions.

8 Therefore, to summarize you need in-pile
9 for the reasons I mentioned and to have the right
10 balloon size. Therefore, with such things in mind, we
11 are ready to imagine what kind of tests we need.
12 Therefore, what we intend to do is to first study the
13 fuel relocation characteristics.

14 And according to what we said, we need at
15 least one high burnup --

16 DR. WALLIS: By high burnup, you mean
17 around 30 or something like that?

18 DR. MAILLIAT: We need something which is
19 closer to what we have today, around 50.

20 DR. WALLIS: Around 50?

21 DR. MAILLIAT: And basically in the next
22 two decades 70.

23 DR. WALLIS: And so you are talking about
24 60 to 70 for high burnup?

25 DR. MAILLIAT: Absolutely. And you know

1 around 50 there is a big change in the fuel structure.
2 And there is a part which is -- which is fixed on the
3 cladding, and what we need to be aware of is a
4 transient.
5 Okay. So this is basically a set of
6 tests, and there is a blowdown phase to explore if
7 there is any consequence for the blowdown phase during
8 transient fuel relocation.
9 Then the second part of test will be to
10 study fuel cage and quenching. And coolability of
11 fuel rods.
12 Next slide, please.
13 Therefore, the initial conditions would be
14 -- at least the initial conditions themselves
15 represented are the PWR operation conditions. We
16 intend to reach exactly the PWR conditions because we
17 think that is between 150 and 120 megapascal.
18 For cost reduction we intend to run the
19 test from 12Mpa. And the pressurization and inter
20 phase will explore - presently we are exploring three
21 possibilities two breaks with both cold and hot legs
22 which is typical of a large break LOCA. But we are
23 also exploring one break with two possible locations,
24 bundle foot or head for technical reasons, but we are
25 not only interested in large break LOCA.

1 We are also interested in a small break
2 kind of study. And obviously for the test condition
3 we intend to have reflooding, and we are studying two
4 possibilities, and one is imposed mass flow rate and
5 gravity driven.
6 Next slide, please.
7 In the '70s, we had a facility. We used
8 the largest part of this facility and, and we , which
9 was mentioned by Michel Schwarz a while ago. Next
10 slide, please.
11 One crucial thing is instrumentation, and
12 this is a change for the design of inside the bundle,
13 inside the high burnup fuel rod. We have a special
14 system with fresh fuels and we can put thermocouplers
15 on. And we have a connector here here, and there are
16 several parts with a simple solution. We have a kind
17 of -- which can be made in these pictures as -- one
18 guide tube in which you can --
19 And this special system here, we need to
20 reduce the fuel rods, high burnup fuel rods, and each
21 rod after each rod you put your rod in hot lab, or in
22 a hot cell. Collection will made from these high
23 pressure foot connectors, and then the high part of
24 the bundle will be produced in the fuel bundle.
25 And all the equipment and the tubes needed

1 to perform such kind of an assembly will be
2 for working in hot labs most likely.
3 Next slide, please.
4 The fuel rods, and the foot valve mounting
5 -- and a bundle arrangement between 9 to 25 rods,
6 including control rods, because control rods are --
7 and change rods of the size of the balloon. This is
8 a kind of a -- the blue rods here are the fresh rods,
9 and the red ones are those which were included in the
10 -- and put in the center of the system.
11 And you see that you can have also -- 25
12 rods, although the smallest number is 9 rods. It is
13 a crucial point was to design the bundle in two parts,
14 making it easy to put the instrumentation on the high
15 developed fuel rods in the one part of the -- and hot
16 cell, and -
17 Thank you. Next slide.
18 Now, if you did what we have from the
19 PHEBUS experience, and -- to produce -- location of
20 the space. And for fuel locations and for
21 destination, and -- , we intend to use the same --
22 gamma tomography --.
23 Now, what was produced for the PHEBUS
24 tests, and here is a definition of the information is
25 100 microns, and here you see what is a good idea of

1 the formation, and we intend to enhance the system,
2 which will provide several points inside the cladding.
3 But the -- after the test -- data *8 and
4 good enough to compute codes --. Next slide, please.
5 Therefore, to summarize --
6 DR. WALLIS: Are the codes going to
7 represent --
8 DR. ROSEN: What I would like you to do is
9 to go back and run it again.
10 DR. MAILLIAT: One more tie.
11 DR. WALLIS: Are the codes going to
12 represent this geometry?
13 DR. MAILLIAT: Now that you -- they are
14 good data.
15 DR. WALLIS: Yes, but I wonder how the
16 codes represent this kind of geometry.
17 DR. MAILLIAT: Maybe we -- computes the
18 right information, and -- the size -- inside the
19 cladding. There is presently -- a model for such a
20 code. -- what we need.
21 DR. WALLIS: It seems to me that if you
22 did the experiment twice, you would not get the same
23 shape. You would not get exactly the same shape if
24 you did the experiment twice. You would get a very
25 different one.

1 DR. MAILLIAT: I am convinced that in
2 terms of fuel relocations -- 9 high developed fuel
3 rods, and the thing is that we have 9 -- and the
4 question is how much fuel --, and what is the ratio.
5 And there is --, because if you look -- the
6 information that you are looking for.
7 The shape of the balloon is very precise,
8 and the amount of fuel you get in the balloon, because
9 once more if you -- information. --. Thank you.
10 -- high burnup studies next year --
11 reactor, and the first test -- in 2007, and this kind
12 of test could be made tentatively --, and we are
13 preparing -- in such a way that -- the same equipment
14 for the first program. So this is for --. Next
15 slide, please.
16 Now, we are checking to -- and we change
17 the subject, and -- in LOCA. Next slide, please.
18 Now, what are the pending questions. The
19 first pending question is which is the high burnup and
20 the MOX on the release rates. We know that the fuel
21 structure is different, and high burnup impacts fuel
22 stoichiometry.
23 Very high burnup in Pu rich clusters, we
24 have a very high burnup, and the Pu-an U chemistries
25 is different --, especially with regard to oxygen.

1 And what we observed earlier for MOX, we
2 are thinking that the MOX release is different. --.
3 Two tests, ST1 and ST2, -- experience a transient,
4 which is this one here -- , and -- two tests, and we
5 have -- for the MOX test. For high burnup --, and
6 some of them are a stronger -- -- impact.
7 DR. POWERS: Call those low releases for
8 those elements is astounding.
9 DR. MAILLIAT: Okay. That's --
10 degradation, and there is a lot of --, and if there is
11 a kind of fuel forming process, -- process, it -- .
12 DR. WALLIS: That's 40 percent by volume
13 is there?
14 DR. MAILLIAT: Yes.
15 DR. POWERS: Yes, it completely -- and it
16 will change the entire degradation process.
17 DR. WALLIS: I'm just surprised that there
18 is enough room for a 40 percent --
19 DR. POWERS: The only reason -- is you run
20 running out of room. I mean, that's what happens.
21 DR. MAILLIAT: As far as I know, there is
22 no -- computer code --. -- our computer --
23 DR. WALLIS: But as you just said, this
24 thing doesn't happen in a regulatory space.
25 DR. MAILLIAT: And the last --. The --

1 database -- concerning -- and MOX fuel. Next slide,
2 please.
3 -- during severe accidents. And according
4 to what we learned from our single rod tests in
5 Germany and in Hungary, -- the degradation process
6 could be --, and the current oxidation -- steam, and
7 as -- steam, and as energy generation with air is --
8 may be two times greater than --.
9 And here also -- is the impact due to air
10 entering the system. This is -- and here we have --
11 for the test -- decrease due to air entering the
12 system.
13 So -- is important, and -- when air is
14 entering --. And furthermore, as we mentioned, that
15 there is for a large break, for example, severe
16 accidents, and -- transfer from hot condition to cold
17 condition -- and cannot reach equilibrium chemistry
18 conditions, except that you have a risk of -- ,
19 especially in the containment. This is the pending
20 question for error. Next slide, please.
21 Now, one of the crucial pending questions
22 -- is the quenching. We have *8 results for quenching
23 a core. How much corium will be involved in the
24 interaction with water, and which are the reacting
25 corium properties.

1 How much steam and hydrogen will be
2 produced during the degradation process, and
3 especially during the core quenching. You will see
4 that -- in the composition.
5 We have some information, but not a lot,
6 available for representative conditions of a severe
7 accident. We have some information available from
8 separate effects tests or electrically powered tests -
9 - at the beginning of the degree of the quenching.
10 If you have no huge degradation, which is
11 with weapons systems has some kind of program with the
12 information that leads to a bundle that would react at
13 some other temperature. But if you have the boost
14 back we have the information.
15 Furthermore, are there any risks of a late
16 pressurization or steam explosion in the primary
17 circuit, and are there any predictions of containment
18 bypass. For example, SGT rupture, because of left on
19 too high the pressure of the chute was observed, up to
20 20 or 40 bars, and if you are resisting the other tube
21 in high temperature and you have pressure peaks in the
22 system, that would be a consequence of the system.
23 In addition, additional releases from fuel
24 induced by temperature escalation, there is a question
25 of important fuel temperature escalation, and there is

1 some evidence from LOFT-LP that there is something
2 during this phase that we are unsure of fragmentation,
3 and we are, I would say, we don't know, we have the
4 information, because we have no fuel tests for
5 quenching.
6 And in addition during such quenching, we
7 have a huge amount of steam produced when putting
8 water in the system, and so one of the questions is
9 re-entrapment of previously deposited materials in and
10 above the core by the large steam flow, especially if
11 you have progress at this time as steam turns into
12 water.
13 And in addition, if you really try to get
14 the steam materials, you will have a very difficult
15 situation facing you. Next slide.
16 Once more, how to produce the right result
17 we need, and here are the results on why oxidation is
18 present in various compositions than oxidation of
19 molybdenum alloy in the oxygen composed. And you can
20 see that the condition of the oxidation rate change a
21 lot according to the composition of the metals. It
22 means that if you intend to produce the right type of
23 fission production, for example, that you need to have
24 the right materials.
25 And keeping in mind that in the core, you

1 have measurement situations. You have to have a
2 representative situation of the various composition in
3 your bundle to perform a representative test.
4 Therefore, three points are essential to
5 obtain such a correctness. We need the actual
6 irradiated fuel, with the appropriate burnup. Once
7 more the question is to get the right degradation
8 correctness, is to the right heat source while the
9 fuel heats. After that is fuel movement that will be
10 the metallurgical transformation, or chemical
11 transformation of the fuel and the release rates and
12 to produce such correctness as regeneration is in the
13 test.
14 And we have observed in demonstrations
15 that there is a strong connection of FP release and
16 degradation, and if you change the degradation
17 process, or the degradation aspect, you change the
18 release, and you can imagine if you are correct would
19 result in the right degradation process. Therefore, we
20 also use in pile tests to produce the right fuel
21 release.
22 Next slide, please.
23 It was assumed therefore to write a new
24 program. We have the experience of FP and our
25 intention was to change the way to proceed. Keeping

that in mind the objective we have now are not so large that we are under FP objectives. You see that we have no chemistry objective. We have no containment, inorganic chemistry, and organic chemistry and so on.

The four objectives of this new program is small compared to the finished one. And furthermore we don't need to have such high temperatures in the system. We do not need to transport vapor, fission product to the steam tubes, and to explore the degradation in the steam generator tubes.

It means we have adopted high temperature component in the system. We adjusted the bundle, and to transport the release from the bundle to a measurement point.

So we if we change a lot of our philosophy in order to have reduced, simplified, integral integration of the components, obviously because they less important but to reduce the costs.

Next slide, please.

Therefore, Simplification of circuits. We don't need a high temperature, and there is no more need for one week re-irradiation because we don't need to run a case chemistry. We have no more need for experimental needs in the containments.

1 For a simplified sampling, we intend to
2 have one sampling location just above the bundle and
3 a second location in the caisson, including all the
4 required experimental measurements in the PHEBUS FP
5 the equipment to change first by test, and redesigned
6 roughly from test to test. I remember someone asking
7 for electrostatic measurement.
8 DR. POWERS: No one would ask for --
9 (Laughter.)
10 DR. MAILLIAT: Therefore, this philosophy
11 is over. What we intend to do to all the equipment is
12 standard forms, and our objective is to reduce time
13 between the tests, and instead of there being one test
14 each three years, we intend to have two tests in the
15 same period, and a reduced investment in terms of
16 cost, and to divide the costs of the investment for
17 one test by two.
18 Next slide, please.
19 Therefore, I will try to give you rapidly
20 now about the difference between PHEBUS FP now and the
21 new PHEBUS 2K equipment. Because it is the same
22 bundle, as is the sampling location just below the
23 bundle, this is the FPT-4. Here you can have up to 6
24 thermal gradient tubes above the bundle. There is
25 nothing else.

1 Next slide, please.

2 This is a view of the quench test train.
3 The main problem we had was to design the train for
4 quench test, because before you run the system you
5 have to demonstrate to the authorities that your
6 system will be safe. Therefore, we found the
7 solution by including additional free volume closed
8 between the first test and mobilized in case of an
9 energetic event during reflooding. By this way
10 obviously we lose volume and we need to increase it so
11 that the thickness of the pressure tube around the
12 bundle.

13 So basically we will have less fuel rods
14 in the quench test train than in the PHEBUS FP train.
15 Her we have 16 fuel rods instead of 21.

16 Next slide, please.

17 The main changes in fact take place in the
18 caisson. We have a measurement compartment located in
19 the caisson instead of 250 samplings mentioned by
20 Michel Schwarz one hour ago.

21 All the equipment will be located in the
22 furnace at 150 degrees C, and in such a furnace will
23 have 16 sampling instruments with standardized
24 connectors removable through remote operations.

25 In the PHEBUS FP You have to keep in mind

1 that due to the high temperature that there is
2 designed specific equipment, and there is no way to
3 build the system or decontaminate the system. It was
4 a complex process for continuation of the electric
5 system and the tubes and so on. Therefore this
6 system, PHEBUS-2K is how you say, supermarket
7 connectors.
8 Therefore, each sampling instrument is
9 equipped with commercial self-sealing low pollution
10 quick disconnect coupling. After sampling removals,
11 sleeves replace the instruments and the
12 decontamination is performed.
13 Therefore, there is a large advancement
14 once more with PHEBUS.
15 Here we are thinking about decontamination
16 inside the instrument itself. It gives you a
17 sampling, and decontaminating the reactor. The
18 measurement compartment can be transferred without any
19 dismantling through the equipment lock T3. The
20 measurement compartment will constructed outside from
21 the facility and the new one, a clean one, can be
22 built and save time for building the new test.
23 Next slide, please.
24 Here we have a view of the new equipment.
25 The FP line an then the new line for FP release 2,

1 what we call the measurement compartment. This the
2 top view, reactor pool, and this line in here and
3 measurement compartment.
4 Next slide, please.
5 Here was have a better view of these
6 measurement compartments inside you have two plates
7 with 16 sampling equipment. And in front of them you
8 have gamma detectors. Here are more details of the
9 system.
10 So for on-line test and after the test you
11 can have on-line measurements of these samplings. And
12 after the test, you can decide those of the sampling
13 which will be directed to the PT analysis or for those
14 which it is sufficient to have the on-line information
15 provided by the gamma.
16 We have to keep in mind that a large part
17 of the first test costs related to specific
18 examinations. And for the more on-line gamma
19 detection, we have some very precise information some
20 radio elements. For all of them, obviously, and this
21 is why we have to optimize the measurement from the
22 gamma spectrometry and from PTA analysis.
23 Next slide, please.
24 And therefore, we design the sampling
25 equipment, and after that the integral filters which

are located in the existing biological shell of the filtering unit, and there we have the trapping of all the aerosols and iodine gases. And the clean gas will be transferred to 502 for condensation.

Next slide, please.

The next one if we have time we will see. We will go to the next one.

Thank you.

Here we have the measurement strategy information during these kinds of tests. The first location is just above the bundle, and inside of the bundle we have a conventional measurement with the pressure, temperatures, and mass flow rates, and so on.

Then the tubes and filters will decide kind of equipment we will use, and provide sequential information, such as release rate, deposit rate, resuspension rate. In this system we can open them at the beginning or close them later and so on.

And then with the Post test, we can have gamma spectrometry of the system as usual in the PHEBUS facility, and then destructive examinations, and chemical analyses of the deposits there.

With that information just above the bundle, then the second location is the measurement

compartment. Once more on sampling here we have on the gamma spectrometry, once more we can extract the sampling and transfer them for analysis, providing release rates, and obviously gamma spectrometry, destructive examinations, chemical analyses.

Next test. Next test? Sorry. Next slide.

Okay. Just a word about this. It is basically the same one as the previous one. In fact, we are a bit in advance on this PHEBUS-2K feasibility studies are over. We have started basic design studies across the next nine months, and in July 2003 we start detailed design studies, and we envision the first test in the year 2007, and alternately with high burnup LOCA tests.

And this is the last slide, and thank you very much for your attention.

CHAIRMAN APOSTOLAKIS: Are there any questions for the speaker?

DR. POWERS: Let me ask you a question. Do you envision these two programs to be again an international cooperative effort?

DR. MAILLIAT: Excuse me?

DR. POWERS: Do you envision these two programs to be a cooperative -- an international

1 cooperative effort?

2 DR. MAILLIAT: Yes.

3 DR. POWERS: Would it be organized in a

4 similar fashion with interpretation circles and

5 scientific analysis working groups?

6 DR. MAILLIAT: It is clear according to

7 the success we observe in the interest in the

8 international community. Whether it will be the same

9 name for the groups, I don't know. But we learn a lot

10 with such exchange, it would be stupid to refuse that.

11 DR. POWERS: I think I agree with you a

12 hundred percent. The PHEBUS program is an

13 extraordinarily successful way to have partners from

14 different countries with different contacts working in

15 a cooperative fashion, and that may be the biggest

16 triumph for the PHEBUS-2K program, is figuring out how

17 to do that in an efficient way.

18 DR. MAILLIAT: It was very impressive to

19 me to see how much different the predictions could be

20 when it comes to codes, and if you have such a

21 platform for putting all the guys around the table and

22 chatting about the situation is like this, you will

23 realize a lot.

24 MR. LEE: I think we have two good reasons

25 to have that, to have international cooperation. The

first one obviously is the cost of these experiments, and they are costly, and so we need -- IRSN cannnot perform such tests alone, and so we need to establish international cooperation.

DR. POWERS: The third reason that I think it is important for cooperative programs is the trend toward uniformity especially among Western reactors in their approach to safety and the way they analyze things. We don't want one type of reactor in one country being vastly primitive compared to everybody else.

DR. MAILLIAT: And since it is the platform that is very efficient regarding severe accidents, it could also be a good platform for high burnup LOCA, and we are trying to organize something within the next few years to try to put everybody thinking about such question because it is not an easy business. And we value the discussion we had in high burnup through NRC panels and so on, and that is where we also need to discuss a lot.

CHAIRMAN APOSTOLAKIS: Any other questions people would like to pose?

DR. RANSOM: I don't know if this is appropriate to ask the speaker, and yes, maybe it is, but I thought the Germans and the French were

1 cooperating on a core expulsion design for a PWR, and
2 I am wondering how these experiments tie in to shed
3 data on that type of design, or are the experiments
4 necessary for that type of design.
5 DR. POWERS: I don't know anything about
6 it.
7 DR. RANSOM: I mean, are they going to
8 blow the core and cool it down there?
9 MR. TINKLER: Are you talking about the
10 core catcher?
11 DR. RANSOM: Right. Is that now passe or
12 is it still --
13 MR. TINKLER: I don't think it is passe,
14 but they are looking at even with all this research to
15 try to predict how core melt progression will go, and
16 if the accident continue to grow and attack the lower
17 half, what would be the effect of trying to find a
18 spreading area to be able to assure core quality even
19 if the vessel, and it is another layer in this
20 research program.
21 DR. RANSOM: I guess the other comment
22 would be that thinking back to the AP600 and all the
23 scaling work and issues that went on with that, and
24 now you are coupling the early part of the accident
25 with the more severe part, it would seem here again

1 that some of these scaling issues should be addressed
2 ahead of time if you are really hoping to answer a lot
3 of the questions that will come up in the future with
4 regard to applicability of these results.
5 DR. MAILLIAT: Well the question of
6 scaling is obviously, but maybe I can put on the table
7 some words you can examine. If you burn 10 kilograms
8 of wood, and you consider chemistry and physics inside
9 the fire, you think that if put, how you say, 100
10 kilograms or 1 ton of wood and you burn it, I would
11 say that inside each piece of wood it would change but
12 10 kilograms of wood burning or 1 ton of wood, physics
13 will change. I would say maybe the extension of the
14 heat transfer, or maybe the view of the measure which
15 would be involved with the flow. That is basic
16 physics, and basic physics laws are no different.
17 The extension of your physics is changed, but the
18 physics is the same.
19 If you have 10 kilograms of fuel there,
20 and processes, metallurgical transformations, would
21 not be changed.
22 DR. RANSOM: Well, but I think --
23 DR. MAILLIAT: That is the point to
24 explore, scaling is one thing, and physics has to be
25 considered in terms of the process and the extension

1 of the process. If you consider fire 10 kilograms or
2 1 tone is the same physics and the same chemistry for
3 each piece of wood. What would be changed is the
4 extension of that flow. And there is no change in
5 the physics. It is just an extension of the process
6 that changes.
7 DR. RANSOM: Well, there are two constants
8 that enter into the process, and you have absorption
9 of material, and I think even some of your experiments
10 that you showed in the lower containment, and how long
11 does it take for material to be absorbed.
12 You mentioned natural circulation as a
13 possibility, and certainly scaling issues, in terms of
14 the thermal hydraulics of the system become very
15 important if you are to simulate what might happen.
16 DR. MAILLIAT: We don't intend to
17 represent some hydraulics of the system, that is
18 clear, and what we intend to represent is the physical
19 process, the chemical process, and the scaling
20 philosophy to have the right amount of fuel, the right
21 amount of materials, and the right amount of steam,
22 and keeping in mind -- the physics will not be changed
23 if you burn 10 kilograms or 1 ton.
24 DR. RANSOM: Well, some of these might be
25 answered by applying, say, CATHORN to the early part

1 of the accident to your experimental setup, you know,
2 to understand how it behaves. I don't know if you
3 intend to do that.
4 MR. TINKLER: We do use ICARE, which is
5 comparable to CATHORN, in order to make some studies,
6 yes.
7 DR. MAILLIAT: We use CATHORN for LOCA
8 studies.
9 DR. RANSOM: The early part, yes.
10 DR. POWERS: If these tests are anything
11 like the FP tests, there is roughly a year of pre-test
12 calculations to get things right, and there can be an
13 amazing number of calculations that have to be done,
14 and they can be viewed from these interpretation
15 circles, and compared against other codes.
16 In fact, that is exactly what they are
17 going through right now for the FPT-3 test, is that
18 they have used the CATHORN code to pre-predict the
19 test, and now they are inviting, begging everybody
20 else with different codes to calculate them in order
21 to bolster the safety case that they are making, using
22 the FPT-1 and FPT-2 results to calibrate those codes
23 for a pre-test prediction.
24 And it is absolutely fascinating to see
25 how the codes, which really are addressing the same

1 physics, get somewhat different results. And the
2 phenomena that seems to be especially dominant is
3 related to the user.
4 If there are no other questions, I thank
5 you for an outstanding presentation and the exciting
6 possibilities for follow-on work here. I would turn
7 it back to the Chairman, noting of course that as
8 usual the Fuel Subcommittee is exactly on time.
9 CHAIRMAN APOSTOLAKIS: Yes, sir?
10 DR. MAILLIAT: I wanted to thank you for
11 giving me the opportunity to explain our high risk
12 programs.
13 CHAIRMAN APOSTOLAKIS: Well, we appreciate
14 you coming here every much. Thank you very much, and
15 we shall see you this evening. We have a few things
16 to do, and so I suggest we take a short break now and
17 try to finish with the P&P report before lunch. Would
18 you be happy coming back at 20 of?
19 (Whereupon, the meeting was recessed at
20 11:31 a.m.)
21
22
23
24
25

CERTIFICATE

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

Name of Proceeding: 492nd ACRS Meeting

Docket Number: N/A

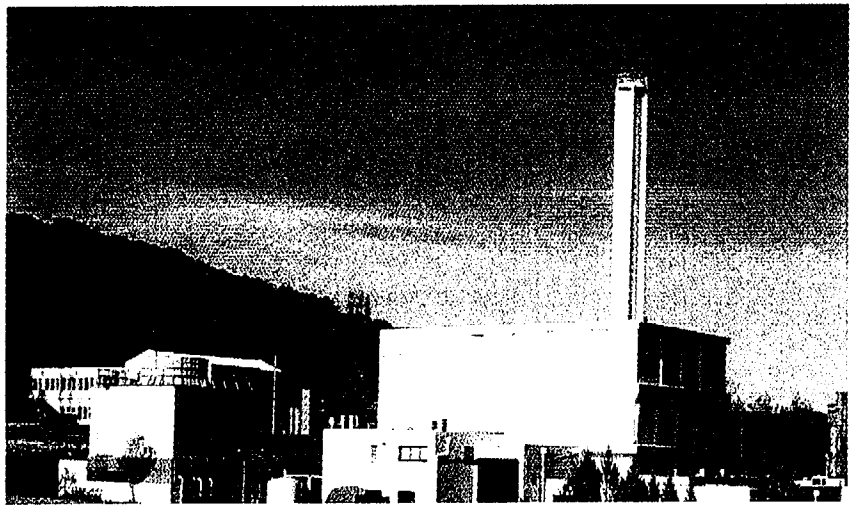
Location: Rockville, Maryland

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

/s/ Debra Wilensky
Debra Wilensky
Official Reporter
Neal R. Gross & Co., Inc.

IRSN THE INTERNATIONAL PHEBUS-FP PROGRAMME

❑ OUTLINE



- *Objectives*
- *Facility*
- *Test matrix*
- *International cooperative efforts*
- *Separate effect tests*
- *Main achievements and lessons*
- *Conclusion*

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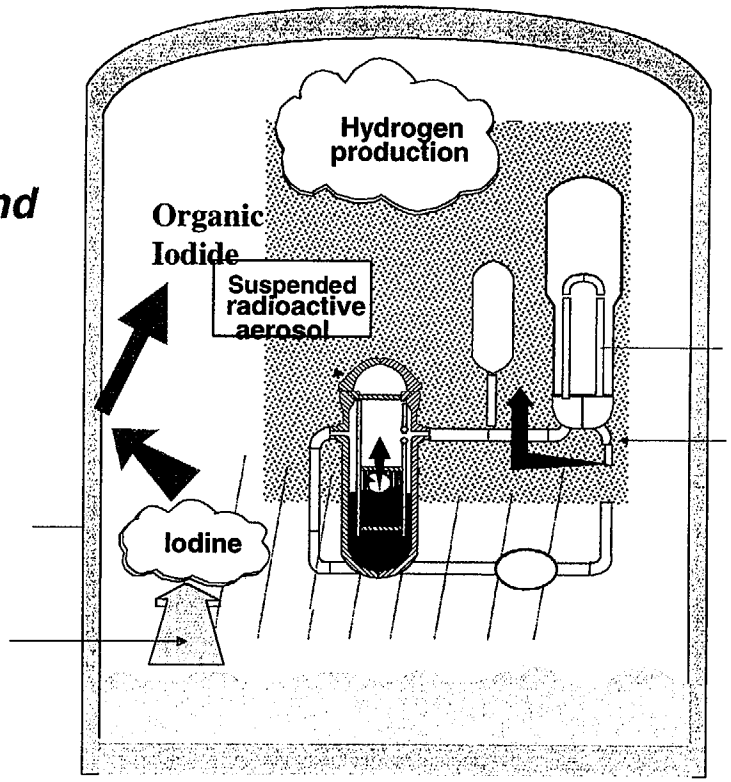
❑ OBJECTIVES (1/1)

- *Contribution to LWR SA phenomena understanding: core melt progression and source term issues*
- *Integral tests using real core materials under prototypical physico-chemical conditions*

⇨ *Complement separate effect tests: representativity?*
Important phenomenon missing?

⇨ *Validate code systems as ASTEC, MELCOR, ICARE, ATHLET CD, SCADP,...*



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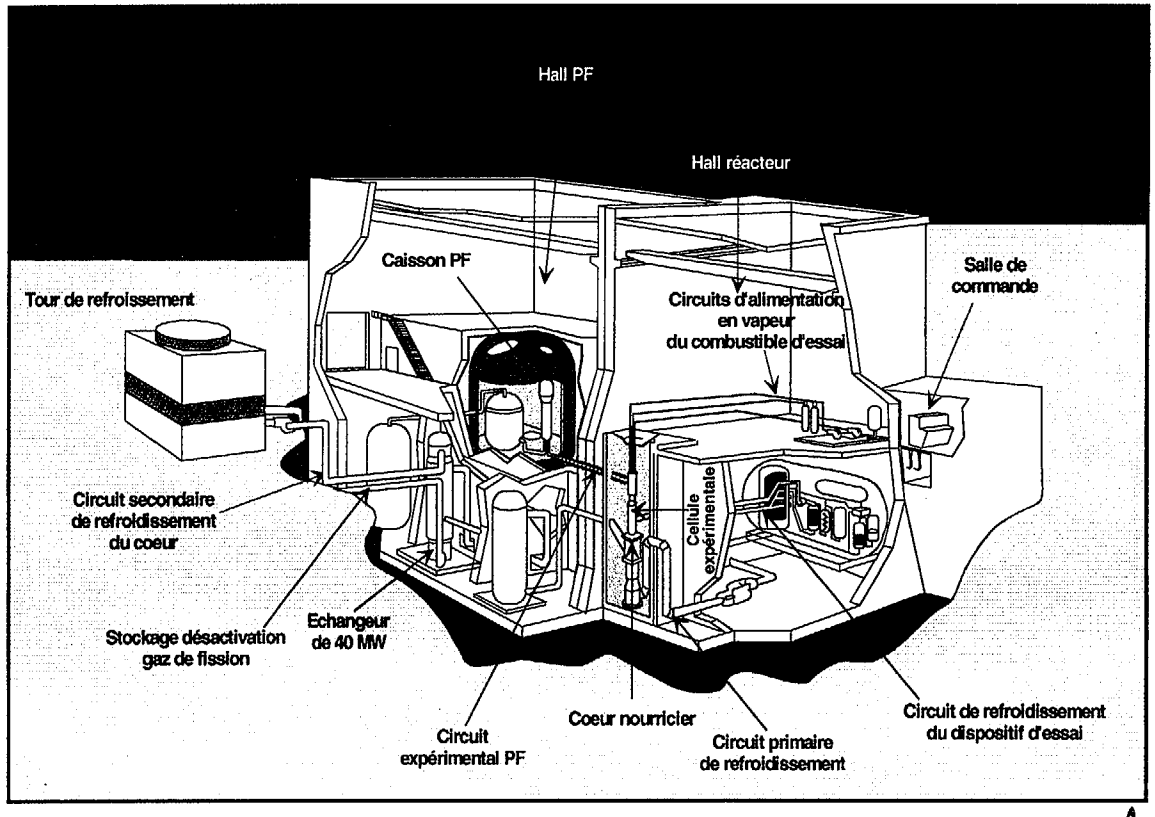
THE INTERNATIONAL PHEBUS-FP PROGRAMME

❑ THE FACILITY (1/9)

- *Test reactor built in late 70s*
- *Phebus LOCA*
- *Phebus SFD (80s)*
- *Phebus FP*
  - *FP Extension*
  - *Reinforcement*
  - *Cooling tower*
  - *FPT-0 (93)*



⇨ *Quite unique facility in the world*

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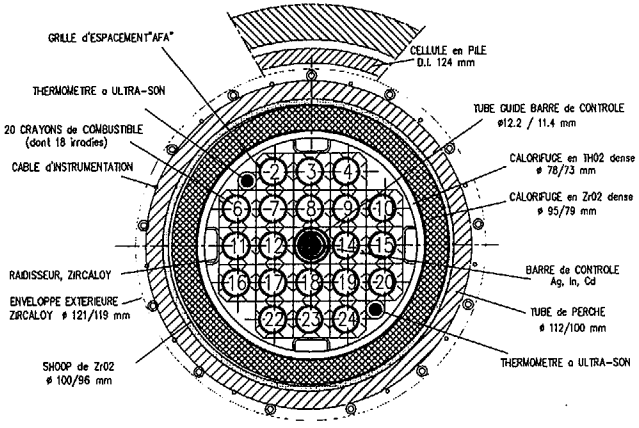
THE FACILITY (2/9)

Phébus PF

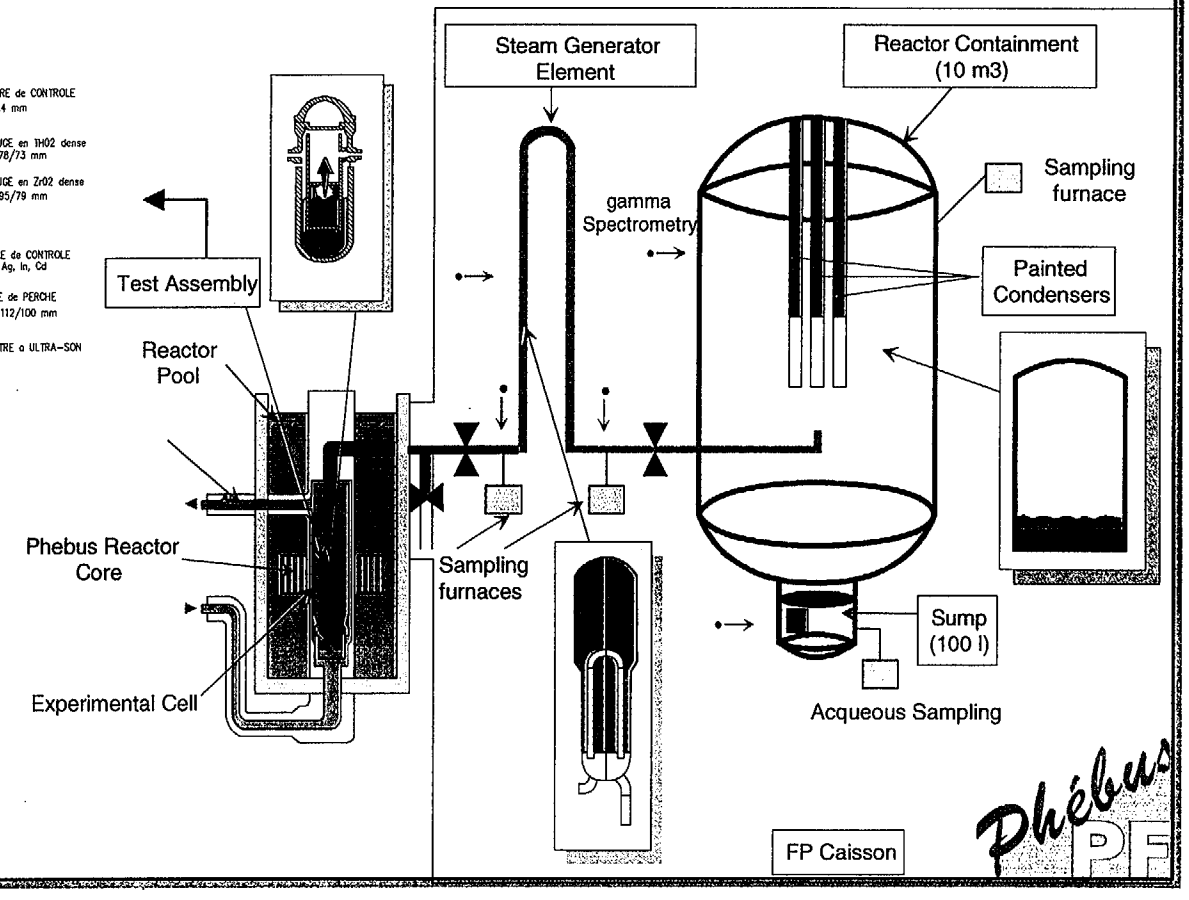
4

THE FACILITY (3/9)

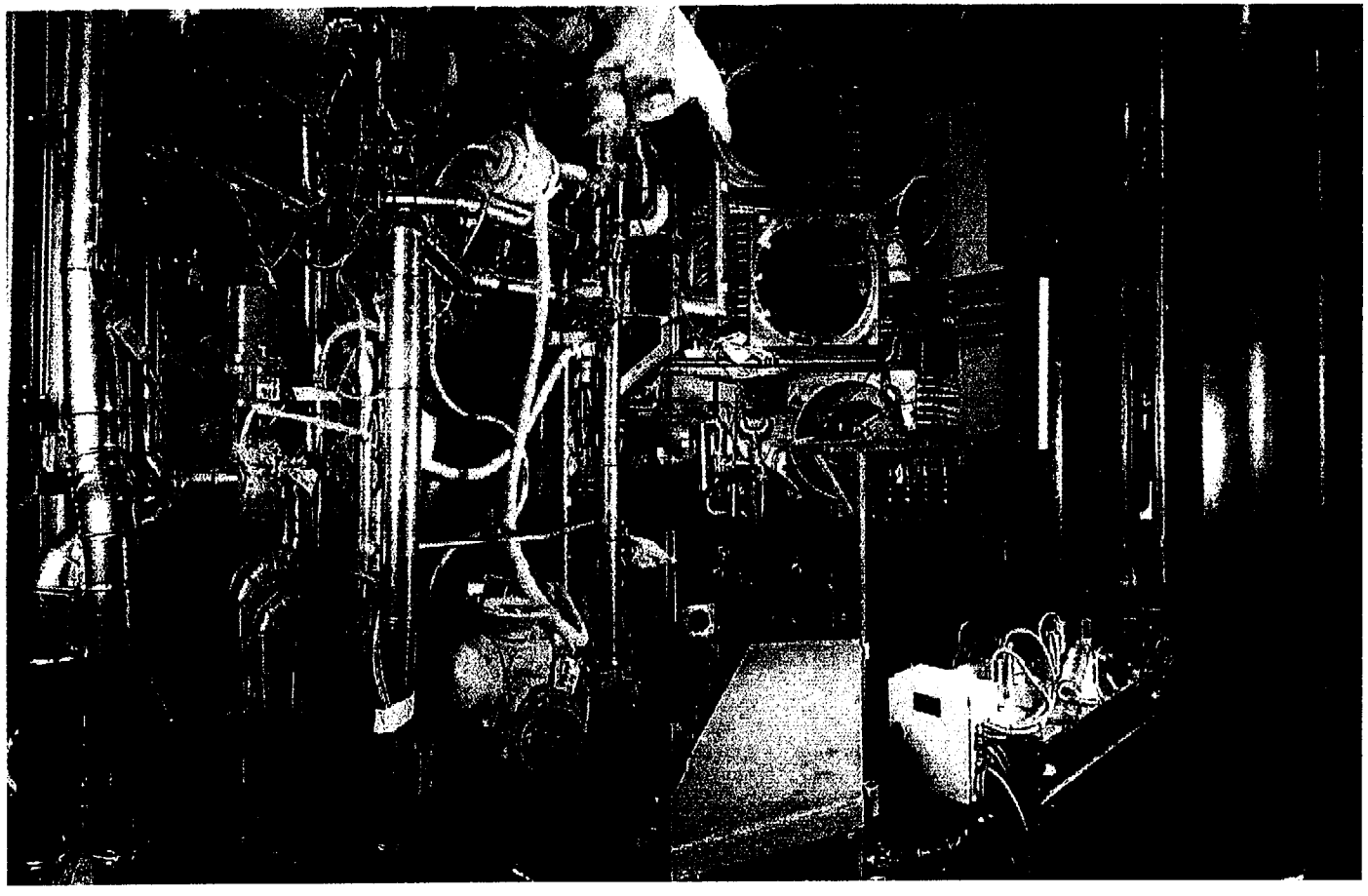


Scale ~1/5000

(vs 900 MWe PWR)



❑ THE FACILITY (4/9)



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❑ THE FACILITY (5/9)

- ~250 sensors:

  Power, temperatures, pressures, steam flowrate, fluid composition, humidity, pH

  On-line FP identification and quantification using γ spectrometers

  Aerosol density using photometers, aerosol sizing using impactors

  Iodine form descrimination (particle, molecular, organic) using Maypacks, on-line & post-test γ scanned

  FP concentrations using filters and gas & liquid bulbs, post-test γ scanned

- Completed by

  X- ray radiograms, tomograms, γ emission tomograms of bundle

  Extensive destructive examination of fuel and chemical analyses of samples in various european Labs (XRD, ICPMS, ICPOES, solubility measurements, image analyses

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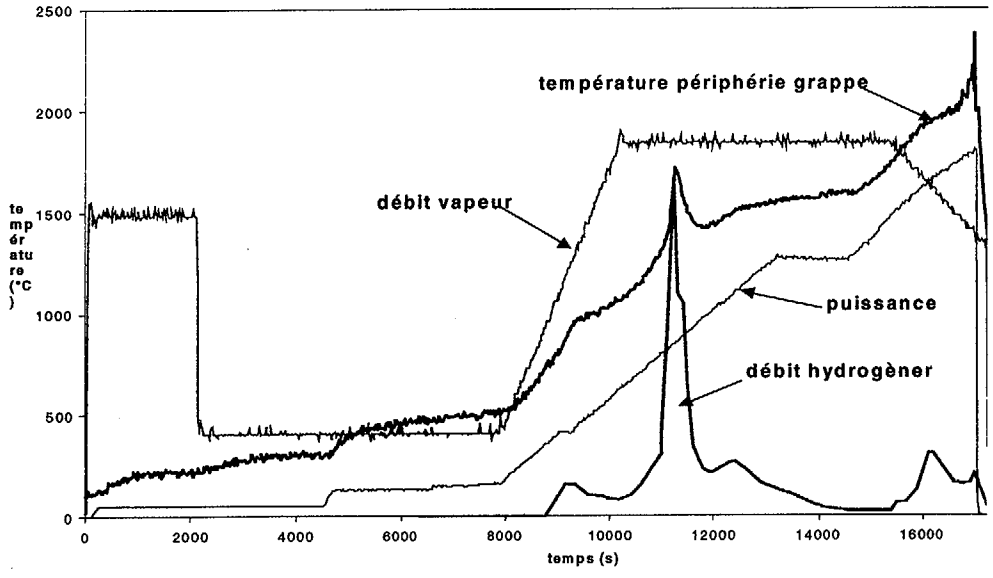
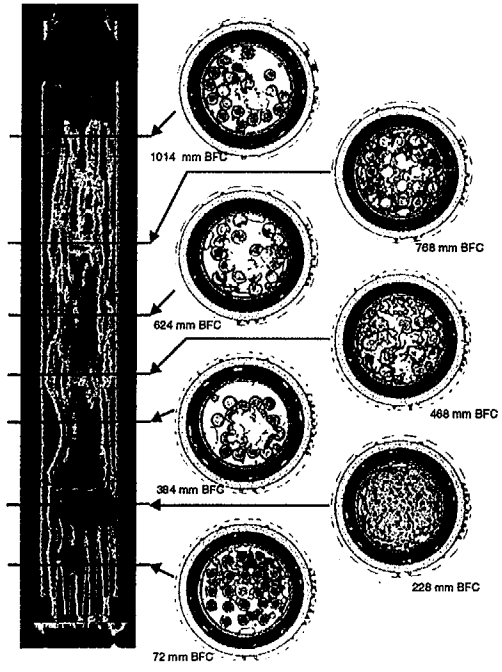
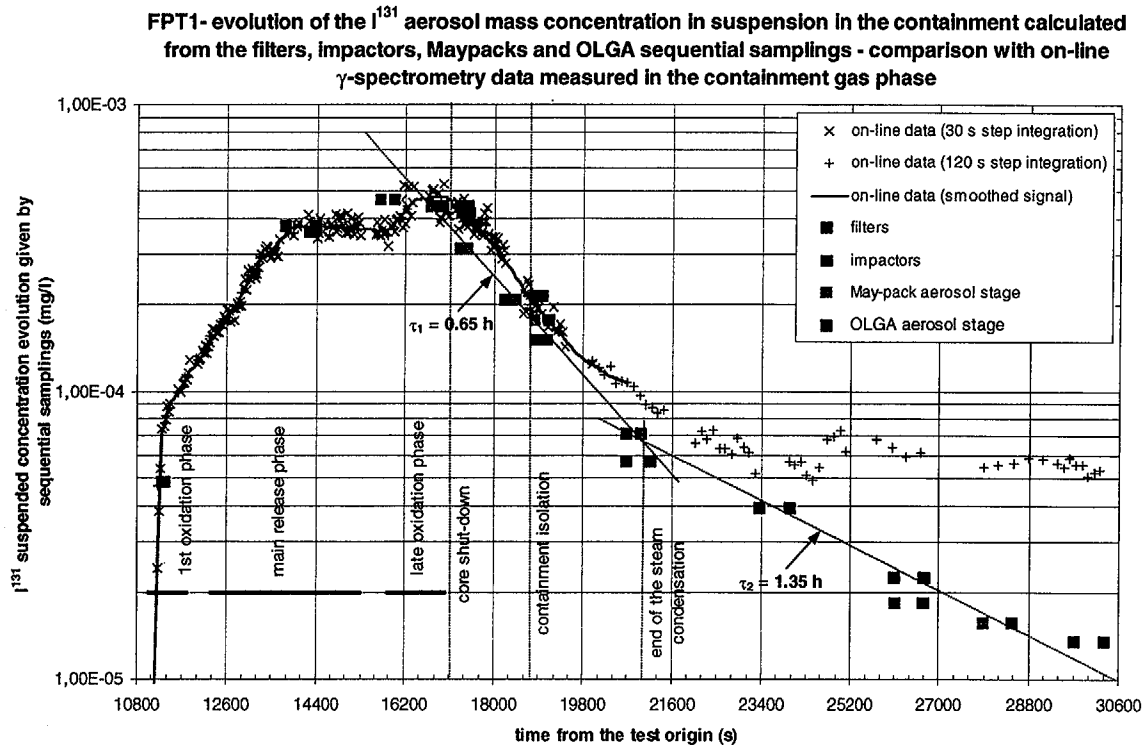
THE FACILITY (6/9)





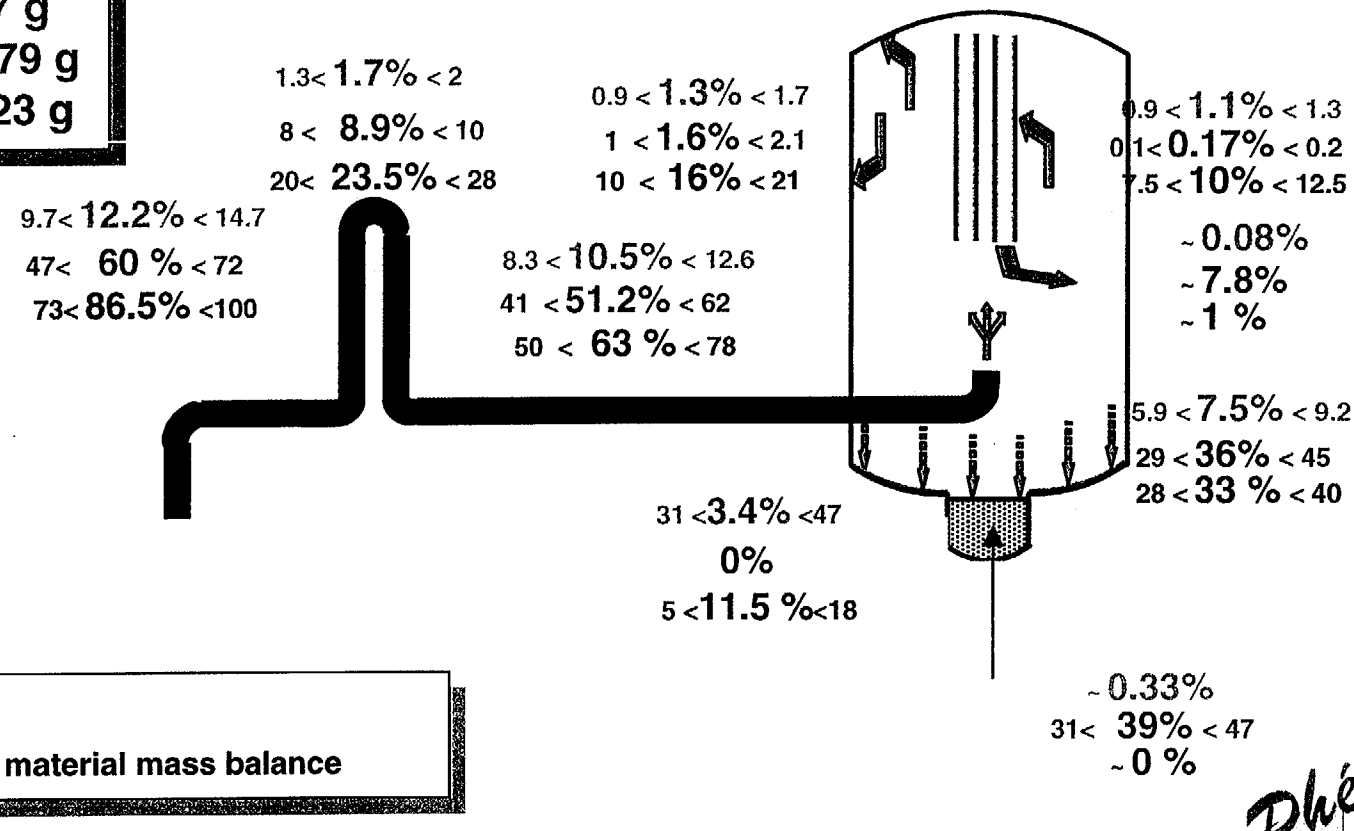
FPT-1 test scenario

THE FACILITY (7/9)



❑ THE FACILITY (8/9)

^{110m}Ag: M = 477 g
^{137}Cs : M = 0,079 g
^{131}I : M = 0,023 g



FPT-0 test:

FP & Structure material mass balance

THE INTERNATIONAL PHEBUS-FP PROGRAMME

❑ THE FACILITY (9/9)

Y - 4	Test objectives Test protocol
Y - 3	Experimental circuit – Test device fabrication Pre-test calculations
Y - 2	Test conduct preparation – safety file
Y - 1	On-site circuit assembly Shake down tests
Y	EXPERIMENT: fuel degradation = 5 hours; FP behaviour in containment = 5 days
Y + 1	Circuit decontamination & dismantling – caisson clean up Data evaluation, analysis of 100 000 γ spectra PIEs - PTAs
Y + 4	Final data evaluation from PTAs and γ spectra analyses Final test report

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IRSN THE INTERNATIONAL PHEBUS-FP PROGRAMME

Phébus PF

Washington DC - May 3, 2002

THE INTERNATIONAL PHEBUS-FP PROGRAMME

❑ TEST MATRIX (1/1)

	FPT-0	FPT-1	FPT-2	FPT-4	FPT-3
Date	Dec 12, 1993	July 26, 1996	Oct 12, 2000	July 22, 1999	Planned late 2003 early 2004
Flow conditions	Steam rich (oxidizing)	Steam rich (oxidizing)	Steam poor (reducing) + boric acid		Steam poor (reducing)
Fuel	Trace irradiated + SIC	BR3 23 GWd/tU + SIC	BR3 32 GWd/tU + SIC		BR3 23 GWd/tU + B4C
Containment	Acidic sump Cold sump	Acidic sump Cold sump	Alkalin sump hot sump		Acidic sump hot sump

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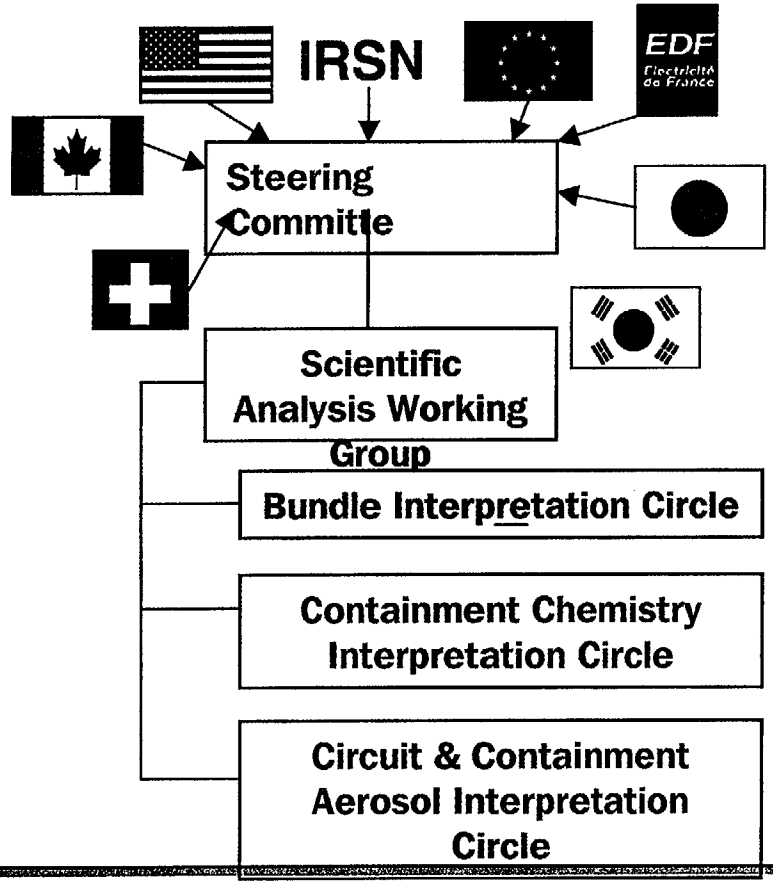
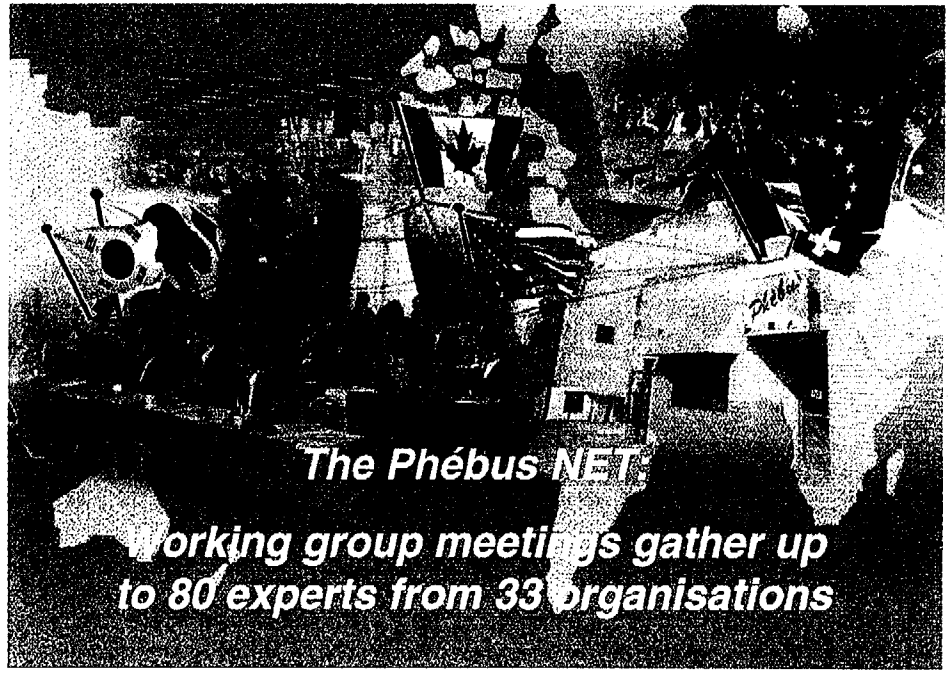
IRSN THE INTERNATIONAL PHEBUS-FP PROGRAMME

❑ INTERNATIONAL COOPERATIVE EFFORTS (1/1)





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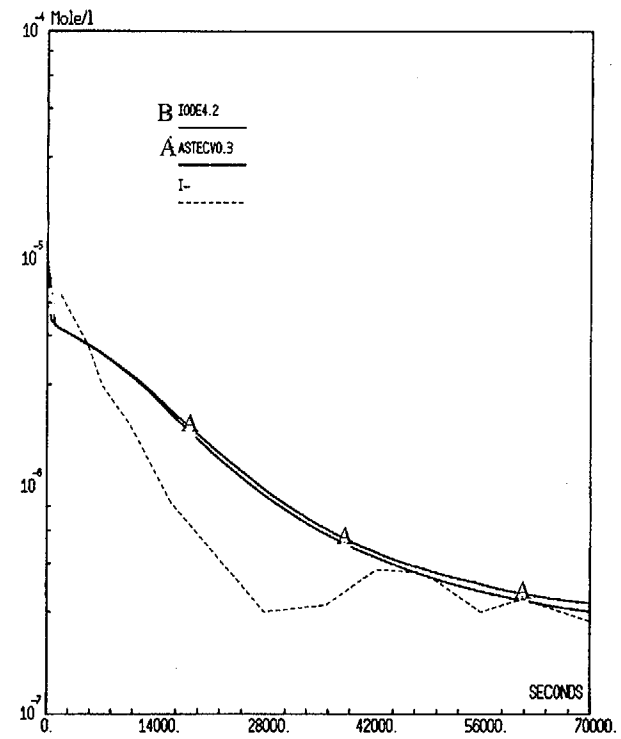
❑ SEPARATE EFFECT TESTS (1/2)

→ **SPECIFIC PHEBUS-RTF EXPERIMENTS IN RTF (AECL - Whiteshell)**

- **Iodine Behaviour in the Containment:** reproduction of Phebus-FP conditions (presence of silver, pH, dose rate...) + parametric studies (pH, Ag/I ratio...)
- **Validation of newly developed models of Ag/I reactions in liquid phase: IODE** module of ASTEC system code - example: Calculation of total dissolved iodine concentration in Phebus-RTF 3 (typical of FPT-1)

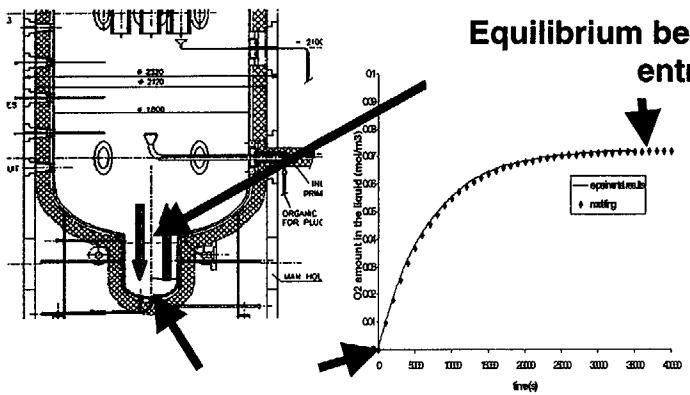


PHEBUS RTF3 Kc:8.3E-6 Khum:5E-6 Kgaz:6.5E-4 Kads_st_g:2E-5 Kdes_st_g:2E-6
I total EN PHASE aqueuse

❑ SEPARATE EFFECT TESTS (2/2)

→ ***SISYPHE EXPERIMENTS: 1/1 mock-up of Phebus Containment***

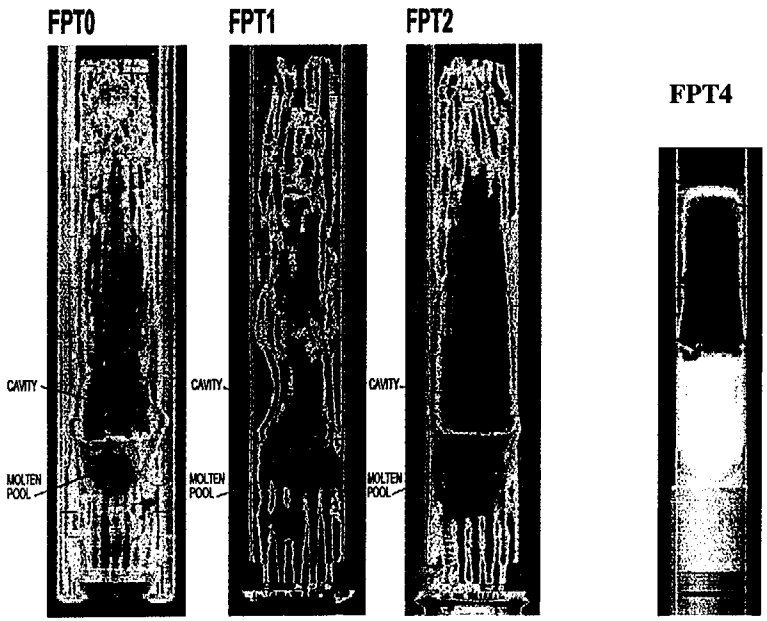
- ***Thermal-hydraulics tests:*** *condensation/evaporation rates - steady-state and transient conditions....*
- ***Iodine mass transfer tests between sump water and containment atmosphere:*** *oxygen used as simulant under evaporating and non evaporating conditions*



O2-Sulfite reaction ⇒
Concentration in liquid = 0

❑ MAIN ACHIEVEMENTS AND LESSONS (1/8)

BUNDLE RADIOGRAPHIES AFTER TESTS



FPT0: Final report issued (1600 p + tapes) Interpretation being finalized

FPT1: Same

FPT2: Draft preliminary report for review Interpretation in progress

FPT4: Preliminary report issued; final report expected for mid of 2003 Interpretation in progress

❑ MAIN ACHIEVEMENTS AND LESSONS (2/8)

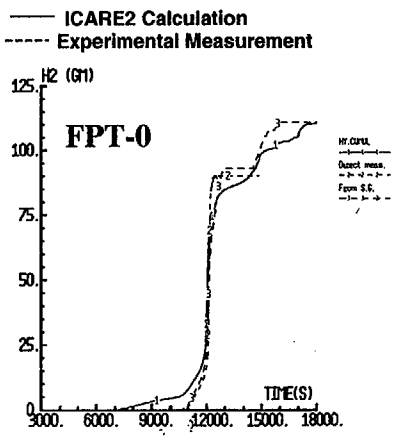
➢ ***Core melt-down aspect:***

➲ ***H2 production kinetics underestimated under steam rich conditions by most codes by factor 2***

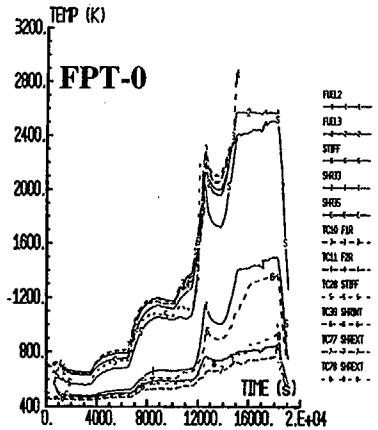
- ***Cladding dislocation criteria inappropriate***
- ***Codes corrected***

⇨ ***Important for H_2 risk mitigation***

➲ ***Adequate code predictions under steam poor conditions***



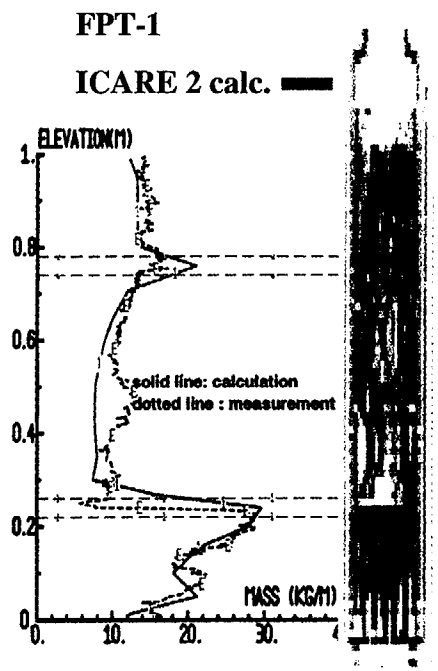
Hydrogen Mass in the Containment



Bundle and Shroud Temperatures

❑ MAIN ACHIEVEMENTS AND LESSONS (3/8)

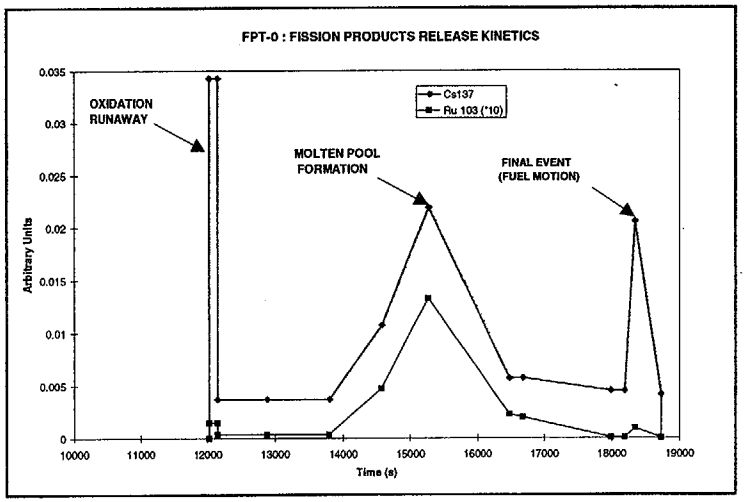
- ➲ *Massive fuel relocation at 2450 K (vs 2800 K in most codes) under steam rich conditions*
  - *Interaction between fuel and ZrO, Fe_xO_y, not correctly modelled*
- ➲ *Relocation at 2650 K under steam poor conditions*
  - *Degree of interaction dependent on strength of cladding oxidation runaway*
- ⇨ *May be important to assess state of core for accident management*



❑ MAIN ACHIEVEMENTS AND LESSONS (4/8)

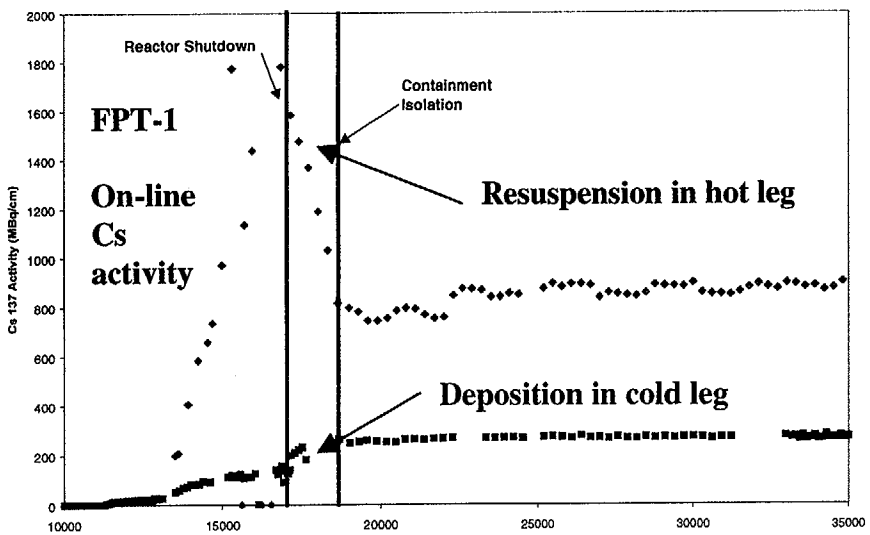
➢ ***Fission product release:***

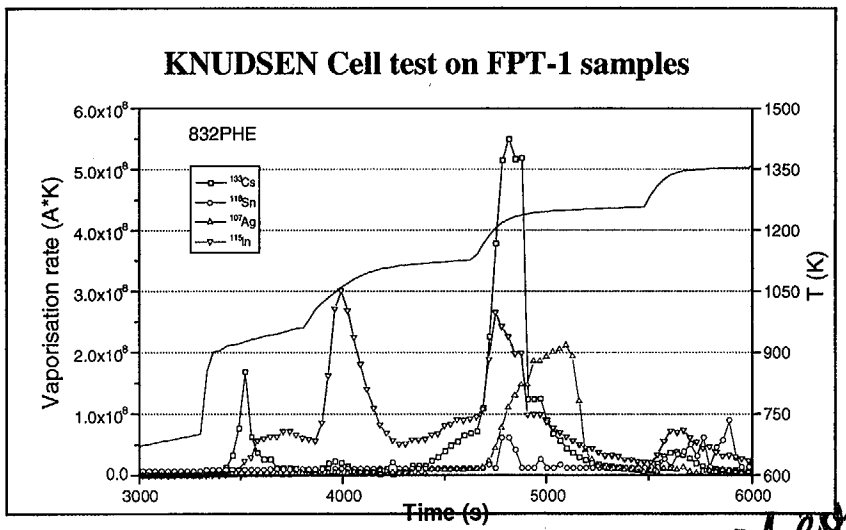
- ***Fractional release of FPs and actinides as expected (except Ba: release divided by 10 vs. ORNL/VERCORS separate effect test results - important for residual power)***
- ***Low release from molten pool configuration (mass transfer + thermochemistry effects suspected - not yet in codes)***



MAIN ACHIEVEMENTS AND LESSONS (5/8)

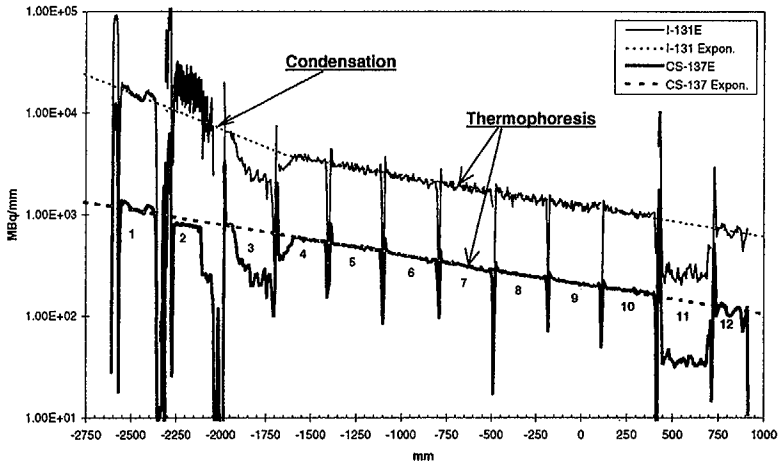
- **Fission product transport:**
  - Cs chemistry in RCS different from expected (no CsOH, likely Cs_2MO_4) and more complex (revaporisation in FPT-1, dedicated revaporisation tests on FPT-1 samples)





❑ MAIN ACHIEVEMENTS AND LESSONS (6/8)

- ➲ ***Deposition in SG overestimated by codes***



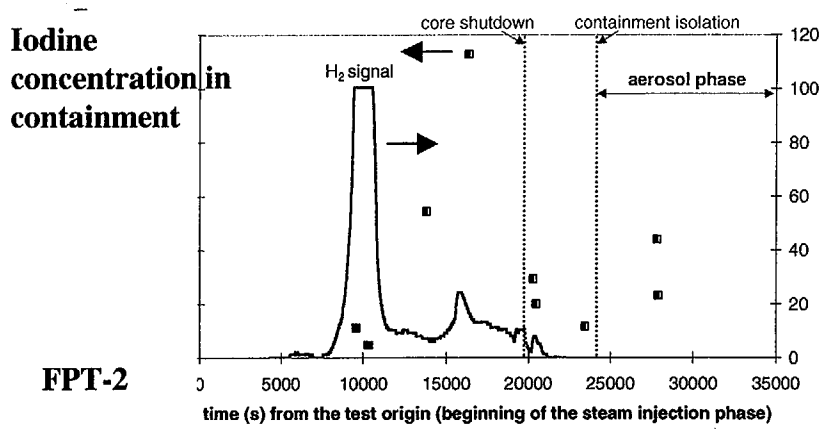
- ➲ ***Multicomponent aerosol mainly made of structure materials: average aeros. = 25% Ag, 22w% Re, 12% Sn, 12% Cd, 8% U, 5% In, + 5% Cs,+ 4% Mo, + 1% Pu + ...***

- ➲ ***AMMD of 3 µm with SD of 2 in cold leg***

❑ MAIN ACHIEVEMENTS AND LESSONS (7/8)

➢ ***Iodine behaviour:***

➲ ***Early presence of gaseous iodine in containment:***



- ***Gaseous iodine in significant amount at break (up to 30% in FPT-0, 3% in FPT-1 during cladding oxidation runaway)***

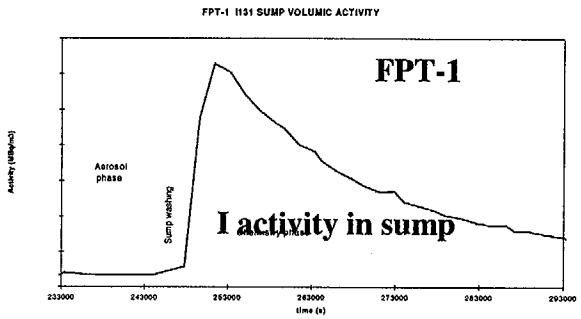
➔ ***non chemical equilibrium? (Investigated in CHIP)***

➔ ***Volatilisation of condensed I when arriving in containment?***

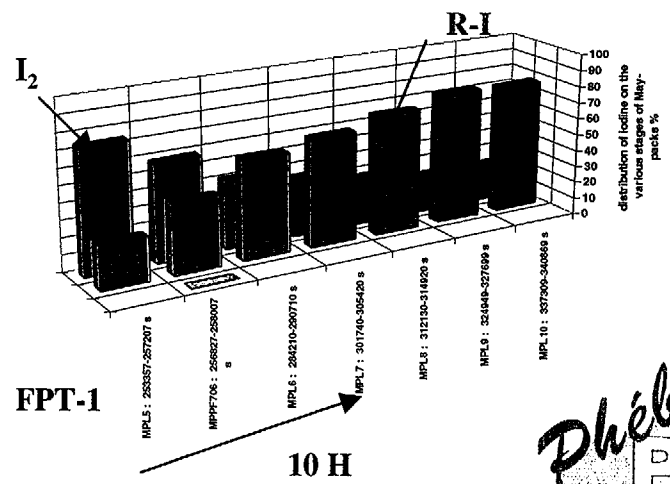
❑ MAIN ACHIEVEMENTS AND LESSONS (8/8)

➢ *Iodine behaviour (cont'd):*

- ➲ *Iodine become insoluble in sump*
- ➲ *Very low volatilisation of I_2 from sump (not expected!): iodine trapped by Ag from CR in acidic sump*



➲ *Highly volatile organic iodide dominant in atmosphere (not totally expected): conversion of I_2 by aerial paints*



⇨ *VERY IMPORTANT LESSONS for source term evaluation new separate effect tests launched (@PSI + @ IRSN: CHIP, EPICUR)*

CONCLUSION (1/1)

- Phebus FP integral test programme fully justified
- Important lessons drawn in particular on iodine volatility
- Valuable experimental database for system code validation and training of new experts
- Re-orientation of and new separate effect test programmes
- Results on B_4C effect still to come

CONCLUSION (1/1)

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