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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

PUBLIC MEETING

BRIEFING BY BATTELLE ON SPENT FUEL STORAGE

Room 1130
1717 H Street, N.W.
Washington, D. C.

Tuesday, 28 February 1978

The meeting of the Commissioners was convened at 2:20 p.m., pursuant to notice, JOSEPH HENDRIE, Chairman, presiding.

PRESENT:

JOSEPH HENDRIE, Chairman
RICHARD KENNEDY, Commissioner
VICTOR GILINSKY, Commissioner
PETER BRADFORD, Commissioner

ALSO PRESENT:

A. B. Johnson, Jr.,
Corrosion Research and Engineering, Battelle,
Pacific Northwest Laboratories, Richland, Washington

P R O C E E D I N G S

CHAIRMAN HENDRIE: Okay, let's convene.

We are very pleased to have Dr. Johnson from Battelle Northwest with us today. To start it out, I believe, Commmissioner Gilinsky learned that you would be in town talking about spent fuels behavior which is looked at in water pools obviously with great interest from the standpoint of the current disucssions about the spent fuel storage policy and facilities, and I believe that Commissioner Gilinsky asked if you would come over and talk to him about it and the rest of us have leaped aboard and created a full-fledged meeting of the Commission on it. We are very grateful you were willing to come here and talk to us.

If there are no other comments from this side of the table, why please go ahead.

MR. JOHNSON: I have slides, so I would propose to talk from there.

CHAIRMAN HENDRIE: Please do.

MR. JOHNSON: The status of nuclear fuel has moved from probable reprocessing to improbable reprocessing and at the same time we recognize at that time , we recognize that we need to start asking ourselves a different set of questions.

Those questions revolve around a central question: How long can you then leave the fuel in the pools since that is

the only option that we have at the present time. So this central question raises other questions such as: What is the condition of the stored fuel now in pool storage; and what are the characteristics of this fuel; how much Burnup; how long has it been there; what are the materials that are involved?

Then we come to the question of the storage conditions; what are the range of conditions that this fuel will be called upon to endure in terms of temperatures, water chemistries, radiation levels and then how do these conditions relate to the corrosion properties materials.

I will start with a slide which shows the history of pool storage.

(Slide)

The first pools were really associated with the first reactors which were built in 1943. However, the cladding in these reactors was aluminum, and therefore, it is of little relevance to the current fuel characteristics.

The first Zircaloy-clad PWR came on line in 1957, the shipping core reactor. The first Zircaloy-clad and stainless, I might add, BRW came on line in 1960, the Dresden plant. The first Canadian CANDU reactor came on line in 1962.

Now, some of the fuel from these earlier plants was reprocessed at NFS, so not all of the fuel discharged from these reactors has remained in pool storage. However, we will

point to some from Shippingport which is still in pool storage.

The next series of slides will not be in the handout because they show views of fuel pools. I thought it would be useful to give you some concept of what goes on in the fuel pool.

(Slide)

This shows a schematic cross-section of the Morris, Illinois fuel pool. The unloading pit is here, a cask is brought in, opened, in a vertical position, the fuel is removed and placed into canisters and we will see and actual photo of that operation.

Then the fuel is moved in to one of two pools where it resides. There are skimmers to keep the top of the pool clean, there is a provision for ion exchange and filtration, and there is a provision for heat exchange.

(Slide)

The next slide shows an actual view of the Morris, Illinois fuel pool. What you see here are stainless steel canisters, the dark squares are the fuel bundles and the blue glow is not terricolt radiation, it is reflected light. The pool is about 28 and a half feet deep, the tops of the fuel bundles are about 14 feet from the pool surface.

Now, we might stop here and say what if there were defective fuel, how would that be shown. The fact is that there

hundreds of bundles in here which have defective fuel. That is, during the reactor exposure there was a defect developed in one or more pins or rods of several hundreds of these bundles.

When I visited the pool I asked: What would happen if I were to fall into the pool and they said it is essentially operating at the maximum permissible concentration which means you could essentially swim in it or drink it or whatever despite the fact that there are bundles in there with defects.

The purification system which I showed in the previous slide is able to maintain both the radiation levels and the chemistry of the pool within respectible limits. But if a defect developed in this pool it would be manifest first by bubbles since the fuel has some internal pressure so we would be able to see a defect as it developed by the emission of bubbles. Presumably if there were a number of defects one would then see that manifest in either the air monitors or the radiation levels in the pool water or both.

(Slide)

The next slide shows the fuel transfer operation from the shipping cask to either a BWR canister or a PWR canister. These canisters are stainless steel and the BWR holds nine fuel bundles, the PWR holds four and they sit on the same rack locations.

So here you see an irradiated fuel bundle, this

is a boiling water reactor fuel bundle and if there were a defect developing it would be somewhat difficult to see it in this sort of a transfer operation. In other words, we would see defects when they were far advanced by this sort of transfer. But there have been no cases where a fuel pool operator has seen any gross defect developing in a pool bundle. Each bundle is handled ordinarily several times during its pool residence, some only once or twice, but some numerous times.

(Slide)

The next slide shows the canister now filled with the nine fuel bundles being transferred to a rack position in the pool.

(Slide)

Now, we switch on the next slide to the technology in Canada where there is a fuel pool 27 feet deep, there are trays, so-called, which hold -- Canadian fuel bundles are only about a foot and a half long and so their needs are quite different from ours in terms of the receptacle.

What you see here then are these trays or receptacles stacked one on top of the other to within about 12 feet of the pool's surface and there are provisions for the circulation of coolant.

(Slide)

The next slide shows an actual shot of the Pickering

pool where you see the trays in the pool.

CHAIRMAN HENDRIE: Those slugs or elements are horizontal there, aren't they?

MR. JOHNSON: In here?

CHAIRMAN HENDRIE: Yes.

MR. JOHNSON: In some pools they are horizontal and in some they are vertical. The Canadians use both orientations. In this pool I'm not sure whether they are horizontal or vertical, but the use ---

CHAIRMAN HENDRIE: Let's see, the Pickering pressure tubes are horizontal, I think, aren't they ---

MR. JOHNSON: In the reactor that's true.

CHAIRMAN HENDRIE: The load,the loading and unloading machine as a horizontal configuration?

MR. JOHNSON: Yes, that's true in the reactor.

Here in the pool, again the fuel may be either horizontal or vertical depending on the particular type of trays that are used.

(Slide)

The next slide shows a view of the WAK pool, this is a schematic showing how it interfaces with the reprocessing demonstration plant, which is here. The pool is located here. There is an unloading pit here and the storage area is here and the next slide shows a view --

(Slide)

-- this is a cask being unloaded at the WAK pool.

(Slide)

The next slide shows the pool, the storage pool. There are aluminum racks here which were installed when the pool first went online and the racks on this side are stainless steel, so they use both types of racks at this pool.

The found, when they first started the pool up that the aluminum had not been sufficiently passivated. In fact, they could see hydrogen evolution caused by the corrosion. They took the canisters out, passivated them and over some eight years since they have performed satisfactory.

When they store a failed fuel pin they have a loose-fitting lid which they can pick up. It is not a closed sort of canister, but there is a loose-fitting lid that fits over the canister where the failed fuel bundle is located.

(Slide)

The next slide shows a summary of how I view the technology. It is an existing technology, it is one that we have been using since 1943. It is evolved to meet changing needs. It is a relatively simple technology. The fuel sits static and it is visable; the fuel bundles are accessible. There has been minimal mechanical damage in fuel handling, and I will talk about that a little more quantitatively later.

(Slide)

In the next three slides I have summarized my own experience in regard to the fuel pools. I have observed fuel handling operations in five of the Hanford pools, going back to 1961. I have observed fuel handling, again, at Big Rock Point and Pickering. The Trojan reactor is not yet begun to discharge fuel, but I have visited that pool.

I visited two ISFSI or AFR pools; GE-Morris and NFS and I would now add WAK to that list.

I visited three research and development pools, NRU, NRX at Chalk River in Canada and the ATR pool at Idaho Falls.

(Slide)

The next slide shows the -- again, discussions that provided the basis for the report that was written on the behavior of spent fuel. I have had direct discussions, not at the pool side, but with operators of three BWR pools or three sites, five pools. One PWR site with three pools and a pressurized heavy water -- I went to the Toronto headquaters of Ontario Hydro and they provided me with information from their six pools.

Telephone discussions: BWR, two pools; PWR, 11 pools; R&D sites, three pools.

(Slide)

The next slide summarizes the literature. There was a hearing in Windscale in the United Kingdom, which I'm sure

you are familiar with where there was a systematic assessment of pool storage in connection with that hearing, and I have received the proceedings of that hearing. I have a paper in German on the WAK experience. I have a TWIX from the Norwegians summarizing their experience. I have reviewed the allied general nuclear services PSAR from the Barnwell plant, and then have had numerous discussions with corrosion experts in various aspects of pool corrosion. I have myself conducted about 10 years of corrosion studies both in reactor and out of reactors on Zircaloy,Inconel-stainless steel and aluminum.

(Slide)

The next slide summarizes the stored fuel inventory in Canada and the U.S. At the end of 1976 there were about 70,000 of these short bundles in the Canadian pools. There were approximately 8700 bundles in U.S. pools and the bundle sizes are shown here.

This includes both stainless steel and Zircaloy cladding in the U.S. pools, but about 90 percent of that cladding is Zircaloy as of the end of 1976.

I have recently had opportunities to talk with European pool operators and can add to this experience now, about five years of experience in Sweden, 11 years in the United Kingdom, 10 years in Belgium, 9 years in Norway, and about 5 years at WAK in Germany.

(Slide)

The next slide shows the maximum pool residence for Zircaloy-clad Canadian CANDU fuel. The storage experience goes back to 1963 at the NRU pool at Chalk River. This bundle is the granddaddy of all of the Zircaloy clad fuel bundles. It has been in storage since 1959, about 18 years at -- it is now at ECF in Idaho Falls.

There are 47 bundles, stainless steel pressurized water reactor fuel from 1970 at GE-Morris. There are approximately 60 R&D bundles, stainless clad from the Vallecitos Boiling Water Reactor that were stored for about 12 years. They have not been reprocessed at Savannah River.

So this is a summary then of the length, the maximum pool residence for Canadian and U.S. fuel. I mentioned that the European experience goes up to about 11 years, it is not as long as the U.S. -- the maximum U.S. experience, but it has now become a substantial experience.

(Slide)

The next slide summarizes the maximum burnups. I understand that there are some burnups that go as high as 40,000 for fuel now stored, but for this survey the highest numbers that I found are shown here; 25,000 for Zircaloy-clad BWR; 33,000 for Zircloy-4 PWR; 33,000 for stainless steel PWR and 22,000 for stainless steel BWR.

(Slide)

The next slide summarizes pool conditions under which the fuel is stored. The bulk water temperatures vary from 20 to 50 degrees centigrade. The fuel surface temperature will be anywhere from one to 10 degrees higher than that due to the heat transfer.

The water chemistries for BWR, Pressurized Heavy Water Reactor and IFSFI pools, it is deionized water and it pHs from 5.3 to 7.5. For the PWR pools the chemistry is deionized water with about 2000 ppm of boron as boric acid, pH of 5.4 to 6. The boric acid is used in the PWR pools to be compatible with the primary system coolant chemistry so that when there is a transfer of fuel and a concomitant transfer of coolant there will be a compatability between the pool and the primary system.

COMMISSIONER GILINSKY: Let me ask you. When you say the fuel surface don't fatigue, that presumably depends on how old the fuel is?

MR. JOHNSON: That's correct. So for all fuel it would be about one degree above the bulk water temperature for ---

COMMISSIONER GILINSKY: And are you saying when you put fuel into the pool initially the difference is only 10 degrees?

MR. JOHNSON: My thermalhydrolsis tell me that the temperature is -- for fresh fuel is about 10 degrees centigrade

above the bulk water temperature.

COMMISSIONER GILINSKY: In other words, if it weren't for the radiation you could go put your hand on it?

MR. JOHNSON: If you would be willing to swim down under and put your hand on it, you wouldn't burn yourself.

COMMISSIONER GILINSKY: Okay.

MR. JOHNSON: The pools, of course, are oxygen saturated, being open to the air.

(Slide)

The next slide summarizes the fuel bundle and pool materials. The fuel cladding is either stainless steel or Zircaloy with now very few reactors in the U.S. There are only three reactors that I'm aware of which still use stainless steel, that is, reactors which are commercial power reactors.

The storage canisters are either stainless steel or aluminum. The pool liners are stainless steel or epoxy or fiber glass.

(Slide)

The next silde, then, sort of puts together the matrix of conditions. We can have stainless steel cladding, in either stainless steel or aluminum canisters with either boric acid or deionized water chemistry and similarly for the Zircaloy the fuel may be stored in either stainless steel or aluminum alloys with either boric acid or deionized water

chemistries.

Now, I have found no problems with compatibility in any of these arrays, except that there are some cases where aluminum canisters have undergone some corrosion. The general experience is that this is -- I only know of one pool where there has been a crevice-corrosion problem which is given any concern. Other pools which operate on deionized water chemistry have looked, after 8 years at the crevice between the stainless steel pool bottom and the aluminum canister and they have found no evidence of crevice corrosion. So I think the general experience has been that even with the alluminum alloys the pool chemistries have been compatable.

(Slide)

The next slide summarizes the fission products which are most prominent in the pool waters. The iodines decay off quickly, eight-day half life for iodine 131. There is an iodine 129 which has a very long half-life, but its abundance is relatively small. Cesiums are very prominent in reactors which have had fuel failures, the cesiums are generally the predominent species in the fuel pools. Tritium, strontium, cerium, ruthenium, the zirconium-niobium pair make up the rest of the principal isotopes.

(Slide)

The next slide summarizes the activation products. During the residence of the fuel bundle in the reactor there

will be corrosion products from the primary circuit which coat the outer surface of the fuel pins. Now, this is called "crud" since the circuits are iron base or nickel base alloys in general with some copper alloy heat exchangers the crud will reflect that composition. So the crud then will contain cobalt, chromium, iron, manganese, zinc in boiling water plants which have admiralty heat exchangers, and the nickel and tungsten from hard facing materials.

So in addition then to the fission products from fuel which has failed in the reactor we may have also isotopes generated by activation of corrosion products which are carried through the primary circuit and which then played on the fuel bundles. Then this crud is carried into the pool with the fuel.

In boiling water reactors the outter layer of crude will be Fe_2O_3, the hematite a reddish brown, relative flocculent and loose and some of that can be seen when the fuel bundle is moved through the pool, at least in the first transfer.

With the pressurized water reactor crud that is generally much more tenacious and not as likely to spall or come loose in the fuel pool. Even in the pools where the Fe_2O_3 is transported the filter system and the vacuum system -- they use vacuum cleaners to clean up anything that falls to the bottom of the pool, skimmers to take up anything on the top and then ion exchange and filters to remove anything that

is suspended in the pool water.

The ranges of radiation levels in the pool water are shown in the report in detail. They vary from one reactor to another. The fuel pool at GE-Morris is able to maintain a radiation level of about 4 times 10 minus the minus 4th microcuries per ml. In some of the reactor pools during fuel discharges the levels will go up toward 10 minus 2 microcuries per milliliter.

(Slide)

The next slide summarizes the experience with handling and storage of defective fuel. I mentioned that there are several hundred bundles with defective fuel in storage ---

COMMISSIONER GILINSKY: What are these defects, are they pin holes in the fuel or cracks?

MR. JOHNSON: They can vary from pin holes to even pieces of fuel where there has been a break in the fuel rod, and in a few cases one would be able to see the fuel pellet at a very severe defect. Now, that type of defect is very -- it occurs very seldom ---

COMMISSIONER GILINSKY: Would you have to put that kind of fuel in a canister?

MR. JOHNSON: They frequently are put in canisters, in fact, I would say in most cases they are placed in canisters if there is a break, an obvious break where there are pellets that might fall out of the fuel pan.

In other cases where there is a small leak the fuel is stored essentially like intact fuel with no apparent problems.

I find that the approach to handling defective fuel varies from one country to another. Some countries will store every defective bundle in an enclosed canister, some of those closed canisters will be dry inside, they will be stored in a pool but they will be dry inside. Some of them are wet inside and stored in the pool and then there is the other case where the fuel is simply stored like any other fuel.

Equipment is available for handling defective fuel. We have mentioned the closed canisters. If a bundle were to develop a leak and begin to evolve gases then there is a hood design which can be placed over that fuel and the gases can be channeled off then to the ventilation system.

So in summary, then most of the defective fuel in the U.S. is satisfactorily stored on the same basis as intact fuel.

COMMISSIONER GILINSKY: What fraction of fuel is defective?

MR. JOHNSON: I have seen an unpublished summary which I think I would hesitate to quote because I'm not sure it is accurate.

CHAIRMAN HENDRIE: It's of the order, it seems to me, of tenths of a percent.

Let's see, we use to operate on something line a one percent failed fuel licensing standard, that is, where you tried -- when you want to calculate what sort of residual activities would be in the water for one reason or another against a hypothetical accident sequence you would use one percent. It seems to me that most plants operate well down from that, although there may be on occasion a plant that gets a load of fuel with some hydriding problems or something like that that meant will run up toward it.

John, do you ---

MR. JOHNSON: On the bundle basis I would say that we have about 1500 out of the 8700 bundles. That's -- they have one or more pins which are defective.

Now, on a pin basis the percentage is much lower than that. I have seen one statement that current technology should provide for operating with about one failure in 10,000 pins which would mean four to five failures per reactor per year, but our history in the past has not been that good, obviously, as we were learning the hydriding -- how to control hydriding and densification. There were a few crud-induced failures ---

CHAIRMAN HENDRIE: And mechanical clad interactions ---

MR. JOHNSON: -- clad interaction is the one remaining major problem in fuel failure

(Slide)

The next slide shows a summary of fuel which has failed pools and we found that there had been some cases where the fuel had failed. Two cases, notably, one Zircaloy-clad uranium fuel such as is used in the Hanford end reactor where there were defects in the cladding. During discharge there are some defects that are formed and these expose uranium metal to the water. The uranium is much less corrosion resistant than the Zircaloy and therefore there were cases where fuel stored at NFS, back in the late 1960s and early '70s where there were significant numbers of failures.

They were able to clean that pool out, however, and these failures were then manageable.

The other case involves stainless-clad gas reactor fuel. The Oak Ridge National Laboratory had two or three pins which failed back in the 1960s. They were stainless-clad pins which had been exposed in a gas reactor in a temperature regime which sensitized the stainless steel. Now, that's 450 to 600 degrees centigrade, say 650 centigrade and the fuel resided for its reactor life in that temperature range.

Recently the British have found a similar phenomenon from their gas reactor, their AGR stainless-clad fuel where the fuel sensitized and in the pool over a period of four to five years they are now beginning to see intergranular failure of the sensitized stainless steel.

Their own experience with stainless steel components

from the SGHWR, which were exposed at about 300 degrees centigrade, which is below the range where sensitization would occur have shown no evidence of this type of intergranular failure and we would expect that the U.S. stainless-clad light water reactor fuel would also have not been subjected to this type of sensitization which would cause corrosion.

So those are the two cases where we did find pool-induced failures. And I should add that we don't expect either of these to provide problems in light water reactor technology.

(Slide)

The next slide shows examinations which have been conducted on fuel that has been in pools. There hasn't been very much of this type of examination done because no one expected that the fuel would be in the pools and that there would need to be a verification, but there have been some examinations performed and I will summarize those briefly.

There was a metallurgical examination on some Canadian CANDU fuel; there was no evidence -- they would cut into the fuel, look at it metalographically, look at the corrosion and hydriding and concluded then that there was no pool-induced corrosion after 11 years in the pool.

COMMISSIONER GILINSKY: In other words you couldn't tell the difference between that and that which had just been put in the pool, is that correct?

MR. JOHNSON: That's correct, and the way they verify that is that they -- from this same bundle or from a bundle that was discharged at the same time they have done a previous examination to define what happened in the reactor. Now after 11 years they go back to the same fuel and do another examination and they compare the two and they find no difference.

Now admittedly this is CANDU fuel, it has a relatively low burnup, but nonetheless it is substantial experience which suggests that there is no -- either from the inside or the outside surface, no corrosion reaction that is going on.

COMMISSIONER GILINSKY: What is it, like 5,000 ---

MR. JOHNSON: Between 5 and 10,000. This particular bundle, I think, was 6,500.

The British, in connection with the Windscale hearings have done quite a bit of metalographic examination. One very interesting bundle which they examined was an SGHWR bundle which had a burnup as low, I think about 1900 megawatt days per ton, but this fuel was stored in a closed canister, it had two failures, two failed pins. It was stored in the closed canister, they monitored the radiation levels and found that they were quite low, I have forgotten the number exactly, but most important is that they went back and did a metallurgical examination, they found no evidence of degradation of the Zircaloy cladding at the defects, and also very interesting is that they found no

evidence of a conversion of UO_2 to U_3O_8, which if it did occur would tend to cause a swelling and possible progression of the failure, but after nine years they didn't see any evidence that that was occurring.

COMMISSIONER GILINSKY: Did you say anything about magnox fuel?

MR. JOHNSON: The magnox fuel is a magnesium-based alloy which is used in some of the British gas reactors, and this, as we would all expect, magnesium is not a very corrosion-resistant material and there have been some problems with corrosion of the magnesium fuel. I did not include it in the survey because it was in the aluminum ballpark and I didn't feel that that was pertinent to the power reactor fuel, but there have been some corrosion failures of the magnox fuel in the pools.

Going on then with the evidence of fuel integrity after pool exposures, the Canadians have returned three bundles to NPD -- I'm sorry, this is NRU -- after 10, 9 and 5 years respectively in the pool. In other words, they took it out of the pool after it had been there for 10 years, put it back in the reactor at about the same power ratings as they now us in Pickering and the fuel performed quite satisfactory suggesting that there had not been significant degradation during the pool exposure.

The Germans at WAK have started a modest but interesting

surveillance program where they removed two fuel bundles which they have specified now as their test bundles, and they remove them at least once a year, take them to a hot cell, lay them out,photograph them on all four sides. If the fuel includes at least one pin with a defect so they can monitor the performance of that defect and they plan to pursue this program in the future.

COMMISSIONER GILINSKY: What sort of corrosion would you expect? What would the mechanism be?

MR. JOHNSON: I am going to go through the mechanisms that we consider in one of the subsequent slides and if you would like to defer the question, we can take it up at that point.

COMMISSIONER GILINSKY: That's fine.

MR. JOHNSON: In fact, we are just about at that point.

(Slide)

The next slide shows a cross section, my artist got a little carried away here with colors, but this shows a cross section of a PWR fuel rod and the BWR rod would not differ substantially but many of them have a getter, a hydrogen getter in the plenum.

We see the blue being the Zircaloy, the end cap and the cladding, the green the fuel pellets. We see here the spring and then an aluminum oxide pellet at the bottom.

We considered mechanism, which I will go through in some detail, which might occur both in the outside surface end and from the inside surface out, taking into account the fission products which might be present, taking into account the crud layer which is on the surface, the water chemistries, the temperatures and so forth.

(Slide)

So the next slide summarizes the corrosion mechanisms which we considered possibly to occur from the outside surface. We looked at oxidation and simply after looking at the corrosion data decided that that was not a threat. In one hundred years, even if we left the fuel in the reactor for one hundred years we would not expect that more than about 10 percent of the cladding would degrade.

The Canadians have fuel, in fact, that has been in NPD for up to 15 years. They have looked at it periodically metalographically and they are quite satisfied with its performance in the reactor at 285 centigrade with the neutron flux.

COMMISSIONER GILINSKY: Now, all of the mechanisms presumably grow much faster at higher temperatures, correct?

MR. JOHNSON: That's generally correct.

COMMISSIONER GILINSKY: And this is some kind of an expediential dependence isn't it?

MR. JOHNSON: It may or may not be expediential, but generally the rates would be expected to be higher at higher

temperatures.

COMMISSIONER GILINSKY: Well, what I'm trying to get at here is that a short period in the reactor must be equivalent to a very long period in the pool.

MR. JOHNSON: Very true.

COMMISSIONER GILINSKY: So surviving for several years in a reactor ---

MR. JOHNSON: It is good evidence that the fuel ----

COMMISSIONER GILINSKY: -- Yes, that they can survive for tens or hundreds regardles of how many years at much lower temperatures.

MR. JOHNSON: We could point to a few cases where there are mechanisms that can go on at low temperatures that are not well known at high temperatures or may not occur, but in general we would expect these to go on, well, biological corrosion obviously would occur at low temperatures and generally not at high temperatures, but generally we would expect the severity to increase with temperature. Maybe not expedientially in all cases, but certainly increasing.

So oxidation we simply feel is not a threat. The uniform corrosion of the materials in the pool is not a credible threat.

Stress corrosion cracking is certainly something that's frequently seen with the stainless steel particularly. There are regimes where Zircaloy will stress-crack, but in

aqueous systems it is generally regarded as immune to stress cracking with one or two exceptions, for example, if we if we have the Zircaloy stressed beyond yield with 50 ppm or above of chloride and with a nautic potential, a potential that was quite a nautic, there are some cases where it would crack. We simply do not expect those conditions to exist in the pool.

Hydriding can occur on Zircaloy at low temperatures like we have seen it at 90 degrees centigrade, on Zircaloy without an oxide film coupled to aluminum or with an impressed cathodic potential in impure water. Now, any pool operator that came to me and said that's how we are going to store our fuel, I'd say you are out of your mind, but when they tell me they are going to store it in high purety water or even in boric acid, they are going to leave the oxide film on it that formed in the reactor, they are going to use -- the temperatures are below the regime we expect, I say, I don't see a problem.

Galvanic corrosion, I'll cover that in some additional detail, again, what we are dealing with here are materials that are generally quite immuned to galvanic corrosion with a possible exception of aluminum and even there there has been minimumal evidence that there is a problem.

Pitting corrosion similarly. Biological corrosion is not very likely to be a threat on radiated fuel rods until very far into the future. So there may be some biological

corrosion on pool parts, but that has also not been seen to this point. The pools which use high purity water appear to deprive the biological species of nutrients and biological intrusions have not been a problem in any of the pools which I am aware of.

Radiation effects, there are some cases where radiation has enhanced corrosion, but we know what those are as they have involved with the Zircaloys. The combination of high neutron fluxes and oxygen in the cooler. In other words, BWR conditions will accelerate corrosion, but the corrosion is still manageable, but it is a case where radiation has accelerated corrosion. We don't expect that type of problem in the pool.

(Slide)

The next slide indicates the mechanisms which we considered to possibly occur from the interior surface, hydriding being one. In most cases the hydrogen which was associated with impurities in the fuel has long since dissipated into the cladding. So it would be only with very green fuel which was discharged for some reason early that one would expect to find a gaseous hydrogen atmosphere inside the fuel. Nonetheless, there is already hydriding which has occurred in the cladding so we asked ourselves is there any mechanism which might progress then over a period of time on cladding which has already been hydrided. There is a

mechanism called "delayed hydrogen cracking" which the Canadians have observed in the Pickering reactor. I have talked with them in some detail, I am aware of a Scandinavian -- recent Scandinavian report which went through a fairly comprehensive assessment of that mechanism and the conclusion was that it is not a threat under the relatively low stresses that we expect will be characteristic of the fuel in the pools.

Fission product attack, again, I could go on in some detail and would be happy to unless you want to move on, but there are fission products, iodine and cesium which can cause Zircaloy to crack if the stresses are high enough and if the concentrations are high enough. Iodine decays away quickly so we don't expect that it will be a threat for pool stored fuel.

Cesium appears to be tied up in a uranium cesium oxide and not available a matallic cesium. Helium embrittlement I simply waive off. I don't think that's a problem.

The next ---

COMMISSIONER GILINSKY: What do you see as the one main mechanism here? In other words, what would come into play first?

MR. JOHNSON: It depends on whether we are talking about stainless steel or Zircaloy. i think we still have to keep our eye on the stress cracking and I think a localized corrosion mechanism, most likely stress cracking would be the

thing that would be of most concern. There is also the possibility of crevice corrosion with the stainless steels. There is no evidence that that is occurring at the present time, but as we keep track of -- well, I would put it this way that as we look at a fuel bundle, I think we should approach it without any preconceived notions and say well, let's just look at stress cracking and then the rest of the things won't bother us. I think we should look for the range of things that we have seen here and see if any of them are beginning to develop, but I guess that either stress cracking or pitting, particularly the stainless steels is the thing that I would look hardest for.

CHAIRMAN HENDRIE: But even there in order for it to be really troublesome a modest amount of pitting corrosion, which gives you some water access to the oxide, pellets occurring on out decades into the storage period, after all you put rods, you know, that have come to reactor spent fuel pools a couple of years out of core in to this pool. If you could manage the fission products of the water contact on the outside then, why you would be able to manage it out 15-20 years down the line and unless the attack on the cladding is so wide spread that there is an overall structural degradation, so you have got clad all broken up and the pellets just falling down to the bottom of the pool, why a few pits and a few stress corrosion cracks aren't really going to degrade the

system much. You know, it is possible and a fact that if you go up and you could have a very long pliable life for these elements in water and it isn't well beyond the sort of times that people talk about. Your corrosion rates or level is extrapolated out of a hundred years and that doesn't set any apparent limit on Zircaloy.

MR. JOHNSON: Well, this is a point which I had planned to make is that even if the fuel were to fail we have a technology for dealing with failures and therefore we can tolerate failures even if they were occurring. We don't see evidence to this point that they are occurring, but the other point is if they were occurring they are manageable.

There may be cases where the bales would corrode and crack after a hundred years. We ought to be aware that that is going on, but I don't think that we need to put a large effort into defining the fuel. I think that with the judicious use of resources that -- and cooperation and in fact there is an IAEA meeting going on now. I think by trading information among countries that we can greatly minimize the resources that are required to define this, what I think is a very minimal problem.

COMMISSIONER GILINSKY: What is the cladding thickness there?

MR. JOHNSON: The cladding thickness -- I'm sorry, I have corrected this on your handout. This should be a micro

rather than a milli.

COMMISSIONER GILINSKY: Oh, yes, I see.

MR. JOHNSON: So I share your concern, but we are talking about a few tenths of a micron of corrosion ---

COMMISSIONER GILINSKY: I see.

MR. JOHNSON: -- for Zircaloy if we extrapolate what we now know to a hundred years, and that's .05 to .07 percent of the cladding.

COMMISSIONER GILINSKY: I see. So from what we know now and if nothing sort of unexpected came up ---

MR. JOHNSON: That's right.

COMMISSIONER GILINSKY: -- this kind of time period doesn't seem unreasonable.

MR. JOHNSON: That's correct. And I have seen a recent Scandinavian report which is not yet released which takes that same point of view. The Windscale hearings produced that same point of view including the examinations that they did on their fuel. And I think that that's the concensus of those who have now looked either on paper or in their pools.

COMMISSIONER GILINSKY: So in other words, we don't really see what the limiting mechanism yet ---

MR. JOHNSON: That's correct. We have not yet seen a mechanism that is even discernible for the light water reactor fuel.

Now, there are a few other slides if you want to

take time to look through them, but I think that's the principal thrust.

Let's look briefly at the next slide which summarizes the galvanic couples.

(Slide)

Let me simply say that they don't look like a problem. We can point them out, but ---

COMMISSIONER GILINSKY: Let me ask you this: is this view shared by others who have looked at this problem?

MR. JOHNSON: I mentioned this -- there is a Scandinavian report which has not been released which goes into some additional detail beyond what I have done in this report and they don't see a problem.

They talk about 50 years there is no problem for storage.

COMMISSIONER GILINSKY: You mentioned talking with the Germans, what do they say?

MR. JOHNSON: The Germans are reprocessing, or at leas they are aiming toward reprocessing so they don't visualize the need for extended storage, but they don't see any problem out to five years in these methodical examinations that they have performed.

COMMISSIONER GILINSKY: But the interesting thing there is that they make the point that they are reprocessing not to get plutonium but precisely to avoid these problems with

corrosion of spent fuels. So I was curious, you know, what they say about that?

MR. JOHNSON: I spoke with only one technical man, but he certainly has the view that there is no problem with that, at least out -- he mentioned the time 10 years in a technical publication, that they don't expect to see any problem in at least out to 10 years.

The Scandinavian -- well, the British as I will show you on a subsequent slide state two to three decades as being an area where they don't see any problem. The Scandinavian publication says we don't see a problem out to at least 50 years and I can show you a Canadian publication which says they don't expect problems out to 100 years.

COMMISSIONER GILINSKY: Could you identify that publication sometime later?

MR. JOHNSON: Which publication?

COMMISSIONER GILINSKY: The Canadian one, actually the Swedish one too for that matter.

MR. JOHNSON: The Swedish one is not yet released, so I think it would be inappropriate to cite that specifically by number, but the Canadian publication is referenced in here ---

COMMISSIONER GILINSKY: Oh, good.

MR. JOHNSON: -- and I can find it for you after the presentation.

CHAIRMAN HENDRIE: Okay, I'll tell you what, why don't we sort of leap through sort of the last three slides --

MR. JOHNSON: Okay.

CHAIRMAN HENDRIE: -- and conclusions.

MR. JOHNSON: Could we go to Slide No. 36.

(Slide)

It is somewhat a misnomer to call these national programs, because in some cases they are sort of individual laboratory efforts, so I put quotations around National Programs here. I have not indicated what is going on in the U.S. because this is a talk I am giving tomorrow at the IAEA and that is being handled by other speakers. So I haven't summarized that.

In Canada there is a plan underway to examine fuel which in 1977 had 14 years of pool residence and they plan to examine that fuel about every five years going back to the same bundles through about 1995.

In the United Kingdom there have been metallurgical exams, I have a slide which summarize these in terms of burnups and pool residence, but out to about 10 years with burnups up to 33,000 megawatt days per ton. The high burnup fuel, though, had only about six years of pool residence. So there are some seven fuel pins in the U.K. program which have already been examined and they plan to examine about 10 more, maybe more than that.

In the German Federal Republic I have mentioned this periodic visual examination which is under way. Now, there are -- I am aware of other programs, not major ones, but there are programs going on in other countries which have been discussed in so far unreleased publications, but this is a sampling of what is going on. An evidence that there is interest, that there is a concern in developing a sufficient basis for qualifying the fuel, not simply waiving it off and saying there isn't a problem. There is a general feeling that we ought to confirm it, but at some level which is reasonable.

(Slide)

The next slide then -- well, this shows that plot of which fuel bundles are being examined and here is the SGHWR that had failed fuel. There is a PWR stainless steel bundle which has had examination, so what you see is the high burnup fuel has relatively low pool exposure.

Here's our grandfather out here, the 18-year Shippingport bundle which has not been examined, but which would be a candidate, but admittedly it has low burnup.

(Slide)

The next slide then summarizes the experience. No pool operator has seen evidence that failures have occurred or are developing on water reactor stainless or Zircaloy-cladd oxide fuel. This is by visual inspection, by radioactivity

monitoring and then I summarized the metallurgical examinations which have also been done and which confirm this view, even though there are relatively few of those, they are quite in agreement with this point of view.

Mechanical damage to the fuel bundles during handling is minimal. I found nine damage events indicated in the NRC incident reports for 1974 to '76. Only two of these caused any gas release from the fuel.and this is in thousands of sorties of fuel handling events.

(Slide)

The next slide is the conclusion, the integrity of stainless and Zircaloy-clad spent nuclear fuel has been satisfactory in water pool storage, including fuel with reactor-induced cladding defects.

The longest pool exposures are 18 years for Zircaloy-clad fuel; 12 years for stainless-clad. Mechanical danage has been minor, and then finally, the last slide ---

(Slide)

-- the recommendations are that some routine surveillance and exploratory fuel examinations appears justified, but that the favorable experience justifies expansion of the fuel storage capacities and extension of the storage times for commercial reactor fuel.

CHAIRMAN HENDRIE: Very good. Comments?

That is a very interesting subject, especially at

this time and we are very pleased that you could come.

(Whereupon, the meeting concluded at 3:20 p.m. and moved on to other business.)