Risk of Sump Plugging
Experimental program on chemical effects

Jean Marie MATTEI, Yves ARMAND*
Ivan VICENA, Bela SOLTESZ, Jozef BATALIK, Vladimir GUBCO**
Marek LISKA, Andrea KLEMENTOVA***

**IRSN, B.P. 17, 92262 Fontenay-aux-Roses, France*
***VUEZ, a. s. Levice, Sv. Michala 4, 934 80 Levice, Slovakia*
**** TRENCIN UNIVERSITY / VITRUM LAUGARICIO (VILA) – Joint Glass Center of the Institute of Inorganic Chemistry SAS, Alexander Dubček University of Trenčín, and RONA, a.s.Študentská 2, Trenčín, SK-91150, Slovakia*

IRSN
BO 17, 92262 Fontenay-Aux-Roses, France
phone +33158358299, +33158358207,
e-mail: jean-marie.mattei@irsn.fr; yves.armand@irsn.fr
VUEZ, a.s., LEVICE
Hviezdoslavova 35, P.O. Box 153, 934 39 Levice, Slovak Republic,
Phone +421 36 6355311, fax +421 36 6355313, e-mail : vicena@vuez.sk
TRENCIN UNIVERSITY
Slovak Republic,
e-mail : liska@tnuni.sk

1. INTRODUCTION

The assessment of the operational characteristics of the filtration function used during the recirculation phase of safety injection system (SI) and containment spray system (SS), in the event of a primary system break in the containment, has been performed by the "Institut de Radioprotection et de Sûreté Nucléaire" (IRSN) for the French pressurized reactors (58 reactors). Those one have been designed according with the RG 1.82 (rev. 1). The IRSN has focused in particular on the CPY series, 900 MWe 3 loops pressurized water reactors (28 reactors).

A general overview of the literature has been conducted between October 1999 and November 2000, which resulting in defining an approach methodology and in writing technical specifications for an experimental program of studies on the sump plugging risk. Those studies have been carried out for the different sizes of primary breaks: large, intermediate and small LOCA. For each size of break, located on the welding between SG and hot leg, the different characteristics of generated debris, flows of SI and SS systems have been defined. Methodology of event trees has been used to define the characteristics of the debris and their arrival point at the bottom of the containment using the results of the performed tests.

To estimate the risk involved in each case, the following points were studied:

- ⇨ An inventory of debris generated. This consists of the following types:
    - ⇨ Glass wool thermal insulation fibers (spherical model: L = 12.D),
    - ⇨ Paints, particulates and dusts present in the containment,
- ⇨ Vertical transfer of debris,
- ⇨ Structural modification of debris in the containment,
- ⇨ Horizontal transfer of debris at the bottom of the containment,
- ⇨ Filtration efficiency and modification of sump hydraulics / air and debris ingestion,
- ⇨ Operation of equipment with mud and air.

The subjects giving rise to important questions have been collected and a corresponding full-scale experimental program was chosen in order to answer to questions raised from a preliminary study. The following points were currently under experimental investigation:

⇨ IVANA loop (VUEZ / SLOVAKIA): grinding of fibrous debris on the grating system (mechanical action of falling water),

⇨ VITRA loop (EREC / RUSSIA): horizontal transfer speed of debris,

⇨ MANON loop (VUEZ / SLOVAKIA): pressure drop and air and debris ingestion at the sump filters,

⇨ ELISA loop (VUEZ / SLOVAKIA): chemical action of water, effect of temperature, establishment of different correlations.

On the 12th of June 2003, the standing group endorses the strong concern of IRSN that Electricity de France has to perform the necessary actions to deal with the question of the efficiency of the filters of all the plants. At the end of October (30th October 2003), French nuclear safety authority (DGSNR) has told Electricity de France to accelerate the study of the risk of sump strainer clogging in all 58 of its PWRs and to report by the end of the year. Electricity de France position has been presented at the end of 2003. Electricity de France considered that improvements are needed for all the French series to cope with primary breaks higher than 4".

Consequently, important phases related to the sump plugging issue have been developed for the last years (references 1 to 7). Nevertheless, questions are remaining opened in particular the LOCA induced long-term debris, as a combined action of the temperature and the chemistry of the water, in correlation with the nature of the water (references 8 to 11). The chemical effects issue represents the materials transformations inside the containment due to the combined temperature and chemical impact. It includes the transformation of debris carried or already on the strainers or in the containment.

The head loss across the containment sump screen in post-LOCA environment could increase due to collection of corrosion products on fibrous insulation. Concerns have been raised about the potential for different ions corrosion products to significantly block a fiber bed and increase its head loss.

Little information is available on corrosion product release with representative post-LOCA conditions. No study has been performed in the world on this specific item.

In 2003, IRSN managed a preliminary study on chemical effects with its contractor VUEZ showing creation of precipitates increasing the head loss of the fiber bed deposited on the filters of Safety Injection System (SIS) and Spray system (SS). A program to establish the knowledge of the chemical effects on the fiber bed created on the filtering systems during recirculation was proposed, in 2004, to be performed with the sub-contractor VUEZ and TRENCIN academy.

This report presents the main scientific knowledge provided by this research program.

2. LITERATURE

In the report OECD/PWG1: Updated Knowledge Base for ECCS Recirculation Reliability (April 2000), it is underlined:

–“*Following a LOCA, a plant may be required to operate for an extended period of time in a recirculation mode to maintain core cooling, depending on the circumstances of the LOCA, such as the location of the break. When a debris-laden strainer is in service for an extended period (days), there may be a noticeable increase in head loss. The magnitude of the increase may depend on the composition and initial size of the bed and the chemical environment. Results reported by the different insulation vendors vary.*

– Long time recirculation tests were conducted as part of the Ringhals 2 Steam Generator Replacement Project. These tests were conducted at representative post-LOCA conditions for temperature and chemistry. Pressure drop was reported to increase without limit after 120 hours.
–The long-term increase in pressure drop was attributed to the following factors:

- *NaOH present in the recirculation pool was causing SiO2 to be removed from the fiberglass fibers, resulting in an increase in the viscosity of the pool water.*
- *Glass fibers become less resilient as a result of the above chemical reaction, allowing the debris bed to be packed more densely.*
- *Debris captured by the fiber bed migrate deeper into the bed. As the bed compresses, the debris will form a less porous bed, resulting in further compression and head loss.*

– This general area is one area where additional research is needed to develop understanding of the basic phenomena and enable development of appropriate long term accident management strategies."

3. PRELIMINARY STUDY

During the previous test realized on ELISA loop in 2003, it was observed that if tap water was used (initial pH of about 8 at 20°C), after adding 2g/l H_3BO_3 and NaOH to adjust pH of the solution to 9, precipitates were formed and, after adding NaOH, circulating fluid changed into a turbid suspension. These precipitates affected substantially the course of the experiment since they were collected in the insulation bed on filters and reduced thus its permeability for circulating fluid, which resulted in a substantial increase of head loss.

In 2003, a preliminary study has been performed to investigate the kinetics of glass fiber dissolution:

- Definition of time behavior of concentrations of selected dissolved components;
- Measurement of kinetics of glass fiber dissolution under different temperatures;
- Investigation of changed fiber morphology and precipitate formation on fiber surface during the leaching experiment using scanning electron microscope.

It appeared that exposure of glass to liquid media was accompanied with glass corrosion. It is a complex process consisting of several elementary phenomena including chemical reactions and diffusion. Glass corrosion results in gradual dissolution of glass accompanied in some cases also with formation of insoluble products that are formed on the surface of corroded glass and are dispersed mechanically throughout the liquid medium.

When exposed to the effects of liquid media, chemical resistance of glass fibers depends on four essential factors:

- Temperature,
- Glass composition,
- Leaching liquor composition,
- Hydrodynamic conditions.

4. IRSN PROPOSAL

Taking into account the following data's:

– Data 1: OECD/PWG1: "This general area (long term effects) may be one where additional research is needed to develop understanding of the basic phenomena and enable development of appropriate long term accident management strategies."

– Data 2: IRSN preliminary investigations demonstrated the risk of increase of the head loss under LOCA conditions.

IRSN proposed to realize an experimental program on the chemical effects during PWR-LOCA conditions.

The main steps of the program are:

- First to verify the precipitate creation and to determine the concentration of precipitates and, if possible, gelatinous compounds which can be produced at long-term.
- Second to determine the effect of amount of precipitates (crystal and gelatinous compounds) on head loss of the fiber bed fixed on the filtering devices.

Realization of a global assessment on chemical effects through this experimental program was submitted by IRSN to CSNI partners and discussed during CSNI meeting in Paris (May, 2004). In spite of positive technical conclusion, due to lack of interest of the partners, realization of the program was finally decided by IRSN on its funds (0,4 MEuros) (May 2004 to May 2005).

5. IRSN CHEMICAL EFFECTS PROGRAM

The chemical effects issue represents the materials transformations inside the containment due to the combined temperature and chemical impact. The primary dependent variable will be the characterization of corrosion product release. The corrosion rate, corrosion product release rate, and the form of the corrosion products from different sources have to be investigated.

5.1. Aim

The aim of the program is the characterization of the behavior of the head loss of the fiber bed fixed on the filtering devices during accidental conditions and under precipitation effects. The program is focused on the design basis accidents of the existing units. The treatment of the severe accidents will be investigated later.

Accidental conditions during recirculation phase are mainly linked with the following parameters: pH and temperature. The given pH of the sump solution (9,3) has a large effect on corrosion and precipitation reactions. Concerning the temperature, the maximum expected sump temperature is 113˚C and this temperature is achieved very quickly. Within long term, the temperature decreases to about 35˚C. The compounds and products are of a major interest under those thermo dynamical conditions, foreseen at the equilibrium. The pressure is not considered as an important parameter. For French units, it has to be underlined that during recirculation phase, the sumps are always under water.

To be able to use the results of the program for different units with different quantities and varieties of debris, the following topics are considered:

•First step:
Aim: To establish models to characterize the quality of the precipitation forms.

a/ Determination of the *nature of the water involved*. The IRWST water, the possible injection of NaOH and in addition the compounds, which are inside the primary circuit water are considered.

b/ Measurements of the *degradation kinetic rates* (dissolution / corrosion) for the main types of "material of interest" (latent debris and so-called short-term debris related with the debris generation due to the jet effects).

c/ *Computer modeling of time evolution of complex system*. This step requires the use of a computer code. PHREEQC was chosen. The objective is to calculate the nature and the quantity of complex at the equilibrium (pH=9.3, T=65°C-30°C), inside the containment.

PHREEQC version 2 is described hereafter:

"PHREEQC version 2 is a computer program written in the C language that is designed to perform a wide variety of low-temperature aqueous geochemical calculations. PHREEQC is based on an ion-association aqueous model and has capabilities for speciation and saturation-index calculations; batch-reaction and one-dimensional (1D) transport calculations involving reversible reactions, which include aqueous, mineral, gas, solid-solution, surface-complexation, and ion-

exchange equilibria, and irreversible reactions, which include specified mole transfers of reactants, kinetically controlled reactions, mixing of solutions, and temperature changes; and inverse modeling, which finds sets of mineral and gas mole transfers that account for differences in composition between waters, within specified compositional uncertainty limits.

PHREEQC version 2 includes capabilities to model kinetic reactions with user-defined rate expressions, to model the formation or dissolution of ideal, multicomponent or nonideal, binary solid solutions, to allow the number of surface or exchange sites to vary with the dissolution or precipitation of minerals or kinetic reactants, to include isotope mole balances in inverse modeling calculations, to automatically use multiple sets of convergence parameters, to print user-defined quantities to the primary output file and (or) to a file suitable for importation into a spreadsheet, and to define solution compositions in a format more compatible with spreadsheet programs."

•Second step:

Aim: To establish a model to characterize the evolution of the head loss depending on the quality and the quantity of the precipitation forms (gelatinous or crystallization).

d/ *Head loss tests.* The goal of the tests was to quantify the respective influence on the filter head loss of insulation leaching, of precipitation crystal forms and of precipitation gelatinous forms.

5.2. Input data's

Different species can directly clog a filter bed, or indirectly clog the bed through precipitation processes within the sump or within the filter cake. Materials as Zn, Al, Si, Fe, Ca, Mg, Sn, Pb, Na, P, and Cl are contained in the recirculation water, the insulation and all the materials destroyed under the jet effect or carried by the water flow (paints, concrete, dirt, dust, seals, cables, etc). The respective sources able to create precipitates are the following:

- The different contents of the water (IRWST: 1600m^3 and primary water: 200m^3);
- The damaged insulation. The volume of insulation damaged is calculated using a ratio L/D = 12 and vertical transport factor of 63%,
- The different other debris (paints, concrete, dirt, dust, cables, seals, others).

Preliminary chemical analyses have been performed on the solution and on the main different debris to precise their initial chemical composition. French composition of flowing fluid complies with 2000 ppm H_3BO_3 and NaOH. The corresponding pH is 9,3. Concerning insulation, two kinds of insulation (TELISOL, BOURRE) are used on the French NPP. Composition of insulation has been defined by a chemical analysis. Corresponding results are presented in % (weight) of sample annealed at a temperature of 500°C and represent an average value obtained from two independent determinations. Loss induced by annealing at 500°C for the given sample was 1.9 %(weight). As far as the chemical compositions of BOURRE and TELISOL fibers are sufficiently close, only BOURRE glass fibers is considered.

Constituent	Result [% Weight]	Uncertainty [% Weight]
% SiO_2	64.82	± 0.20
% Al_2O_3	1.95	± 0.05
% B_2O_3	5.41	± 0.10
% total iron in terms of Fe_2O_3	0.55	± 0.03
% TiO_2	0.140	± 0.010
% CaO	7.10	± 0.10
% MgO	3.01	± 0.06
% MnO	0.23	± 0.02
% BaO	0.17	± 0.03
% K_2O	0.68	± 0.05
% Na_2O	15.25	± 0.16
% SO_3	0.21	± 0.02
% Cr_2O_3	0.004	± 0.001

5.3. Chemical sub-program

Two types of tests are performed:

- Static leaching tests

For glass insulation the test are performed on glass fibers and on glass powder with grains of prescribed diameter obtained by sieving. The same tests are performed for types of materials as concrete. The objectives are to determine concentrations (activities) of all components at various temperatures and for various compositions of starting leaching solution and to study the chemical composition and structure of dried gelatinous product.

- Flow through leaching tests

The aim is to study the kinetics of leaching of individual components (i.e. oxides in the case of glass). Various temperatures and various compositions of leaching solution are considered. In combination with the equilibrium data obtained from static leaching tests, the mathematical model describing the time course of corrosion of given material (glass, concrete, dust, dirt, paint, …) for an arbitrary time-temperature schedule is formulated.

Currently, the most successful long-term dissolution models for boro-silicate glasses employ the rate equation consistent with the transition state theory together with geochemical code calculations. A generalized form of a rate law that is applicable to surface reaction-controlled processes is given by (Aagaard and Helgeson, Lasaga):

$$Rate = k_0 S \exp(-E_{\mathrm{a}} / RT)(a_{\mathrm{H}^+})^{n_{\mathrm{H}+}} g(I) \prod_i (a_i)^{n_i} f(\Delta_{\mathrm{r}} G)$$

Where:

k_0 is the intrinsic rate constant,

S - reactive surface area,

E_{a} - activation energy,

R - universal gas constant,

T – thermodynamic temperature,

a_i – activity of component i,

$(a_i)^{ni}$ describes the net catalytic or inhibitory effects of rate influencing species (H_3O^+ is included explicitly),

$g(I)$ accounts for the dependence on ionic strength I,

$f(\Delta_{\mathrm{r}}G)$ is a reaction affinity term, i.e. reaction free energy function describing the reaction rate dependence on the deviation from equilibrium.

For the purpose of glass dissolution modeling, a simplified transition state theory rate law has been employed by numerous authors. The general form of the rate law is:

$$Rate_i = k_0 \nu_i \exp(-E_{\mathrm{a}} / RT)(a_{\mathrm{H}^+})^n \left[1 - (Q/K)\right]$$

Where:

$Rate_i$ is the release rate of glass component i,

ν_i the stoechiometric coefficient for element i,

Q the activity product of the rate-limiting reaction,

K the equilibrium constant of this reaction.

The last square-bracketed term describes the thermodynamic reaction affinity. Experimentally determined parameters, such as the intrinsic rate constant, apparent activation energy for dissolution, pH dependence (when the leaching takes place in un-buffered solutions), the affinity effect on dissolution rate, and information about the composition of secondary alteration products are required for this modeling approach. To determine these parameters, a set of static and flow-through leaching tests is conducted.

The table of chemical tests can be summarized as follows:

Characteristics (types, mass)	x, y, z, t, u, v	x, y, z, t, u, v	x, y, z, t, u, v	x, y, z, t, u, v	**Data**
Types	Fiber Grain	Grain	Grain	Grain	**Data**
Distilled Water Recirculation	Distilled water Others: x, y, z, t, u, v, , Boron (2500 ppm), Soda, pH = 9,3				**Data**
Temperature	Some values				**Data**
"Static leaching tests"	<u>To get</u>: Equilibrium concentrations : f (solution, temperature) Creation conditions of precipitates Chemical composition of precipitates				**Experiment**
"Flow through tests"	<u>To get</u>: Corrosion rates Initial corrosion rate <u>To study precipitate formation</u>.				**Experiment**

The duration of one static experiment, i.e. the time needed to establish the equilibrium can be roughly estimated as 20-30 days. The typical duration of flow through experiment, i.e. the time needed to attain stationary state, is about 8 days.

5.4. Head loss sub-program

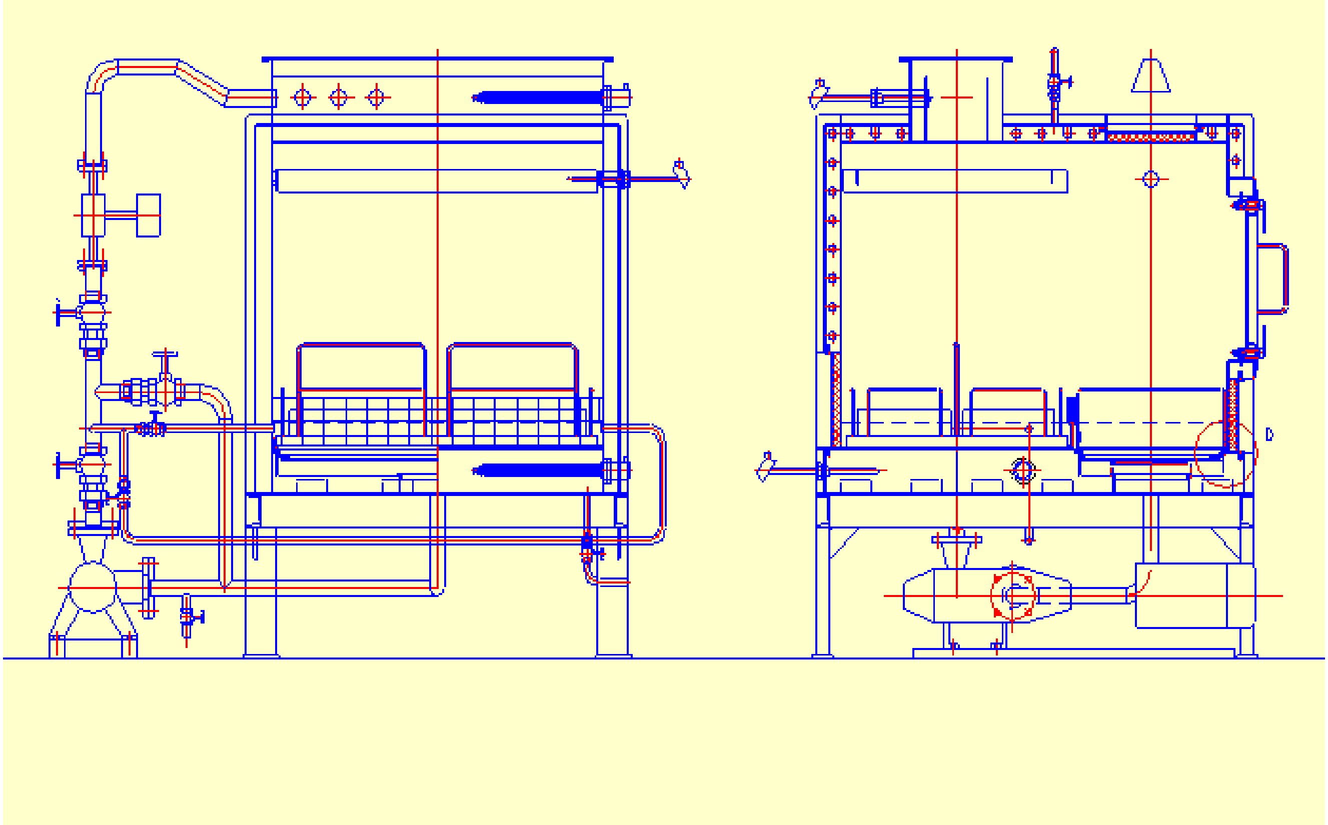
The goal of the head loss experimental program conducted on the ELISA loop from VUEZ is to quantify the respective influence on the filter head loss of:

- Insulation leaching,
- Effect of dust on precipitation formation,
- Precipitation crystal forms,
- Precipitation gelatinous forms.

Parameters with the highest impact on Head Loss Experimental Program are as follows:

- Quality of initial water used to prepare solution (content of soluble salts),
- Composition of circulating fluid (H_3BO_3 content, pH),
- Temperature of circulating fluid,
- Amount of insulation used for experiment and corresponding to the spectrum of LOCA accidents,
- Amount of particles of different types,
- Flow-rate of circulating fluid through the filter box.

The ELISA loop was used to perform the tests (figures 1 and 2).



<u>Figure 1</u>: ELISA loop

<u>Figure 2</u>: ELISA loop

To be as close as possible of the real conditions, a specific “basket” with holes was defined:

- In one hand, allowing creation and possible migration of the different precipitates issued from the different settled debris,
- In the other hand, avoiding concentration of all the debris on the filtering bed.

An improvement of the existing loop was made by installing two pumps in parallel in normal backup and an electrical backup of the pumps and the heaters.

Diverse tests are performed on the ELISA loop. Their objectives are for example:

- Test 1: To assess, at 60°C, the effect on the fiber bed head loss of the precipitates formed due to the lixiviation of the fiber bed, and to verify the possible formation of the crystal form and gelatinous form of the precipitates,
- Test 2: To assess, at 60°C, the effect on the fiber bed head loss of the precipitates formed due to the lixiviation of the settled insulation, and to verify the possible formation of the crystal form and gelatinous form of the precipitates,
- Test 6: To assess, at 60°C, the effect on the fiber bed head loss of the precipitates formed due to the corrosion of the different settled debris (insulation, dust, paints, concrete), and to verify the possible formation of the crystal form and gelatinous form of the precipitates.
- Test 6bis: To assess, at variable temperature depending on the residual heat, the effect on the fiber bed head loss of the precipitates formed due to the corrosion of the different settled debris (insulation, dust, paints, concrete), and to verify the possible formation of the crystal form and gelatinous form of the precipitates.

During the ELISA experiments, the samples of the solution were taken. They were delivered for chemical analysis by atomic absorption spectroscopy (AAS) and colorimetry. All analysis was performed by the TRENCIN Institute.

To define the average operating conditions of the tests and the scale ratios, the following has been used. The ratio of water volume will be maintained (1 500 000/ 550 = 2727). The other quantities have been defined by calculation using this ratio or by expert judgment.

With the corresponding quantity of insulation, a quick evaluation shows that homogeneous filter bed will be created on the ELISA filter.

	UNIT (kg)	ELISA (kg)	RATIO
Water	1 500 000	550	2727
Insulation for fiber bed	1 550	0,568	2727
Settled insulation	730	0,268	2727
Concrete	125 (estimation)	0,046	2727
Dust	125 (estimation)	0,046	2727
Paints	125 (estimation)	0,046	2727

5.5. Link between chemical sub-program and head loss sub-program

The following logic diagram provides the link between the chemical sub-program results and the head loss sub-program model (figure 3).

This diagram uses the results of the two programs, summarized hereafter:

- R0 (possible precipitates) known by PHREEQC calculation,
- R1 (maximal precipitates quantities) known by calculation at the equilibrium,
- R2 (Precipitates forms – gel/precipitates) visually observed but not quantified,
- R3 (dissolved form) known from chemical tests,
- R4 (kinetics) known about glass grain from chemical tests,
- R5 (DP evolution) known for decrease of temperature until 38°C,
- R6 (maximal quantity, curve form) depending in particular on temperature, fiber, grain and concrete corrosion, gas.

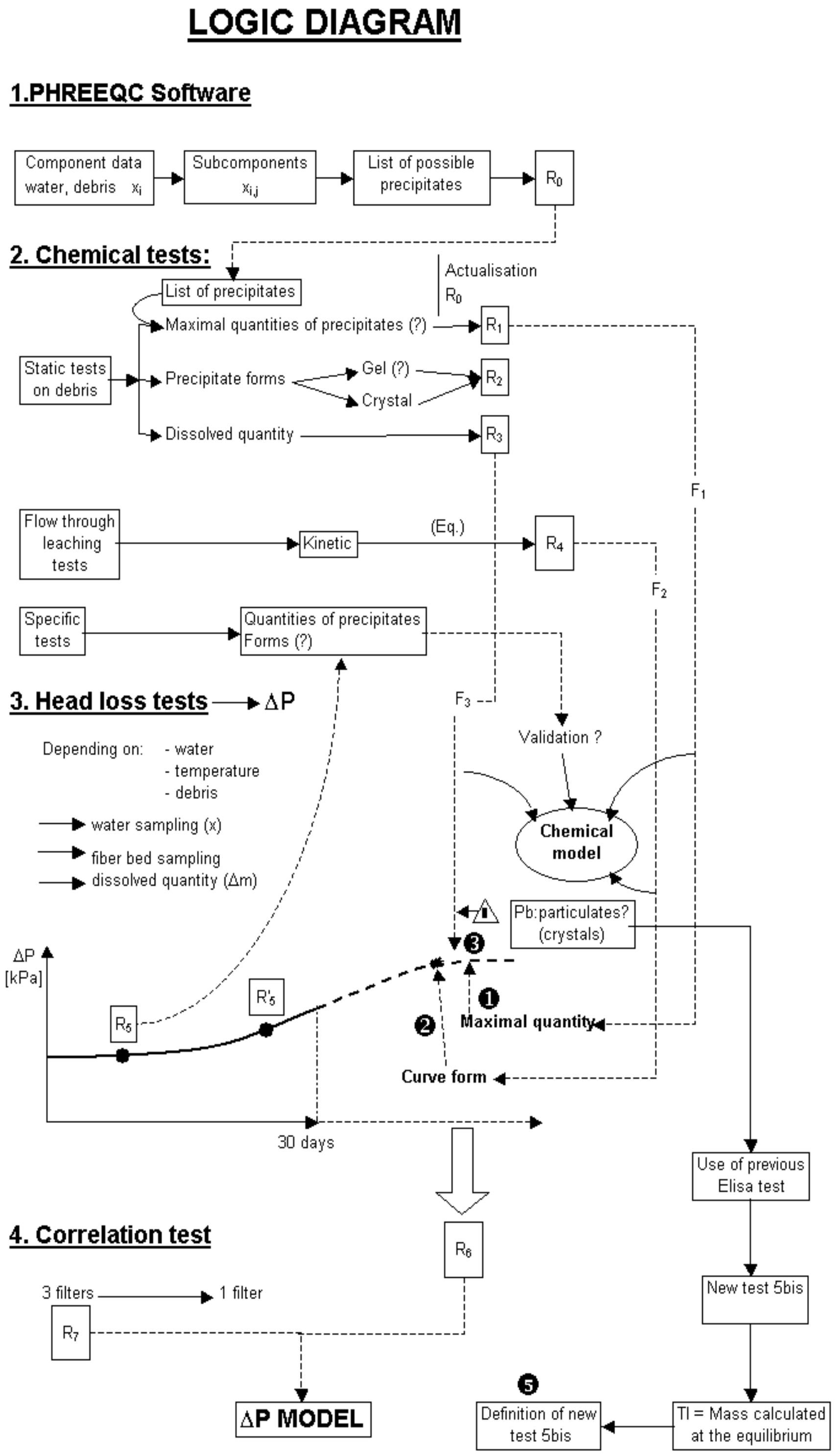


Figure 3:*Logic diagram*

6. MAIN RESULTS

During experiments, it appeared that temperature had a large influence and depending on its value this parameter could modify kinds and nature of precipitates coming from chemical reactions. Consequently, it was decided to include a temperature profile in accordance with decay heat removal for a 900 MWe plant. So, to-day, all the steps of the logic diagram have not been totally fulfilled.

From October 2004, the last steps of the program have been focused on the influence of the temperature on the DP evolution. Consequently, only preliminary chemical model and DP model are proposed.

A. The main preliminary lessons are:

–Even in an initial distilled water, fiber corrosion leads quickly to an alkaline solution (figure 4).

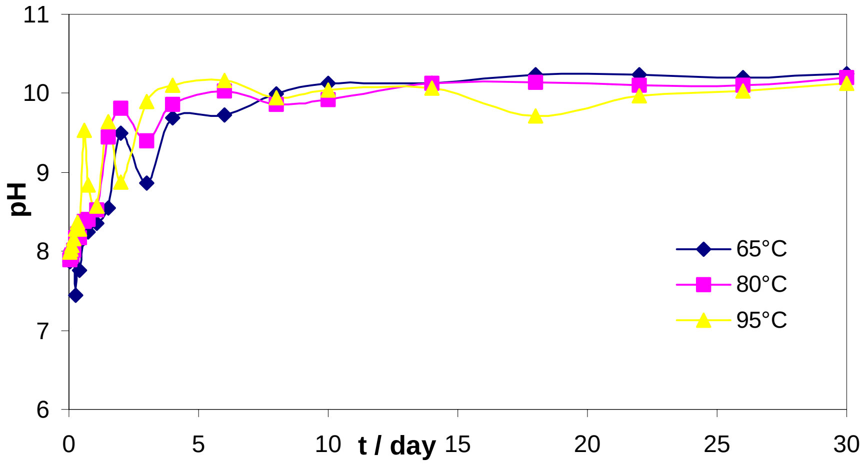


Figure 4

-Corrosion rates are defined (figure 5), where NL(i) is the normalized leached amount of the element i

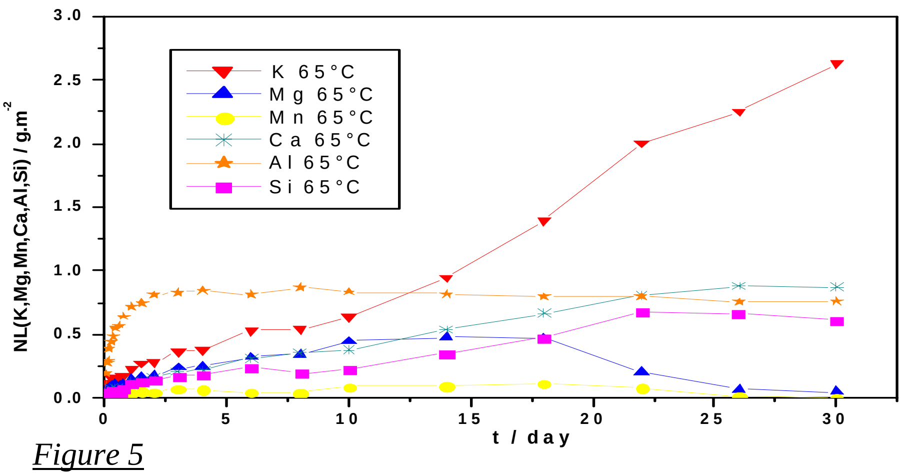
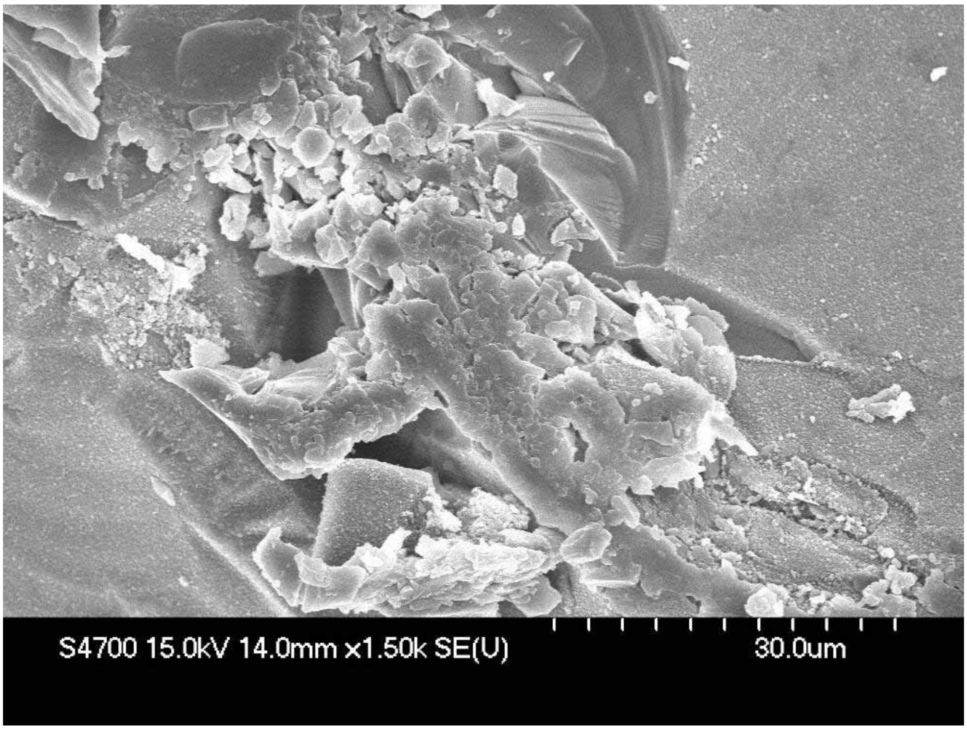
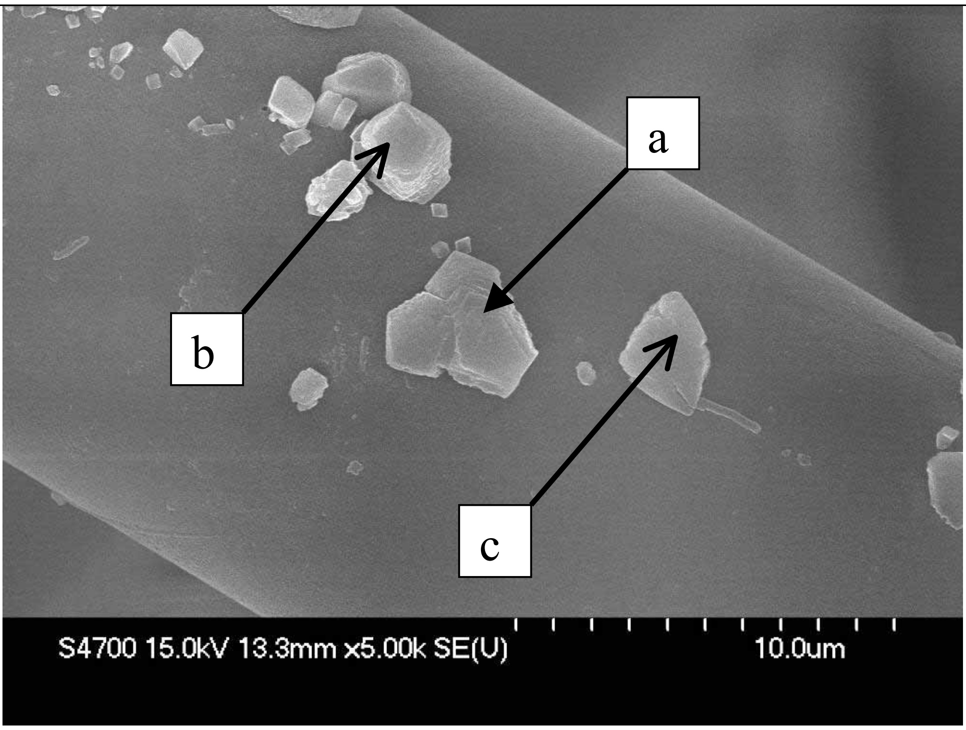


Figure 5

–Precipitates are created under crystal forms and gel forms (figures 6 to 10).



<u>Figure 6</u>: Corroded area (distillate water, grain)



<u>Figure 7</u>: Precipitates a, b et c (sump water, fibers)

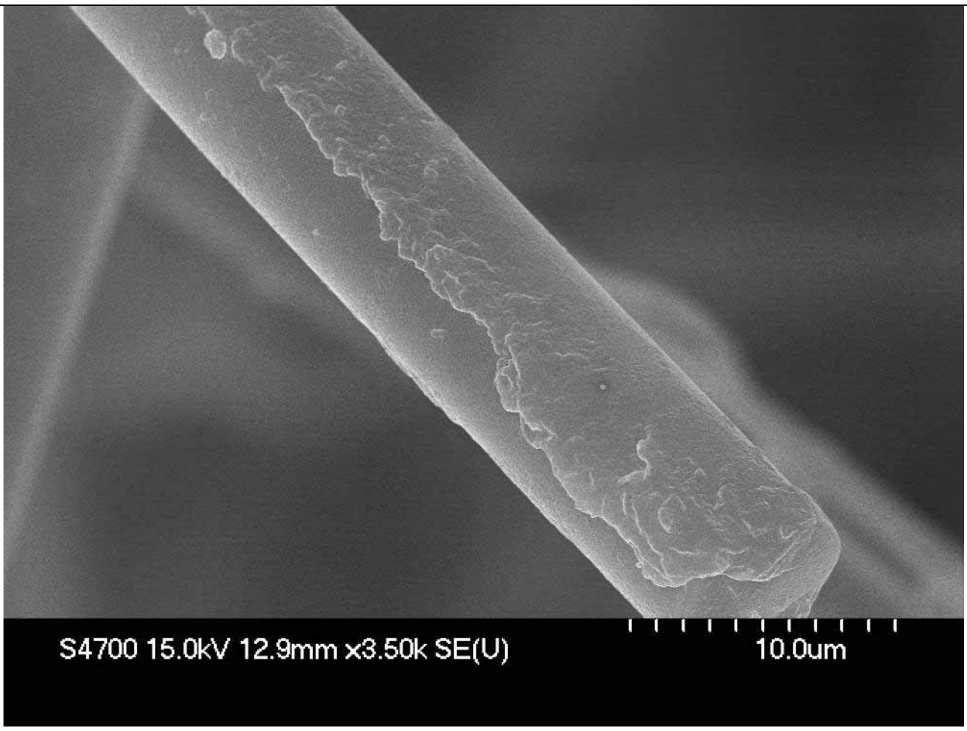


***Figure 8*: Precipitates covering fiber (sump water, fibers)**

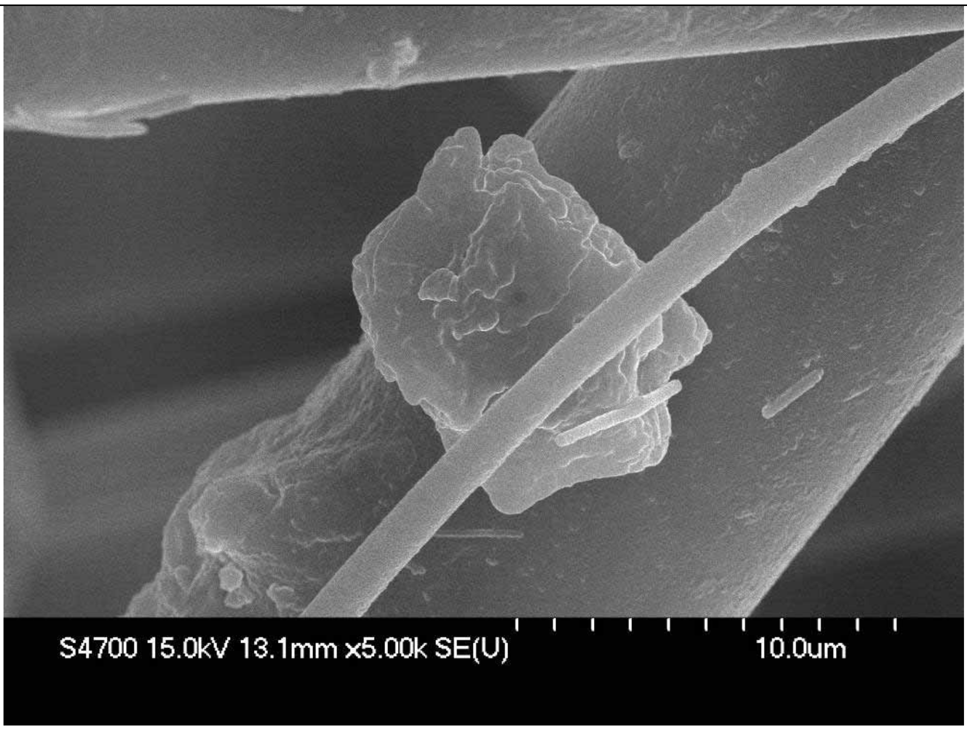


***Figure 9*: Precipitates under crystal forms (sump water, fibers)**

Oxides	Na_2O	K_2O	MgO	CaO	BaO	Al_2O_3	SiO_2
Fiber	16.4	0.7	3.2	7.6	0.2	2.1	69.7
Figure 6	11.3	2.2	4.0	5.8	2.5	4.8	69.4
Figure 7a	12.7	2.0	2.0	11.9	0	2.4	68.8
Figure 7b	2.21	0.8	1.9	76.8		3.7	14.6
Figure 7c	13.4	0	3.6	10.8	0	2.0	68.1
Figure 8	13.0	1.0	2.5	6.15	0	4.9	72.5
Figure 9	6.7	2.5	1.8	30.2	0	8.0	50.8

Figure10:* *Chemical analysis results (% of oxides weight).

–Collected precipitates are under crystal forms but gel forms are created mainly under some stimuli. The fiber and debris degradation leads to a difficult compounds characterization, due to the presence of a mixture of precipitates, gel and gas (figure 11),

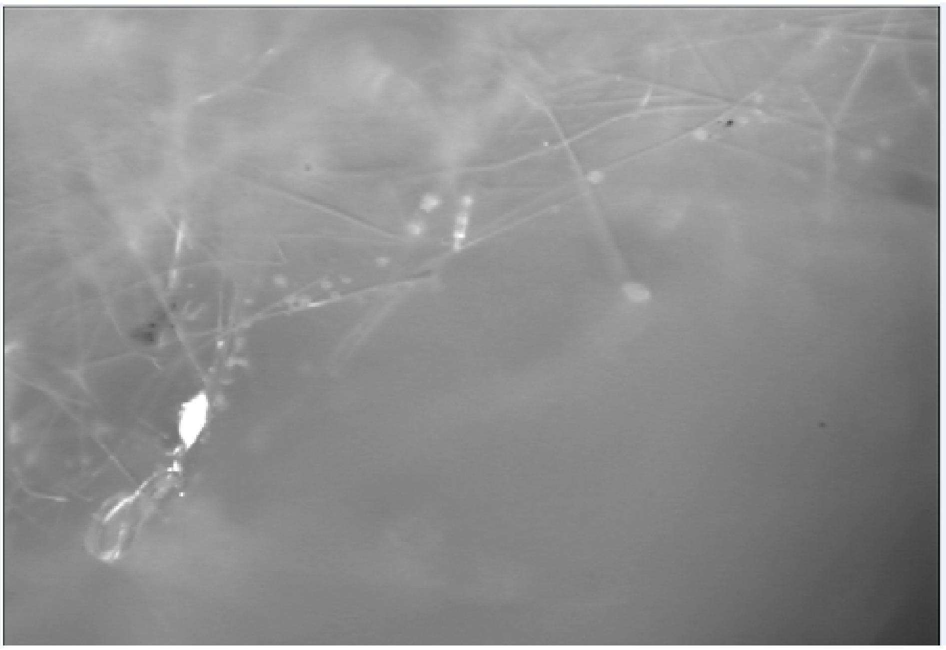


***Figure 11**: Example of gel and gas*

–In comparison with the test facility conditions, additional stimuli met on the nuclear plant (as for example local temperature, drops,..) could increase significantly precipitate formation (figures 12 and 13).

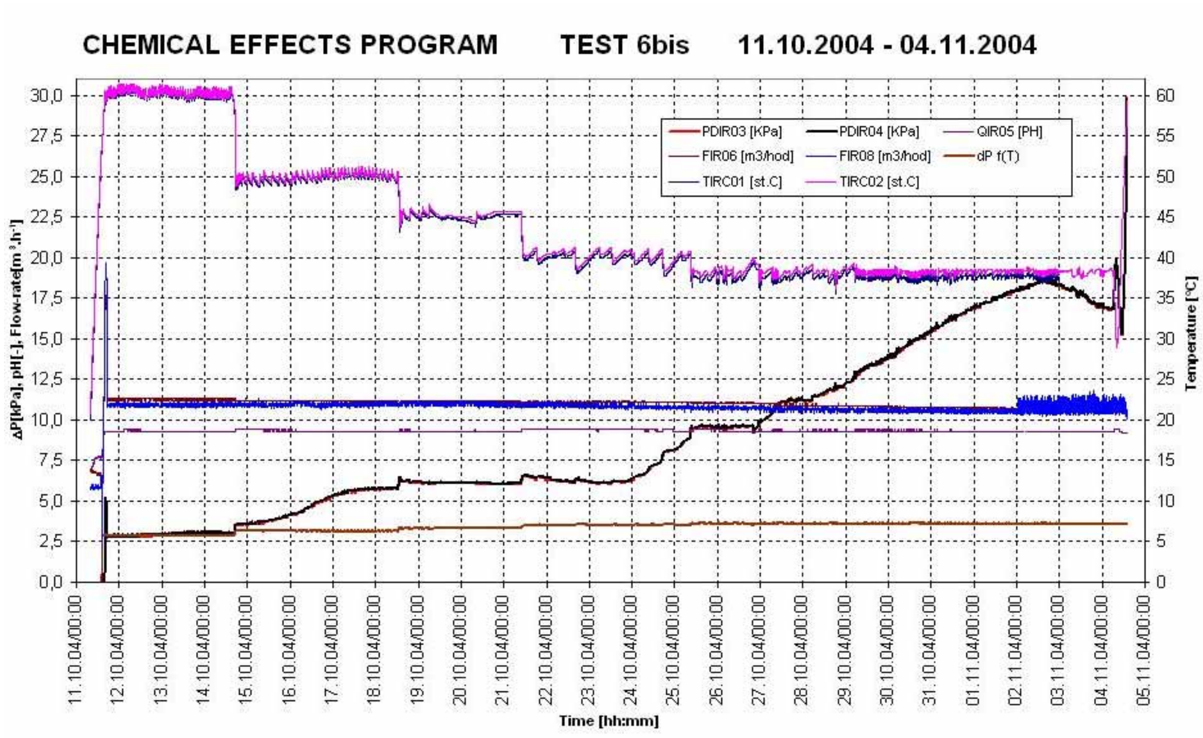


Figure 12: Test 6bis: results (11/10/04 to 4/11/04)

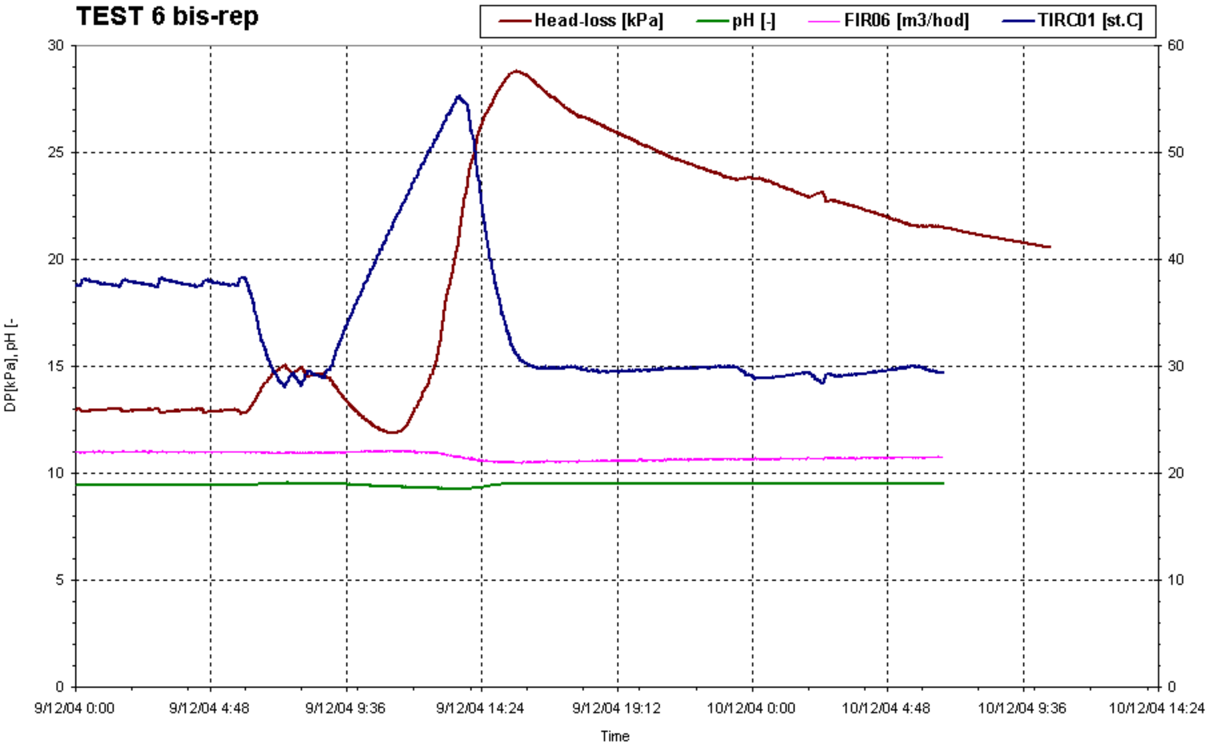


Figure 13: Test 6bisrep: results (9/12/04)

–The possible forms of precipitates are given as an example on the figure 14 showing the results of a calculation using PHREEQC model for a temperature of 60°C.

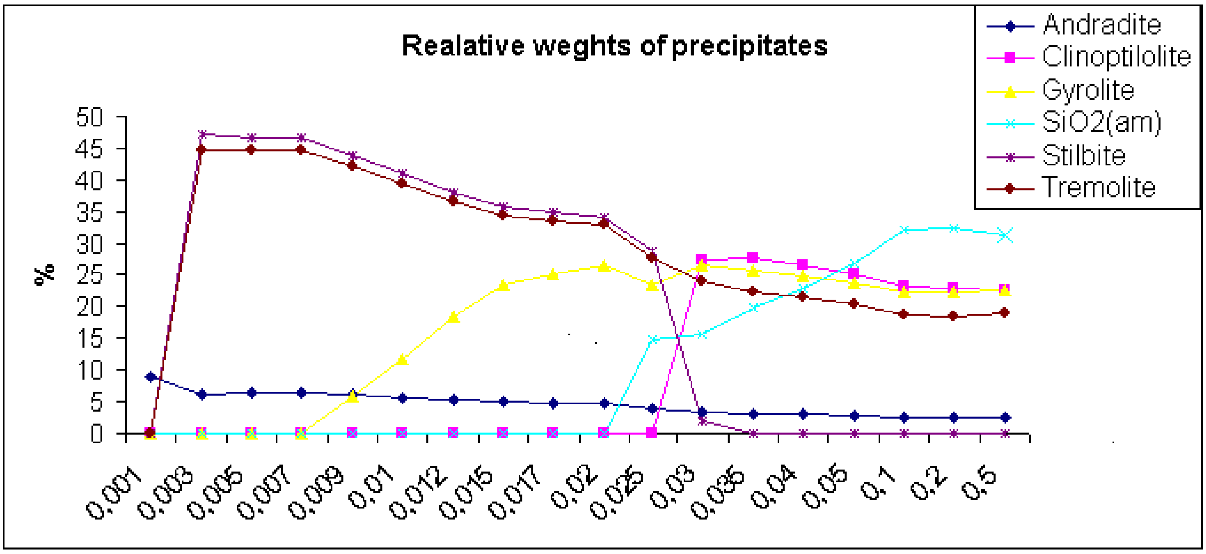


***Figure 14*: Composition of precipitates for various amounts of dissolved glass**

- The diameters of the fibers have been measured before and after corrosion. The distributions have been adjusted using a log – normal rule

It appears that the mean initial value of fiber is 4.01 um ; after corrosion, it became 4.54 um. Increase of diameter is linked with precipitate creation (figures 15 and 16).

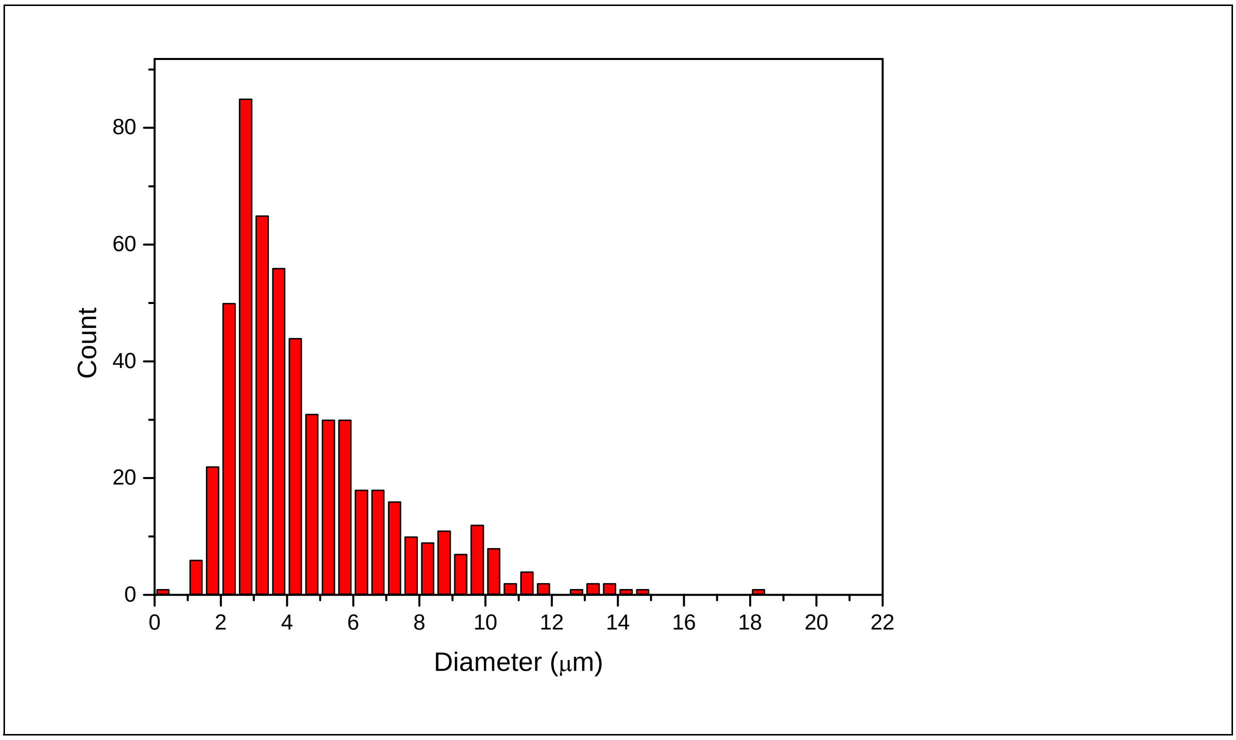
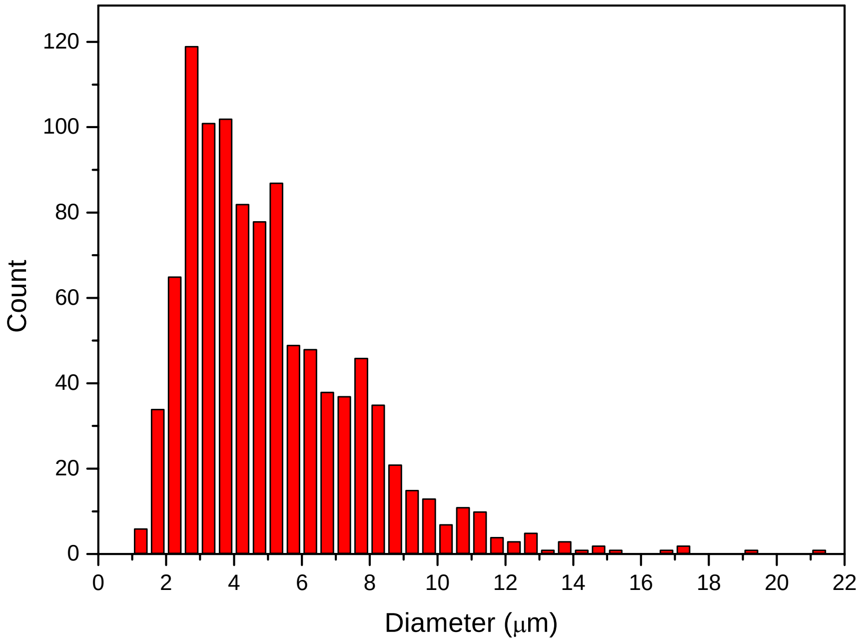


***Figure 15*:Initial distribution**



<u>Figure 16</u>: Distribution after fiber corrosion

B. Following main parameters were underlined for their influence on the DP evolution:

–The involved masses and types of insulation that influenced corrosion rates

–The involved concrete masses. It was underlined balance between Mg and Ca and possible local influence of concrete dust injected during tests to create precipitate containing Ca and SiO2 instead of precipitates containing Mg and Si02,

–The temperature profile and the history. For the tests, sump temperature profile was defined according to residual heat removal for a 900 MWe.

C. The following factors have been identified but not quantified and need additional investigations:

–Precipitate under gel forms,

–Stability of gel forms depending on temperature,

–Creation of gas in the fiber bed depending on gel forms and of temperature.

D. Using the different available observations, one possible theory to characterize morphology changes of the fiber bed is proposed as follows:

A. At the initial state (t=t0), temperature is closed to 60°C. Fibers and debris that are present are carried partly to the filter and create the fiber bed,

B. At t=t1, for T=60°C, fibers corrosion starts and fibers are partly dissolved. As soon as over-saturation of contents in the solution is reached, some precipitates, mainly under crystal forms (**assumption 1**), are created and deposited on the corroded fibers. DP starts to increase **(assumption 2)**,

C. At t=t2, if T is decreased from 60°C to 45°C then to 38°C, precipitates are growing because DP continues to increase not only from viscosity effect (**assumption 3**). Depending of the changes of temperatures, some already created precipitates can be dissolved and replaced by other kinds of precipitates. It is assumed that some gel forms are present (**assumption 4**).

D. Without any spurious quick and spurious changes of temperature, no gas seem to be captured in the fiber bed or seem to be present in the gel form of the fiber bed **(assumption 5),**

E. At t=t3, if T is suddenly increased from 38°C to 50°C, gas phase (or similar) seems to be created and captured by the fiber bed (**assumption 6**). Three hypotheses are possible for this gas presence. The first one (**assumption 7.1**) consists on possible gas release coming from chemical reactions. The second one (**assumption 7.2**) consists on possible gas release of the solution in particular during transfer through the fiber bed and precipitates due to local continuous decrease of pressure for which vapor pressure could be reached for existing temperature. The third one (**assumption 7.3**) consists on gas release at the top of the filtering box coming from water at hot temperature and decrease of local pressure but due to the respective pressures the transfer of this gas to fiber bed is questionable. Increase of DP for the first increases of temperature is noted due to simultaneous increase of amount of precipitates by chemical reactions **(assumption 8)** or capture of gas increasing the volume of the fiber bed **(assumption 9),**

F. Several quick transients of temperatures artificially created, which activate strong mechanical or chemical reactions, lead finally to a progressive decrease of DP due to gel form dissolution **(assumption 10)** or to gel forms washing by mechanical stresses from flow, gas or other origin **(assumption 11),**

G. For long duration time with T=30°C, evolution of DP will be low because corrosion is reduced (**assumption 12).**

H. Using a temperature profile decreasing without any quick transients of temperatures as artificially created at 38°C during tests 6bis, 6bisrep and 6bistro, an increase of DP could be observed due to additional precipitate creation **(assumption 13).**

The objective of the proposed program remains to establish a model usable for different NPP. After assessment, among the different specificities of the different NPP, one has a main importance: the type of insulation (glass-wool or mineral wool). So, it is proposed to perform a specific test on mineral wool. Consequently, additional investigations need to be performed on:

- Glasswool corrosion during long time and final temperature at 30°C,
- Mineral wool corrosion during long time and final temperature at 30°C,
- Concrete corrosion by washing,
- Gas phase (or similar) creation or capture by the fiber bed (assumption 6) coming from chemical reactions or from local continuous decrease of pressure for which vapor pressure could be reached for existing temperature (assumption 7),
- Increase of DP for the first elevation of temperature due to simultaneous increase of amount of precipitates by chemical reactions (assumption 8) or capture of gas increasing the volume of the fiber bed (assumption 9),
- Effects of quick transients of temperatures artificially created: progressive decrease of DP due to gel form dissolution (assumption 10) or to gel forms washing by mechanical stresses from flow, gas or other origin (assumption 11) followed by new increase of DP for long duration (assumption 13),
- For long duration time with T=30°C, increase of DP assessment (assumption 12).
- Using a temperature profile decreasing without any quick transients of temperatures as artificially created at 38°C during tests 6bis, 6bisrep and 6bistro, increase of DP due to additional precipitate creation (assumption 13).

E. Consequently, a complementary program is in progress. The proposed tests of the future program (2005-2006) are the following:

•Test 1: with all types/ quantities of debris (insulation, dust, concrete, paints).
Measurement: DP evolution

•Test 2: with all types/ quantities of debris (insulation, dust, concrete, paints).
Measurement: DP evolution including spurious stimuli of temperature

Specificity: as soon as 30°c will be reached, five successive changes of temperature (from 30°C to 60°C and finally to 30°C)

•Test 3: with only insulation (glasswool).
Measurement: DP evolution due to fiber corrosion

•Test 4: with insulation and concrete.
Measurement: DP evolution due to fiber and concrete corrosion

•Test 5: with glass wool to create thin bed.
Measurement: DP evolution.

•Test 6: with mineral wool
Measurement: DP evolution under profile temperature depending on severe accidents.

7. CONCLUSION

During last decades, the chemical durability of glass was and is frequently discussed in connection with the vitrification process of high level nuclear waste material. In minds of people from Nuclear Power Plant (NPP) field as well as for those from the glass science and technology, this is the most important connection between the glass chemical durability, and glass itself, on one side and the nuclear energy on the other side.

A great deal of the theory of the process of glass corrosion by liquid media was born within this connection – see e.g. the numerous publications in Nuclear Waste Management Journal.

Nowadays, a new phenomenon was pointed out in a new manner to this old theme, namely the problem of the sump screens clogging during the Loss of Coolant Accident (LOCA) in Pressurized Water Reactor (PWR) based NPP. In this case, a huge amount of debris coming from the glass fiber insulation is generated by the jet effect of the water vapor. Together with other kinds of debris (concrete, dust, paints, metal chips) the glass fibers are trapped on the containment sump screens. The crude hydrodynamic conditions of the solution falling down from the spraying system cause the mechanical disintegration of the fibers.

This phenomenon was thoroughly studied in IRSN with respect to the possible clogging of the containment sump screens. But moreover, the alkaline (pH=9.3 at 60°C-25°C) sodium borate solution of the spray system causes a significant chemical corrosion-dissolution of the glass accompanied with a back-precipitation of the dissolved glassy material, that can be in some cases accompanied by the generation of a thermodynamically unstable intermediates in gelatinous (i.e. colloidal) forms. The precipitated matter (and the gelatinous forms) is trapped in the thin layer of the filtration bed adhering to the screens and causes the screen clogging (reference 12).

Three years ago (i.e. in the year 2003), this glass fiber dissolution phenomenon was identified and partially quantified simultaneously in USA (University of New Mexico & Los Alamos National Laboratories) and in the Vitrum Laugaricio Glass Centre (VILA) in Trenčín.

The results obtained led to the identification of serious risks for the safety of NPP in a specific LOCA situation. This moment is extraordinary important in case of small diameter fibrous glassy material, where all the glass volume can be chemically changed (corroded) in relatively short time.

On the other hand, the models can be applied for the initial stages of the glass dissolution and open new research fields for the glass industry.

8. REFERENCES

1) Synthesis report IRSN/DES/SERS/400 (10/14/03)
2) IVANA report - VUEZ SA – TS-OTS-1318 (May 2002)

3) VITRA report - EREC – MT DA 118 1.091-02 (2002)
4) MANON report - VUEZ SA – TS-OTS-1336 (December 2002)
5) MANON report - VUEZ SA – TS-OTS-1398 (October 2003)
6) ELISA report - VUEZ SA – ZZ-OTS-1331 (August 2002)
7) ELISA report - VUEZ SA – TS-OTS-1397 (October 2003)
8) Albuquerque Workshop (2004) – Issue on French PWR – Y. Armand, JM. Mattéi - IRSN (France)
9) Albuquerque Workshop (2004) – Experimental program - Y. Armand, JM. Mattéi - IRSN (France)
10) Albuquerque Workshop (2004) – Opened questions – Y. Armand, JM. Mattéi - IRSN (France)
11) Albuquerque Workshop (2004) – Action plan proposal – Y. Armand, JM. Mattéi - IRSN (France)
12) Synthesis report IRSN/DESTQ/DIR/05-001 (July, 2005)