RAS 8251

DOCKETED
USNRC

August 9, 2004 (11:45AM)

OFFICE OF SECRETARY
RULEMAKINGS AND
ADJUDICATIONS STAFF

Exhibit 5

NUCLEAR REGULATORY COMMISSION

Docket No. 50-413/414-OLA Official Exh. No. 5

In the matter of Duke Catawba

Staff ____ IDENTIFIED 7/14/04

Applicant ✓ RECEIVED 7/14/04

Intervenor ____ REJECTED ____

Cont'g Off'r ____

Contractor ____ DATE ____

Other ____ Witness ____

Reporter [signature]

Template=SECY-028

SECY-02

Guillard, V., et. al., "Use of CATHARE2 Reactor Calculations to Anticipate Research Needs," SEGFSM Topical Meeting on LOCA Issues, Argonne, May 2004

SEGFSM Topical Meeting on LOCA Issues
Argonne National Laboratory, May 25-26, 2004.

USE OF CATHARE2 REACTOR CALCULATIONS TO ANTICIPATE RESEARCH NEEDS

V. Guillard[1], C. Grandjean, S. Bourdon, P. Chatelard
Institut de Radioprotection et de Sûreté Nucléaire
IRSN/DPAM : BP3 - 13115 St Paul-Lez-Durance, France
valia.guillard@irsn.fr

ABSTRACT

To analyze the consequences of the introduction, in Nuclear Power Plants, of advanced fuels at high burn-up, decided by most of the utilities in western countries in order to reduce the fuel cycle costs, IRSN has initiated a research program focused on the study of such PWR fuel behavior in LOCA conditions.

A first step of this program, comprising analytical and experimental parts, has been to identify the main physical phenomena, linked with thermomechanical behavior of irradiated rods in bundle geometry, to be taken into account in reactor safety analysis : cladding deformation and flow section restriction in bundle geometry, mechanical interaction between neighbor rods or structures, axial extension of balloons ; cladding oxidation and secondary hydriding ; fuel fragmentation and relocation, balloons filling rate and FP release ; fuel rods thermal behavior in bundle geometry during reflooding conditions, rewetting of the claddings around ballooned regions with fuel relocation ; mechanical resistance of irradiated claddings in post-quench conditions.

This paper summarizes an analysis of sensitivity calculations performed with CATHARE2 "Best-Estimate" code, used in France in the frame of realistic methodology to evaluate safety margins.

The objective of these calculations is to point out, among parameters affecting last-mentioned phenomena, those for which taking into account basic uncertainties lead to important uncertainty on global code response (Peak Cladding Temperature, oxidation rate ...). That is the case of fuel relocation phenomena, whose impact is highly dependent on parameters such as, in the example of LB LOCA transient, cladding radial and axial deformations in bundle geometry, burst criteria, balloon filling rate, thermalhydraulics around balloons. A lack of knowledge on theses parameters for irradiated UO2 and particularly MOX fuel may lead to reduce safety margins.

This study may provide some elements to identify future research needs to complement present experimental data base, reduce uncertainties and develop more realistic calculation models, which may better fit the thermomechanical behavior of advanced irradiated fuels.

[1] Corresponding author

USE OF CATHARE2 REACTOR CALCULATIONS TO ANTICIPATE RESEARCH NEEDS

V. GUILLARD, C. GRANDJEAN, S. BOURDON, P. CHATELARD

Institute for Radiological Protection and Nuclear Safety (IRSN)
Major Accident Prevention Division / Fuel in Accident Situations Department
BP3 - 13115 St-Paul-Lez-Durance Cedex - France

Content of the presentation

- **Introduction**
- **Main physical phenomena to be modeled**
- **Main hypotheses of the calculations**
- **Main results of the LB LOCA calculations**
- **Conclusion and perspectives**

INTRODUCTION

- **General Background**

  Foreseen and expected evolutions of
  - core management
  - fuel materials
  - cladding materials

  IRSN LOCA Program
  Study of PWR rods thermo-mechanical behavior in LOCA conditions

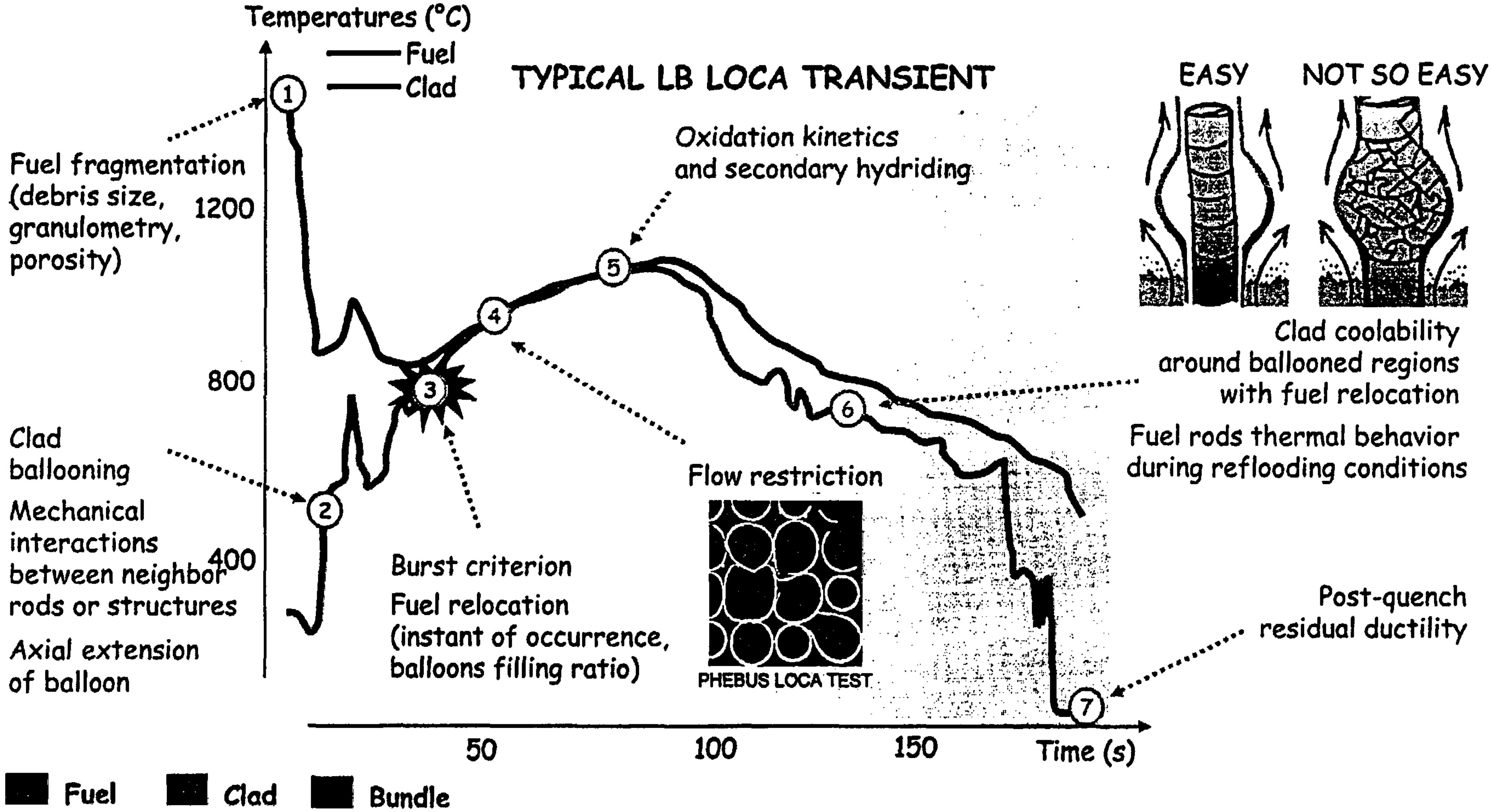
  Reactor studies with CATHARE2

- **CATHARE2**
  - French thermalhydraulics system code with CATHACOMB fuel module
- **Objectives**
  - Identify future research needs for new generation of fuels
  - Improve knowledge, models and calculation methodologies
- **Approach used to reach this objective**
  - Identify physical phenomena involved in thermo-mechanical behavior of **advanced irradiated rods in bundle geometry (State Of the Art by C. Grandjean & G. Hache)**
  - **Take them into account in the modeling**
  - **Quantify basic uncertainties (CIRCE** tool and sensitivity calculations)
  - **Evaluate global uncertainty on CATHARE2 code response (SUNSET** tool)

CATHARE2 used to define boundary conditions for further more precise fuel thermo-mechanical calculations and analysis under LOCA conditions

3 MAIN PHYSICAL PHENOMENA TO BE MODELED linked with the use of advanced fuels at high burn-up

Reference : C. GRANDJEAN & G. HACHE
"LOCA Issues Related to Ballooning, Relocation, Flow Blockage and Coolability: Main Findings from a Review of Past Experimental Programs."



CATHARE2 CALCULATIONS
Main hypotheses

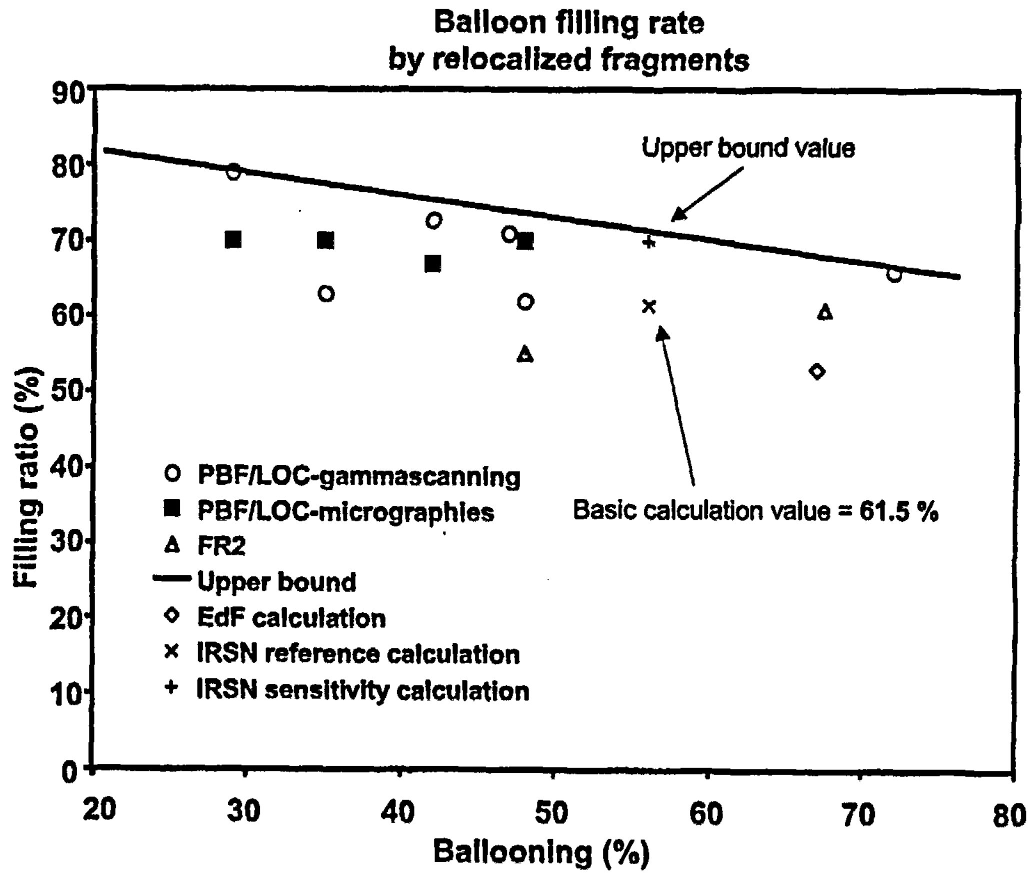
- **Calculation of several transients including Large & Intermediate breaks LOCA**
- **Use of standard CATHARE2 versions (V1.3L, V2.5)**
- **Basic uncertainties on CATHARE2 models taken into account**
  - **Consistent with PIRT implications**
- **Zry-4 cladding without hydrogen uptake effect on mechanical properties**
- **Hypothesis linked with the use of irradiated fuel at high burn-up**
  - **Modification of thermal properties**
    - conductivity and thermal capacity laws from SCANAIR code
  - **Deletion of protective effect of initial oxide layer** on transient oxidation
    - outcome from experimental ANL and TAGCIR program analysis on irradiated Zry
  - Introduction of **Baker-Just** correlation to calculate **oxidation rate**
- **Initial state of irradiated rods given by METEOR code**
  - Gap width and pressure, radial and axial fuel power profile, external cladding oxidation profile, cladding thickness ...

Example **:** **Calculation of the impact of irradiated fuel relocation in Large Break conditions on a PWR900Mwe**

CATHARE2 LBLOCA CALCULATIONS
Simulation of fuel relocation phenomena

❑ Main hypothesis

- **Relocation mesh** = burst location mesh filled by fuel debris from upper meshes
- **Filling ratio of the balloon** = function (balloon size)
- **Balloon size** derived from CATHACOMB calculation of mean elongation
- Modification of the **power factor** and the fuel mass in the relocation mesh
- Considering relocated fuel as a **porous medium** (Imura-Yagi model for the conductivity calculation)
- **Flow blockages** : impact on T/H and fuel cooling not taken into account

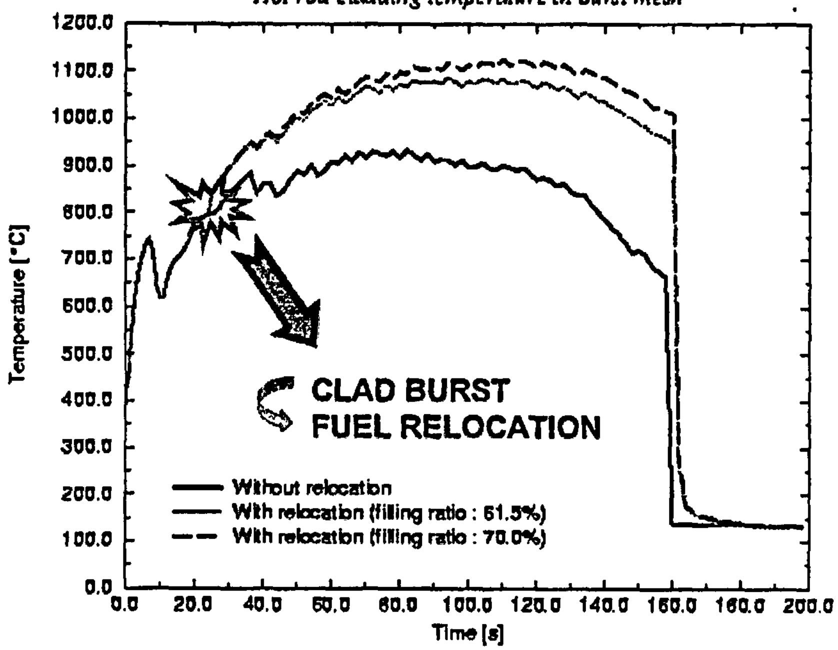


CATHARE2 LBLOCA CALCULATIONS
Main results for high burn-up UO2 fuel (1/2)

- High sensitivity of the relocation impact on PCT
  - Burst at 24 s on stress criterion deduced from EDGAR experiments (ε at rupture = 57.5%)

LB LOCA – Irradiated UO2

Hot rod cladding temperature at burst mesh

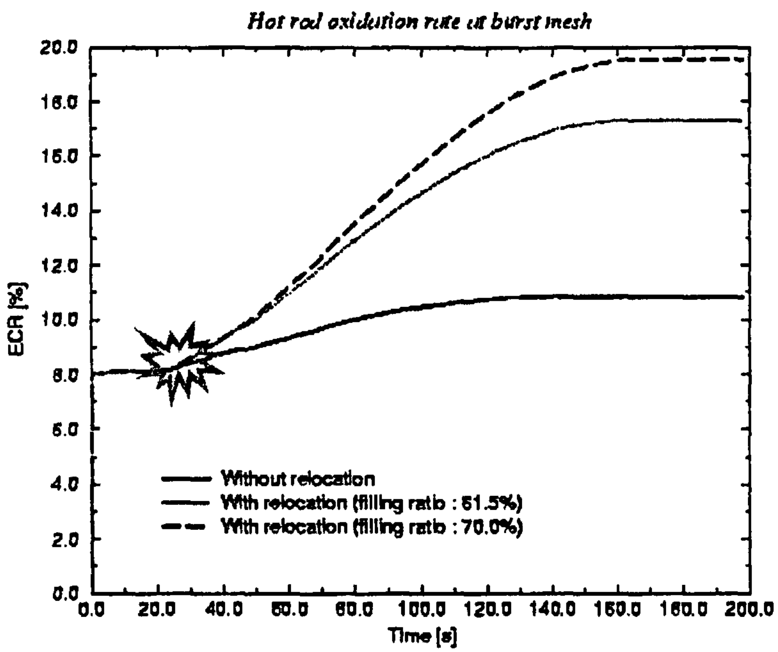


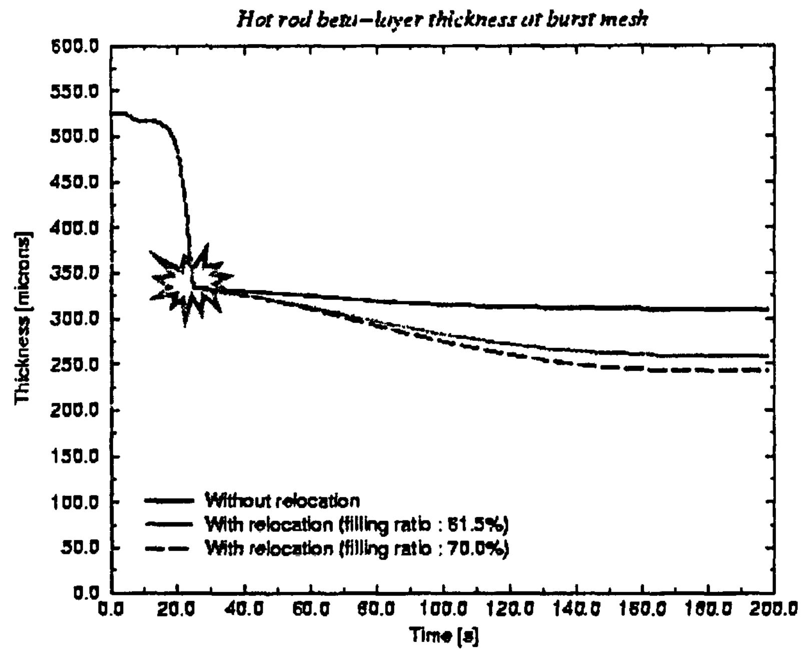
Fuel relocation impact depends on :
- burst time, which determines the energy re-distribution in the burst mesh
- balloon size and filling ratio, which determines relocated fuel mass

+ 110°C to 150°C on PCT
(depending on balloon filling ratio : 61.5 to 70%)

CATHARE2 LBLOCA CALCULATIONS
Main results for high burn-up UO2 fuel (2/2)

- Fuel relocation impact on ECR and residual β-layer
  - Burst at 24 s on stress criterion deduced from EDGAR experiments (ε at rupture = 57.5%)





+ 5% to 7% on ECR
(depending on balloon filling ratio : 61.5 to 70%)

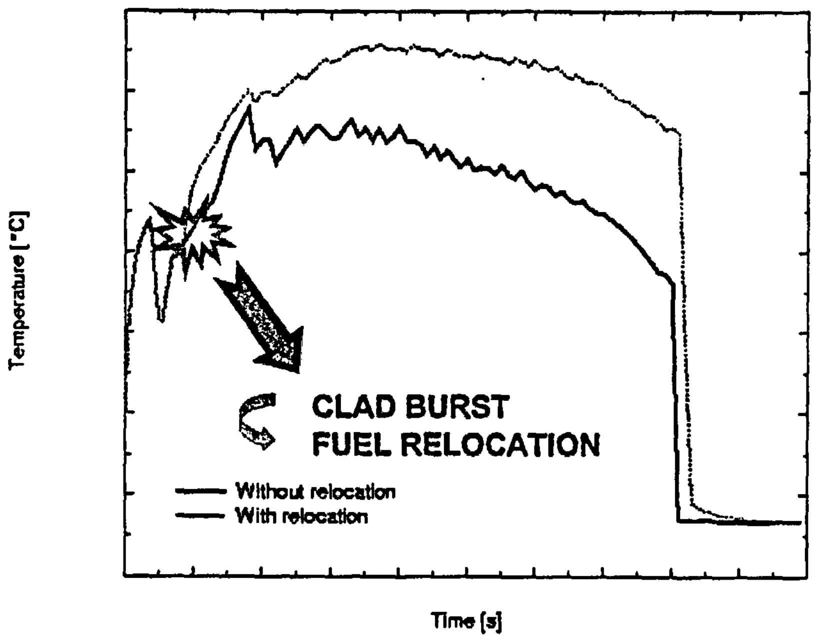
- 50μm to 67μm on residual β-layer thickness
(depending on balloon filling ratio : 61.5 to 70%)

CATHARE2 LBLOCA CALCULATIONS
Sensitivity to fuel type : MOX (1/2)

- **Fuel relocation impact on PCT**
  - **Burst at 18 s on stress criterion deduced from EDGAR experiments (ε at rupture = 58.7 %)**

LB LOCA – Irradiated MOX

Hot rod cladding temperature at burst mesh



Higher initial energy

Enhance of fuel relocation impact

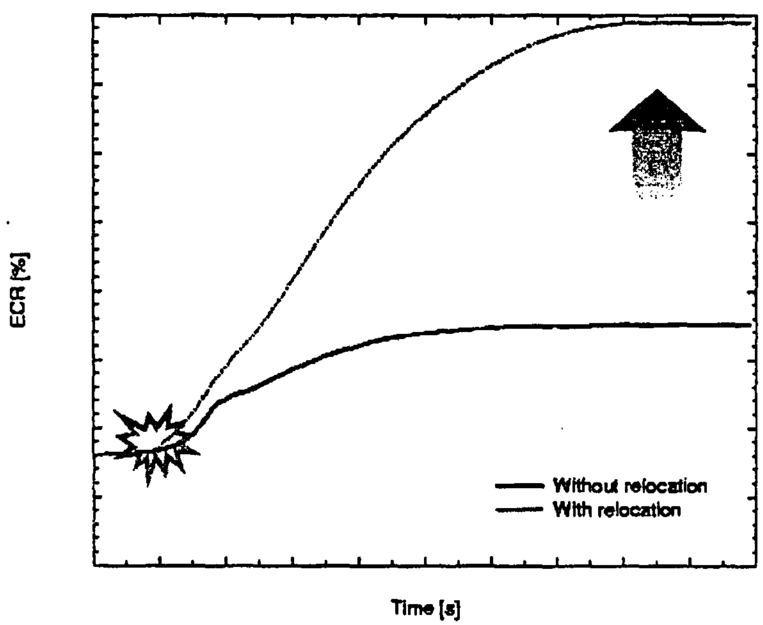
+ 160 °C on PCT

CATHARE2 LBLOCA CALCULATIONS
Sensitivity to fuel type : MOX (2/2)

- Fuel relocation impact on ECR and residual β-layer
  - Burst at 18 s on stress criterion deduced from EDGAR experiments (ε at rupture = 58.7 %)

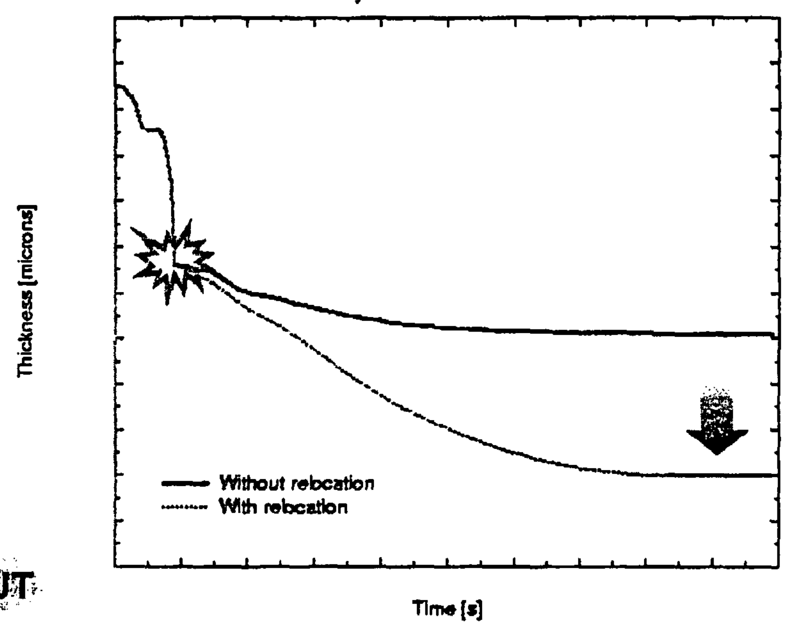
LB LOCA – Irradiated MOX

Hot rod oxidation rate at burst mesh



LB LOCA – Irradiated MOX

Hot rod beta–layer residual thickness at burst mesh



Higher impact on ECR and residual β-layer

BUT

Large uncertainty on hydrogen uptake effect and mechanical properties depending on clad alloy

Need to reduce uncertainties

CONCLUSION AND PERSPECTIVES

- **Use of CATHARE2 code for high burn-up fuel analysis under LOCA conditions**
  - **Example of Large Break transient**
  - **Emphasis on fuel relocation phenomena impact**
  - **Main results : PCT and ECR increased**

- **High uncertainty on global code response due to identified lack of knowledge**
  - **Instant of fuel movement** ← HALDEN ?
    - imposed as **burst time** in the simulation
    - depends on **clad ballooning/deformation** and burst criterion
  - **Balloon size** ← HALDEN ?
    - which is also linked with **ballooning/deformation** model
  - **Filling ratio** ← FR2, PBF, HALDEN ?
  - **Relocated fuel properties**
    - fragments size, granulometry, porosity, conductivity, ... ← ANL, HALDEN ?
  - **Bundle effects** ← Need of integral test
    - Axial extension of balloon
    - Flow blockages
    - Clad coolability around ballooned regions with fuel relocation

CONCLUSION AND PERSPECTIVES

- **Perspectives**

  - **Modification of clad mechanical properties to take into account hydrogen uptake effect**

  - Study to be complemented by calculations using **CATHARE / FRETA**
    - **rods 3D thermo-mechanics**
    - **rod-to-rod interactions models**
    - **cooling and reflooding models for overall bundle**

  - Use of **NEPTUNE 3D local module** for flow blockage cooling calculations

  - IRSN plans to develop a **new code for fuel LOCA calculations**

- **State Of the Art (C. Grandjean & G. Hache) + Analytical studies**

  ⇒ **Identification of knowledge improvements on irradiated rod behavior under LOCA conditions**

  - **Develop new generation of fuel and bundle models**

  - **Reduce uncertainties and gain new margins**