IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

IRSN APPROACH REGARDING THE RIA CRITERIA UPGRADE

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OUTLINE

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3 – IRSN principles for the definition of the RIA criteria

4 – IRSN approach regarding the RIA criteria upgrade

5 - Comparison with REP-Na tests results

6 - Comparison with the US proposed limits

7 - Comparison with the NRC approach

INTRODUCTION

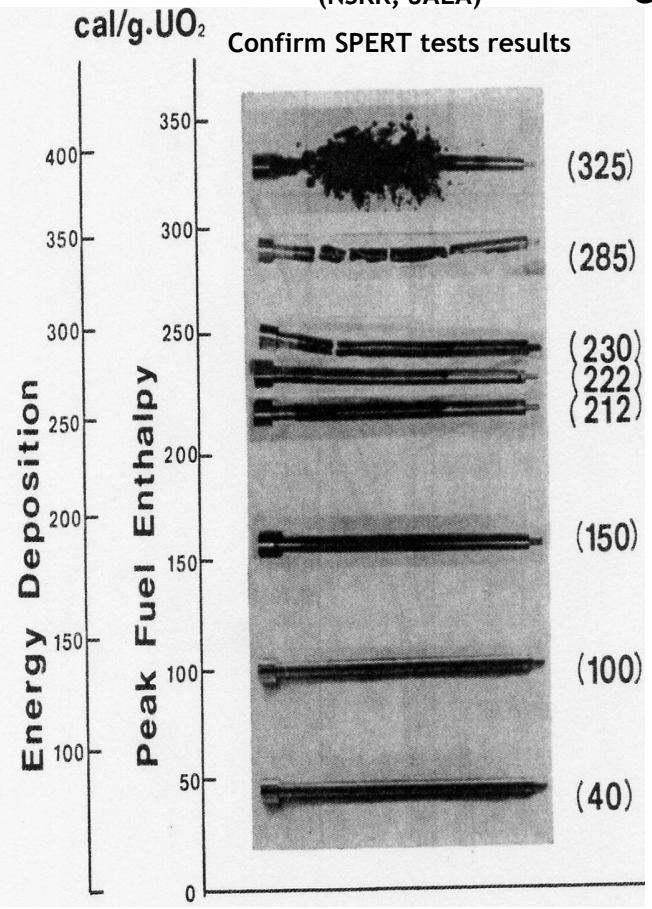
Among all the reactivity insertion transients, the control rod ejection is bounding all other transients and therefore is systematically studied. The associated safety objective is to **ensure the core coolability**. This objective is kept by IRSN as the main basis to consider for a revision of the RIA acceptance criteria.

FRENCH CRITERIA BACKGROUND HISTORY (1/2)

(1970s) SPERT tests (BU<30GWd/tU, 20°C, stagnant water, pulse width : 15-20ms, Zy-2 clad)

(NSRR, JAEA)

Confirm SPERT tests results



Clad failure max. enthalpy

Clad fragmentation max. enthalpy

240

200 (fresh)

140 (irrad.)

French criteria

(avoid fuel dispersion

ensure core coolability

<u>Clad failure not excluded</u>)

H < 225 cal/g (fresh)

H < 200 cal/g (irrad)

In addition :

T clad, hot core spot < 1482°C

V molten fuel, hot core spot < 10%

FRENCH CRITERIA BACKGROUND HISTORY (2/2)

(1990s) French utility requested authorization for BU up to 47 GWd/tU (1988)**, then 52 GWd/tU** (1998)

=> French Nuclear Safety Authority asked EDF to justify that the criteria were still valid

=> A large research program IRSN/EDF was initiated in 1993 :

CABRI (with NRC support), PROMETRA, PATRICIA

REP-Na tests in CABRI

=> clad failure <u>with fuel dispersion</u> for enthalpies < SPERT threshold for clad failure (140 cal/g)

=> Previous criteria in question

It is necessary to upgrade the criteria

IRSN PRINCIPLES FOR THE DEFINITION OF THE RIA CRITERIA (1/10)

1st PRINCIPLE

As :

- All the performed tests can not be representative of all the rods in reactor, in terms of physical conditions, clad and fuel materials, power history of each rod,…

=> the performed tests should be used to **understand the physics**

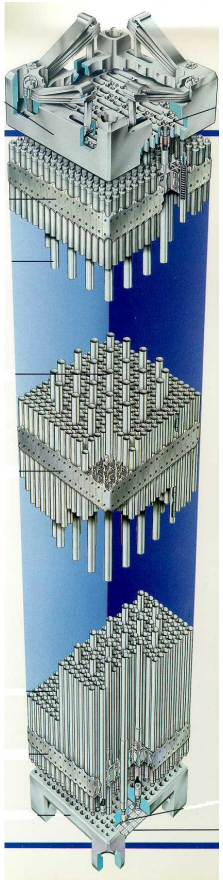
-The criteria should be adapted to all the types of fuel rods present in core (different fuel materials, different clad materials, different core managements, …)

- the criteria should foresee the future types of rods (**durable criteria**)

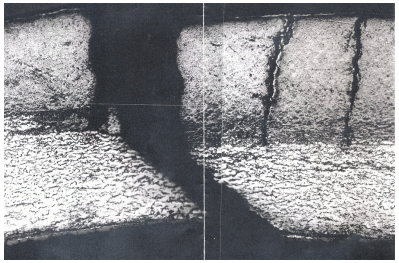
THE CRITERIA SHOULD BE BASED ON A THOROUGH ANALYSIS OF THE PHYSICAL PHENOMENA INVOLVED DURING A RIA AND A GOOD UNDERSTANDING AND MODELING OF THE BASIC MECHANISMS INVOLVED IN THE PHENOMENOLOGY

IRSN PRINCIPLES FOR THE DEFINITION OF THE RIA CRITERIA (2/10)

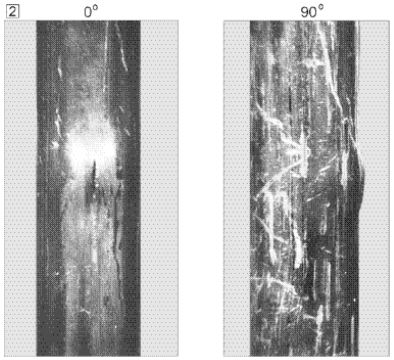
CABRI (REP-Na and CIP), NSRR (Japan) and BIGR (Russia) tests improved the knowledge of the 2 phases of the RIA :



Earlier transient phase : PCMI



Later transient phase : post-boiling (possibly)



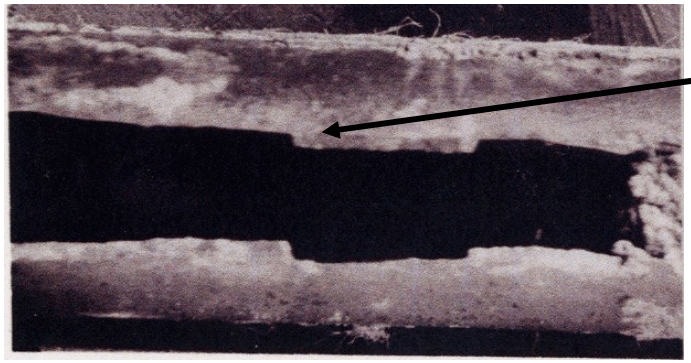
IRSN PRINCIPLES FOR THE DEFINITION OF THE RIA CRITERIA (3/10)

1st phase : Pellet Clad Mechanical Interaction (PCMI)

- intense stresses in the clad
- "cold" clad
- embrittlement by hydrides

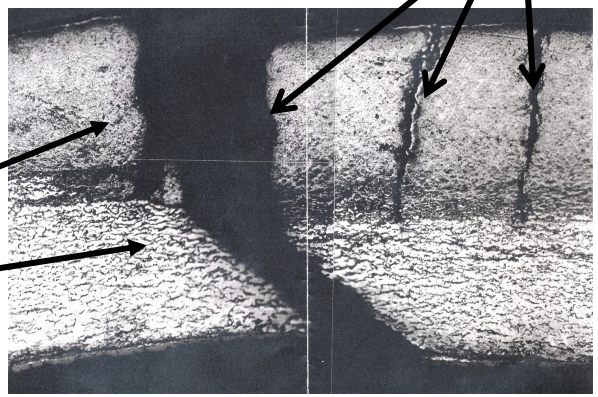
=> Risk of brittle failure

CABRI REP-Na7



Typical longitudinal RIA failure

CABRI REP-Na8



IRSN PRINCIPLES FOR THE DEFINITION OF THE RIA CRITERIA (4/10)

2nd phase : Post-boiling phase

Vapor film may form along the clad, Tclad increases drastically

- clad resistance decreases
- internal rod pressure increases

(fission gas release)

- creep

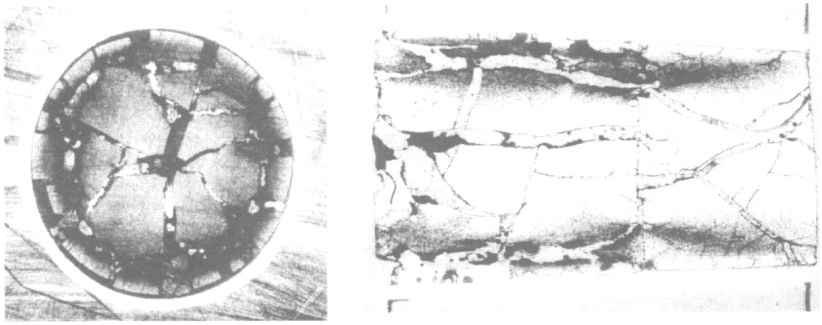
=> Risk of plastic failure at boiling onset

=> Risk of failure due to excessive strains

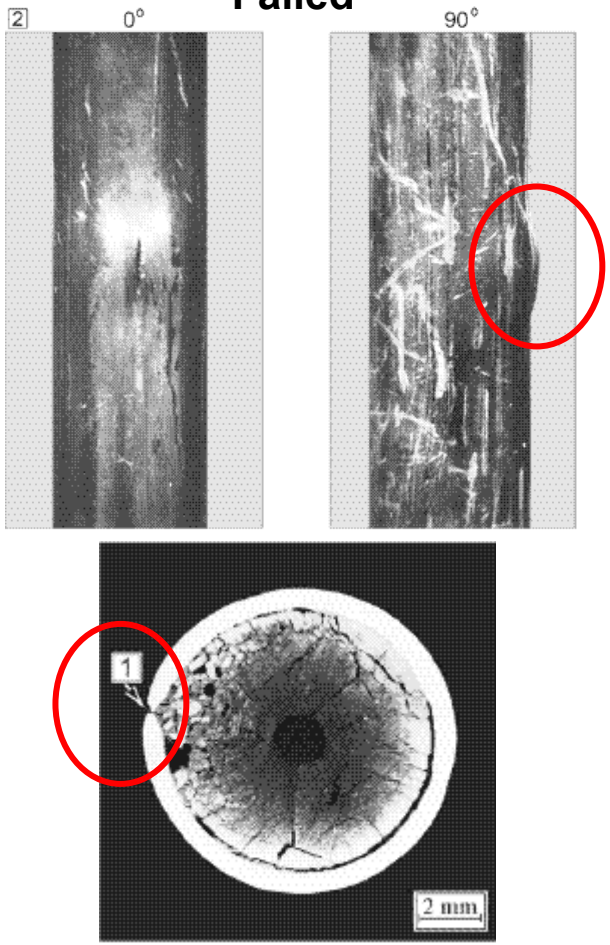
IRSN PRINCIPLES FOR THE DEFINITION OF THE RIA CRITERIA (5/10)

Illustration of post-boiling strains

NSRR TK-1 (38 GWd/tU-126 cal/g) Non-failed



BIGR RT-8 (60GWd/tU-164 cal/g) Failed



In this phase, the strains levels are high, due to the fission gas release.

The failure mechanisms are specific, and different from PCMI failure mechanisms.

IRSN PRINCIPLES FOR THE DEFINITION OF THE RIA CRITERIA (6/10)

Phenomena in the post-boiling phase will be investigated in the water loop within CABRI International Program (IRSN/EDF/OCDE) and in NSRR reactor.

⇒Better understanding of involved physical phenomena as basis of the RIA criteria upgrade

Different physical mechanisms involved during the 2 phases of the RIA

=> 1st principle :

THE CRITERIA SHOULD BE BASED ON A THOROUGH ANALYSIS OF THE PHYSICAL PHENOMENA INVOLVED DURING A RIA AND A GOOD UNDERSTANDING AND MODELING OF THE BASIC MECHANISMS INVOLVED IN THE PHENOMENOLOGY

IRSN PRINCIPLES FOR THE DEFINITION OF THE RIA CRITERIA (7/10)

2ND PRINCIPLE

The non-failure of the clad is not imposed. Restrictive IRSN choice to prevent fuel dispersion, can be justified by the **difficulties to demonstrate the core coolability in case of fuel dispersion**.

- Which conditions would lead to fuel dispersion in case of clad failure ?
- If dispersion of the fuel in the coolant, relocation (aggregation or melting) => which fuel geometries ? Too few failure tests in PWR conditions to know.

Today this geometry can not be evaluated, the coolability of the damaged core seems extremely difficult to investigate

=>2nd principle :

THE CRITERION SHOULD BE A FAILURE CRITERION

IRSN PRINCIPLES FOR THE DEFINITION OF THE RIA CRITERIA (8/10)

3RD PRINCIPLE

In spite of the cladding failure criterion, fuel dispersion is a concern for the 2nd barrier integrity.

Could be due to :

- initial defect (reasonably possible among the 2.5 millions rods in core today in France)
- hydride blisters (for ex. due to in-reactor zirconia spallation)
- failures due to currently non-identified causes.

=>3rd principle :

THE 2ND BARRIER INTEGRITY SHOULD BE VERIFIED IN CASE OF FUEL DISPERSION (DEFENSE IN DEPTH)

IRSN PRINCIPLES FOR THE DEFINITION OF THE RIA CRITERIA (9/10)

The 3 previous principles aim at ensuring the core coolability.

To be exhaustive, it must also be verified that the partial blocking of the flow potentially induced by the important clad strains will not unacceptably reduce the cooling efficiency.

This point seems unlikely, but has to be verified.

IRSN PRINCIPLES FOR THE DEFINITION OF THE RIA CRITERIA (10/10)

3 PRINCIPLES :

- **THE CRITERIA SHOULD BE BASED ON A THOROUGH ANALYSIS OF THE PHYSICAL PHENOMENA INVOLVED DURING A RIA AND A GOOD UNDERSTANDING AND MODELING OF THE BASIC MECHANISMS INVOLVED IN THE PHENOMENOLOGY**

- **THE CRITERION SHOULD BE A FAILURE CRITERION**

- **THE 2ND BARRIER INTEGRITY SHOULD BE VERIFIED IN CASE OF FUEL DISPERSION**

IRSN APPROACH (1/4)

BEST UNDERSTANDING AS POSSIBLE OF BASIS MECHANISMS

- Integral tests
- Analytical tests
- R&D

↓

DETERMINATION OF THE PHYSICAL LIMITS

- Dev. & Use of a calculation tool (FRAPCON, SCANAIR, …)
- Failure Criterion
- Choice of the relevant parameters to study
- 2nd barrier integrity in case of fuel dispersion
- Determination of the limit
- Sensitivity study

↓

TECHNICAL BASIS FOR CRITERIA

The criteria should integrate the respect of each principle

IRSN APPROACH (2/4)

FAILURE CRITERION

For each of the 2 RIA phases (PCMI + post-boiling) :

1 – Development and validation of appropriate codes

(thanks to global and analytical tests) :

SCANAIR, benchmark with FRAPTRAN/FALCON

2 – Definition of the assumptions related to the initial state of the rod

Must be provided by specific studies, use of FRAPCON for example

3 – Determination of a failure limit

4 – Sensitivity study on some parameters

IRSN APPROACH (3/4)

2ND BARRIER INTEGRITY IN CASE OF FUEL DISPERSION

Evaluation of the pressure peak and evolution in the primary circuit and evaluation of its consequence on the sensitive equipments

⇒ Maximum admissible quantity of dispersed fuel

⇒ Maximum admissible number of failed rods

FUEL DISPERSION CONDITIONS AND CONSEQUENCES

Additional need of R&D identified.

Attention paid on the progress regarding fuel dispersion, conversion of thermal energy into mechanical energy,… to evaluate the dispersion consequences.

SUMMARY of IRSN APPROACH (4/4)

IRSN approach is based on several principles. The most fundamental one is to take account of the physical phenomena involved in the different failure modes observed during the tests.

The work is under progress for the determination of a failure limit for different fuel and cladding materials in PCMI. The post-boiling phase will be studied, as well as the 2nd barrier integrity.

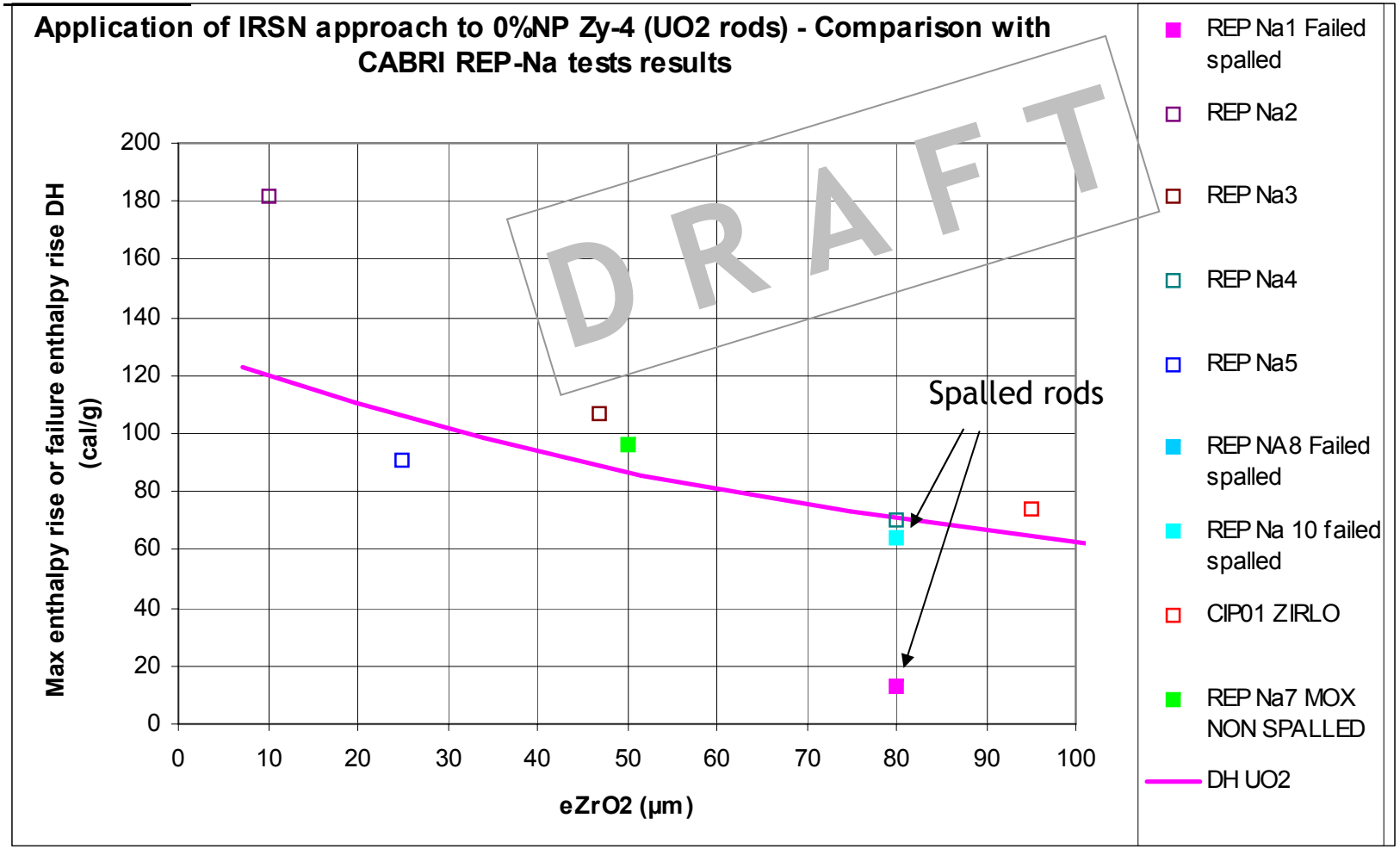
Carrying out this approach :

- will allow to ensure the durability of the criteria,
- will allow the IRSN to have a technical advice on the different criteria.

COMPARISON WITH REP-Na TESTS RESULTS

1st results for a UO2 rod cladded with Zy-4 - Initial state = Hot Zero Power

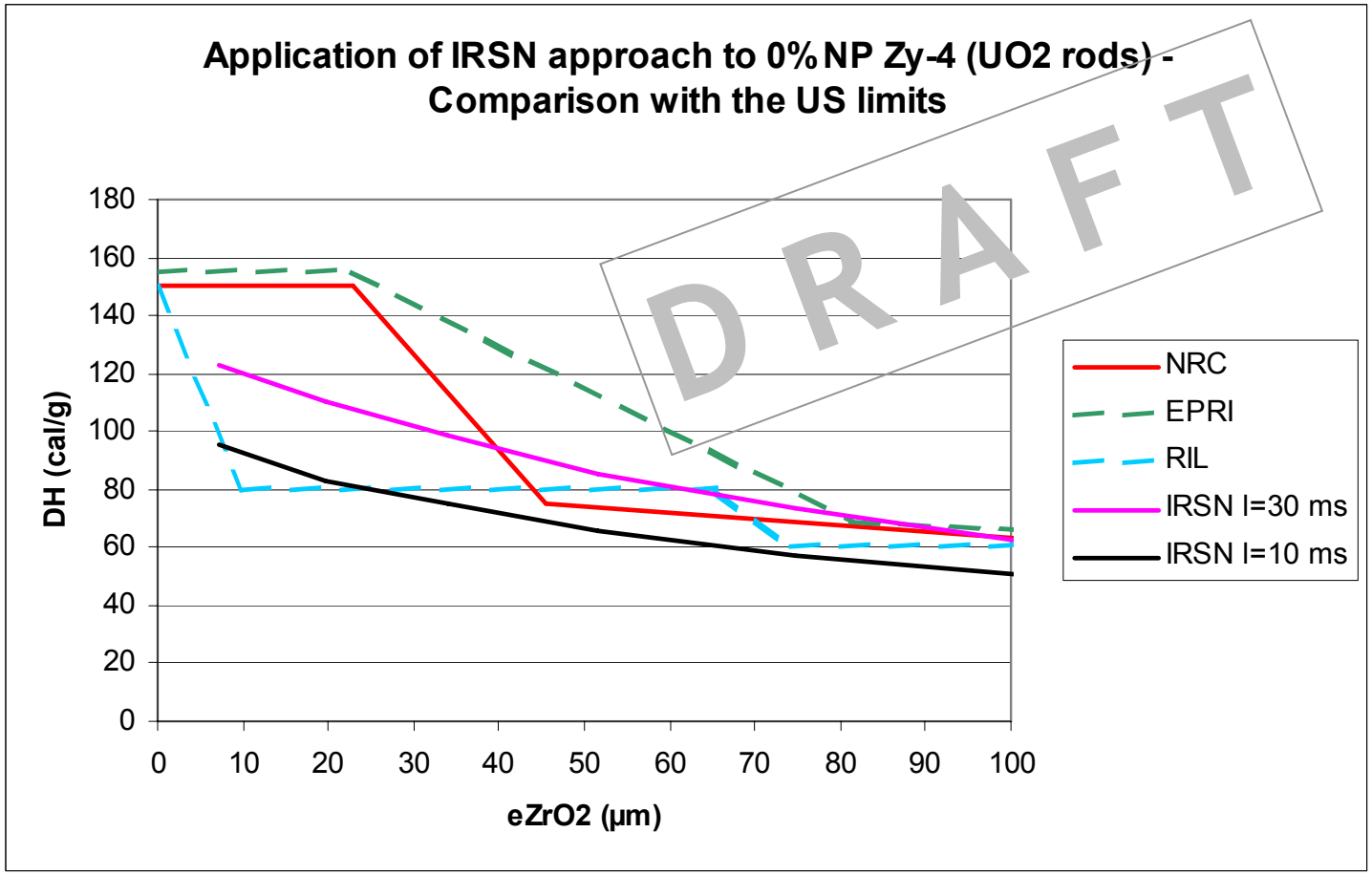
PCMI limit



COMPARISON WITH THE US PROPOSED LIMITS

1st results for a UO2 rod cladded with Zy-4 - Initial state = Hot Zero Power

PCMI limit



COMPARISON WITH THE NRC APPROACH

NRC approach empirical : founded on tests results + correction to take account of other conditions, such as temperature effect.

The temperature effect is the difference between fuel response at room temperature and pressure (conditions for some test reactors) compared to the fuel response under operating reactor conditions.

IRSN approach is based on :

- considering the different failure modes,
- test results understanding and modeling,

⇒ the temperature effect (or pulse width effect ,…) is already modeled.

In particular, the temperature effect is crucial and is specially addressed in the paper "A Comparative Analysis of CABRI CIP-01 and NSRR VA-2 Reactivity Initiated Accident tests" presented in 2007 in Eurosafe.