IRSN Views on the R & D Needs and Strategy Towards a Revision of LOCA Acceptance Criteria in France

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Need to Revise LOCA Acceptance Criteria ?

Since the LOCA acceptance criteria were established in 1973:

- *significant increase in fuel discharge burnup as a result of new fuel management schemes,*
- *use of advanced cladding alloys,*
- *large amount of R&D results showing new phenomena previously unknown (hydrogen effects, fuel relocation…),*

Thus for IRSN, there is a clear need to reassess the adequacy of acceptance criteria with respect to the current fuel characteristics and to investigate possible additive requirements associated with previously unknown phenomena.

↳ to be examined in a specific meeting of the French Advisory Committee for Nuclear Reactors by the end of 2009

Phenomena under study

Three topics have been identified with pending issues, which are considered by IRSN important to solve to guarantee core coolability in a postulated LOCA transient :

A. Cladding embrittlement
(loss of cladding integrity upon quench and post-quench loads)

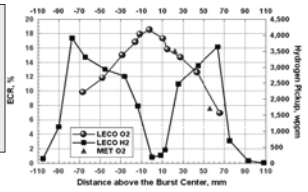
B. Axial fuel relocation in balloons

C. Flow blockage and its coolability

Research & Development Needs

A - Cladding embrittlement (1)

For IRSN, post-quench ductility appears as an **inappropriate parameter** to define an embrittlement threshold, since **no practical limit can be derived to ensure ductility retention in the cladding balloon** *(RIL 0801)*



However, the results from ANL 4-point bending tests at room temperature on unirradiated samples after integral testing suggest that, below some oxidation limit, fuel rod would resist fragmentation when subjected to quench and post-quench loads

- A **strength-based** approach addressing the **structural response of the whole cladding**, instead of a ductility approach, might provide an acceptable alternative

Research & Development Needs

A - Cladding embrittlement (2)

IRSN R&D Strategy

I. Quantification of a relevant embrittlement threshold

Based on:

1. Identification and quantification of mechanical loads that should be supported by fuel rods during quench and post-quench phases of LOCA transient (from numerical simulations in bundle geometry)
2. Definition of appropriate embrittlement tests taking into account bounding mechanical loads (quench under controlled loading, impact tests, …) to determine embrittlement threshold
3. Support from F.E. calculations with typical cladding geometry and properties to verify that the experimental domain covered by this type of tests is adequate; this step may require appropriate analytical tests to characterize the evolution of clad properties, in particular at the location of the balloons.

Research & Development Needs

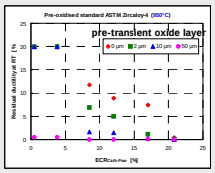
A - Cladding embrittlement (3)

IRSN R&D Strategy

II. Selection of the most appropriate parameter on which to correlate post-quench embrittlement (alternative to ECR)

Based on:

- ✓ Previous work from early investigators :
  Hobson(1973), Pawel (1973), Sawatzky (1978), Chung & Kassner (1980),…
- ✓ Results from recent investigations showing that oxygen diffusion from the pre-transient oxide layer may embrittle the metal layer without significant increase in oxidation rate ECR
  (under SB LOCA time x Temp. conditions) ☞
  (to be confirmed)



UJP test data (Czech Republic)

☞ **For IRSN, an embrittlement threshold should be better based on residual thickness of prior β-Zr layer with low oxigen content as function of H content**

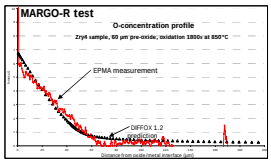
Research & Development Needs

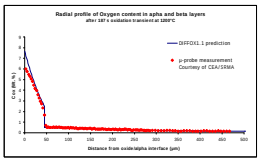
A - Cladding embrittlement (4)

IRSN R&D Strategy

II. Selection of the most appropriate parameter on which to correlate post-quench embrittlement (cont.)

Computer code development (diffusion code DIFFOX) at IRSN, with the support of specific tests and experimental techniques (IRSN MARGO-R tests) make it possible to correctly evaluate the thickness of the β layer and the oxygen distribution in this layer





Research & Development Needs

B - Axial Fuel Relocation (1)

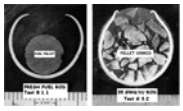
Fuel relocation occurrence during LOCA transient is widely recognized as it has been observed in **all** burst tests with irradiated fuel rods from low to high burnup levels

At low and medium burn-up :

- **PBF/LOC** (INEL)
- **FR-2** (KFK)
- **FLASH-5** (CEA)

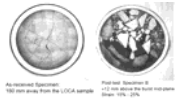
At high burn-up :

- **ANL integral test**
- **Halden IFA-650 tests**



FR2
Fresh fuel

FR2
35 GWD/tU



ANL ICL-2
56 GWd/tU

Halden IFA-650.4
92 GWd/tU

Research & Development Needs

B - Axial Fuel Relocation (2)

IRSN R&D Strategy

Based on:

1. Interpretation of the IFA-650 test series at Halden, and considering complementary tests (**CABRI** with the use of the hodoscope);
2. Support from Laboratory studies to understand the basic mechanisms of fuel fragments slumping and accumulation in a cladding balloon
3. Modelling fuel fragmentation as function of burn-up and power load history (French specificity)

☞ balloon filling ratio as function of fuel rod characteristics

Research & Development Needs

C – Flow Blockage and its coolability (1)

What could be the cumulative effects of irradiation (more uniform azimuthal temperature distribution) on the main characteristics of the blockage:

- *maximum flow restriction ratio?*
- *axial extent ?*

Based on a comparison of the burst strains obtained in ORNL Single rod/ Multirod tests and in PBF-LOC tests with fresh rods / irradiated rods

☞ *INEL recommended to perform in-pile bundle tests of sufficient bundle size with irradiated rods (J.M. Broughton, Sun Valley, 1981)*

However, such a strategy might lead to significant costs; indeed, a short series of in-pile integral bundle tests could close the issue for a given fuel but let it open for another type of fuel; in addition, in-pile experimental facilities for testing bundle with large size more and more difficult to find (PHEBUS has been shutdown!)….

Research & Development Needs

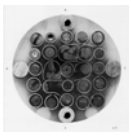
C – Flow Blockage and its coolability (2)

IRSN R&D Strategy

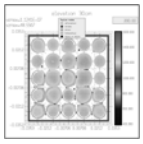
☞ "Simulation" strategy based, in particular, on the use of a detailed and well assessed code: **DRACCAR code** under development at IRSN

3-D thermomechanics code, multirod with mechanical and thermal interactions between rods, coupled with subchannel type two-phase flow codes (CATHARE, COBRA, ...)

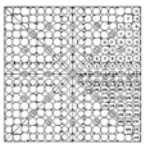
Phebus LOCA test 215-R *(1983)*



DRACCAR Simulation



Simulation of PWR fuel assembly under typical LOCA transient



Research & Development Needs

C – Flow Blockage and its coolability (3)

IRSN R&D Strategy

☞ **DRACCAR code** assessment prior to reactor applications

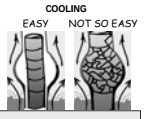
Model validation will be :

1. Based on in-pile tests with single irradiated fuel rods in a well instrumented prototypical environment (that could consist in fresh fuel rods or electrically heated rods or shroud in **CABRI**) plus possibly complementary "small" bundle tests in **Jules Horrowitz Reactor (JHR)**
2. Supported if necessary by more analytical out of pile clad tests focusing on clad-to-clad thermomechanical interactions and axial balloon extension

Research & Development Needs

C – Flow Blockage and its coolability (4)

No blockage coolability experiment (see FLECHT-SEASET and FEBA) has been carried out simulating heat source remaining in contact with cladding



IRSN R&D strategy :

1. Based on out-of-pile experiments with a partially blocked full-length bundle, with realistic simulation of fuel relocation in the balloons, in view of updating the upper bound value of maximum blockage remaining coolable
2. Supported by some more analytical tests addressing basic phenomena (droplet impact and fragmentation, heat transfer on balloon walls, flow redistribution…) to:
   - reach a better understanding of phenomena
   - select the most appropriate form of heat transfer correlations for DRACCAR

Schedule of LOCA Acceptance Criteria Instruction

End of 2009, the French Advisory Committee for Nuclear Reactors will have to give its position concerning :

- **the relevance of the current acceptance criteria taking into account cladding alloy evolutions, BU increase, results of R&D works and possible evolutions in safety demonstration (break size)**
- **the necessity to revise or complement the criteria while associating (or not) new requirements for the demonstration of fuel behavior safety under LOCA**

A further meeting of the Advisory Committee will be dedicated to the examination of the proposed Revised Criteria (☞ 2011)

SUMMARY

1. Pending questions have been well identified concerning three main topics regarding LOCA acceptance criteria.

IRSN has defined a strategy to address them by means of a consistent R&D program.

Close cooperation in this domain with the USNRC highly valuable.

Cooperation within CSNI frame also very beneficial and must be pursued.

2. The French Advisory Committee for Nuclear Reactors will give its position by the end of 2009 concerning:

- **the relevance of the current LOCA acceptance criteria**
- **the necessity to revise or complement them with possibly new requirements for safety demonstration**