IRSN Views on LOCA Acceptance Criteria

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Background

- **Ergen Task Force (1967)**
- **Interim Acceptance Criteria (IAC) for ECCS, (USAEC, 1971)**
- **ECCS Rule-Making Hearing (1972-1973)**

Current ECCS acceptance criteria (10 CFR50.46)

Opinion of the Commission, Docket RM-50-1, December 28th ,1973:

"In view of the fundamental and historical importance of maintaining core coolability, we retain this criterion as a basic objective, in a more general form than it appeared in the IAC".

New Basis for a Revision of the Acceptance Criteria ?

Within current considerations for a future revision of the LOCA acceptance criteria, the original objective of *maintaining core coolability* **is kept by IRSN as the main reflection line,**

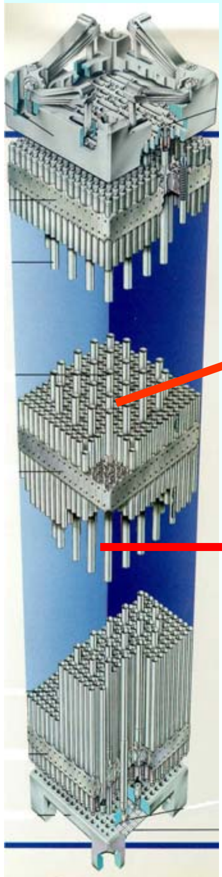
even if it will complemented by aspects addressing additional concerns:

- *Prevent dispersal of fuel particles in the reactor primary circuit,*
- *Maintain structural material integrity,*
- *Limit radiological release.*

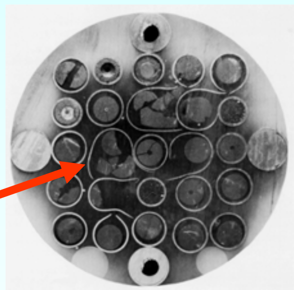
=> Maintaining Core Coolability is the guideline of the presentation.

Maintaining the Core Coolability

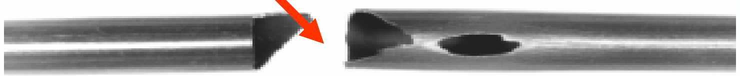
In LOCAs there are two modes that may affect the core geometry and impair the core coolability:



1. Ductile mode : Clad ballooning leading to partial blockage of the FA channels

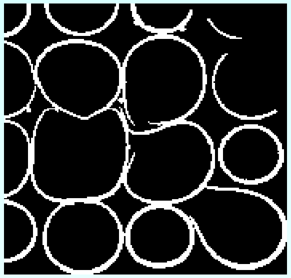


2. Brittle mode : Loss of cladding integrity upon quench and post-quench loads



Maintaining the Core Coolability and LOCA acceptance Criteria

1. Ductile mode : Clad ballooning leading to partial blockage of the FA channels



PHEBUS LOCA TEST

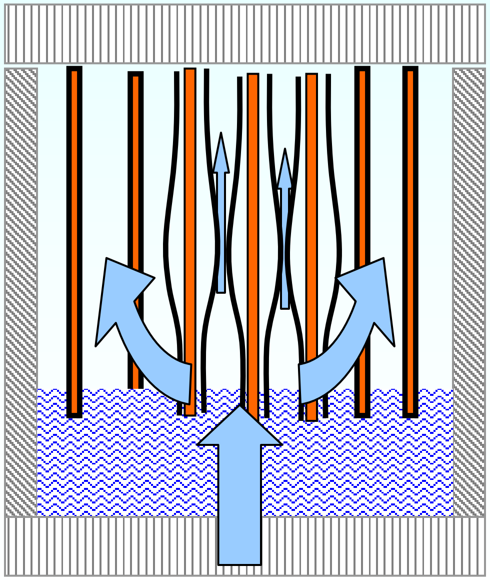
☞ **addressed in 10CFR50.46 by:**

(b)(4) : Coolable geometry

(b)(5) : Long-term cooling

➩ Calculated changes in core geometry shall be such that the core remains amenable to cooling,

➩ and the calculated temperature shall be maintained at an acceptable low value…for the extended period of time required by long-lived radioactivity remaining in the core.



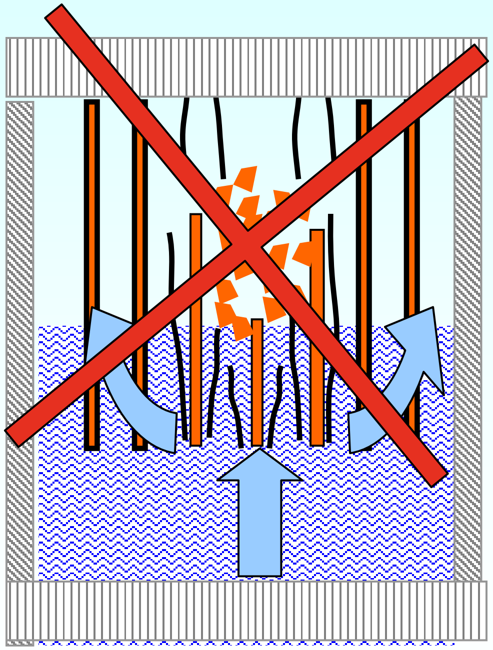
Maintaining the Core Coolability and LOCA acceptance Criteria

2. Brittle mode : Loss of cladding integrity upon quench and post-quench loads

☞**addressed in 10CFR50.46 by the well-known non-embrittlement limits:**

- **(b)(1) : Peak cladding temperature : PCT < 2200°F (1204°C).**
- **(b)(2) : Maximum cladding oxidation : ECR < 17%.**

so as to keep the fuel rod structure in place and essentially intact

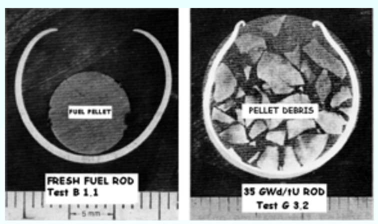


Coolability of Partially Blocked Assemblies under LOCA Conditions

☞ In the 80s, the requirement was considered as met, in consideration of :

- **the results of FEBA/SEFLEX experiments (coolability of blocked arrays) showing that a 90% blockage keeps coolable**

Do not take into account experimental evidence of relocation of fuel in the ballooned cladding => Recognized to day as non conservative.

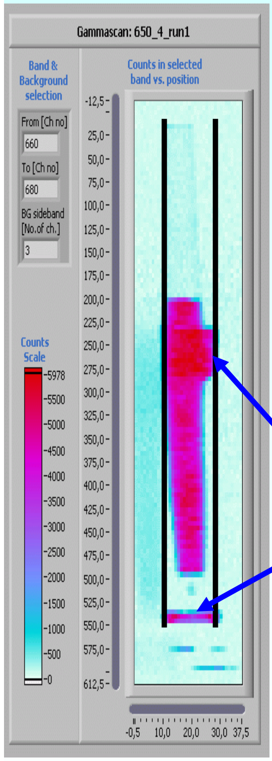


- **the maximum flow blockage ratio, inferred from NUREG-630 review (~71%)**

Was recognized as non conservative, more, should be reconsidered for advanced alloys.

Towards a revision of LOCA acceptance criteria

Coolability of Partially Blocked Assemblies under LOCA Conditions



Requirement to be considered:

- The maximum flow blockage that can be obtained in an assembly of (advanced or not, irradiated or un-irradiated) fuel rods shall not impair the cooling of the assembly with taking into account of a <u>relocation of fragmented fuel in the ballooned claddings</u>.

Pending questions:

- Should the requirement consider the possibility of fuel relocation out of the ballooned clad?

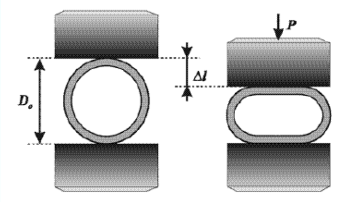
- Could this coolability issue be covered entirely by an ad-hoc non-embrittlement criteria?

Towards a revision of LOCA acceptance criteria

Cladding integrity upon quench and post-quench loads

☞ Basic current requirement is to preclude the clad fragmentation or break in several pieces upon quench and post-quench loads at any location, **including the ballooned and burst region.**

☞ Retain some post-quench ductility in the cladding.



☞ *10CFR50-46:* **Cladding oxidation (ECR: 17%) and temperature (PCT: 2200°F) limits derived from Hobson's ring compression tests on oxidized and quenched samples of un-irradiated Zr cladding.**

The non-embrittlement limits of 10CFR50-46 have been established without any consideration of the effects of burnup and of secondary hydriding.

Towards a revision of LOCA acceptance criteria

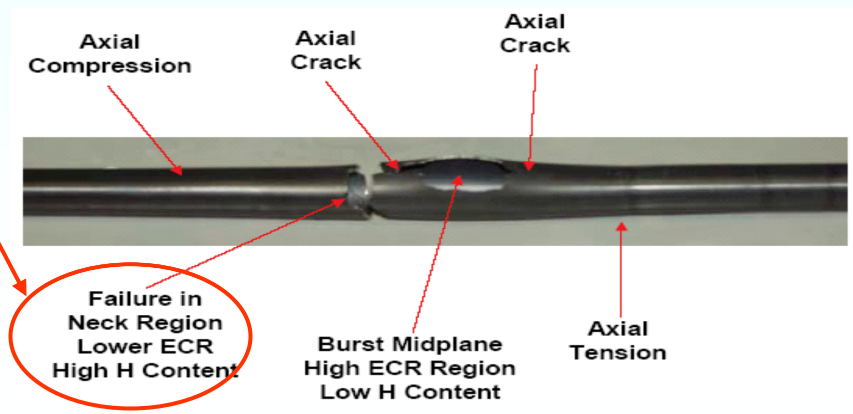
Summary of Main Results of LOCA Research with respect to retention of post-quench ductility

☞ ***Ductile-brittle transition ECR-CP threshold > 17% for un-irradiated un-ballooned cladding,***

☞ ***Low ECR threshold for high burnup Zircaloy un-deformed cladding due to hydrogen influence (ECR threshold < 5% for the HBR quenched sample),***

☞ ***Very low ECR threshold for irradiated cladding after oxidation at T<1000°C due to O diffusion from initial oxide layer into metal sub-layer, (to be confirmed !),***

☞ ***No practical limit can be derived to ensure ductility retention in balloons due to the <u>very large H content</u> upon absorption on clad inner side (secondary hydriding)***



Towards a revision of LOCA acceptance criteria

Cladding integrity upon quench and post-quench loads

Selection of an adequate parameter to quantify an embrittlement limit:

- The ECR (any combination of transient and initial oxidation) does not appear as the most appropriate since its relates essentially to the amount of oxide brittle phase and very indirectly to the properties of the ductile **phase (β layer).**

- The thickness of the remaining Zr β layer and its oxygen content, as proposed by Chung and Kassner, appear to be more appropriate.

  - Would lead to the following type of formulation:

    amount < n wt% oxygen in > x mm β layer

  - Sound basis because directly related to parameters that control the remaining clad ductility.

  - Modeling progress makes it possible to correctly evaluate the thickness of the β layer and the oxygen distribution in β layer (IRSN advanced code DIFFOX).

Cladding integrity upon quench and post-quench loads

Pending questions (1/2):

Which load shall be considered for a reasonably conservative prevention of fragmentation ?

- **Post-quench mechanical loads**
- **Or quench thermal shock under “realistic” restraints**
- **Or…**

Conservatism of the 17% ECR criterion for quench of as-received or irradiated cladding under unconstrained and “realistic” axial loading conditions

No practical limit can be derived to ensure post-quench ductility retention in balloons due to the very large H content upon absorption on clad inner side (secondary hydriding)

Cladding integrity upon quench and post-quench loads

Pending questions (2/2):

Is it necessary to preclude clad fragmentation upon quench and post quench loads at any location, including the ballooned and burst region?

- If yes, it appears that a post-quench ductility retention in ballooned regions cannot be ensured
  - Which requirement to be applied to ballooned regions ?
  - Can the requirements be different in ballooned and un-ballooned parts of the cladding ? Upon which justification ?

- If no, it will be needed:
  - to define new requirements on the extent of acceptable fragmentation,
  - to evaluate its impact on the core coolability (and on radiological release).

Towards a revision of LOCA acceptance criteria

Preliminary statements

↳ *The fuel relocation in the ballooned claddings shall be taken into account when evaluating if the core remains amenable to cooling.*

↳ *The thickness of the remaining Zr β layer and its oxygen content appears to be a sound basis to elaborate non-embrittlement limits.*

↳ *The coolability issue might be covered entirely by an ad-hoc non-embrittlement criteria, but this cannot be postulated a priori.*

Pending questions related to phenomena following clad bursts

↳ *The low ductility observed in ballooned region rises the question of requiring a post-quench ductility retention at any location (and of the acceptability of a limited fragmentation of ballooned regions…).*

↳ *The recent R&D results rise the question of the way to take into account the effect on core cooling of the observed fuel ejection from a burst balloon.*