CONTRIBUTION OF RESEARCH REACTORS TO THE PROGRAMMES FOR RESEARCH AND TECHNOLOGICAL DEVELOPMENT ON SAFETY

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WHAT VALUE FOR RESEARCH REACTORS ?

MANY APPLICATIONS…

1. Generation of beams of neutrons for scientific purposes (ORPHEE, HFR, FRM II, …)

2. Critical mockups and oscillating reactors, for studying criticality, core physics (EOLE, MINERVE, …)

3. Demonstration reactors used to validate and qualify designs, systems and equipment such as fuel, heat exchangers and steam generators (RAPSODIE, PHENIX fast neutron reactor, …)

4. Reactors used for technological irradiation. To develop and characterise the behaviour of vessel, fuel and cladding specially at high fluence or high burn-up (OSIRIS, R2, Jules Horowitz reactor, …)

5. Reactors specifically designed for use in safety studies (CABRI, PHEBUS, …)

SCOPE OF THE PRESENTATION :

PRESENTATION WILL BE FOCUSED ON THE CONTRIBUTION OF RESEARCH REACTORS TO FRENCH PWR SAFETY

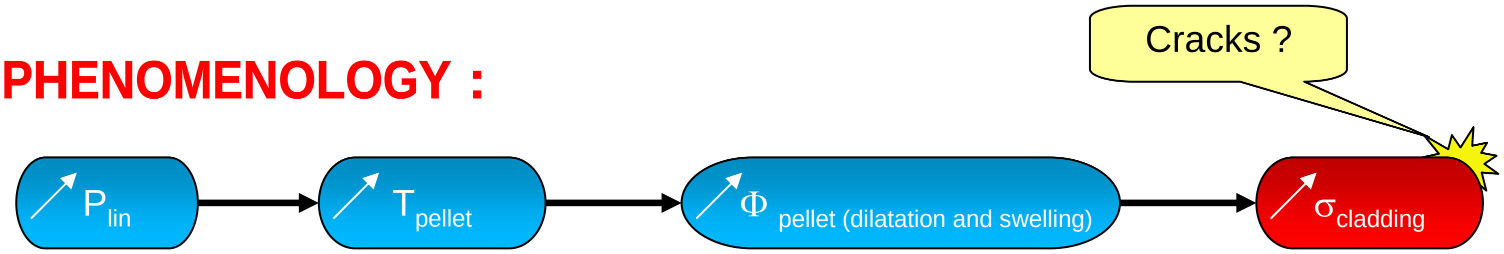
What a contribution for :

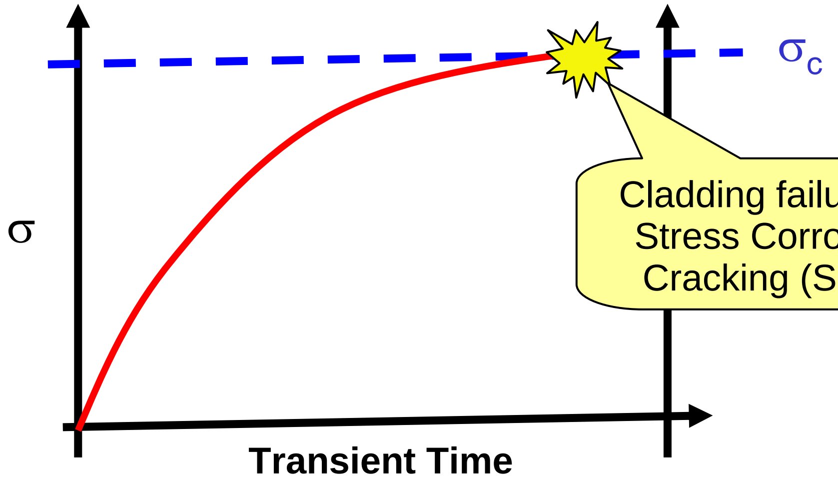
- **Second category transients (Pellet Clad Mechanical Interaction)**
- **Control Rod ejection Accident (RIA)**
- **Loss of Coolant Accident**

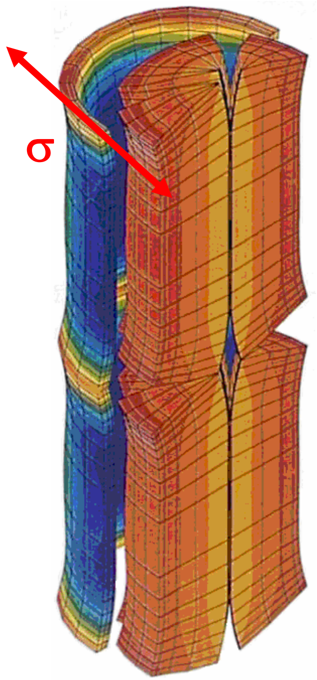
PELLET CLAD MECHANICAL INTERACTION (PCMI) 1/3

BASIC REQUIREMENT : to guarantee fuel rod integrity during second category operating condition (power transients)

PHENOMENOLOGY :







PELLET CLAD MECHANICAL INTERACTION (PCMI) 2/3

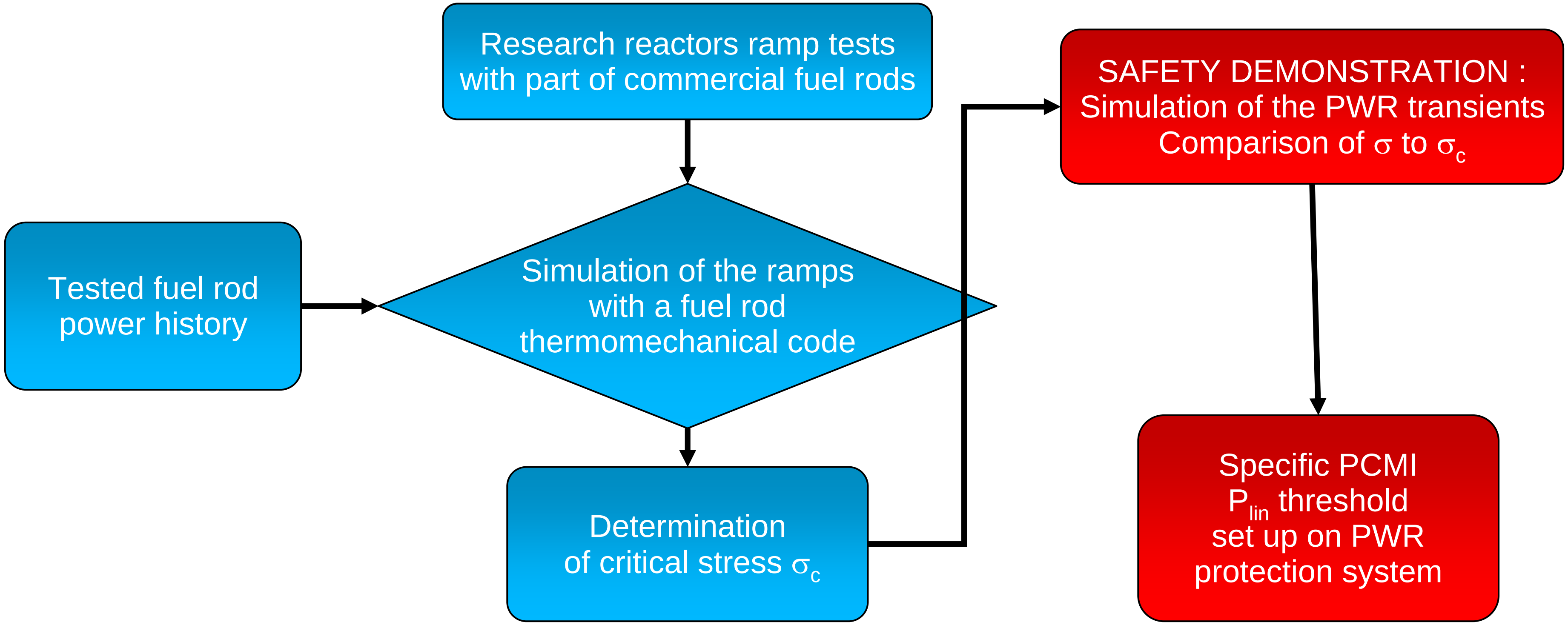
How the fragmented and diabolo shape pellet stress the cladding ?

What is the critical stress (σ_c) for irradiated cladding wich contain some corrosive compounds like iodine ?

To difficult to give answers and therefore to have an analytical approach…

SOLUTION : To perform power-ramp tests with pre-irradiated commercial PWR fuel rods in experimental reactors (R2/Sweden, OSIRIS/France)

PELLET CLAD MECHANICAL INTERACTION (PCMI) 3/3



The reliability of the safety demonstration is provided by :

- **The representativity of the experimental reactor ramp test with respect to PWR transients (fuel rods, power rate, …)**

- **The employement of the same thermomecanical code to simulate both ramp tests and PWR transients (PCMI modelisation not perfect)**

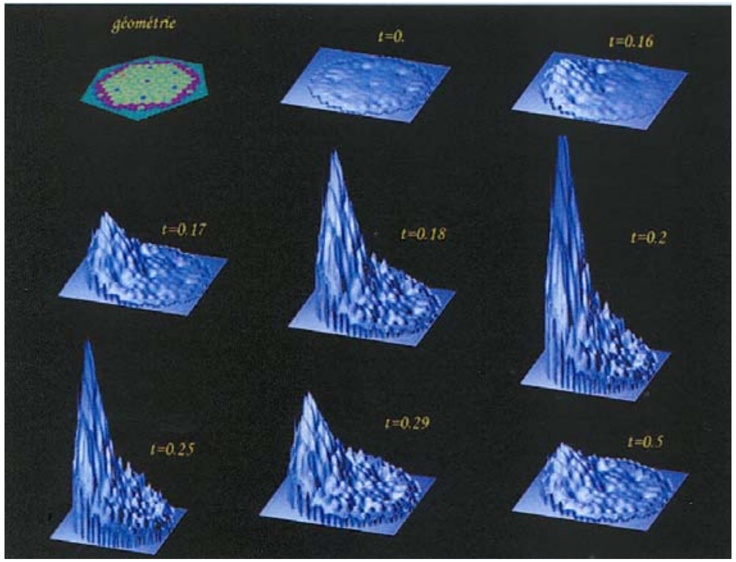
CONTROL ROD EJECTION ACCIDENT 1/3

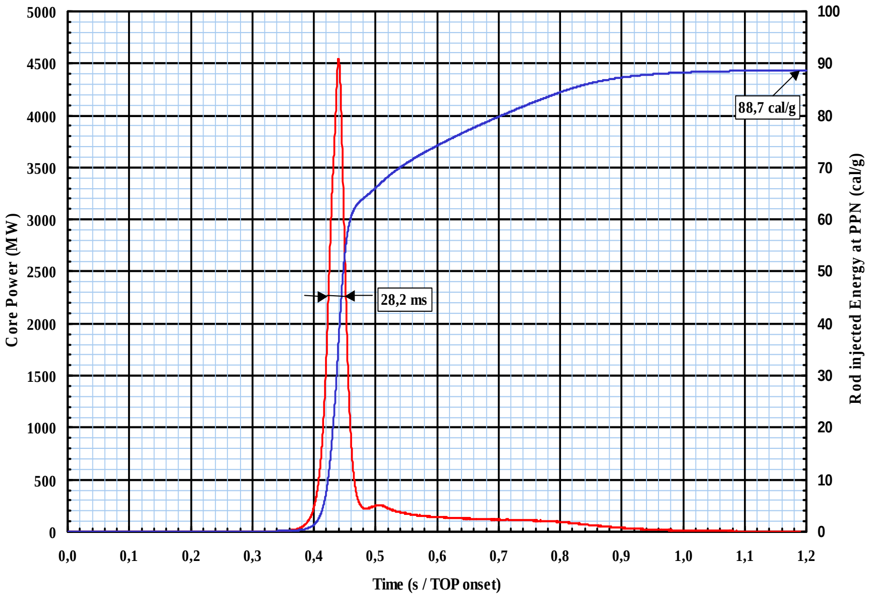
BASIC REQUIREMENT : **to guarantee core coolability**

PHENOMENOLOGY :

- **Ejection of Rod Cluster Control Assembly resulting from sudden breach in the housing of the control mechanism**

- **Power increase in few tens of milliseconds**





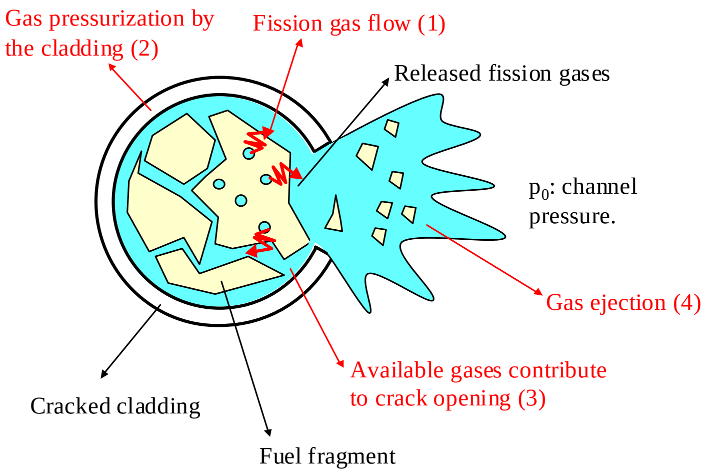
CONTROL ROD EJECTION ACCIDENT 2/3

Close to the ejected RCCA quick expansion of the pellet and quick increase of gas pressure

If the cladding fail hot fragments of solid fuel may be ejected into the primary coolant circuit causing a pressure wave

First Criteria expressed in maximal enthalpy reach during the transient (SPERT tests of 1970) :

- ✓ **225 cal/g for fresh fuel**
- ✓ **200 cal/g for low irradiated fuel**



CONTROL ROD EJECTION ACCIDENT 3/3

MAIN OUTCOMES OF RESEARCH REACTOR TESTS :

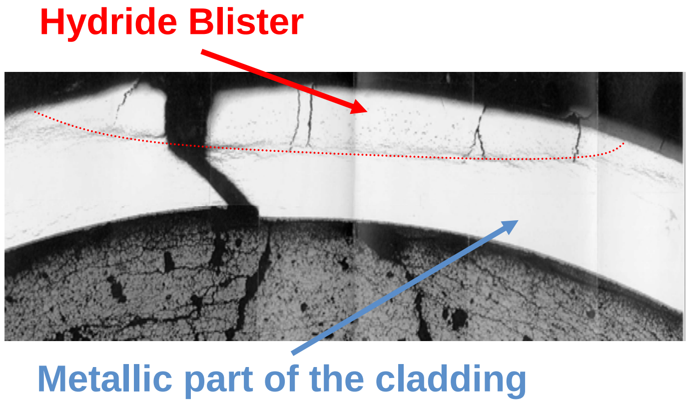
1. Enhanced risk of rod failure due to the formation of hydride blisters resulting from in-reactor oxide spalling

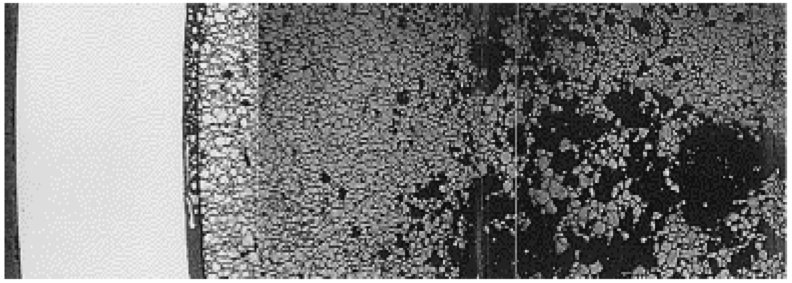
2. Contribution of fission gaz from grain boundary to the mechanical sollicitation of the cladding and to the fuel dispersion in the primary coolant circuit

3. Influence of the energy injection rate (pulse width)

4. Transient oxide spalling influencing clad to coolant heat transfert

5. Need of evolution of present safety criteria

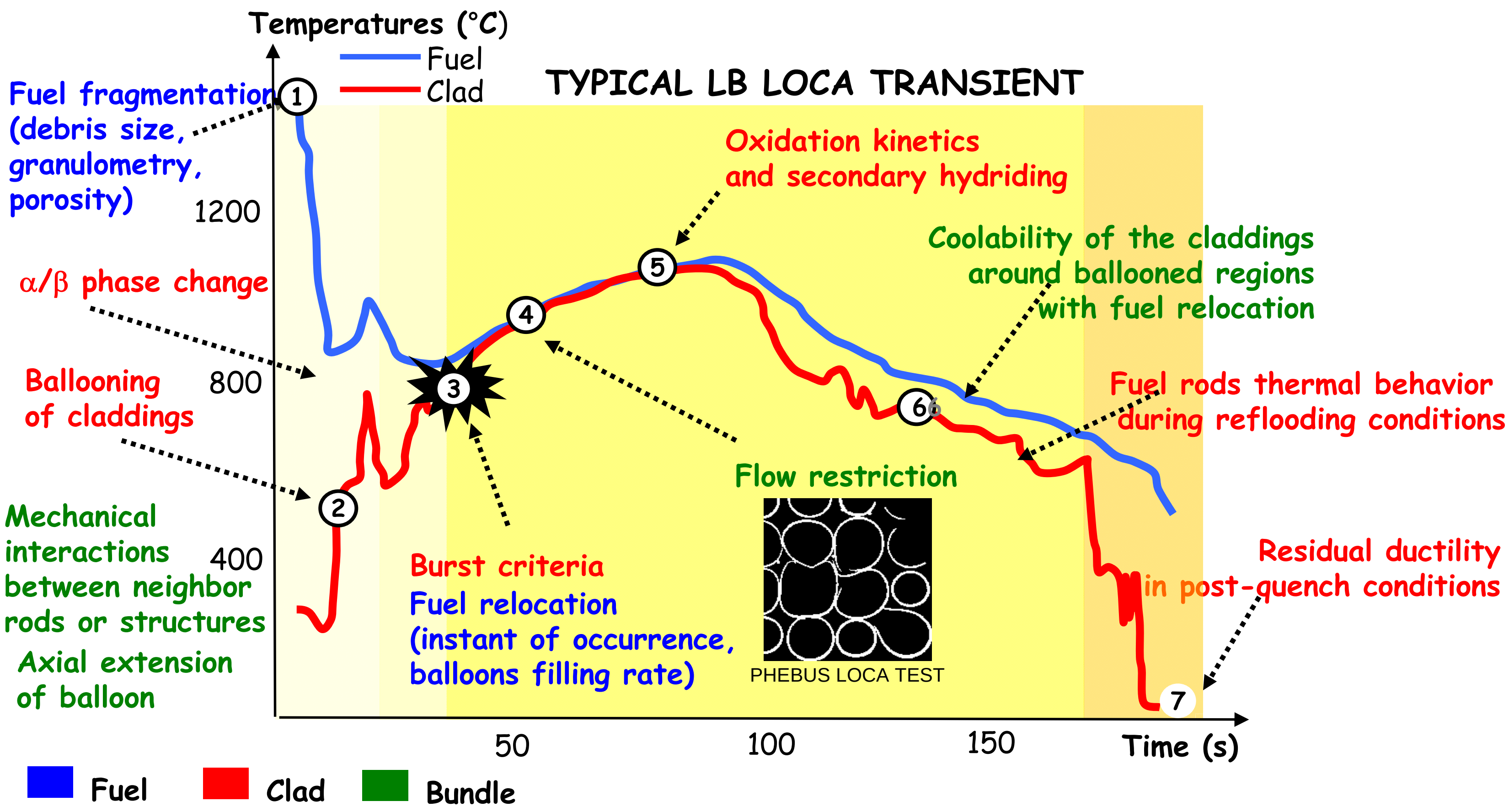




Grain boundary fragmentation

LOSS OF COOLANT ACCIDENT 1/3

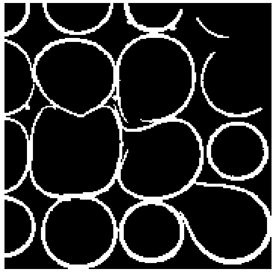
PHENOMENOLOGY :



LOSS OF COOLANT ACCIDENT 2/3

SAFETY MAIN ISSUES :

1. Coolability of the cladding around ballooned regions because of flow restriction



PHEBUS LOCA TEST

Not an issue if the blockage remain below 90%

2. Long terme coolability – post quench embrittlement of cladding

The cladding ductility decrease during high temperature steam oxydation by oxygen and hydrogen absorbtion,

Current decoupling NRC criteria from 1973 (fresh Zy-4 cladding) :

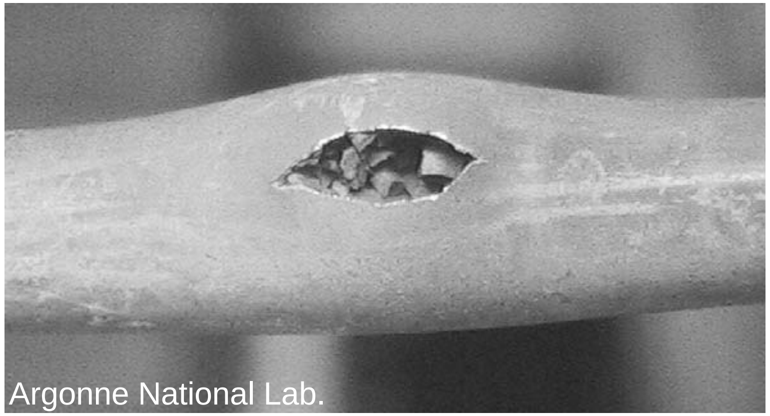
- ✓ **Equivalent Cladding Reacted < 17 % of the initial thickness**
- ✓ **Cladding temperature < 1204 °C**

LOSS OF COOLANT ACCIDENT 3/3

POST DESIGN MAIN OUTCOMES FROM IN RESEARCH REACTOR TESTS :

Cladding burst result in :

- **fuel relocalisation in the ballon if the pellet is fragmented (wich is the case for high burn-up fuel)**



The relocalisation result localy in an increase of linear power and therefore of temperature and clad embritllement by enhancement of hydrogen absorbtion

- **Hydrogen starvation in the ballon and therefore in strong increase of hydrogen and oxygen concentration of the balloning aera**

A revision of the LOCA criteria is in progress in the USA and in France

CONCLUSION

To the power reactor safety point of view **research reactors are essential** to :

1. **Define linear power thresholds** for each type of fuel rods (Zy-4, M5^{TM}, Zirlo^{TM}, …) in order to prevent cladding rupture during second category transients

2. **Highlight some not foreseen phenomena** : hydride blisters embrittlement, gas effect, fuel relocalisation and consequently **define new critera** for RCCA ejection and Loss of Coolant Accident

3. **Contribute to the development and to the global validation of fuel thermomecanical codes.** In France : SCANAIR for RCCA ejection and DRACCAR for the LOCA

Thank you for your attention