

EDF current and future hotlab needs

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EDF in a few figures

- Europe's leading electricity generator
- The energy operator with the lowest CO₂ emission level
- Europe's leading producer of renewable energy
- France's leading investor

- 37.8 million customers worldwide
- Worldwide installed capacity of 128.2 GW
- Worldwide production of 633 TWh, of which 607 TWh in Europe
- A worldwide workforce of 156,500



EDF, world's leading nuclear operator



- 17% of the world's nuclear production capacity
- 58 nuclear reactors operating across 19 sites (63 GW installed capacity in Europe)
- 9 reactors being decommissioned, 1 in the process of construction (EPR)



Nuclear Engineering division Basic design department



◎ Package builder of design bases

- Integrating operating experience feedback and R&D results,
- From fuel pellets to networks, including containment, heat sinks, instrumentation & control, operations documents, etc.
- Neutronics, thermodynamics, fluid/structure/soil mechanics, etc. and interaction between these fields

◎ Ensuring the technical consistency between series

- Series in operations (Operational Engineering) / in design (EPR),
- Over the long term (evolution of the safety doctrine)



Outline of the presentation

- ⦿ Hotlabs exams, a support to operational needs
- ⦿ Basic design studies and fuel performance code development
- ⦿ Power plant manoeuvrability
- ⦿ Safety studies
- ⦿ Lifetime plan assessment
- ⦿ Transport – Interim / short term disposal
- ⦿ Conclusion



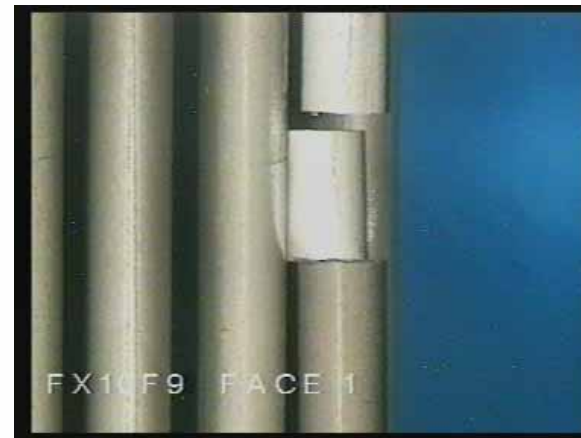
Hotlabs exams, a support to operational needs

◎ Survey programmes

- Pool-side measurements: geometrical measurements, oxidation, wear,
 - check the fuel behave properly
 - validate new fuel design in NPP conditions

◎ Failure processes assessment

- **External hot cells needed to assess failure causes** (debris fretting, grid-to-rod fretting, primary hydriding, end-plug and weld defects)





Basic design studies and fuel performance code development

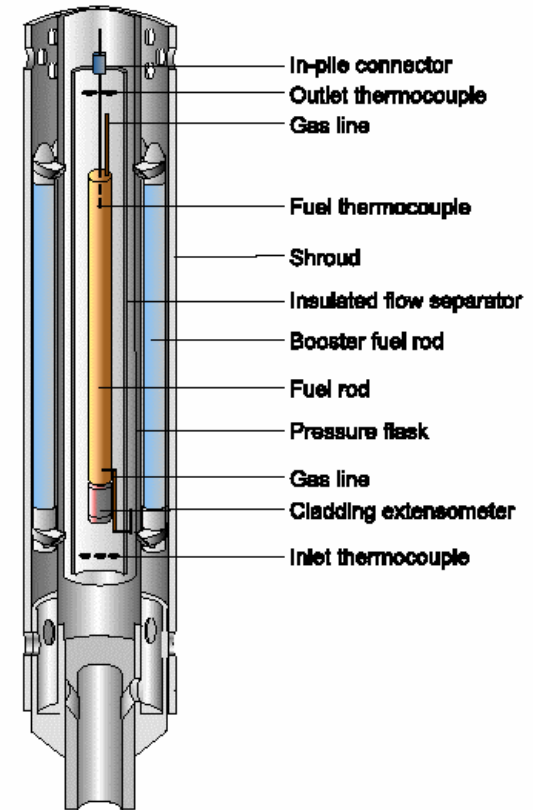
- ◎ Basic design studies are strongly related to fuel performance code calculations
- ◎ EDF fuel performance code CYRANO3 includes empirical and analytical models calibrated using separate parameter measurements on pellets and cladding materials performed on fresh and irradiated pellets and on as-fabricated and irradiated cladding tubes
- ◎ The qualification process performed for each “macroscopic model”: thermal models, mechanical models, fission gas release and internal pressure models, corrosion models

Need for extensive experience feedback and experimental database



Data from experimental programmes

- ◎ Give access to the main physical parameters: linear heat rate, fuel temperature, internal pressure, cladding elongation, fuel stack elongation
- ◎ On-line recording of measurements used to challenge the models **as functions of burnup or power**



- ◎ The final quality of the code depends on the quality of the database

Need for well-characterised data with an accurate evaluation of uncertainties



Data from industrial reactors

- ◎ Commercial rods irradiated in Lead Test Assemblies in Nuclear Power Plants
 - Approximately 500 fuel rods extracted during outage and shipped to hot cells are currently used by EDF
 - Non-destructive and destructive examinations are performed to qualify the code: rod length and outside diameter, corrosion thickness, fuel stack length, internal pressure, fission gas release, free volume, fuel density
 - Data available at different burnup levels (not only EOL PIEs) and representative of current fuel rods
- ◎ Useful data for the validation of the models in actual PWR conditions (flux, moderator temperature and pressure)



Basic design studies and fuel performance code development

- Thanks to these extensive hot cells exams, the current version of CYRANO3 is validated for the following burnup levels:

Product		Maximum Rod Burnup (GWd/tM)
Fuel	Cladding	
UO ₂ / UO ₂ -Gd ₂ O ₃	Zircaloy-4	65
UO ₂ / UO ₂ -Gd ₂ O ₃	M5	70
MOX	Zircaloy-4 / M5	60
UO ₂	ZIRLO	70

In the future the database will have to be continuously updated regarding new fuel products or new boundary conditions



Power plant manoeuvrability

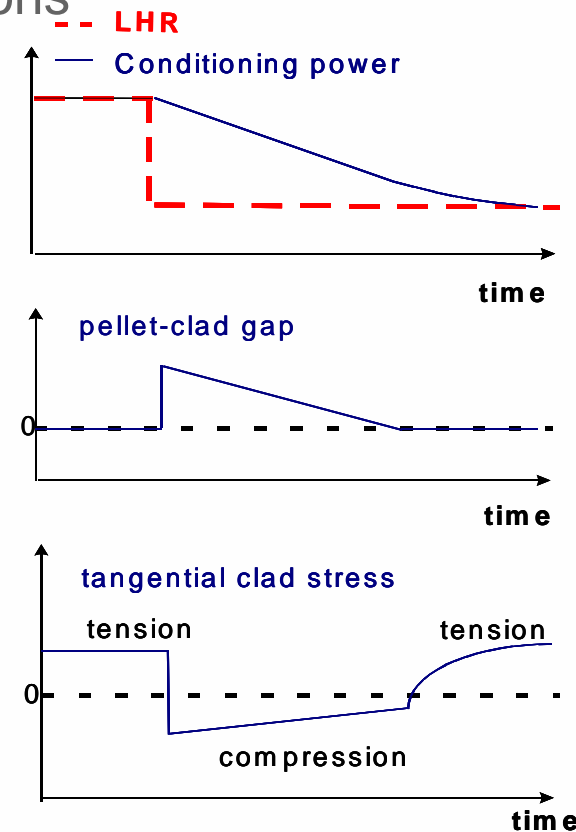
⊙ In France 86 % of the global EDF electricity production comes from NPPs

→ high plant manoeuvrability needs: frequency control, daily load follow, extended reduced power operations

⊙ Deconditioning operations

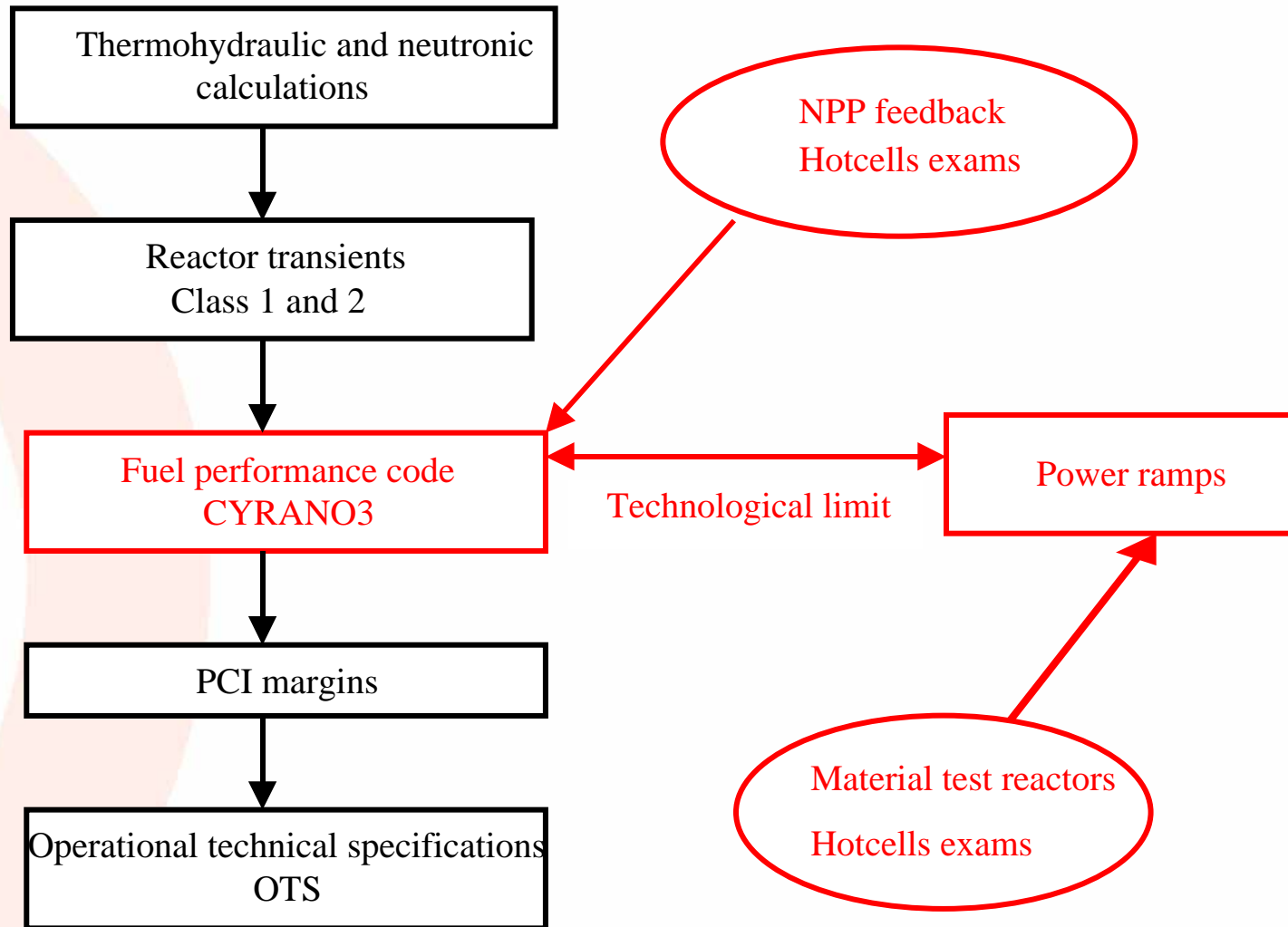
→ Potential increase of PCI failure risk

→ PCI operational technical specifications





PCI OTS determination

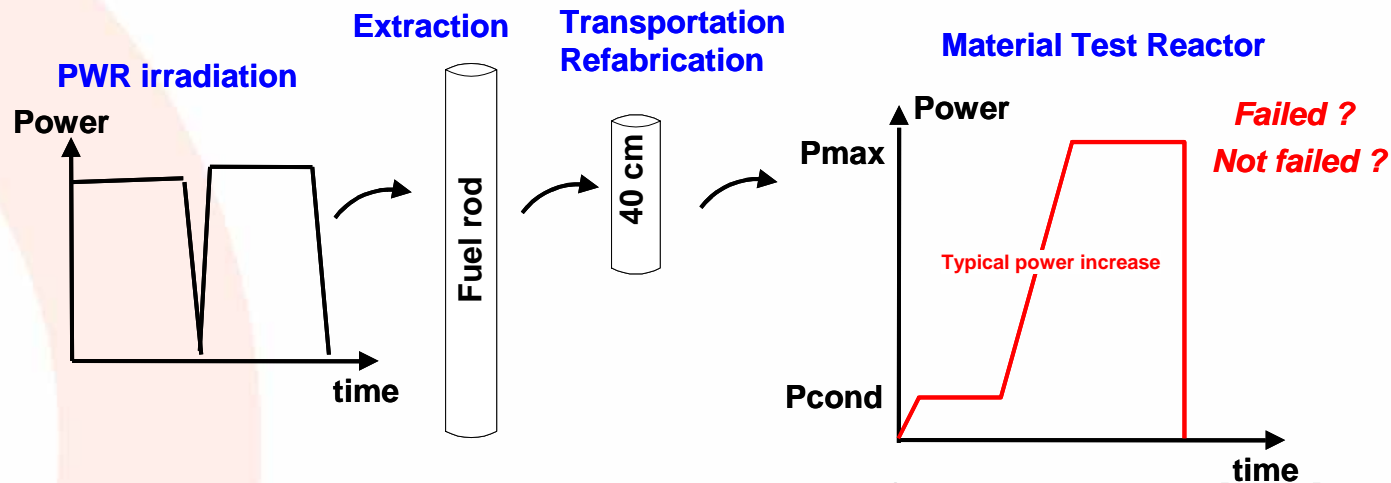




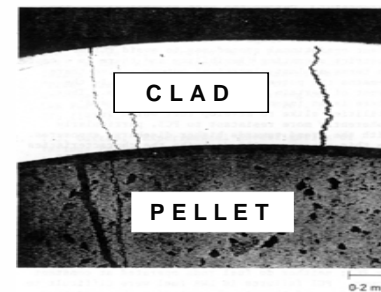
Hotcells support to PCI studies

◎ Power ramps in MTR

- Pre-irradiated segments tested under PWR conditions and typical class 2 power transients



- ◎ Hotcells exams necessary to assess fracture localisation and mechanism: profilometries, eddy current defect determination, metallographies and ceramographies





Hotcells support to PCI studies

◎ PCI studies require specific performance code models qualification

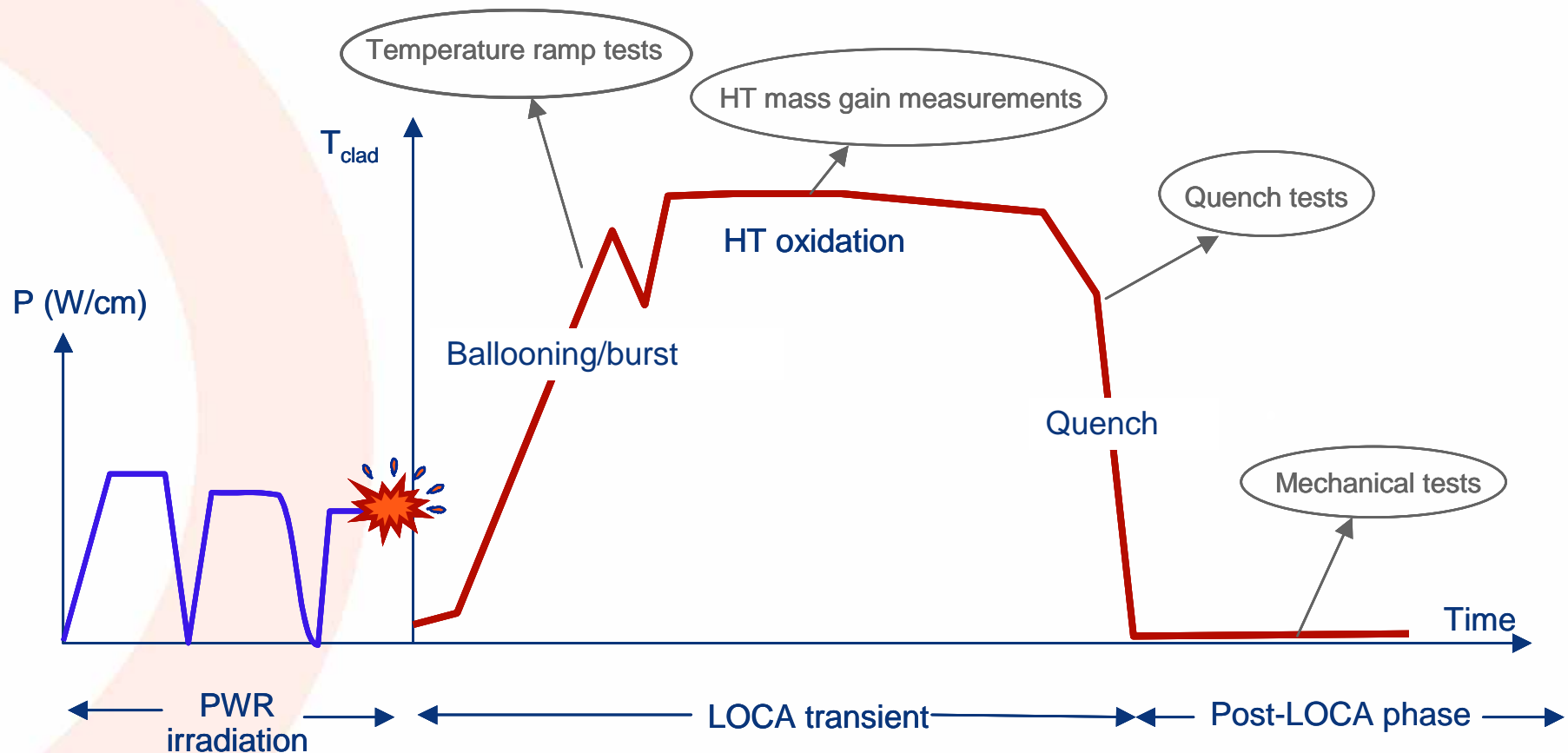
- For the cladding: high temperature creep and high stresses hardening-relaxation tests on fresh and irradiated materials
- For the pellets: gaseous swelling assessment and pellet mechanical behaviour

Currently pellets mechanical properties are determined mainly on fresh materials → **hotcells determination of irradiated pellets properties (such as hardness, tensile behaviour or visco-plasticity) would improve PCI simulation**



Safety studies: LOCA

- Current LOCA studies are based on separate effects tests on fresh and pre-hydrated materials





Safety studies: LOCA

- ◎ Some LOCA issues can't be investigated through SET on fresh materials and need for fuel rod segments and/or irradiated pellets:
 - Fuel relocation in the balloon and filling ratio determination
 - Oxygen diffusion in the cladding from the fuel-clad bounding
 - LOCA source term evaluation

- ◎ The LOCA criteria revision may involve **new types of experiments**



Safety studies: RIA

- ⦿ RIA tests performed in Material Test Reactors (CABRI, NSRR, BIGH) are used to assess fuel behaviour during RIA transient and to develop models
- ⦿ RIA tests must be completed by post-test hot cells expertise
- ⦿ Mechanical tests on the cladding are also needed to qualify new fuel products

In the future, hotcells will still be used to qualify new fuel products under RIA transient conditions



Lifetime plan assessment

- ◎ As the first EDF PWR are approaching 40 years old, lifetime plant assessment has become **a major industrial issue**
- ◎ EDF hotcells (Chinon) and external R&D programmes are used to study degradation mechanisms:
 - IASCC
 - Irradiation enhanced stress relaxation

Need to generate a long term database on potential reactor vessel internals degradation mechanisms



Transport – Interim / short disposal

- ◎ Hotcells exams are needed on
 - The cladding: hydrogen distribution, cladding creep laws
 - The pellets: swelling, fission gas release

In the future, hotcells will still be used to qualify new cladding materials and to improve the knowledge on the assembly structure behaviour



Conclusion

- ◎ All fuel issues will **keep a significant part in the future** and lead to **major requirements** on hot cells exams:
 - Survey programmes and fuel expertise
 - Basic design methodologies and associated fuel performance code development
 - Manoeuvrability optimisation and PCI studies
 - Safety studies and new criteria assessment
 - Lifetime plan assessment
 - Qualification of new advanced fuel products
 - Fuel management schemes with more demanding boundary conditions

The requirements on the current fuel generation are still very important as some operating margins still exist on fuel performance