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INTERNATIONAL SEMINAR ON PELLET-CLAD INTERACTIONS WITH WATER REACTOR FUELS

9-11 March 2004
Aix-en-Provence

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International Seminar on

PELLET-CLAD INTERACTION IN WATER REACTOR FUELS

organised by
CEA Cadarache/DEN/DEC

in co-operation with
OECD/NEA, IAEA, EDF, FRAMATOME ANP, COGEMA

9 - 11 March 2004

Hôtel NOVOTEL PONT-DE-L'ARC
1 avenue Arc de Meyran
13100 Aix en Provence, France

Introduction

This was the third in a series of three seminars that started with the seminar on « Thermal Performance of High Burn-Up LWR Fuel» at Cadarache, France, 3 to 6 of March 1998, followed by « Fission Gas Behaviour in Water Reactor Fuels», also held at Cadarache, from 26-29 September 2000.

The aim of this third seminar was to draw up a comprehensive picture of our current understanding of pellet clad interaction and its impact on the fuel rod, under the widest possible conditions.

Pellet-Clad Interaction

In PWRs and BWRs, once the fuel-clad gap has closed, 1 to 3 years after irradiation started (depending on the materials), the compressive stress experienced by the cladding and due to the primary fluid pressure is reversed to a tensile stress induced by continued fuel swelling.

Enhanced clad stress is likely to occur in the region of the pellets' ends, especially when the fuel rod is submitted to power ramps, in relation for instance with incidental transients in the operation of the reactor.

In the presence of aggressive fission products (e.g. iodine typically) released by the pellets, this situation can lead to stress corrosion induced failures resulting in primary water contamination.

This risk is an important industrial challenge to demonstrate that margins are guaranteed for the different current situations and for classes of transients encountered in reactors operation, and justifies the development of so-called PCI-resistant fuel products.

mechanisms, or by reduction of the power manoeuvrings responsible for PCI. Would therefore such studies be useless, in the possible context of reduction of PCI frequency? Without being pessimistic, the history of the nuclear industry has shown us that unexpected behaviours are ready to occur when pushing the components to a higher duty, a longer life or reduced operational margins. A scientific knowledge of the fuel behaviour beyond what is strictly required to avoid any PCI failure, and we are unfortunately far from such a scientific knowledge, will not be a waste of time or money, but will allow us to react more efficiently in case of such events occurring.

Overall Recommendations and Open Questions

Fuel Material Behaviour in PCI Situation

1) More efforts are needed to develop "clever" devices able to provide data on the evolution of fuel mechanical properties with local burn-up and temperature.
2) Reliable experimental data are needed to better characterize fuel gaseous swelling kinetics (including irradiation induced gas atom re-solution) under different conditions of temperature, stress and fission rate, including the relative importance of intra-granular swelling. Attention should be paid to evaluating the gaseous swelling driving force and its contribution to the local mechanical loading of the clad.
3) Despite considerable improvements of the pellet mechanical modelling in the last decade, further improvements are required. A better characterization of the local stress (stress tensor against hydrostatic pressure) might be necessary for the comprehensive modelling of the different ways stress affects the pellet progressive additional cracking, the viscoplastic flow and the fission gas behaviour. This may necessitate 3D mechanical modelling.

Cladding Behaviour Relevant to PCI

1) Stress corrosion cracking, especially in iodine atmosphere, is known to be responsible for PCI failures. Despite many efforts and good analytical work, the need still exists for developing mechanistic models able to reproduce the mechanical tests performed on pressurized tubes as well as to predict the clad crack propagation in true transient conditions. Knowing that the SCC cracks preferentially develop at the pellet-pellet interface and in front of pellet cracks the need for developing duly validated 3D models becomes clear.
2) In order to better simulate potential clad damage due to power transients, further work is also recommended concerning the migration of potentially aggressive chemical species such as I, Cs, Cd. Since the papers presented in this session focused on the behaviour of I and, to a lesser extent, that of Cs, it is recommended that the experimental efforts be now directed toward understanding the role of Cd.
3) It is recommended that microhardness measurements be pursued to better quantify the evolution of microhardness as a function of burn-up. Such data would be useful not only in understanding PCI SCC but also other phenomena such as secondary damage in failed fuel rods.

In Pile Rod Behaviour

1) The reasons why MOX fuel and Cr-doped fuel appear to behave better with respect to conventional UO_2 under PCI conditions must be tackled further: is it fuel cracking propensity by itself, and/or is it enhanced viscosity reducing the hour-glass effect by dish filling and perhaps favouring peripheral cracking? How does gaseous swelling act, with which kinetics? So there is a need for new experiments in which the contribution of the individual phenomena is evidenced. That is the case for gaseous swelling for zero hold-time ramp tests which have been proposed on Cr-doped fuel. It would be the case for gaseous swelling plus creep at higher ramp rates. In parallel, there is a need for experiments to study the high temperature phenomena not far from fusion conditions without any cladding damage (columnar grain growth, central void formation, etc.).
2) Relevant comparative analytical data with differences in pellet geometry (e.g. short pellets) could contribute as well to this attempt of varying the relative weight of different phenomena.
3) The question of the concurrent cladding improvement might be asked. What kind of benefit can be expected from a new cladding concept?

Modelling of the Mechanical Interaction between Pellet and Cladding

1) The development of de-cohesive models versus diffuse crack models looks promising for the treatment of pellet cracking.
2) Mechanical phenomena are assessed differently by 1D/1.5D and 3D models, only the latter having the potential to approach the phenomenon with accuracy. Nevertheless, running times are long and the results are still dependent on materials data and interaction prediction. So, it seems that both models should be developed, fast-running 1D/1.5D models taking profit of the comprehensive view available from 3D ones
3) The developments on pellets mechanical models to cope with cracking, and the provision of an accurate description of heterogeneous products, should be used as inputs of PCMI codes and could help to understand the differences exhibited by doped fuels and MOX
4) The ultimate goal of all fuel vendors should be a failure free operation, with no limits imposed on operation. PCI resistant products could contribute (see above), but their good performances have to be demonstrated more widely, by modelling and by complementary experiments.
5) It is recommended to extend the use the existing fuel performance databases (e.g. IFPE) for model improvement and validation, and in particular to evaluate PCMI effects on gaseous swelling and vice versa. A FUMEX-III exercise devoted to PCMI/PCI effects should be considered.
6) Predictive PCI modelling should be presented, not just explanations after the event.