

Background

Although in some countries the use of Mixed Oxide (MOX) fuel in Light Water Reactors is today not or no longer considered, several other countries continue the MOX route or have a policy to keep the MOX option open. The same trend of reducing fuel cost and to reduce total waste volume applies for MOX fuel as for conventional UO_2 fuel. When novel fuel or fuel assembly designs are introduced in nuclear reactors, these new designs need to be validated experimentally. In view of the considerable costs associated with such research, this is generally organised in an international context with several institutes and industrial groups involved. GERONIMO and TOPGUN are two such projects, managed by BELGONUCLEAIRE, where SCK·CEN was the central institute for the Post-Irradiation Examination and transient tests in BR2. The majority of the work was executed in the period 2003 to 2005. The programs will be finished in 2006 with the back-shipment of the fuel rod remnants, properly encapsulated, to the power station.

Objectives

The purpose of the GERONIMO & TOPGUN is to establish a validation data base of high burn-up MOX fuel for 9x9 fuel assembly designs for Boiling Water Reactors (BWR). It concerns MOX fuel produced by BELGONUCLEAIRE according to the MIMAS process and irradiated in the Gundremmingen BWR units B and C during 3, 4 or 6 cycles and a peak burn-up ranging between 35 and 65 GWd/tM (GERONIMO) and up to 80 GWd/tM (TOPGUN). Since it is the first time that MOX fuel with such high burn-up was available for detailed post-irradiation examination and testing, several samples of the fuel have been taken to serve in other International Projects (REBUS, MALIBU) and samples or segments have been sent to other laboratories and institutes for further research (CEA, Halden Reactor Project).

The post-irradiation examination programme comprised extensive non-destructive testing (NDT) to investigate the evolution of the fuel rod as a whole (diameter changes, clad oxidation, overall fission product migration, pellet-clad interaction etc.). A very extensive destructive analysis campaign was conducted including rod puncture (fission gas release!), optical and electron microscopic observations, microprobe analysis, thermal diffusivity analysis, radiochemical burn-up determination etc. While the NDT together with the puncture results provide quantitative data for fuel performance code validation, the destructive investigations help to deepen our understanding of nuclear fuel evolution at high and very high burn-up and serve to develop the fuel performance codes themselves. Transient testing in a materials test reactor serves to demonstrate that the fuel rods can also withstand harsh conditions that normally are not encountered in a Nuclear Power Plant and the further investigations after such transient tests helps developing our understanding of fuel behaviour in off-normal conditions.

Principal results

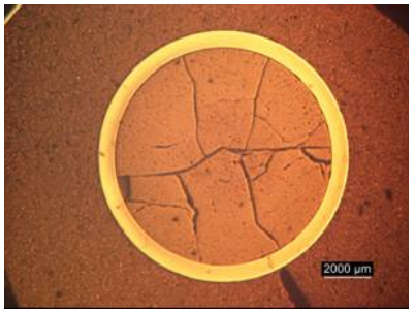
- It was the first time that MOX fuel irradiated to such elevated burn-up (80 GWd/tM) in a commercial light water reactor could be investigated. It is not expected that in the near future these conditions will be reached on standard basis and the TOPGUN program is expected to remain the reference programme that provides "envelope" data on MOX behaviour for a substantial period of time.
- For the GERONIMO programme, it is the wealth of data that is generated that makes the value of this programme. With valuable data on MOX fuel of different enrichment, linear power and accumulated burn-up between 35 and 65 GWd/tM, GERONIMO provides reference data for a broad range of MOX.
- The successful transient tests performed in the BR-2 reactor demonstrated that the important efforts during the past years to improve the calibration of this reactor for such tests were really effective and that BR-2 can again be used for reliable transients.

Future work

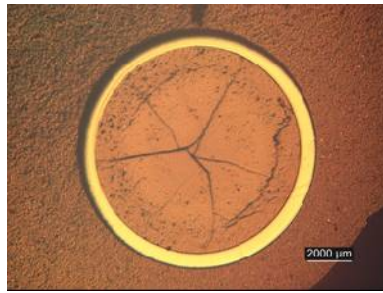
The GERONIMO and TOPGUN projects will be concluded in 2006 with the back-shipment of the fuel rod remnants to the power station for final disposal, but the calculation and code validation work is just starting now. It is expected that new insight in MOX behaviour at high burn-up will lead to improved modelling of MOX in the coming years.

Main contact persons

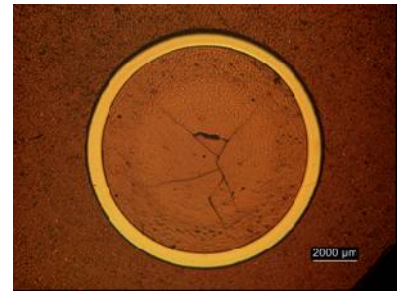
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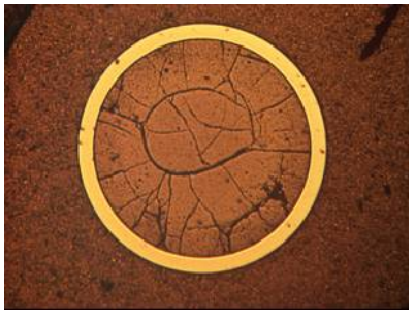
Medium BU (40 GWd/tM), base irradiation



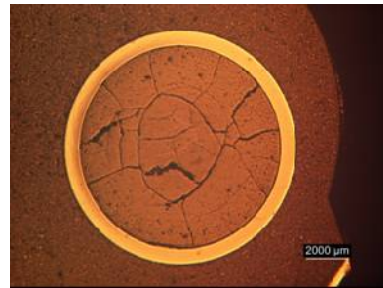
High BU (60 GWd/tM), base irradiation



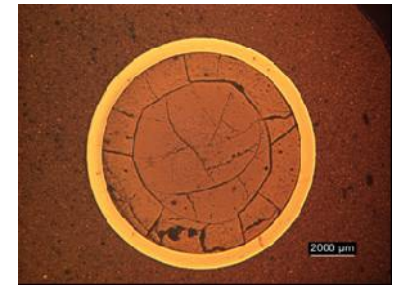
Ultra-high BU (80 GWd/tM), base irradiation



Medium BU, transient to 400 W/cm, 24h hold time



Medium BU, transient to 465 W/cm, 1h hold time



Medium BU, transient to 465 W/cm, 24h hold time

Metallographic sections of a selection of MOX fuels from the GERONIMO & TOPGUN programme. Top row: a comparison of the microstructure evolution from medium (top left) high (top centre) to ultra high burn-up (top right). Note the change in structure of the peripheral zone at elevated burn-up. Bottom row: cross sections of fuel segments that have undergone transient testing. Bottom left: medium level transient for long hold time; centre: high level transient for short hold time, right: high level transient for long hold time. Note the change in crack pattern between transient tested fuel and base irradiated fuel (top left).