In order to avoid criticality risks, a large number of facilities using spent fuels have been designed considering the fuel as fresh. This choice has obviously led to considerable safety margins. In the early 80's, a method was accepted by the French Safety Authorities allowing to consider the changes in the fuel composition during the depletion with some very pessimistic hypothesis: only actinides were considered and the amount of burnup used in the studies was equal to the mean burnup in the 50 least-irradiated centimeters.

As many plants still want to optimize their processes (e.g. transportation, storage, fuel reprocessing), the main companies involved in the French nuclear industry and IRSN set up a Working Group in order to study the way burnup could be taken into account in the criticality calculations, considering some fission products plus a more realistic axial profile of burnup.

French Practice

At the present time, fission products are disregarded and only heavy nuclei are considered for a given amount of the burnup: $^{235}$U, $^{236}$U, $^{238}$U, $^{239}$Pu, $^{240}$Pu, $^{241}$Pu and $^{242}$Pu.

For transportation, pool storage and for the continuous dissolver at La Hague – COGEMA, criticality studies were led out considering a flat profile of the burnup: the amount of the burnup in the fuel assembly was considered as equal to the mean burnup measured over the 50 least-irradiated centimeters.

Work in progress

The objective of the French Working Group is to study how a complete and conservative method could be defined to take fuel burnup into account in the calculations, especially for the PWR fuel assemblies.
Its work is both based on (i) the knowledge related to the fission products that will be used, (ii) the model of the burnup profile for the calculation.

The fission product programs

IRSN carries out experiments using different fission product isotopes to validate the calculation scheme. The criticality calculation chain has already been qualified in 1991 with $^{149}$Sm. The following isotopes have been studied: $^{103}$Rh, $^{133}$Cs, $^{143}$Nd, $^{149}$Sm, $^{152}$Sm and $^{155}$Gd. Another program was led out at CEA/Cadarache, divided in to two parts. The former one is devoted to fuel inventory by chemical analyses and microprobe measurements of PWR pins. The latter one, involving oscillation experiments, is related to the reactivity effect of the different nuclei responsible for the burnup credit.

Calculation methods

As part of burnup axial profile study, 3000 profiles have been measured at La Hague - COGEMA plant. These measurements pointed out that most of the profiles were quite similar. The statistical study of these profiles will allow us to determine a conservative axial profile (for ‘most of the profiles’ already measured). The conservatism of the axial profile used in the studies will however be checked by a measure for each assembly and the measured burnup will have to be greater (at different points along the fuel assembly) than the one used in the criticality studies.

An other point is the definition of some conservative values for the depletion parameters used for DARWIN depletion calculation (including APOLLO 2 code). The cooling time effect and the fuel modelisation effect during the irradiation have been studied. To have a conservative spectrum effect, the presence of the control rods and of burnable poisons is considered during the overall irradiation time. This very pessimistic hypothesis is studied at CEA to determine the effect of the control rods insertion during only one cycle. A possibility of MOX presence in periphery is also studied.

The accuracy of the burnup profiles measurements is also studied in order to determine the uncertainty related to the measured values of (i) the mean burnup, (ii) the axial profile of the burnup.

The new French CRISTAL V.1 package will allow us to perform automated criticality calculations using burnup credit. This package uses the depletion code CESAR 5 or the DARWIN system, the APOLLO 2 computer code for cross sections calculations, and the multigroup Monte Carlo computer code MORET4 (2). CRISTAL V.1 contains an interface (3), coupled with the depletion code. It is designed to issue automatically data files for the criticality calculations. It will automatically take into account:

- corrections factors (applied to the concentrations of the actinides and the 6 chosen fission products) determined by the qualification of the evolution calculations and by the qualification of the cross section,
- the axial profile (flat profile, penalizing profile without measurement verification, conservative profile with precise measurement guarantied),
- the number of axial zones chosen.

Conclusion

The objective of the Working Group is to study the conservatism of a more efficient method, considering fission products and axial burnup profile, in the criticality-safety studies. A method considering fission products and an axial profile of burnup should be submitted to the French Safety Authorities for the licensing of new fuel cycle applications.

References: