Representativity studies of PROTEUS UO_2 fuel for new GEN-III+-type configurations in the EOLE Critical Facility

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Extended abstract

Within the framework of an international collaboration between VENUS, EOLE and PROTEUS experimental teams (VEP), project agreements in the fields of experimental reactor physics design and techniques are proposed to be shared between parties. In this context, the Experimental Physics Division (SPEx) of CEA is currently designing a new program devoted to core physics of GEN-III type lattices that requires higher enriched U5 PWR fuel pins. Those lattices are composed of a central 17x17 5wt% enriched ^{235}U UO_2 assembly, surrounded by portions of 3,7% enriched ^{235}U UO_2 PWR fuel pins. The EOLE stockpile requires manufacturing the central assembly, hence increasing the overall costs of the program. The PROTEUS situation is such that its 5% UO_2 pins stockpile could be used in those lattices, in place of new fuels to be manufactured. Nevertheless, due to their radial size, bigger than traditional PWR pins, a so-called representativity study [1,2] must be started in order to verify that, under some constraints, those PROTEUS fuels could lead to adequate lattices characteristics, both in terms of critical mass, but also in terms of spectrum.

To check this potential feasibility, several preliminary calculations were performed to determine adequate size and pitch of the mixed mock-up. Amongst them, representativity calculations were made, to optimize both overclad thickness and lattice pitch, compatible with the buffer zone. The targets being a 4.95% enriched UO_2 PWR cell, and then assembly, both at hot zero power condition, the process of representativity has been managed in two ways:

- a traditional approach only based on conservation of the moderation ratio [3], and its analysis in terms of sensitivity profiles: the target moderation ratio being fixed once for all by adjusting the overclad thickness,
- a more innovative method based on optimization of the representativity itself [4,5], also based on similarities of the sensitivity profiles, and adding one or more degrees of freedom in technological parameter (clad thickness, pitch, etc…).

The paper is split into 4 parts: after a summary of the experimental program needs and their design, the second chapter details the concept of representativity, as the tools required for this study. A section is devoted to the iterative method built to automatically optimize the representativity factor. The third part details the benchmark, the tools used by each party, as well as the covariance data. The last part makes a comparative analysis of results obtained by each participant, as well as the main feasibility conclusions and forthcoming studies.

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Benchmark description

The benchmark consists in determining the representativity of PROTEUS fuel pins in an EOLE lattice at 20℃ compared to a GEN-III+ UO_2 fuel pin in Hot zero power. The next paragraph will detail the material balances of both unitary cells. The calculation will be performed in 2D, with no axial buckling. For the sake of completeness, calculations will be also performed with 0 ppm of boron. The GEN-III cell corresponds to a 4.95% enriched UO_2 fuel pin in hot zero power condition, as EGERIE corresponds to a 3.7% enriched UO_2 cell or PROTEUS cell, both at 20℃, under atmosphe ric conditions. The cell radial cut-off is reproduced on Figure 1.

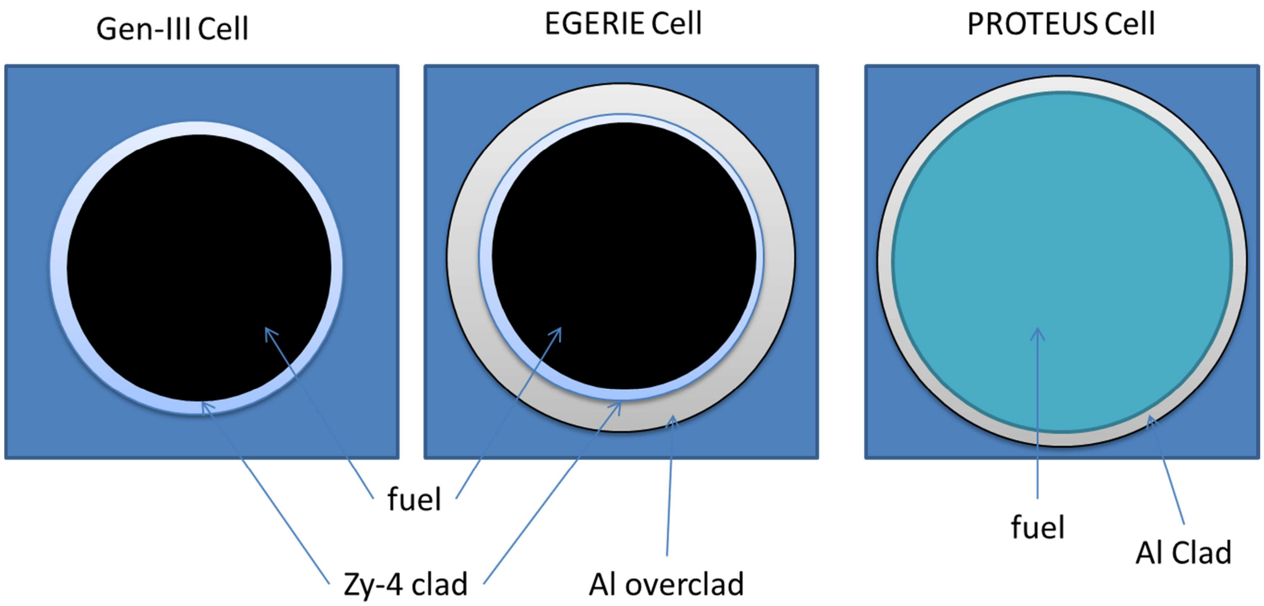

Figure 1. Radial cut-off of the cells

COMAC[6] or SCALE [7,8] covariance data available to both Parties are used for the calculation. The isotopes to be retained are: ^{235}U, ^{238}U, ^{16}O, ^{1}H, Zr, Al. The final result is the representativity. The sensitivity and uncertainty propagation calculations are performed in three steps:

1. Comparison of sensitivity profiles and uncertainties on k_{inf} and spectral indices (e.g. U-238 capture / U-235 fission C8/F5 or F8/F5) for the GEN-III+ UO2 fuel cell obtained with the two labs methodologies (perturbation vs direct) and nuclear data (including variance-covariance matrices).

2. Comparison of representativities of EGERIE and PROTEUS fuel cells *vs* the GEN-III+ UO2 cell in HZP conditions
   - K_{inf} representativity using standard perturbation theory for CEA and direct perturbation for PSI
   - Spectral index (e.g. U-238 capture and U-235 fission) representativity using generalized perturbation theory for CEA and direct perturbation for PSI [9]

3. Optimisation of the PROTEUS fuel cell characteristics *vs* k_{inf} representativity with:
   - Proper choice of overclad thickness, keeping the pitch constant,
   - Lattice pitch adaptation. This last point will have a possible significant impact on the proper choice of the overclad for the EGERIE pins constituting the buffer zone around the central 17x17 PROTEUS assembly.

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