CHARACTERISTICS OF UPPER-BOUND FUEL RODS FOR CRITICALITY STUDIES OF FUEL ASSEMBLY TRANSPORT CASKS

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SUMMARY

The reactivity of light water reactor fresh and spent fuel assemblies depends greatly on the geometrical characteristics of the fuel rods of which they consist, as well as on their moderation.

As concerns the geometrical characteristics, each type of fuel rod can be accurately identified on the basis of the diameter of the pellet, the thickness of the cladding and the outside diameter of the cladding. The values of these three parameters do, however, vary slightly relative to their nominal values, as a result of not only dimensional tolerance limits or changes caused by irradiation.

These tolerance limits are generally mentioned explicitly or implicitly in the descriptions of the permitted contents in the certificates of approval, whereas the criticality studies on which they are based frequently cover only a very small number of fuel rods whose geometrical parameters do not vary. This means that these parameters constitute upper bounds relative to those of the certificates in terms of reactivity, hence the importance of a general method for establishing the set of upper bound parameters.

INTRODUCTION

The aim of this study is to determine the effects of small variations in the geometrical parameters of a fuel rods on their intrinsic reactivity, and to establish a general rule for ranking the reactivity of neighbouring fuel rods of the same type as a function of their geometrical parameters.

Furthermore, application of this rule makes it possible to refine the data included in the certificates of approval for establishing the permitted contents on the basis of the parameters used in the criticality studies.

In return, it also makes it possible to quantitively establish the most reactive fuel rod in a set of fuel rods of the same type.

CALCULATIONS

The calculations are made with the APOLLO 1 code (Hoffmann et al, 1973 - Kavenoky and Sanchez, 1987), associated with the CEA86 cross sections library (Constans and Krebbs, 1991). The neutronic parameter of reactivity considered is the material buckling (B^2_m).

They relate to rods of fuel assemblies representative of the 17x17 pressurised water reactor type with zirconium alloy clad and uranium oxide fuel.

Fuel rods with the following characteristics are covered in the calculations:

- 17x17 PWR type with a zirconium alloy clad and uranium dioxide fuel,
- uranium enrichment = 3.5 %,
- oxide density = 10.6,
- moderation is variable with density of water of 1, characterised by V_{water} / V_{oxide}.

The following tables contain all the data concerning the parameters studied.

Reference fuel rod (all dimensions in millimetres)

Rod No.	Fuel pellet diameter	Gap	Inside diameter	Cladding thickness	Outside diameter
1	8.20	0.12	8.44	0.53	9.50

Pellets diameter variation (all dimensions in millimetres)

Rod No.	Fuel pellet diameter	Gap	Inside diameter	Cladding thickness	Outside diameter
1	8.20	0.12	8.44	0.53	9.50
2	8.44	0	8.44	0.53	9.50
3	7.80	0.32	8.44	0.53	9.50

Variation in cladding thickness with constant outside diameter (all dimensions in millimetres)

Rod No.	Fuel pellet diameter	Gap	Inside diameter	Cladding thickness	Outside diameter
1	8.20	0.12	8.44	0.53	9.50
4	8.20	0.20	8.60	0.45	9.50
5	8.20	0	8.20	0.65	9.50

Variation in cladding thickness with constant inside diameter (all dimensions in millimetres)

Rod No.	Fuel pellet diameter	Gap	Inside diameter	Cladding thickness	Outside diameter
1	8.20	0.12	8.44	0.53	9.50
6	8.20	0.12	8.44	0.60	9.64
7	8.20	0.12	8.44	0.40	9.24

RESULTS

All B^2_m values obtained are given in Table 1.

The results are also given in graph form to show the overall effect of each parameter.

Figures 1 to 3 represent curves of B^2_m as a function of the moderation ratio.

In Figure 1, it can be seen that the fuel rods with the maximum pellet diameters are the most reactive. This effect is associated with the density of fissile material in the cell, which is then at a maximum.

In Figure 2, it can be seen that the fuel rods with the maximum cladding thickness (at constant outside diameter) are the most reactive. This effect results from the neutron diffusing properties of zirconium (σ_s = 6.4 barns) and its low effective capture cross-section (σ_a = 0.185 barn).

In Figure 3, it can be seen that the fuel rods with minimum cladding thickness (at constant inside diameter) are the most reactive. This effect is also associated with the density of fissile material in the cell, which is then at a maximum. For fuel assemblies of fixed active cross-section, this also corresponds to the maximum moderation ratio in the cell.

From these results, the following general rule can be induced:

"For a preset moderation ratio, the most reactive rod is that with the maximum pellet diameter associated with a minimum cladding outside diameter and a minimum cladding inside diameter (minimum gap)".

The conclusions can be extended to other types of light water reactor fuel assemblies with zirconium alloy clad and uranium oxide fuel.

APPLICATION TO CERTIFICATES OF APPROVAL

The above rule can be applied to determine the permitted contents of certificates of approval using all the criticality studies on which they are based. The three main types of situations, which are frequently encountered, can then occur.

- **Criticality studies for fuel rods of preset dimensions with a perceptible gap**

In the case of certificates of approval based on criticality studies for fuel rods of preset dimensions with a perceptible gap, on the whole variation range of the moderation ratio, the permitted contents can be established by specifying the relationships to be observed,

either: pellet diameter ≤ calculated diameter,
outside diameter of fuel rod ≥ calculated diameter,
cladding thickness ≤ calculated thickness,

or: pellet diameter ≤ calculated diameter,
inside diameter of cladding ≥ calculated diameter,
cladding thickness ≥ calculated thickness.

The above two sets of conditions are not mutually exclusive.

- **Criticality studies for fuel rods of preset dimensions without a perceptible gap**

In the case of certificates of approval based on criticality studies for fuel rods of preset dimensions without a perceptible gap, on the whole variation range of the moderation ratio, the permitted contents can be established by specifying the relationships to be observed,

either: pellet diameter ≤ calculated diameter,
outside diameter of fuel rod ≥ calculated diameter,
any cladding thickness,

or: pellet diameter ≤ calculated diameter,
any fuel rod outside diameter,
cladding thickness ≥ calculated thickness.

- **Other criticality studies**

If there are any certificates of approval with descriptions of permitted contents outside the ranges of the parameters resulting from the criticality studies on which they are based, it is necessary to assess the effect of differences in the geometrical parameters of the fuel rods on reactivity, in order to determine their acceptability.

For small differences in the geometrical parameters of the fuel rods, this assessment can be made by directly comparing the intrinsic reactivities of the fissile media, using a neutronic cell code.

Assessment of the effects of larger differences may necessitate a Monte Carlo calculation allowing for the complete configuration of the cask.

APPLICATION TO CRITICALITY STUDIES

The above rule can also be used to determine the most reactive fuel rod in the context of new criticality studies. In such cases, an upper bound approach is to be recommended.

In the case of calculations exploring the whole variation range of the moderation ratio, this could apply, for a single content with dimensions including tolerance limits and for multiple contents, to establishing upper bound dimensions representing the most reactive fuel rod of those of its type, observing the following principles:

pellet diameter: maximum,
cladding thickness: minimum,
gap: imperceptible (outside diameter = pellet diameter + 2 x cladding thickness).

The main advantage of this set of upper bound parameters is simplification of the contents covered, as mentioned above.

In the case where the maximum pellet diameter plus twice the maximum cladding thickness is substantially less than the minimum fuel rod outside diameter, other sets of upper bound parameters which are less severe than the above can also be laid down, observing the following principles:

pellet diameter: maximum,
fuel rod outside diameter: minimum,
gap: imperceptible (if maximum pellet diameter > minimum outside diameter - 2 x maximum cladding thickness),

pellet diameter: maximum,
fuel rod outside diameter: minimum,
gap: minimum (if maximum pellet diameter < minimum outside diameter - 2 x maximum cladding thickness).

If moderation is assumed to be predeterminated (set number of fuel rods per fuel assembly), two situations can arise:

- for fuel rods characterised by a given oxide diameter, when the set number of fuel rods is greater than the optimum number, the others upper-bound parameters are the minimum gap and the minimum cladding thickness (condition identical to those described above),
- for fuel rods characterised by a given outside diameter, when the set number of fuel rods is notably greater than the optimum number, the others upper-bound parameters are the maximum gap and the maximum cladding thickness. The latter condition directly contradicts the conditions described above. In this case, a calculation must be made to determine the upper-bound parameters resulting from the competition between the antagonist effects of reduction in the oxide density in the cell, and the increase in the moderation ratio.

REFERENCES

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TABLE 1

MATERIAL BUCKLING ($B^2_m \times 10^{-2}$ cm^{-2})

V_{water}/V_{ox}	Fuel rod number						
	1	2	3	4	5	6	7
1.9	1.147	1.1998	1.0572	1.1375	1.1609	1.1288	1.1815
2	1.1696	1.2216	1.0807	1.1602	1.1834	1.1516	1.2036
2.5	1.2455	1.2926	1.1637	1.2368	1.2582	1.2287	1.2771
3	1.2778	1.3195	1.2045	1.2701	1.2892	1.2624	1.3067
3.5	1.2793	1.3153	1.2161	1.2725	1.2894	1.2654	1.3053
4	1.2614	1.2921	1.2059	1.2555	1.2702	1.2489	1.2848
4.5	1.2281	1.2536	1.1821	1.223	1.2356	1.2168	1.2489
5	1.1858	1.2068	1.1465	1.1815	1.1922	1.1758	1.2044

FIGURE 1

PELLET DIAMETER VARIATION

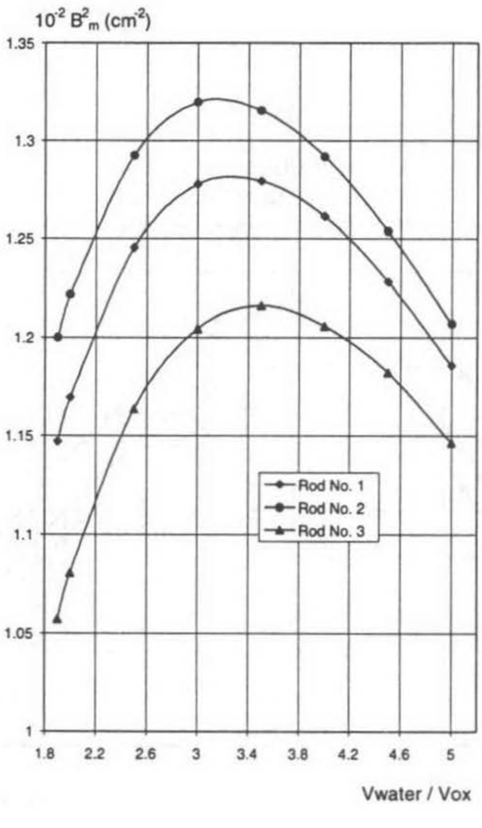

FIGURE 2
VARIATION IN CLADDING THICKNESS
AT CONSTANT OUTSIDE DIAMETER

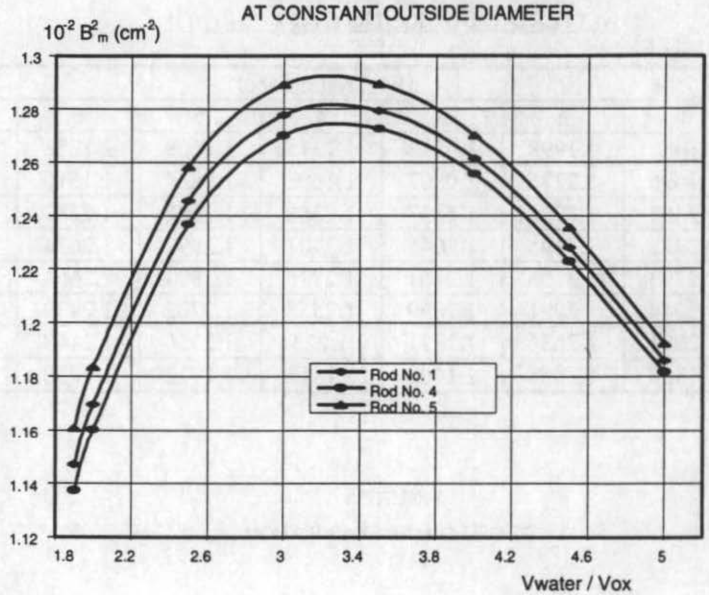

FIGURE 3
VARIATION IN CLADDING THICKNESS
AT CONSTANT INSIDE DIAMETER