MECHANICAL CALCULATIONS ON U-Mo DISPERSION FUEL PLATES WITH MAIA

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ABSTRACT

CEA has developed a 2D thermo-mechanical code, called MAIA, for modelling the behaviour of U-Mo dispersion fuel. MAIA uses a finite element method for the resolution of the thermal and mechanical problems.

Physical models, issued of the DOE-ANL code PLATE, evaluate the fission products swelling and the volume fraction of the interaction between U-Mo and Al. They allow establishing strains in the meat imposed as loading for the mechanical calculation.

MAIA has been validated on the irradiations IRIS 1 and RERTR-3 and a rather good agreement is obtained with post irradiation examinations.

MAIA is used to calculate the last irradiation of the French UMo group, IRIS 2. MAIA predicts a maximum temperature of 112°C and meat swelling of 16%.

Mechanical calculations are finally performed to evaluate the sensitivity to some mechanical hypotheses such as constitutive laws and the way the meat swelling is applied.

1. Introduction

MAIA is a 2D thermo-mechanical code used for modelling the behaviour of U-Mo dispersion fuel plates. The meat is treated as a homogeneous material for the thermal and mechanical resolution with a Finite Element Method (FEM). The evolution of the meat composition is calculated throughout the irradiation taking into account the fading of as-fabricated porosities, the swelling due to fission products and the interaction between the U-Mo particles and the Al matrix. A model also evaluates the cladding oxidation.

2. MAIA Code evolutions

Several improvements have been made on MAIA since the last version of the code presented during RRFM 2004

[1]. A Contact ratio is now used to limit the increase of the interaction compound when the matrix volume fraction become lower and a shape factor on particles is applied to correctly evaluate the volume of the interaction compound for non-spherical particles. These evolutions are issued from PLATE, the code developed by the DOE-ANL [2].

Many improvements on the mechanical calculations have also been made to get more consistent results with more modelling options.

3. Validation

MAIA has first been qualified on analytical test cases to make sure of the good behaviour of the code. Then MAIA has been validated on the available irradiation data: IRIS 1 [3] and RERTR-3 [4]. The Post Irradiation Examinations (PIE) have been compared with MAIA results on the interaction layer thickness and the volume fractions. A rather good agreement is obtained (cf. Figure 5). A benchmark with PLATE has also been carried out in order to make sure of the consistency of the results and to identify improvements in the modelling that were necessary.

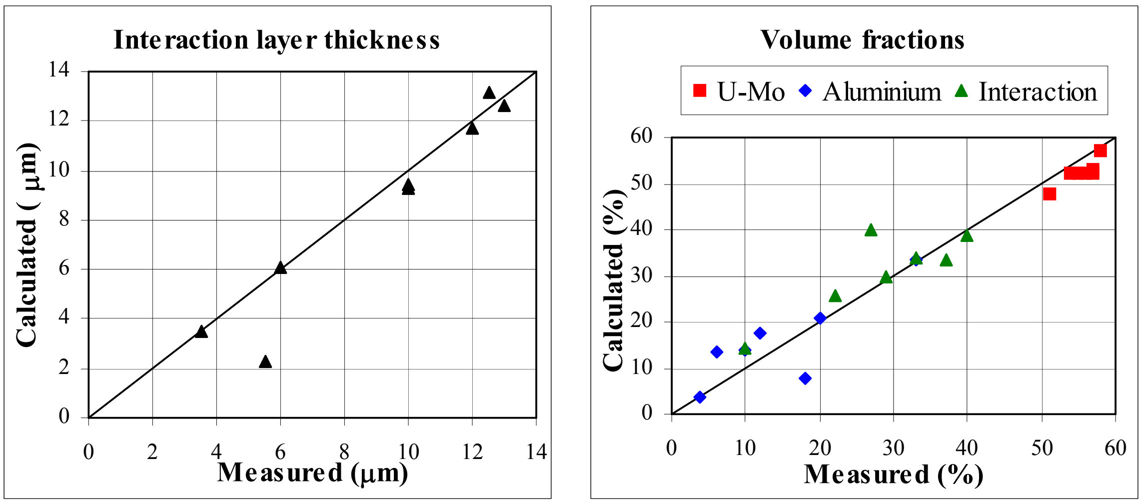

Figure 5: MAIA/PIE comparison on interaction layer thickness (1a) and volume fractions (1b)

4. IRIS 2 results

MAIA has been used to calculate the plate P#02 of the IRIS 2 irradiation (four cycles) [5]. Calculation has been made in the Maximum Flux Plane (MFP). The different results presented in this paper are in the middle of this plane where the flux is locally the highest.
The maximum temperature in the meat calculated by MAIA is 112°C (cf. Figure 6). The external plate temperature in the middle of the MFP decreases from 94°C at beginning of life to 79°C at end of life.

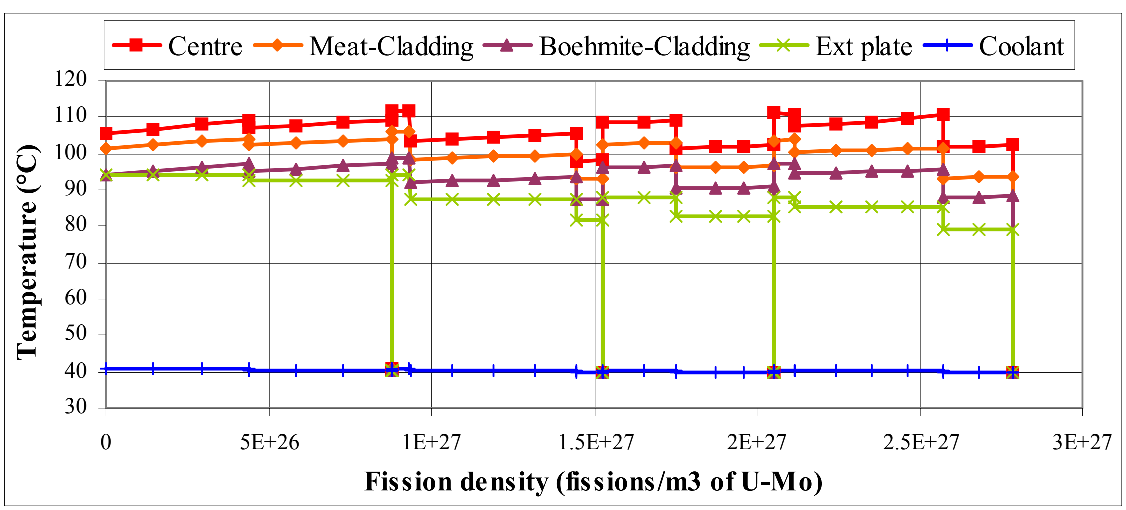

Figure 6: Temperatures in the middle of the plate at the MFP

The results of the code will be compared with PIE as soon as they will be available (cf. Table 3 and Figure 7). It appears that meat swelling (16%) is mainly due to fission product swelling in U-Mo. In MAIA, as-fabricated porosity is supposed to accommodate fission product and interaction product swelling. IRIS 2 plates are made with atomised powder so the as-fabricated porosity is low (1.5%) and total meat swelling begins during first cycle. In IRIS 1, made with ground powder, as-fabricated porosity is much higher (12%) and total meat swelling is delayed because of porosity accommodation.
Above 1.8×10^{27} fissions/m^3 of U-Mo, fission product swelling rate in U-Mo particles gets higher and becomes the dominating phenomenon for meat swelling. It also explains the increase of the U-Mo volume fraction above this threshold.

	Interaction layer thickness (µm)	Oxide layer thickness (µm)
MAIA	3.9	11.6

Table 3: Interaction and oxide layer thickness calculated by MAIA at the MFP

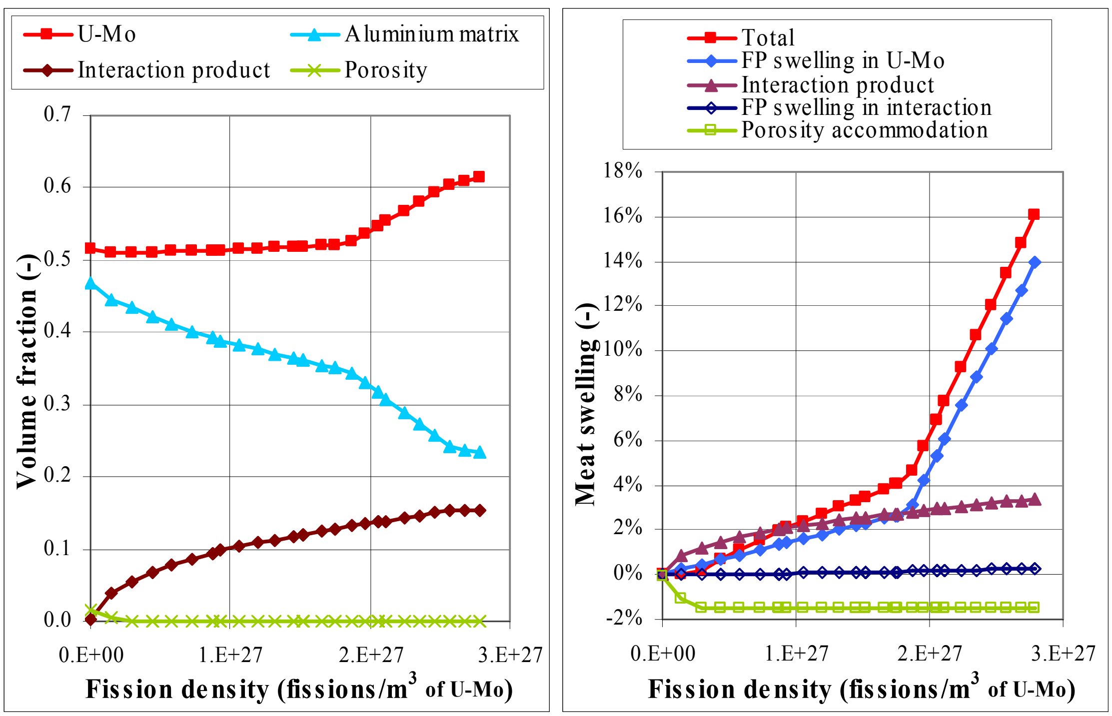

Figure 7: Volume fractions (3a) and meat swelling (3b) in the centre of the meat vs. fission density predicted by MAIA

5. Mechanical results

Mechanical calculations are performed on IRIS 2 with the hypothesis of generalized plane strains. The following results should be analysed as a parametric study to evaluate the sensitivity of some mechanical hypotheses (constitutive laws used and isotropy of meat swelling). The notation for directions of the plate are x (width), y (thickness) and z (length).
In case #1, the mechanical behaviour is elastic and the meat swelling, which is a loading for the mechanical calculation, is only applied in the plate thickness direction. The stresses calculated by MAIA (below 40 MPa) show that the cladding is in compression as the meat is in tension due to a

higher thermal expansion coefficient of the cladding (cf. Figure 8). The meat swelling doesn't generate any significant evolutions on the stresses in the middle of the plate.

In case #2, the constitutive laws used are elasto-viscoplasticity for cladding and plasticity for meat. The meat swelling is still only applied in the plate thickness. The main differences with the previous results are stress relaxation and a sign change of the stresses during inter-cycles (cf. Figure 9).

Case #3 is like case #2 but with isotropic meat swelling. It gives very different results (cf. Figure 10). After the beginning of meat swelling, meat is in compression and cladding in tension. The stresses reached in the meat are much higher that in the previous cases (the yield stress is reached in the meat). In the cladding, because of the creep, the stress remains below 50 MPa. The highest values are reached during the stops of the reactor.

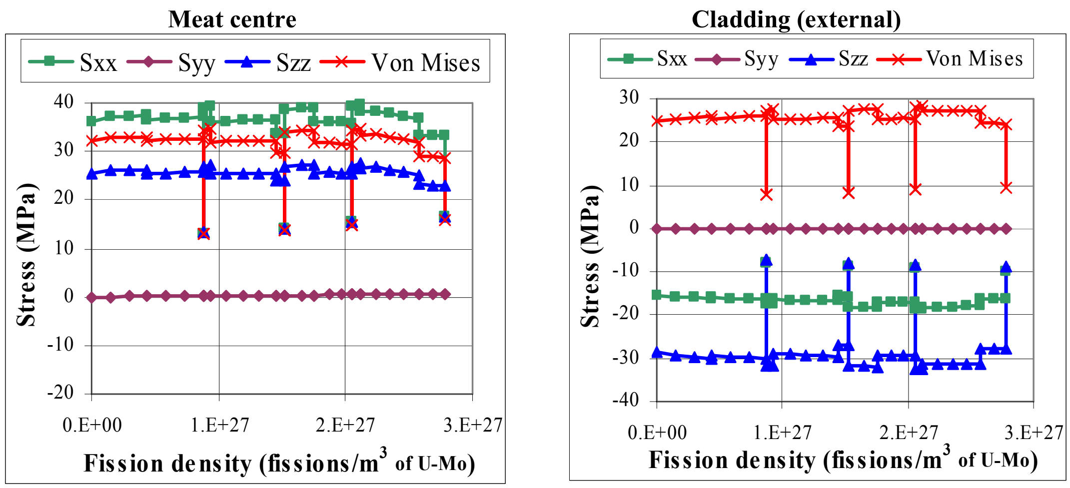

Figure 8: Stresses in meat (4a) and in cladding (4b) – Case #1

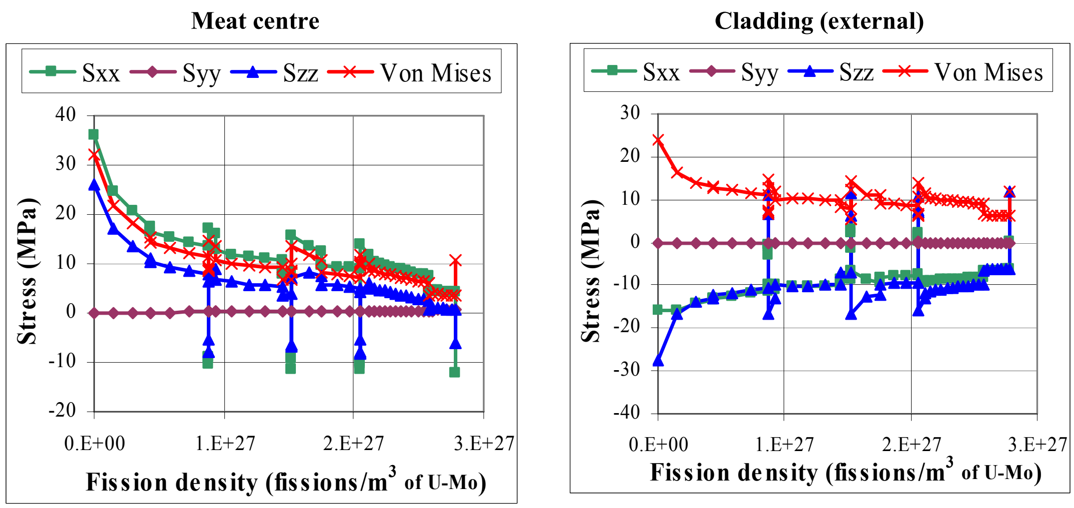

Figure 9: Stresses in meat (5a) and in cladding (5b) – Case #2

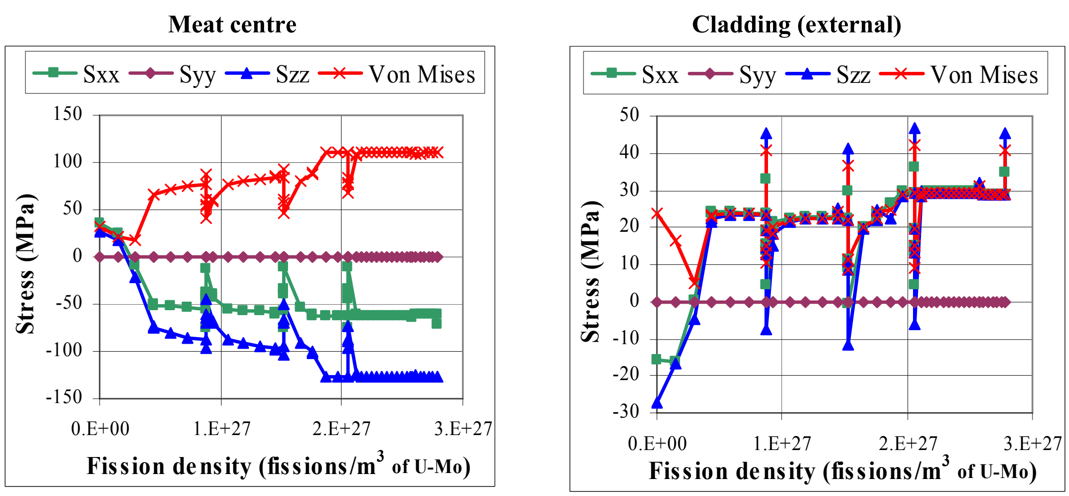

Figure 10: Stresses in meat (6a) and in cladding (6b) – Case #3

Plate thickness increase is similar for cases #1 and #2 (cf. Figure 11): viscoplastic strains are much lower than meat swelling. For IRIS 1, this increase is close to the value given by PIE. For IRIS 2, PIE cannot be compared straight with MAIA results because of the large porosities that appeared in this part of the plate and which are not modelled in MAIA.
In case #3, the plate thickness decreases because of the high strains in the width and the length of the cladding. This hypothesis does not seem very realistic.

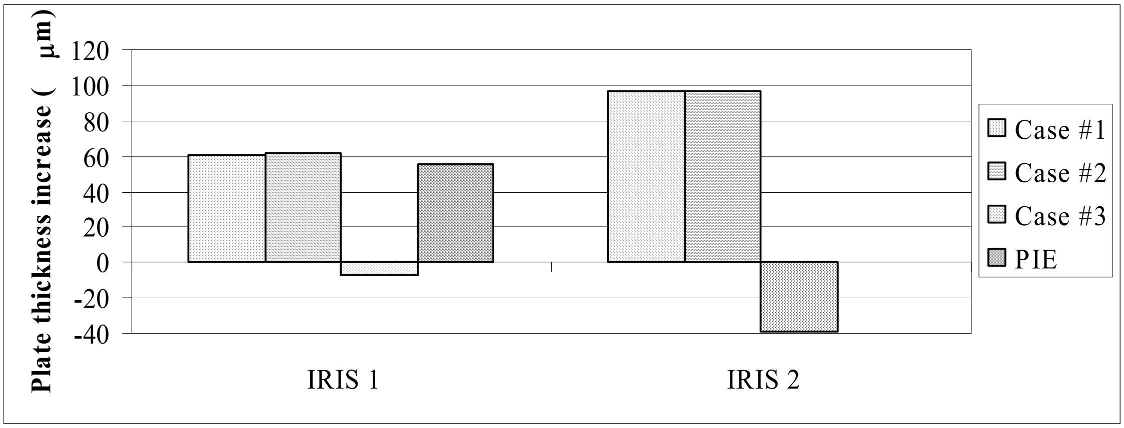

Figure 11: Plate thickness increase

6. Conclusion

MAIA can now be considered as a consistent code for U-Mo dispersion fuel plates thanks to its validation base. It can also be used for mechanical calculations. MAIA is therefore a useful tool to analyse and explain the behaviour of the U-Mo dispersion fuel plates.
Nevertheless the mechanical hypotheses have to be studied further to fix the best options for a realistic modelling. The meat swelling for instance should be mainly applied in the plate thickness.
The mechanical characterizations that are in progress will also improve the modelling through a better knowledge on the material properties of the meat and the cladding.

7. References

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