Analysis of material buckling experiments performed in the masurca facility in support of the astrid sfr prototype core balance

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ANALYSIS OF MATERIAL BUCKLING EXPERIMENTS PERFORMED IN THE MASURCA FACILITY IN SUPPORT OF THE ASTRID SFR PROTOTYPE CORE BALANCE

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ABSTRACT

Sodium Fast Reactors (SFR) are the solution for long term development of nuclear energy production as it allows the use of the entire Uranium ore and enables to burn long live radioactive waste. Since the neutron balance of the core is badly known due to the lack of accuracy in evaluated nuclear data, the material buckling offers a way to improve that situation. Indeed the material buckling is experimentally accessible from the curvatures of the different fission rate traverses in cores built in the MASURCA critical facility.

This analysis takes advantage of the use of recent deterministic codes with a detailed assessment of the experimental uncertainty. This uncertainty is significantly smaller than the one associated to nuclear data. Hence, this offers the opportunity of reducing nuclear data uncertainties when the experimental material buckling from different MASURCA cores such as 1A', 1B, R2 and Z2 will be analyzed. The prediction of the material balance of the ASTRID (Advanced Sodium Technological Reactor for Industrial Demonstration) SFR core will then be significantly improved.

Key Words: **Material Buckling Experiments, MASURCA, ERANOS.**

1. INTRODUCTION

Unfortunately, the neutron balance of Sodium Fast Reactor (SFR) cores is badly known due to the lack of accuracy in evaluated nuclear data. This is the case for the material balance of the ASTRID (Advanced Sodium Technological Reactor for Industrial Demonstration) SFR core under detailed development at CEA. The material buckling offers a way to improve that situation when experimentally accessed from the curvatures of the different fission rate traverses in cores built in the MASURCA critical facility. This provides access to the neutron balance of the fissile zone, whereas the critical mass, much easier to obtain experimentally, depends also on the neutron reflection to the peripheral areas of the core. This analysis takes advantage of the use of recent deterministic codes with a detailed assessment of the experimental uncertainty.

In the following, we get access to the material buckling of 4 different MASURCA cores: 1A ', 1B, R2 and Z2 in order to illustrate the gain we can achieve for the material balance through the analyses of such experiments. First, we describe the necessary steps to get the experimental material buckling (Chapter 2) which is related to the curvature of the average leaking neutrons which is derived by simulation from the curvatures of observables. Experimental uncertainties are related to these steps and to those related to the observables (Chapter 3). Ultimately, comparing these experimental results with those from simulations will be described and commented (Chapter 4).

2. EXPERIMENTAL MATERIAL BUCKLING CHARACTERISATION

2.1 Methodology

The MASURCA facility is designed so as to build different cores of different compositions [1]. This is necessary since there is a wide range of fast reactor cores which needs to be investigated. The cores being studied here are cores representative of gas cooled fast reactor and sodium-cooled cores. In each of these different designs, Uranium enriched and mixed Uranium-Plutonium cores have been built. These cores offer a wide range of fast reactor spectrum and compositions [2].

In these different cores, reaction rate traverses have been measured through axial and radial channels with Pu239, U235, Np237 and U238 fission chambers.
These fission rate traverses exhibit different curvatures as it can be seen on the Figure 1.

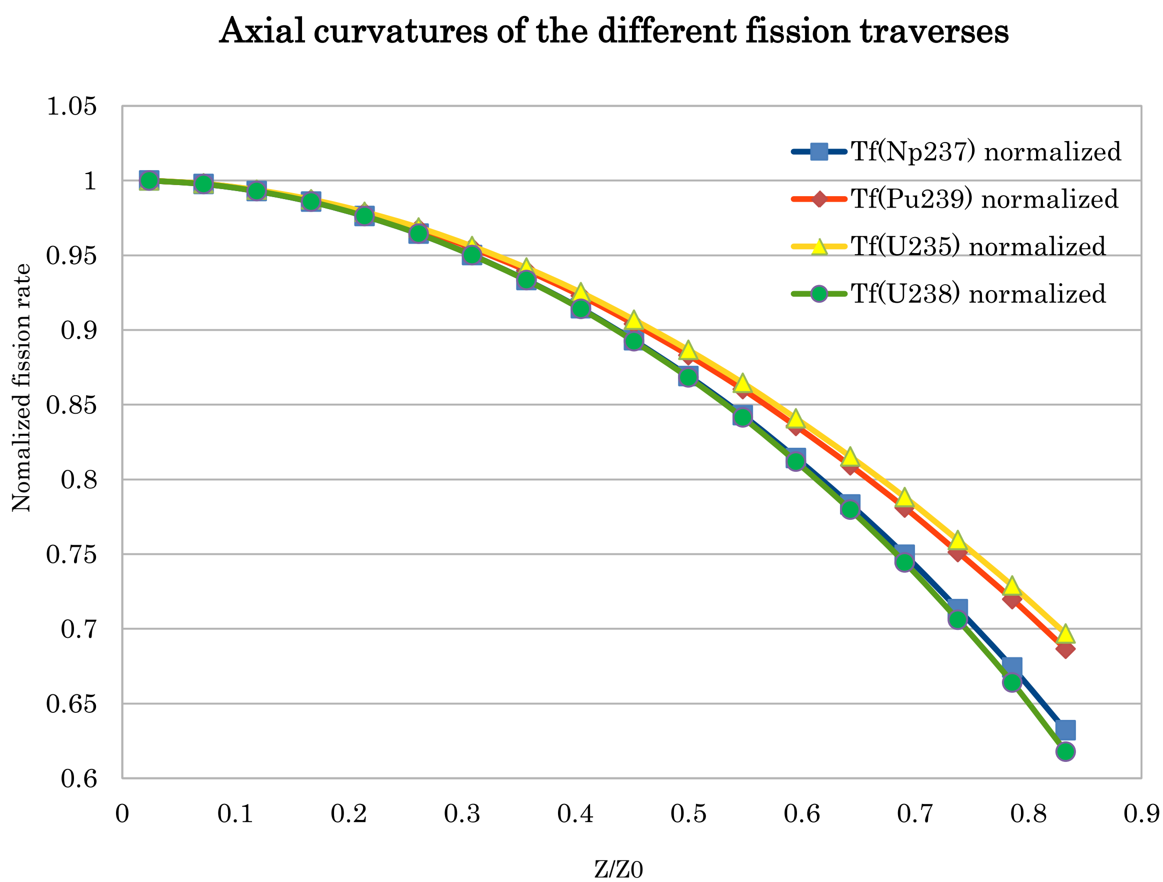

Figure 1: Axial curvatures of the different fission traverses for the MASURCA 1 A' core

Indeed, fast neutrons can escape from the core more easily. Hence, fission reactions rate with threshold energy (U238, Np237) have a sharper curvature. The material buckling corresponds to the curvature of the average leaking neutrons which is given by a computed response $D.\Phi_1^+$, where D is the diffusion coefficient and Φ_1^+ is the neutron importance.

Within the ERANOS code and data system [3], the calculated material buckling can be obtained either within the cell code (here ECCO) by the search of the value which gives the balance critical or within the core calculation (here BISTRO) by studying the traverses of the response function $D.\Phi_1^+$ of the full core. The agreement is almost perfect between these 2 approaches when using the B1 consistent method for calculating the neutron balance in ECCO and when making the core critical by adjusting its dimensions as it can be seen in the Table 1.

Table 1 : Equivalence between the ECCO buckling and the one obtained from the response function $D.\Phi_1^+$.

with JEFF3.1(in pcm)	1A’	1B	Z2	R2
Discrepancy between the ECCO buckling and the one obtained from traverses	51	58	194	216

The experimental material buckling ($B_m^2(D.\Phi_1^+)$) is obtained by projection of numerical simulations on experiments, simulation being performed with the deterministic code ERANOS [3] with the JEFF3.1.1 nuclear data evaluation [4].
An example of such interpolation is being given in Figure 2.

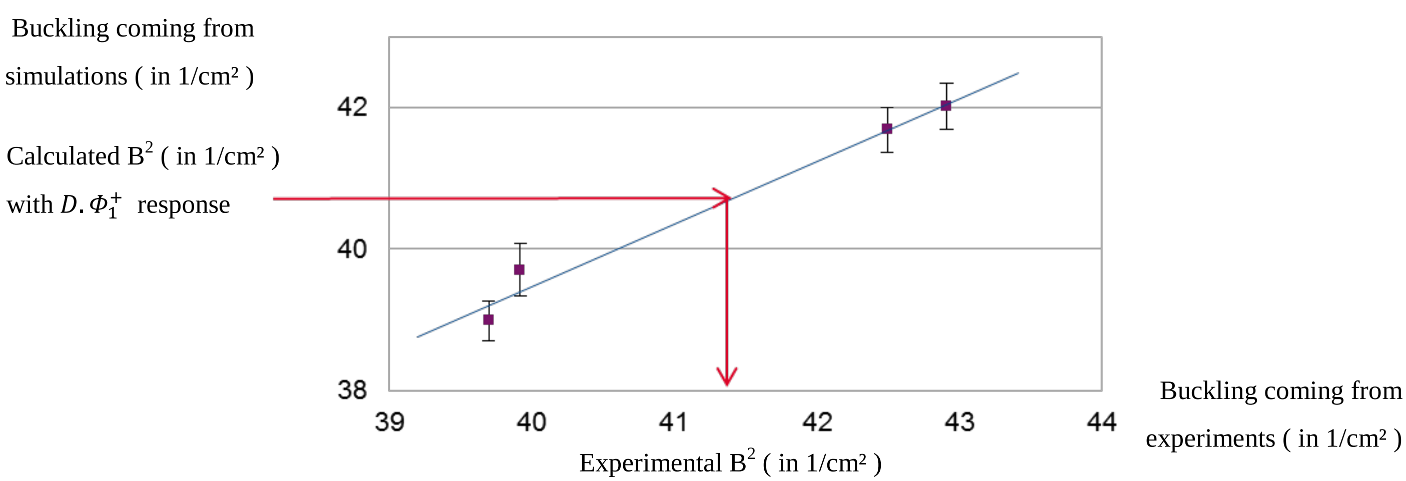

Figure 2: Experimental buckling characterization through the use of the different fission traverse curvatures (calculated and experimental) for the MASURCA 1 A’ core

2.2 Experimental buckling

Calculations of the fission rate traverses are performed with ERANOS with JEFF3.1.1 nuclear data. The curvatures of the different fission rate traverses are presented in Table 2 together with calculated buckling.

Table 2 : Results of simulations performed in Sn transport

(en 1/m²)	1A'	1B	R2	Z2
B²(Np 237)	**42.083**	**44.158**	**X**	**27.957**
B²(Pu 239)	**39.190**	**41.497**	**X**	**25.469**
B²(U5)	**38.731**	**40.804**	**21.787**	**24.957**
B²(U8)	**42.382**	**44.481**	**24.353**	**28.429**
Calculated B²m	**39.817**	**41.681**	**22.896**	**25.989**

We can now proceed with the projection of simulation results on experiments so as to get the experimental buckling. The following table 3 shows the experimental material buckling which are ultimately obtained by interpolation (B²m (exp)) for the different MASURCA cores.

Table 3 : Experimental buckling derived from Experimental fission rate traverses.

		1A'	1B	R2	Z2
B²m (exp)	in 1/m²	39.596	42.047	22.819	25.898

3. UNCERTAINTY ESTIMATION

The calculated values are tainted with uncertainty due to methods and nuclear data. The formers are assessed by comparing standard calculations with those obtained by Monte Carlo calculations (not treated in this work) while the latter are obtained by propagating nuclear data uncertainties to the different neutronic values. The deterministic code ERANOS calculates the sensitivities of the neutronic values to nuclear data with either the direct perturbation method or with the generalized perturbation method [5]. The latter is used to calculate the sensitivity of the curvatures of the different reaction rates to nuclear data. This is done with the ratio of the reaction rates at a peripheral position to the one located at the center. With the sandwich formula using the COMAC covariances associated to nuclear data [6], one can derive the uncertainties on the axial and radial curvatures of the different reaction rate traverses.
This analysis for 1A’ as an example gives in Table 4 the associated uncertainties with dTr and dTz being respectively the uncertainty on radial and axial curvatures.

Table 4: Uncertainties associated to the nuclear data for the 1A' core

Isotope of the fission chamber	dTr or dTz in %		dB^2 (in $1/m^2$)
Np237	dTr=	1.471E-01	0.30
	dTz=	1.130E-01	
Pu239	dTr=	1.776E-01	0.36
	dTz=	1.393E-01	
U235	dTr=	1.875E-01	0.38
	dTz=	1.481E-01	
U238	dTr=	1.487E-01	0.30
	dTz=	1.125E-01	

Correlations between the curvature uncertainties of these different fission rate traverses are also calculated. These correlations are presented in the Table 5 for the 1A' core.

Table 5: Uncertainty correlations associated to the nuclear data for the 1A' core

Correlation coefficients for the 1A' core				
	B^2(U235)	B^2(Pu239)	B^2(Np237)	B^2(U238)
B^2(U235)	1.000	0.988	0.896	0.934
B^2(Pu239)	0.988	1.000	0.939	0.958
B^2(Np237)	0.896	0.939	1.000	0.968
B^2(U238)	0.934	0.958	0.968	1.000

These correlations are all close to 1 which means that there are truly representative of the fundamental mode of the core. This gives ground to the derivation of the material buckling; all the processes being defined until then are only a way to be more accurate in the definition of the material buckling.

Uncertainties on the experimental fission rate traverses include uncertainties on the composition, on the statistics of count rates and on the positioning of fission chambers.
For the uncertainty on compositions, we use a report from the manufacturing fuel department which gives an uncertainty on the linear density of the fuel of 0.35%.
The positioning of the fission chambers is achieved through mechanical stops that give their positioning at the tenth of a millimeter. The uncertainty on the fission rate traverses curvatures is achieved through the most disadvantageous shifts positions which increase or decrease the curvature.
Count rates of the different fission chambers are recorded between 250 000 and 300 000 times. This corresponds to a statistical error in $1/\sqrt{N}$ equal to 0.2%. The impact of this statistical uncertainty on the different fission rate traverses curvatures is performed using a stochastic approach.

In summary, the uncertainties on the compositions, on the statistics of count rates and on the positioning of fission chambers are given in Table 6 for the different fission rate traverses curvatures of the 1A' core.

Table 6 : Experimental uncertainties on the fission rate traverses of the 1A' core

Isotope / dB^2 (en $1/m^2$)	Uncertainty on compositions	Uncertainty on fission counter positioning	Uncertainty on counting rate statistics
Np237	0.001	0.055	0.061
Pu239	0.001	0.082	0.063
U235	0.001	0.068	0.062
U238	0.002	0.055	0.071

These experimental uncertainties are relatively small compared to the one induced by the nuclear data uncertainty. However, this last one could be improved in the future with better evaluated data.

In Table 7, we present the experimental material buckling and their associated uncertainties. These have been obtained from the interpolation with a Monte Carlo method taking into account the uncertainties associated with the different experimental curvatures.

Table 7: Experimental material buckling and their associated global uncertainties for the different MASURCA cores.

(in $1/m^2$)	1A'	1B	R2	Z2
B^2	39.596	42.047	22.819	25.898
ΔB^2 exp (in $1/m^2$)	0.347	0.755	0.352	0.407
ΔB^2 exp (in pcm)	348	672	618	739

This overall uncertainty is of a few hundred of pcm on k_∞ keeping in mind that this could be significantly reduced if uncertainties in nuclear data are reduced. Another solution to acquire more accurate information from the experiments is to use directly experimental fission rate traverses. In this case, the uncertainty due to nuclear data in the methodology to derive the experimental buckling will be eliminated.

4. COMPARISON OF CALCULATIONS WITH EXPERIMENTS

The comparison of the calculated buckling (derived from the calculated traverses) to the experimental one is performed for the different MASURCA cores: 1A', 1B, R2 and Z2. Results are given in Table 8.

Table 8 : Calculation-Experiment Discrepancies

Discrepancy (Experiment-Calculation)/Experiment in transport theory					
		1A'	1B	R2	Z2
$(B^2m\ (exp) - B^2m\ (calc)) / B^2m\ (exp)$	ΔB^2 (pcm)	-221	326	-136	-165

These differences are less than the experimental uncertainty and therefore the simulations are well representing the experiments. This comprehensive agreement actually hides compensating errors that can be identified by subsequent sensitivities studies.

A buckling sensitivity study to nuclear data has been carried out with direct perturbation. With the sandwich formula using the COMAC covariances associated to nuclear data [6], the study gives quite high uncertainties (especially for Uranium enriched cores). The resulting uncertainties are presented in the following table 9 together with the global experimental uncertainties for comparison.

Table 9: Comparison of uncertainties due to nuclear data on the calculated buckling and those on the experimental buckling

in pcm	1A'	1B	R2	Z2
ΔB^2 due to ND	1235	2704	2570	1371
ΔB^2 exp	348	672	618	739

As can be seen in this Table 9, the overall experimental uncertainties are well below those due to nuclear data. This offers the opportunity of reducing nuclear data uncertainties and hence, the prediction of the material balance of the ASTRID (Advanced Sodium Technological Reactor for Industrial Demonstration) SFR core will then be significantly improved [7].

5. CONCLUSIONS

The development of the SFR requires a better knowledge of the neutron balance of their cores and therefore more accurate nuclear data than the ones provided by evaluators. The material buckling as measured in critical facilities as MASURCA can improve that situation. The material buckling is a characteristic of the critical core and gives access to the neutron balance. The experimental value of the material buckling is obtained thanks to the curvatures of the measured axial and radial fission rate traverses and to the projection from simulation results on experimental ones.
This allows access to the neutron balance of the fissile zone whereas the critical mass much easier to obtain experimentally depends also on the neutron reflection to the peripheral areas of the core. This analysis takes advantage of the use of recent deterministic codes with a detailed assessment of the experimental uncertainty.
Contributors to this uncertainty are the derivation of the synthetic value but also of temperature stabilization, the local effect of structural tubes, the presence of steel plug and others. This uncertainty is significantly smaller than the one associated to nuclear data. Hence, this offers the opportunity of reducing nuclear data uncertainties with the experimental material buckling from different MASURCA cores such as 1A '. 1B. R2 and Z2 analyzed.
This work will continue as part of a PhD topic with more MASURCA experiments being analyzed with the aim of better predicting the material balance of the ASTRID (Advanced Sodium Technological Reactor for Industrial Demonstration) SFR core.

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