ANALYSIS OF THE CREOLE EXPERIMENT ON THE REACTIVITY TEMPERATURE COEFFICIENT OF THE UO_2 LIGHT WATER MODERATED LATTICES USING MCNP6.1

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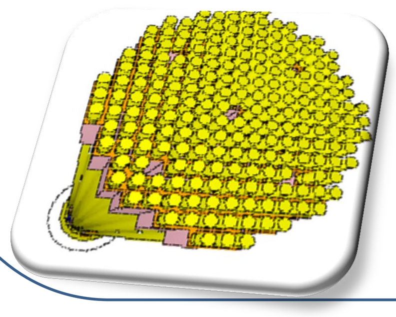

ABSTRACT

The CREOLE experiment have allowed us to get interesting and complete experimental information on the temperature effects in the light water reactor lattices.
To analyze their experiments with accuracy an elaborate calculation scheme using the Monte Carlo method implemented in the MCNP6.1 code and the ENDF/B-VII.1 cross section library has been developed. We have used the ENDF/B-VII.1 data provided with the MCNP6.1.1 version in ACE format and the Makxsf utility to handle the data in the specific temperatures not available in the MCNP6.1.1 original data.
We have analyzed the case of UO2 lattice with 1166 ppm of boron in the ordinary water moderator in specified temperatures. A detailed comparison of the calculated effective multiplication factors with the reference ones [1] in room temperature presented in this work shows a good agreement demonstrating the validation of our 3D modelization.
The discrepancies C - E on the Reactivity temperature Coefficient for the analyzed configuration are relatively small. In addition to the analysis of direct differential measurements of the reactivity temperature coefficient, we have also analyzed integral measurements using equivalency of the integral temperature reactivity worth with the driver core fuel reactivity worth and soluble boron reactivity worth.

CREOLE

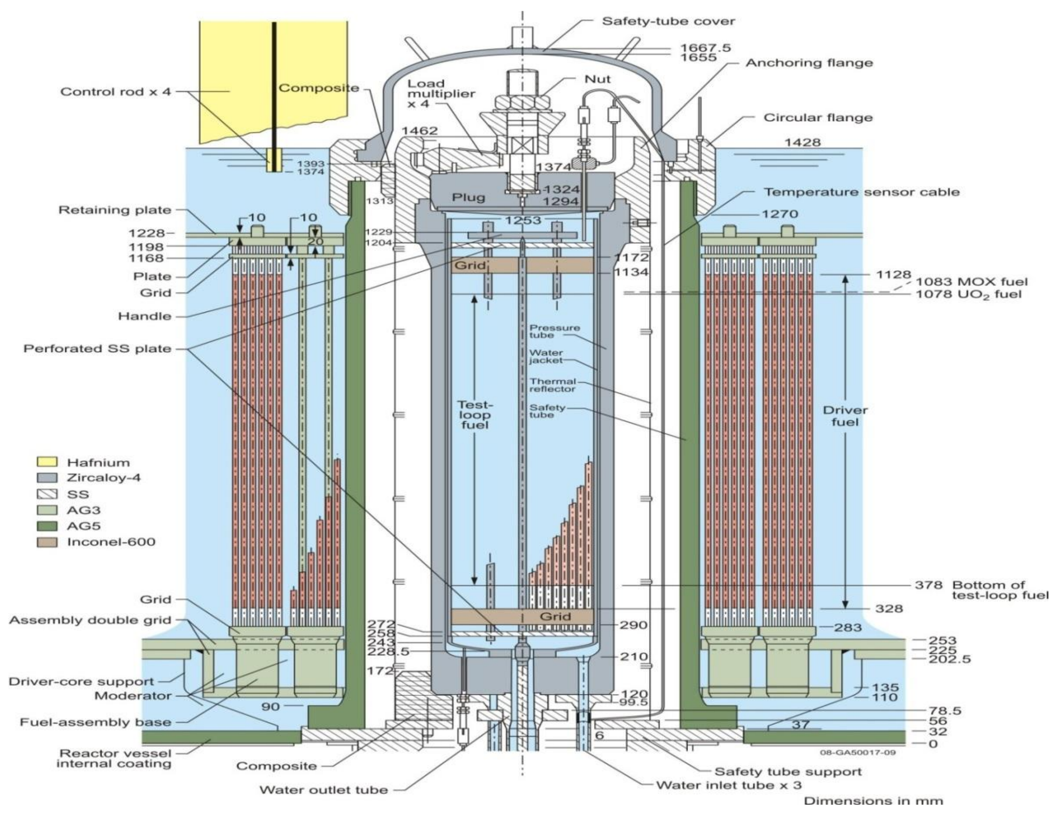

***Figure 1:** Axial cross section of CREOLE reactor*

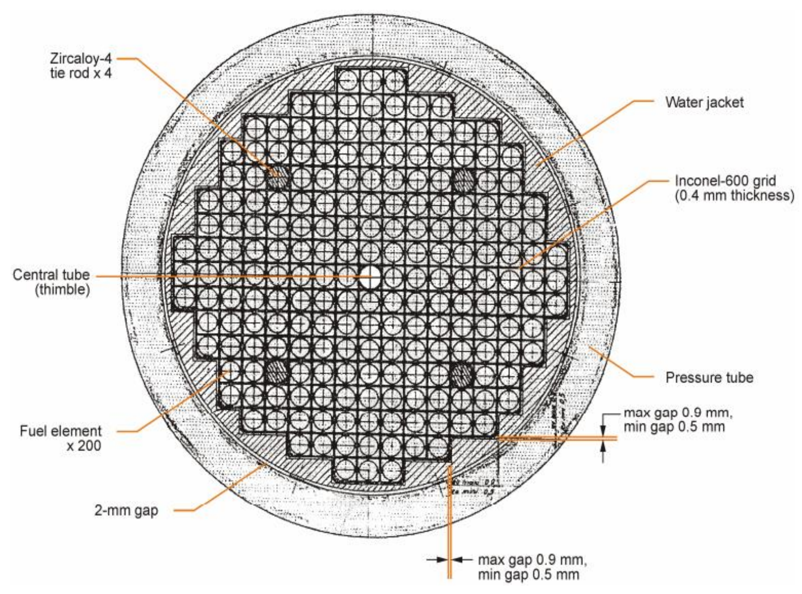

***Figure 2:** Radial cross section of the central loop*

Table I: *Critical sizes at room temperature*

Core configuration	Driver-core temperature (°C)	Central-loop temperature (°C)	Central-loop pressure (bar)	Doubling time (s)	Residual Reactivity (pcm)	Driver-core size (fuel rods)
UO_2 reference	18.5 ± 0.2	20.27 ± 0.2	93.2 ± 0.5	7.06 ± 0.2	312 ± 13	1620
UO_2 1166 ppm boron	19.6 ± 0.2	21.83 ± 0.2	66.5 ± 0.5	6.86 ± 0.2	316 ± 13	1772

UO_2 configuration with 1166 ppm of soluble boron

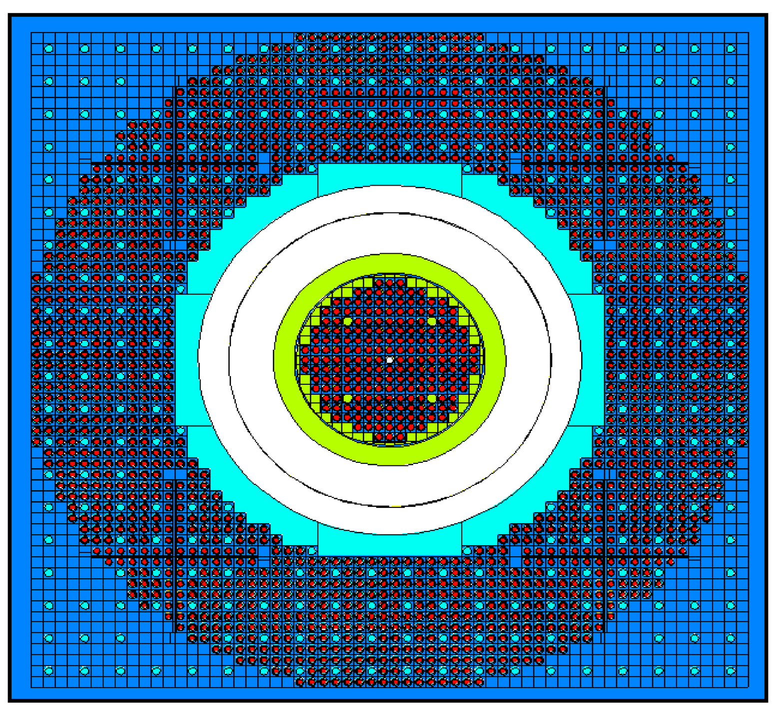

***Figure 3:** Radial cross section of the CREOLE using MCNP code (at all temperatures) – 1772 driver fuel rods.*

Table II : *k_{eff} calculation and experiment comparison at room temperature.*

	Experiment [1]	Model-Benchmark [1,8]	MCNP6.1 ENDF/B7.1	TRIPOLI 4.5 JEFF3.1.1 [1]
k_{eff}	1.00299 ±0.00182	1.00328 ±0.00183	1.00452 ±0.00004	1.00556 ±0.00010

for: 20°C ≤ T ≤ 300°C

$$\rho_{MCNP} = -5.38951\ 10^{-18}\ T^6 + 4.94248\ 10^{-15}\ T^5 - 1.76762\ 10^{-12}\ T^4 + 2.64586\ 10^{-10}\ T^3 + -1.56852\ 10^{-8}\ T^2 + 4.9992\ 10^{-7}\ T - 0.00224$$

Table III : *Analysis of the Differential Measurements of the RTC and (C-E)*

a and C-E (pcm/°C)	20 °C – 111 °C	111 °C – 186 °C	186 °C – 242 °C	242 °C – 296 °C
EXPERIENCE (a) [1]	+ 0.02 ± 0.04	- 0.12 ± 0.04	- 0.35 ± 0.05	- 0.67 ± 0.06
MCNP6.1 (ENDF/B7.1) (C – E)	- 0.08 ± 0.04	+ 0.11 ± 0.04	- 0.02 ± 0.05	+ 0.04 ± 0.06
TRIPOLI4 (JEFF3.1.1) (C -E) [1]	- 0.10 ± 0.06 (0.04)*	+ 0.08 ± 0.06 (0.05)*	- 0.01 ± 0.09 (0.07)*	+ 0.05 ± 0.10 (0.08)*

Table IV : *integration of the differential measurements of RTC and (C-E)*

C-E (pcm/°C)	UO_2 (1166 ppm de bore) 20°C – 296°C
EXPERIENCE (a) [1]	- 0.22 ± 0.02
MCNP6.1 (ENDF/B-VII.1)	- 0.008 ± 0.06
TRIPOLI4 (JEFF3.1.1)	- 0.004 ± 0.07

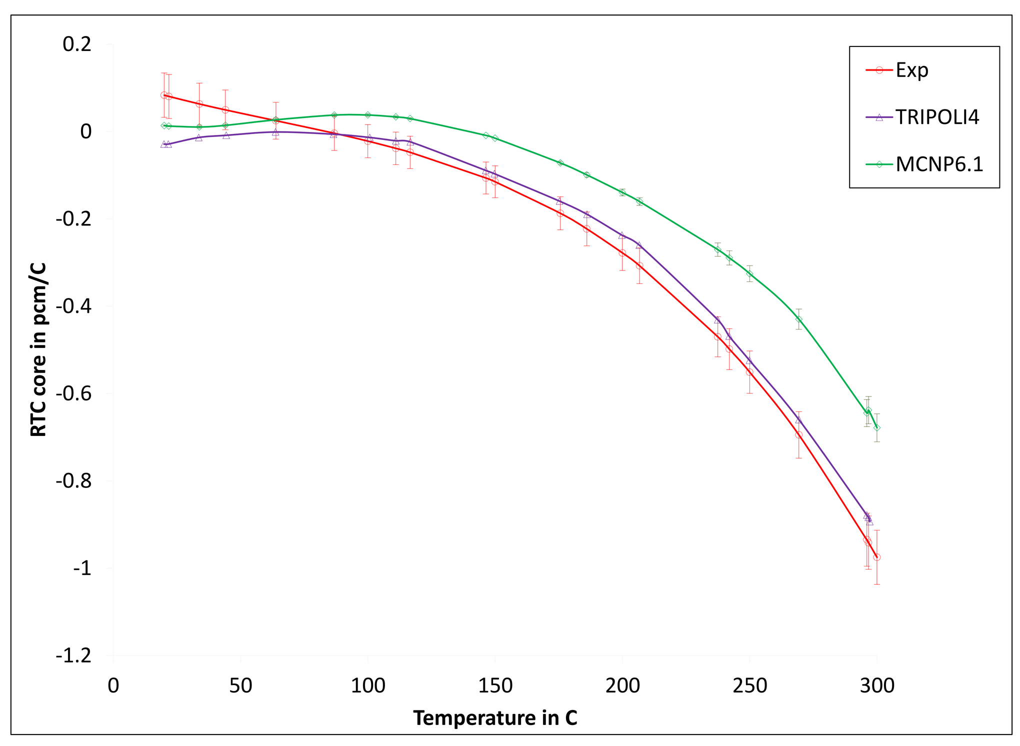

***Figure 4:** Radial Calculated and measured RTC as a function of the loop temperature with fitting curves.*

UO_2 Clean Lattice

Equivalency Between the Temperature Reactivity Worth and Driver Core Fuel Reactivity Worth

Table V : *Benchmark model parameters [1].*

	State A	State B
Residual measured reactivity (pcm)	295	
Driver core loading (rods)	1620	1680
Central loop temperature (°C)	20.27	243.22

Table VI :*The keff for the two states and the calculation bias of the average RTC*

		State A	State B
k_{eff} ± Std (pcm)	MCNP6.1 (ENDF/B7.1)	1.00224 ± 4	1.00221 ± 4
	MCNP6.1 (JENDL-4)	1.00164 ± 4	1.00184± 4
$[\bar{\alpha}_{calc} - \bar{\alpha}_{meas}]$ (pcm/°C)	MCNP6.1 (ENDF/B7.1)	- 0.013 ± 0.06	
	MCNP6.1 (JENDL-4)	+ 0.089 ± 0.04	
	TRIPOLI4 (JEFF3.1.1)	- 0.02 ± 0.05	

$$[\bar{\alpha}_{calc} - \bar{\alpha}_{meas}] = \frac{1}{\Delta T}\left[\frac{(K_{eff})_B - (K_{eff})_A}{(K_{eff})_A . (K_{eff})_B}\right]$$

Equivalency Between the Temperature Reactivity Worth and the Boron Reactivity Worth

Table VII :*Benchmark model parameters [1].*

	State A	State B
Driver core loading (rods)	1680	
Residual measured reactivity (pcm)	139	
Central loop temperature (°C)	18.4	273.51
Boron content (ppm)	454±2	0.

Table VIII :*The keff for the two states and the calculation bias of the average RTC*

		State A	State B
k_{eff} ± Std (pcm)	MCNP6.1 (ENDF/B7.1)	1.00109 ± 4	1.00086 ± 4
	MCNP6.1 (JENDL-4)	1.00063 ± 4	1.00039 ± 4
$[\bar{\alpha}_{calc} - \bar{\alpha}_{meas}]$ (pcm/°C)	MCNP6.1 (ENDF/B7.1)	- 0.09 ± 0.04	
	MCNP6.1 (JENDL-4)	- 0.09 ± 0.04	
	TRIPOLI4 (JEFF3.1.1)	- 0.15 ± 0.06	

Conclusion

The obtained results for the prediction of critical sizes at room temperature show a good agreement between the MCNP6.1 code and the reference ones, which validates our Monte Carlo modeling and assure us for the prediction of the RTC with sufficient accuracy.
The discrepancies between calculations and experiment on the RTC for clean and Boron poisoned UO_2 LWR lattices is small, less than 1 pcm/°C which corresponds to the current target accuracy in LWR design calculations. we should particularly mention the coherence of the results obtained by different type of measurements: direct differential measurements and integral measurements through equivalency.

References