Experimental and modelling neutron fluxes characterization of the carousel irradiation channels in the TRIGA MARK I IPR-R1 reactor, Brazil

Maria Ângela de B. C. Menezes [1a], Radojko Jaćimović [2]

Rita C.O. Sebastião[1b], Alexandre S. Leal[1b],

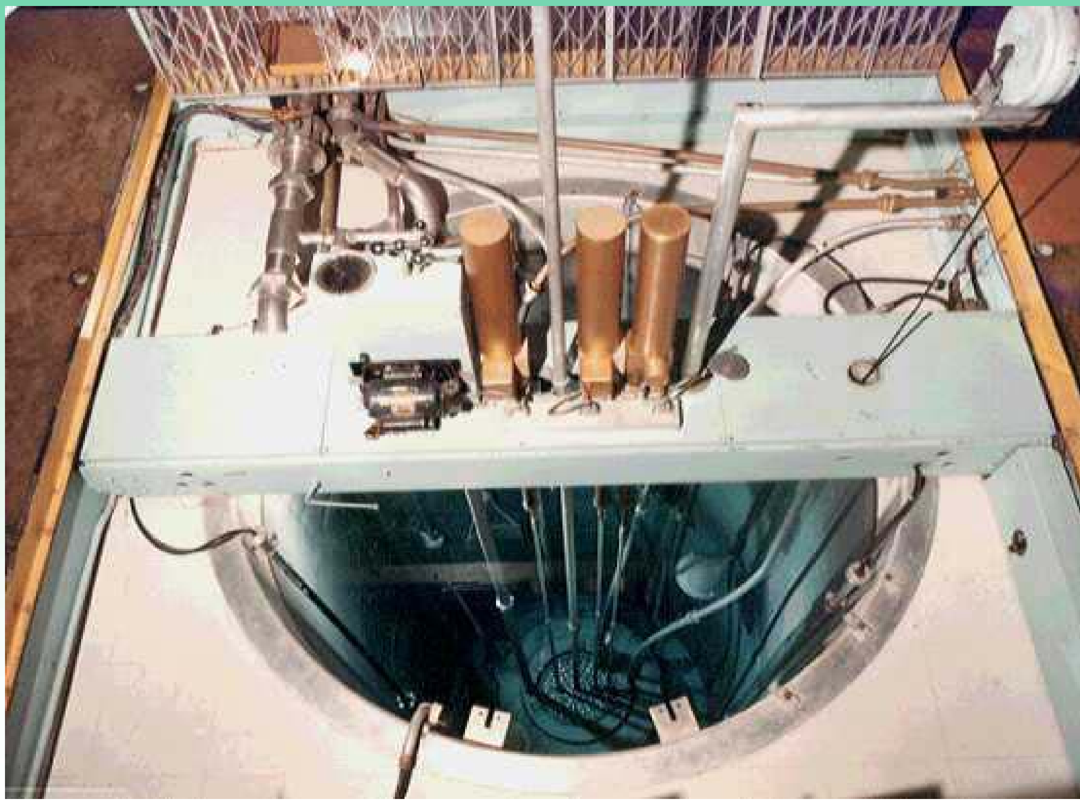
Rose Mary M. G. P. Souza[1b]

[1]Nuclear Technology Development Centre/
Brazilian Commission for Nuclear Energy (CDTN/CNEN)
[a] Laboratory for Neutron Activation Analysis,
[b] Laboratory for Nuclear Measurements
Belo Horizonte, Minas Gerais, Brazil

[2]Jožef Stefan Institute, Department of Environmental Sciences
Ljubljana, Slovenia


Belo Horizonte

Laboratory for Neutron Activation Analysis



1960

Since the starting up of Reactor TRIGA MARK I IPR-R1

Private clients

Universities

from all over the Country

National Research Centres

LNAA

Industries

Meeting the clients' analytical needs and researches developed by the LNAA, by CDTN and by other institutions

MAIN TASKS:

- ✓ carry out the routine analysis
- ✓ optimise the routine analysis
- ✓ develop new analytical procedures

Matrixes analysed

instrumental and radiochemical methods

sediment

water

food

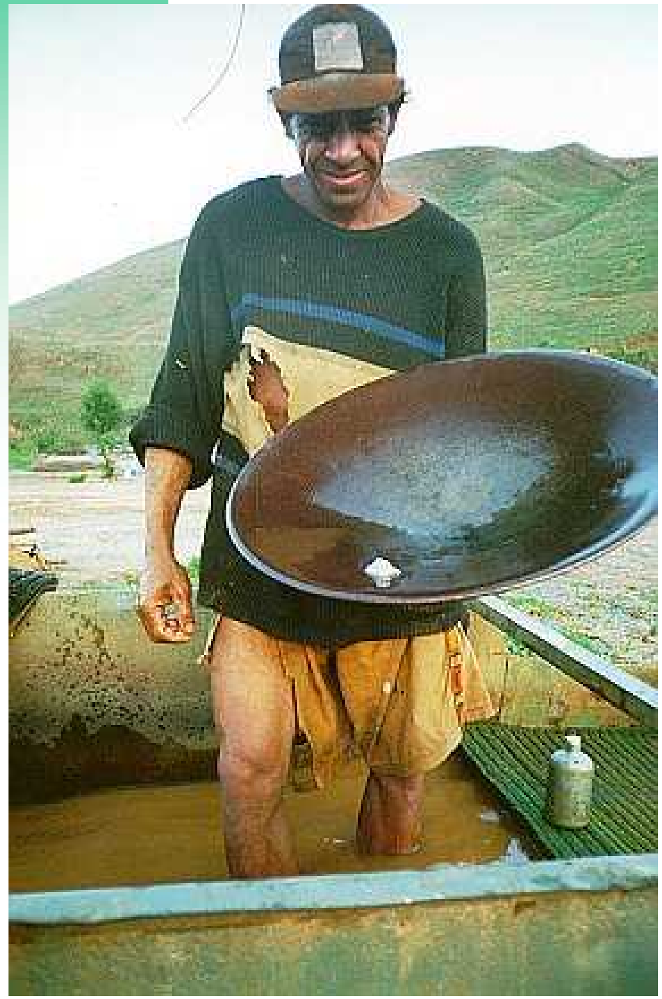
industrial effluent

ore

air filter

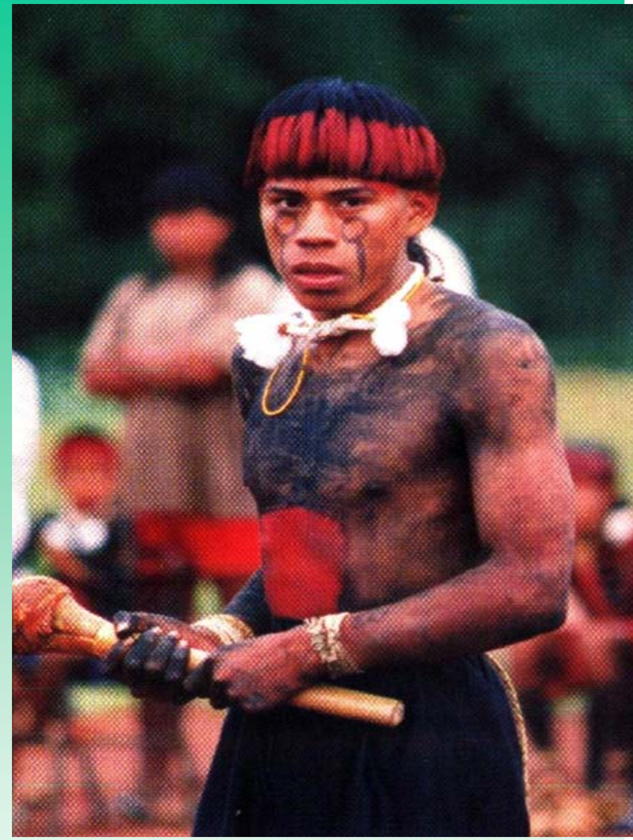
soil

plant



“garimpo” materials

ceramic and clay from Amazon region



assess the exposure and contamination levels in industry

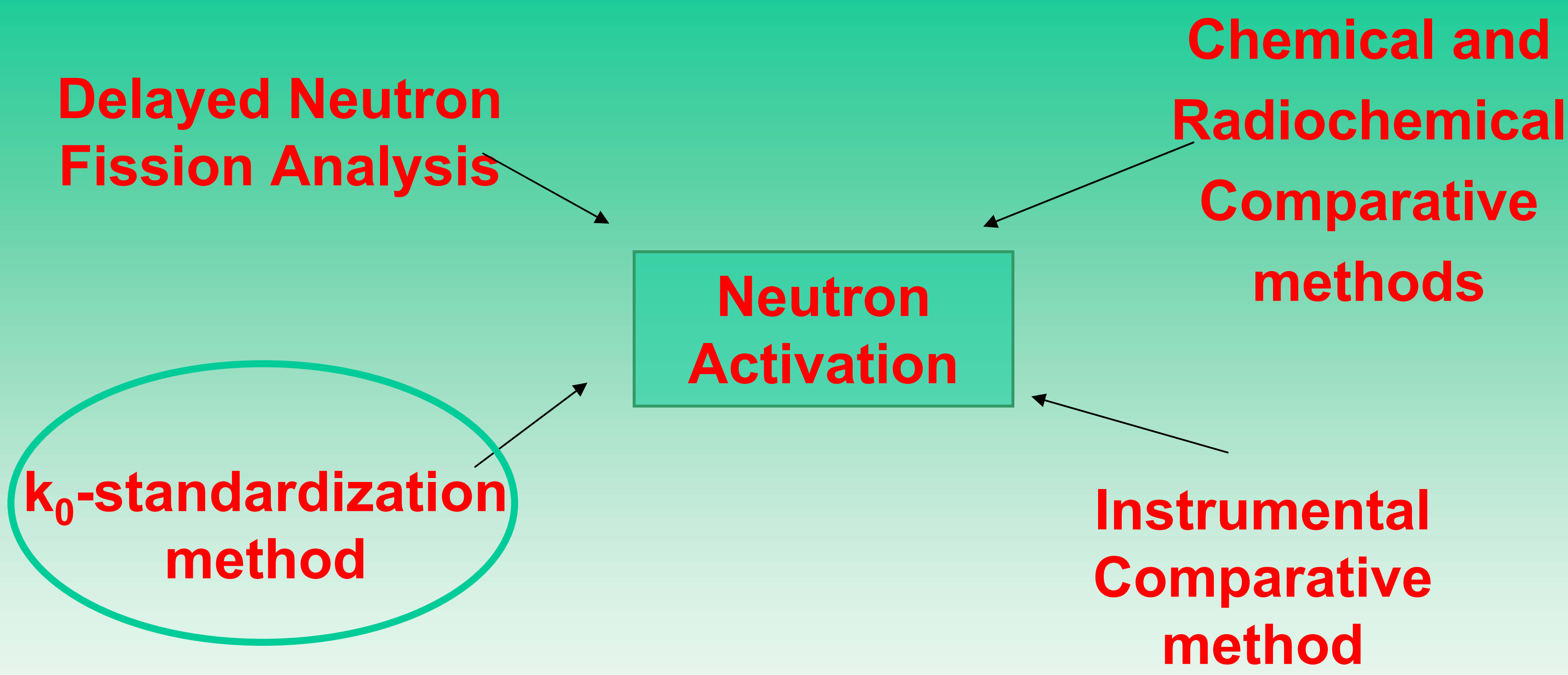
2006: carried out 1.200 samples → 20.000 determinations

This scenery enhances the responsibility of the LNAA/CDTN in providing and assuring the quality of the measurements

Due to the commitment with the quality of the results, this Laboratory is constantly working on improving the methods applied, mainly k_0-INAA

CNEN

CDTN



has been applied in 90% of the all neutron activation analysis demand

In Brazil, CDTN is the only Institute that fully masters the use of the k_0-INAA and its own nuclear reactor TRIGA MARK I IPR-R1

k_0-INAA

✓ 1995 was implanted

- collaboration of Dr. Eduardo Montoya (IPEN-Peru),

ARCAL/IAEA Project

✓symmetry of the core configuration and the rotary rack, no variations in neutron flux distribution in different channels were taken into account

✓average *f* and α

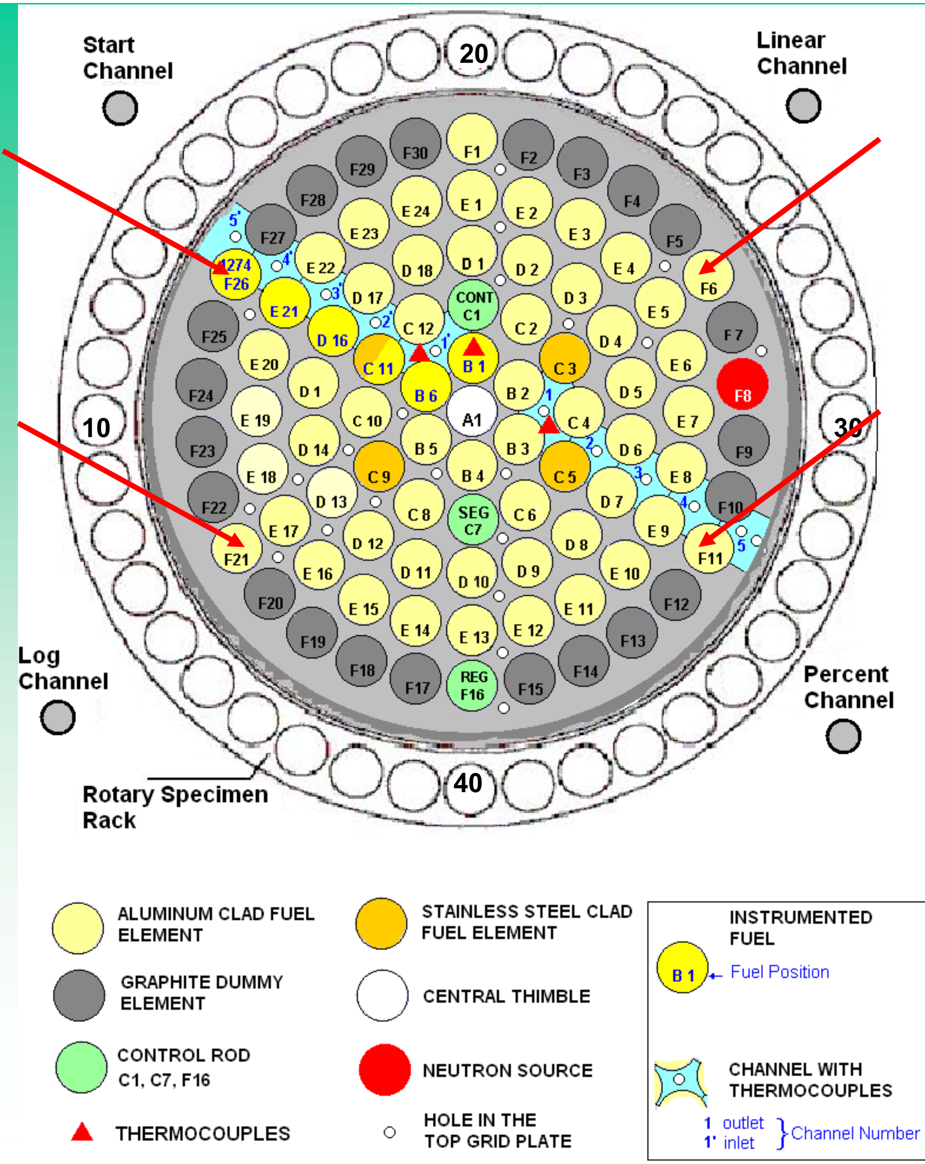
✓average *thermal neutron flux*

k_0-INAA

2001: new configuration changes → to increase the power to 250kW

mechanical problem in the rotary system

it was decided to rotate the CF only when inserting samples in the irradiation channels



k_0-INAA

✓ 2003 was re-establish and optimised

✓ Hyperlab software

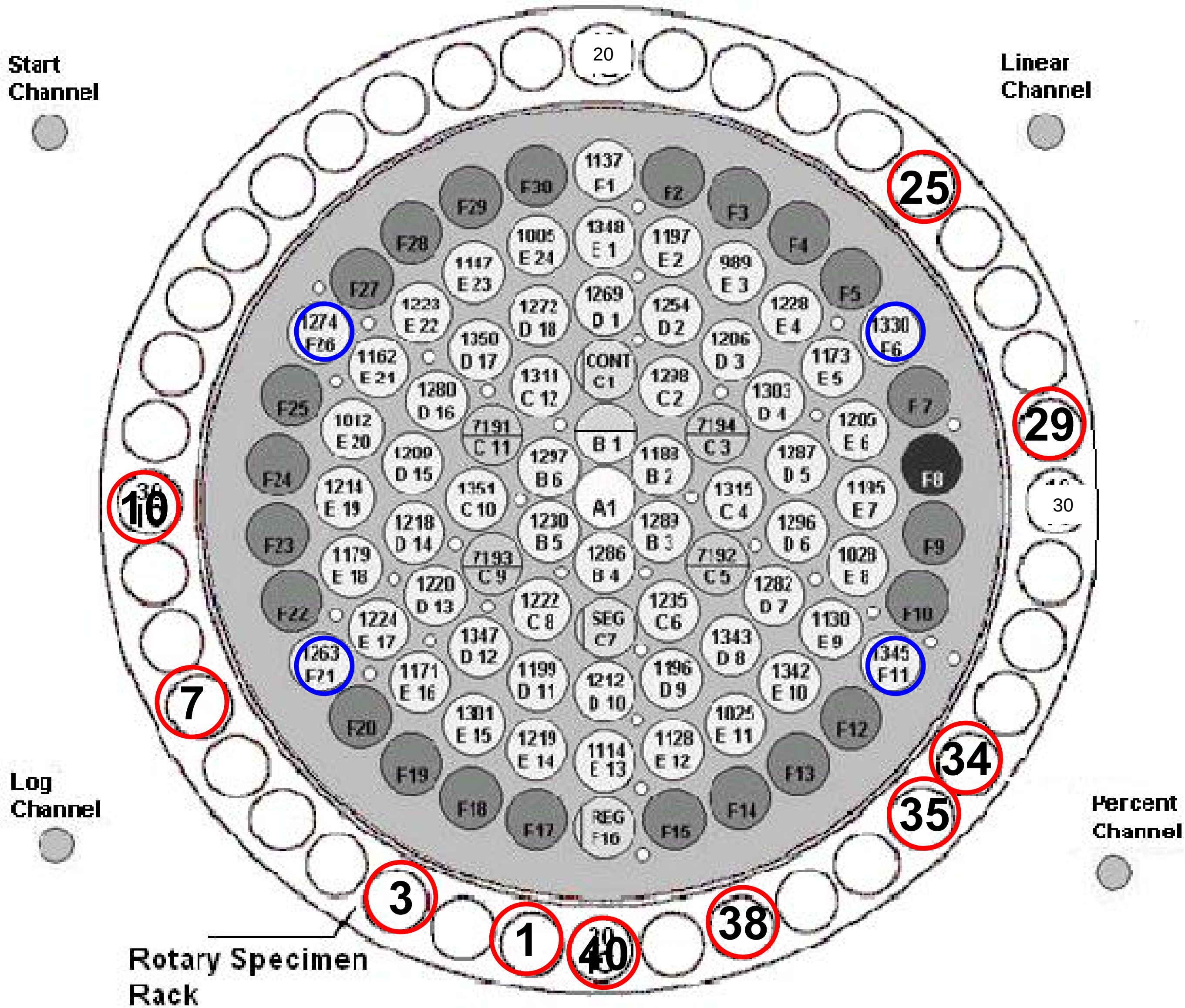
✓ KAYZERO/SOLCOI software package

- collaboration of Dr. Radojko Jaćimović as an Expert – IAEA

✓ 2006

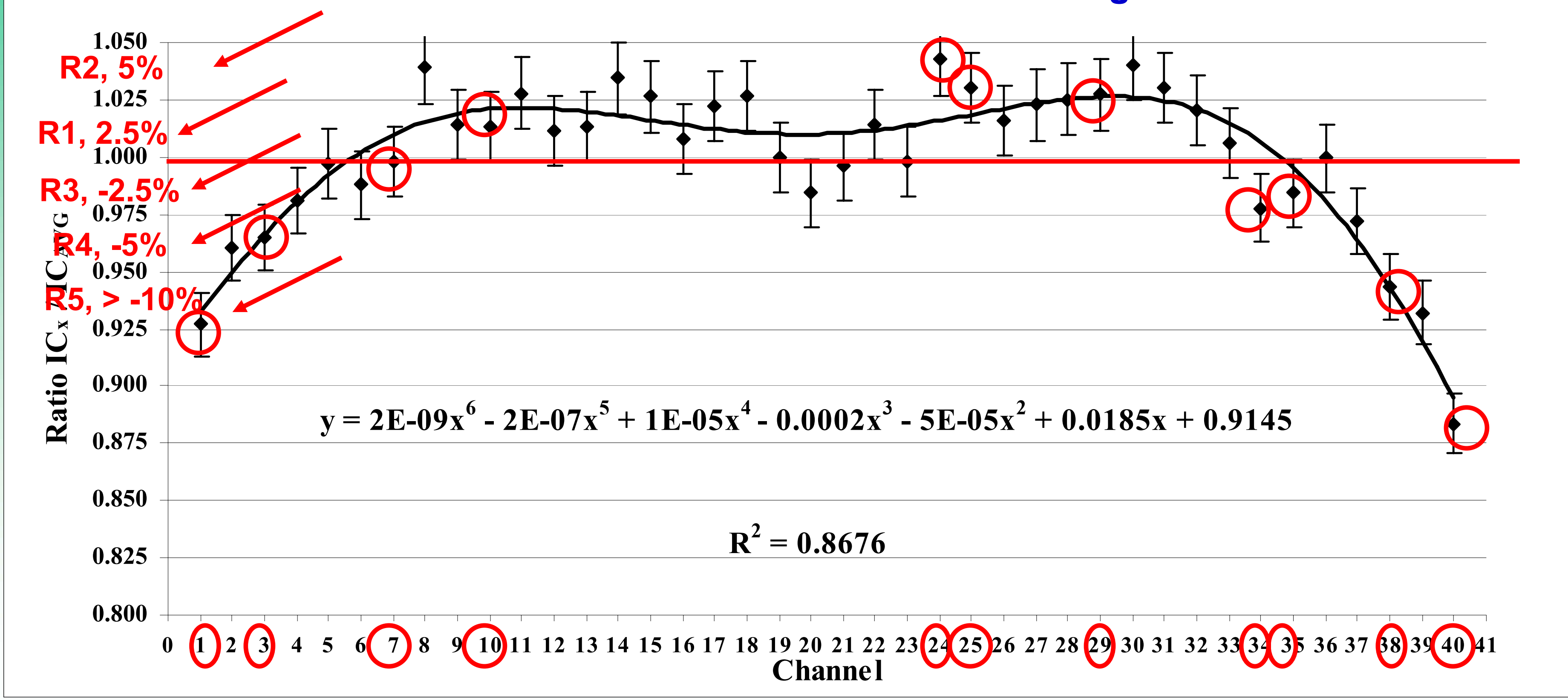
updated to Kayzero for Windows, KayWin

k_0-IAEA Dr. Radojko Jaćimović


Start Channel
Linear Channel
Log Channel
Percent Channel
Rotary Specimen Rack
20
30
25
29
10
7
34
35
3
1
40
38
A1
B 1
CONT C1
SEG C7
REG F16

Normalized specific count rate of ^{198}Au in the CF of the TRIGA reactor

Variability of the specific count rate of ^{198}Au, IC_x, normalized to the average for all channels, IC_{avg}



This study describes:

✓ **neutron fluxes characterization in several channels by experimental method, “Cd-ratio for multi-monitor”,**

and by simulation, Monte Carlo code

✓ **comparison between both methods**

Cd-ratio for multi monitor method

- ✓ Al-(0.1%)Au discs and Zr foils (99.8%)
- ✓ "bare" and "Cd-covered"
- ✓ "bare" discs - irradiated for 1.5 hour and then withdrawn
- ✓ "Cd-covered" samples - irradiated for 3 hours
- ✓ ^{198}Au, ^{97m}Nb and ^{95}Zr - measured on HPGe detector
- ✓ for peak area evaluation, the Hyperlab program
- ✓ for elemental concentration and parameters *f* and α calculations - software package KayWin
- ✓ for thermal flux determination, a home-made program

Monte Carlo simulation

✓ MCNP-4B code

✓ reactor core model used in the simulation was previously developed by Dr. Dalle (CDTN's researcher)

✓ average thermal neutron flux for the carousel as a whole

✓ now, neutron fluxes in each channel

Firstly: simulation - using the KCODE card

k_{eff} , for the modelled core was 1.01853 $\pm$ 0.00020

5000 neutron histories were simulated per cycle, in a total of 250 active cycles

After that: standard MCNP track length estimator

(1) thermal flux, below 0.5 eV and
(2) epithermal flux, 0.5 eV < E < 2 keV

Tab 1. Neutron flux characterization of irradiation channels

IC	Neutron Fluxes ($n\ cm^{-2}\ s^{-1}$) "Cd-ratio for multi-monitor" method		Neutron Fluxes ($n\ cm^{-2}\ s^{-1}$) Monte Carlo		Deviation (in %) between "Cd-ratio for multi-monitor" method and MCNP	
	Thermal	Epithermal	Thermal	Epithermal	Thermal	Epithermal
1	$6.69 \cdot 10^{11}$	$2.78 \cdot 10^{10}$	$6.77 \cdot 10^{11}$	$3.67 \cdot 10^{10}$	-1.13	-31.84
3	$6.55 \cdot 10^{11}$	$2.97 \cdot 10^{10}$	$6.65 \cdot 10^{11}$	$3.77 \cdot 10^{10}$	-1.46	-26.69
7	$6.35 \cdot 10^{11}$	$2.85 \cdot 10^{10}$	$6.67 \cdot 10^{11}$	$4.10 \cdot 10^{10}$	-5.05	-43.98
10	$5.99 \cdot 10^{11}$	$2.90 \cdot 10^{10}$	$6.90 \cdot 10^{11}$	$4.00 \cdot 10^{10}$	-15.12	-37.99
24	$6.94 \cdot 10^{11}$	$3.13\ 10^{10}$	$6.98 \cdot 10^{11}$	$4.20 \cdot 10^{10}$	-0.62	-34.21
25	$6.45 \cdot 10^{11}$	$2.81 \cdot 10^{10}$	$6.86 \cdot 10^{11}$	$4.04 \cdot 10^{10}$	-6.29	-43.70
29	$7.32 \cdot 10^{11}$	$3.08\ 10^{10}$	$6.86 \cdot 10^{11}$	$4.11 \cdot 10^{10}$	6.28	-33.15
34	$7.30 \cdot 10^{11}$	$2.95\ 10^{10}$	$6.73 \cdot 10^{11}$	$4.11 \cdot 10^{10}$	7.82	-39.43
35	$7.18 \cdot 10^{11}$	$4.78\ 10^{10}$	$6.72 \cdot 10^{11}$	$3.99 \cdot 10^{10}$	6.39	-45.37
38	$6.58 \cdot 10^{11}$	$1.25\ 10^{10}$	$6.80 \cdot 10^{11}$	$3.88 \cdot 10^{10}$	-3.36	-43.17
40	$6.16 \cdot 10^{11}$	$3.01 \cdot 10^{10}$	$6.73 \cdot 10^{11}$	$3.61 \cdot 10^{10}$	-9.21	-19.76
Average (this work)	$6.68 \cdot 10^{11}$	$2.90\ 10^{10}$	$6.79 \cdot 10^{11}$	$3.95 \cdot 10^{10}$		
Average value since 1995	$6.00 \cdot 10^{11}$	$2.50 \cdot 10^{10}$				
New onfiguration (previous works)	$6.6 \cdot 10^{11}$ Souza's results		$6.6 \cdot 10^{11}$ Dalle's results	NC		

Tab 2. Comparison of values obtained by the “Cd-ratio for multi-monitor” method and by the Monte Carlo simulation

IC	“Cd-ratio for multi-monitor” method		Monte Carlo simulation	Δ *f*, %
	α	*f*, deviation from average	*f*, deviation from average	
1	0.0016	24.02, (+4.1%)	18.43, (-7.1%)	23.3
3	0.0010	22.02, (+1.6%)	17.63, (-2.5%)	19.9
7	-0.0022	22.32, (+2.9%)	16.29, (+5.3%)	27.0
10	0.0033	20.65, (-4.7%)	17.23, (-0.1%)	16.6
24	0.0029	22.17, (-3.9%)	16.62, (+3.4%)	25.0
25	-0.0087	22.93, (+5.8%)	16.96, (+1.4%)	26.0
29	-0.0047	23.73, (+2.9%)	16.70, (+2.9%)	29.6
34	-0.0006	24.78, (+7.0%)	16.38, (+4.8%)	33.9
35	0.0011	26.14, (+11.9%)	16.83, (+2.2%)	35.6
38	-0.0229	24.26, (+5.0%)	17.51, (-1.8%)	27.8
40	0.0197	20.44, (-5.7%)	18.64, (-8.4%)	8.8
Average	-0.0009 $\pm$ 0.0101	23.04 $\pm$ 1.74	17.20 $\pm$ 0.78	-
Previous average value since 1995	0.0250 $\pm$ 0.0020	24.2 $\pm$ 2.0	NC	-

CONCLUSIONS

✓Thermal fluxes in the CF can be considered similar even with a range of deviation (0.6 to 15%) → experimentally and by the MCNP

The literature accepts 35% deviation MCNP simulation

✓epithermal flux determination by MCNP should be investigated

✓ 10% deviation - thermal neutron flux by "Cd-ratio for multi-monitor" method and the value determined in 1995

→ use of non-suitable monitors at that time:

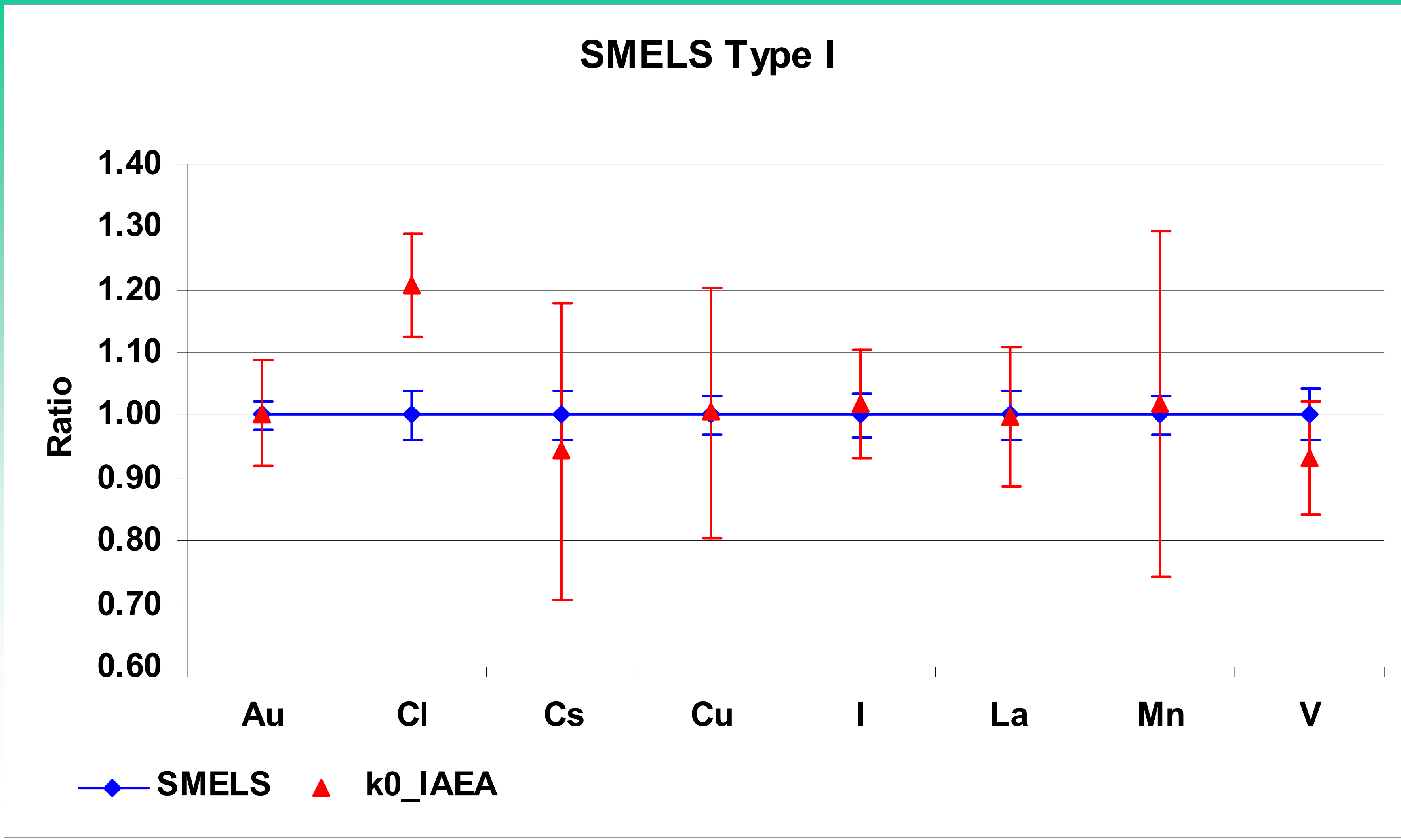
- salts of Zr and Au instead of foils and

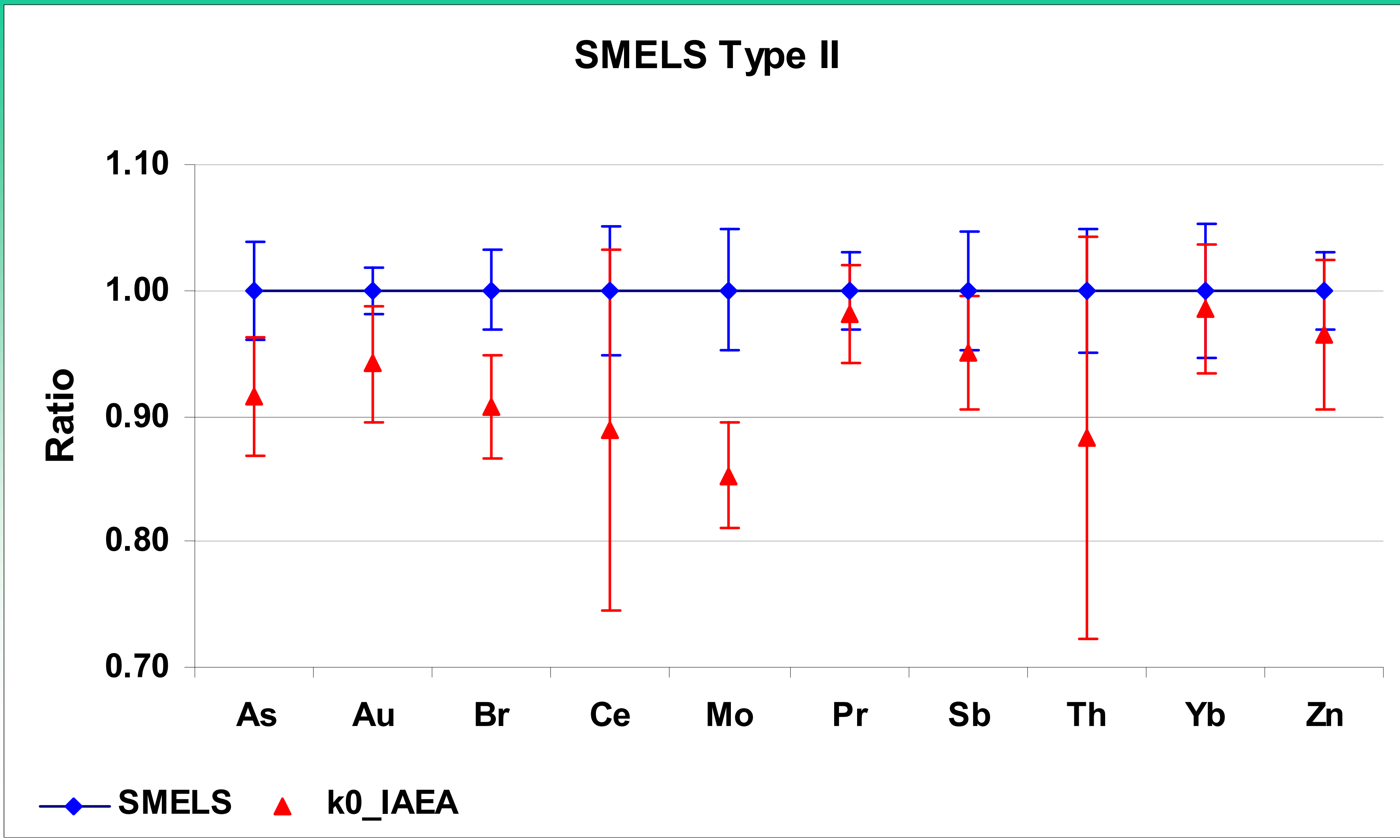
-small changes in the reactor core configuration

CONCLUSIONS

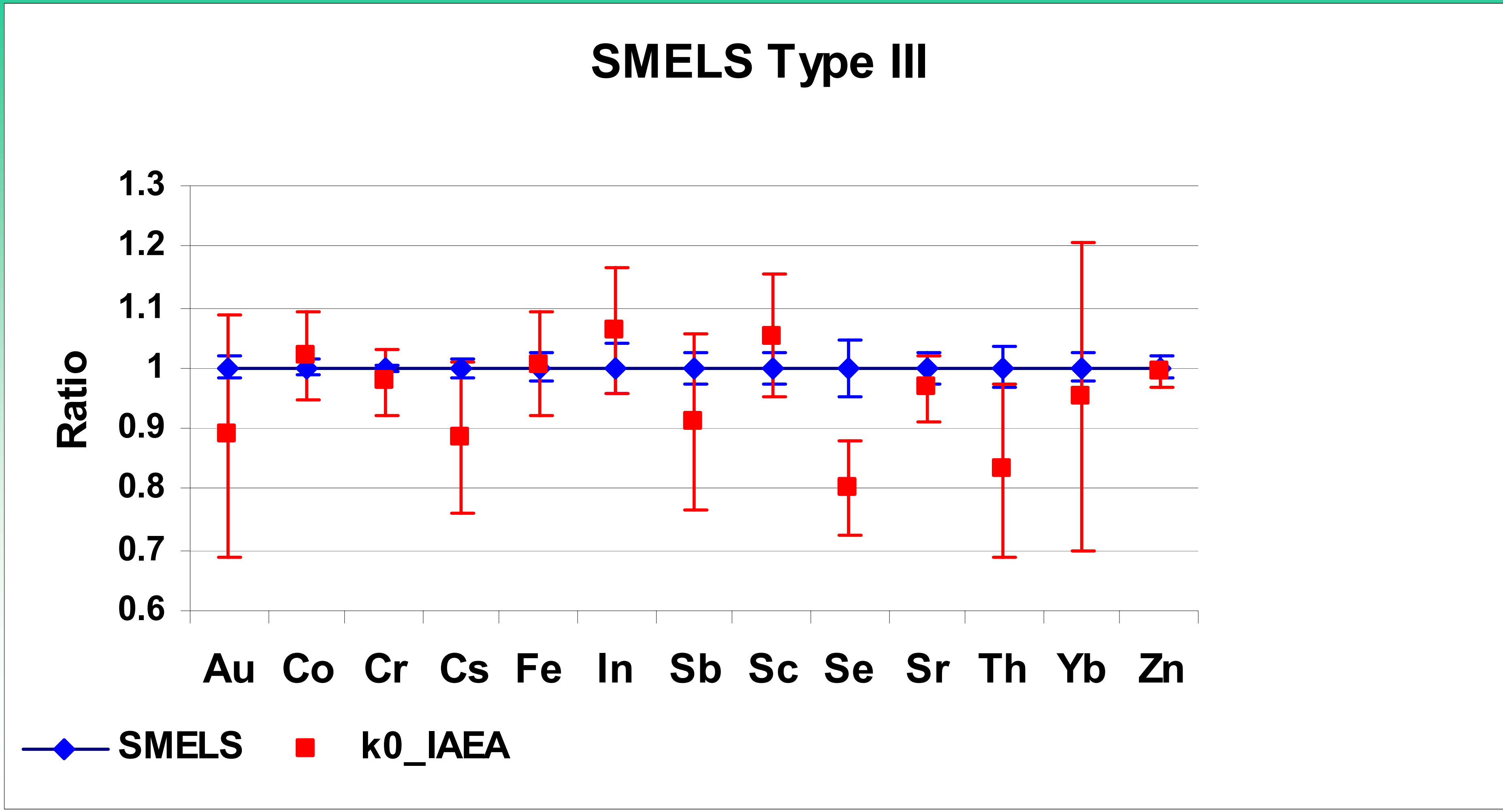
- ✓ concerning MCNP, considering the carousel as a whole, and the average value obtained from the fluxes in several channels → average deviation of 4.6%
- ✓ deviation of *f* obtained by MCNP → will be investigated due to the epithermal flux influence
- ✓ "Cd-ratio for multi monitor" method is adequate in the determination of neutron fluxes
- ✓ MCNP simulation applied in different channels of the carousel facility is an excellent tool in the future characterization in other places in the reactor

where the experimental characterization is difficult or even impossible


SMELS Type I
Ratio
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
Au
Cl
Cs
Cu
I
La
Mn
V
SMELS
k0_IAEA



SMELS Type II
1.10
1.00
0.90
0.80
0.70
Ratio
As
Au
Br
Ce
Mo
Pr
Sb
Th
Yb
Zn
SMELS
k0_IAEA



SMELS Type III
Ratio
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
Au
Co
Cr
Cs
Fe
In
Sb
Sc
Se
Sr
Th
Yb
Zn
SMELS
k0_IAEA

CNEN

CDTN

Reactor Group

Neutron Activation Analysis Group

CNEN

CDTN

Thanks to:

Dr. Trkov and Dr. Kellett

for this opportunity

IAEA

Dr. Smodiš

Expert Missions - Dr. Jaćimović

BELO HORIZONTE

Thank you!

Muito Obrigada!