Neutronics Analysis of TRIGA Mark II Research Reactor

R. Khan, S. Karimzadeh, H. Böck
Vienna University of Technology
Atominstitute

23-03-2010

Contents

- TRIGA Mark II reactor
- MCNP radiation transport code
- MCNP model of first core
- Validation through local experiments
- Burn-up calculations & its applications to MCNP model
- MCNP model of the current core
- Verification of current core model
- Conclusion and outlook
- References

TRIGA Mark II, Vienna

- Operation since 7th March 1962
- Max. P_{Th} = 250 kW
- Max.$(Ø)_{th}$ = $1x10^{13}$ n/cm^2-s^1
- Fuel Mat. U-ZrH
- Mixed core (3-types of fuel)
- Current Core Loading = 83 FE(s)
- Peak P_{Th} = 250 MW
- Irradiation channels in the core
- Experimental facilities outside reactor core
  - Thermal column
  - Radiographic collimator
  - 4 beam tubes

MCNP Transport Code

- MCNP – Monte Carlo based neutronics behaviour simulating code with continuous energy and generalized 3D geometry capabilities
- General purpose radiation transport code (criticality, neutronics and radiation shielding calculations.)
- It simulates neutron, photon, electron independently and also their coupled behaviours
- Energy range
  - For neutrons: 10^{-11} MeV to 20 MeV
  - For photon and electron: 1keV to 1 GeV
- Powerful source cards
- Surface Source Writing (SSW) capability
- 7- tallies (mesh tally- 3D regions of space)– output results
- ENDF/B-VI and JEFF3.1 nuclear data libraries

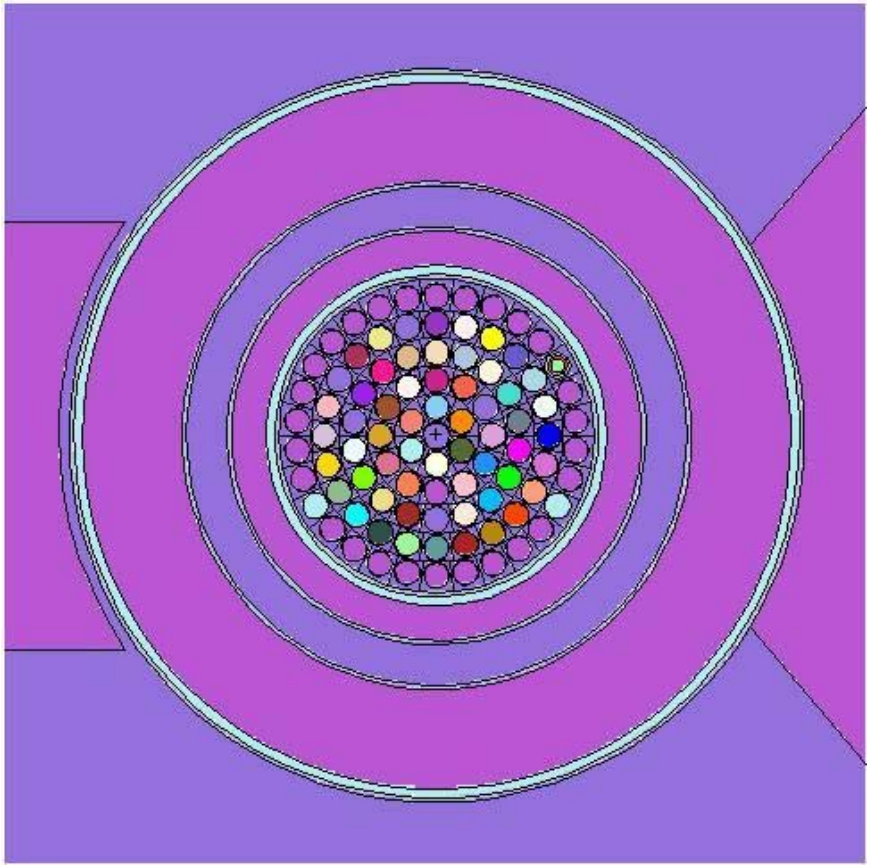
MCNP Model (1st core)

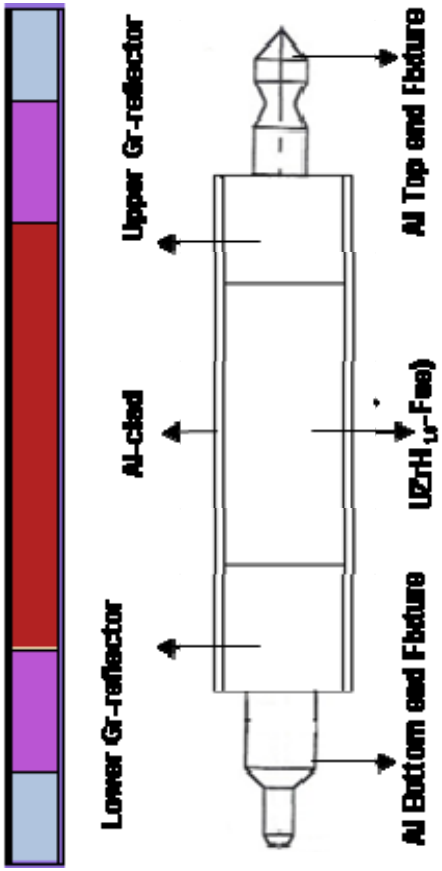
<u>Inside the core</u>

- 57 FE(s)
- 3 CR(s)
- 1 CIR
- 1 (Sb-Be) SE
- 27 GE (s)
- 2 pneumatic transfer sys.

<u>Outside the core</u>

- Annular gr. ref.
- Th. Column
- Thermalizing col.
- 4 beam tubes





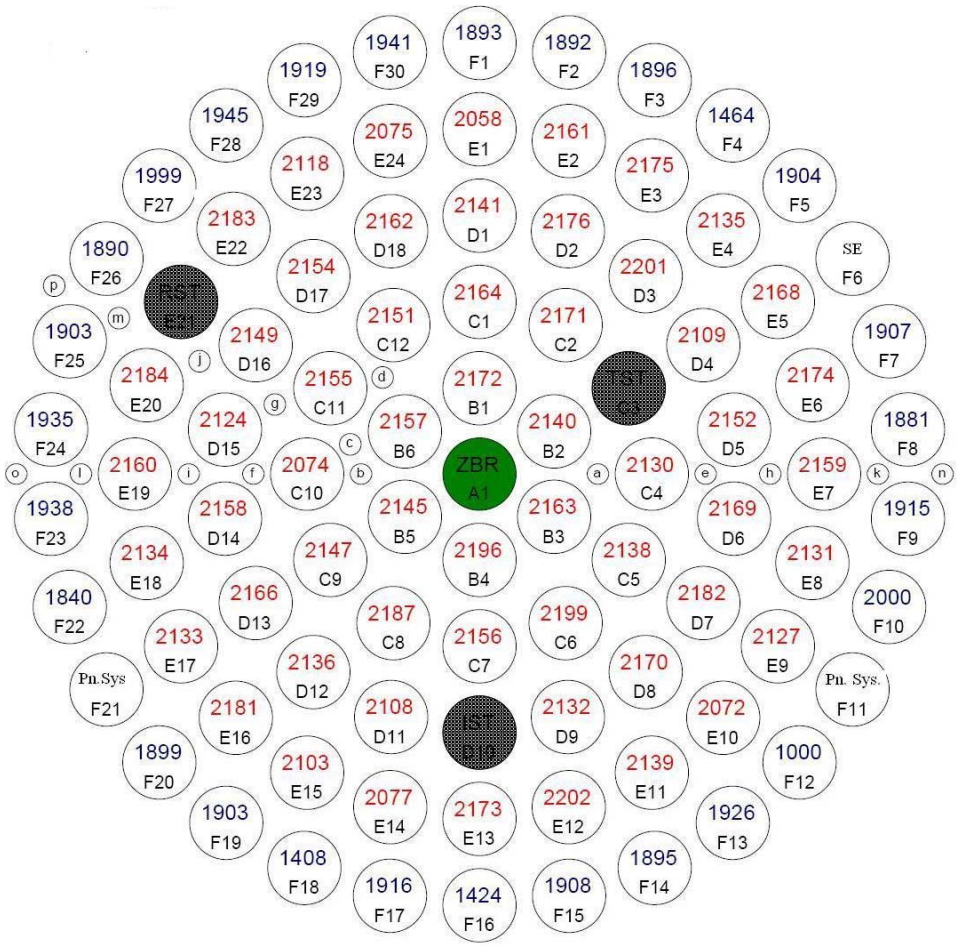
Model Validation (1st core)

First Criticality Experiment
(7th March 1962)

FE Position	MCNP (K-eff)	Exp. (K-eff)
56 th FE	0.99788	Sub-critical
57 th FE	1.00183	1.00114

Measurement = 0.157 $
Calculation = 0. 250 $

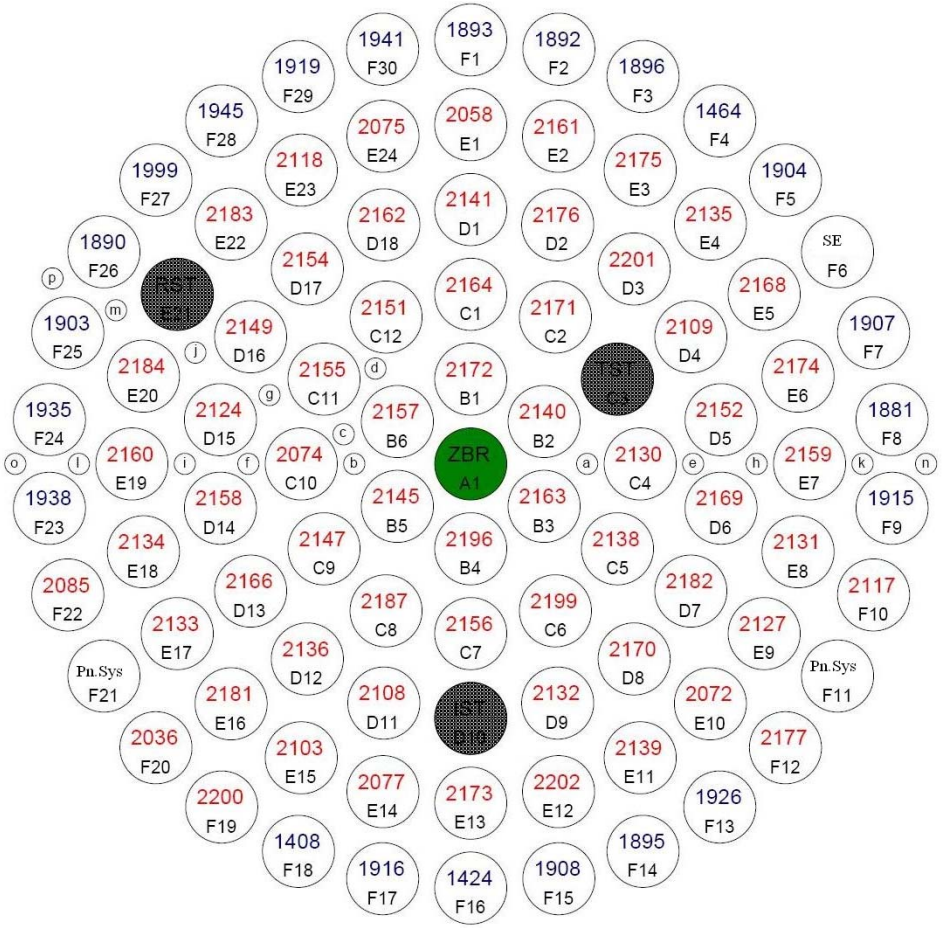
GA also confirm this model



Model Validation (1st core)

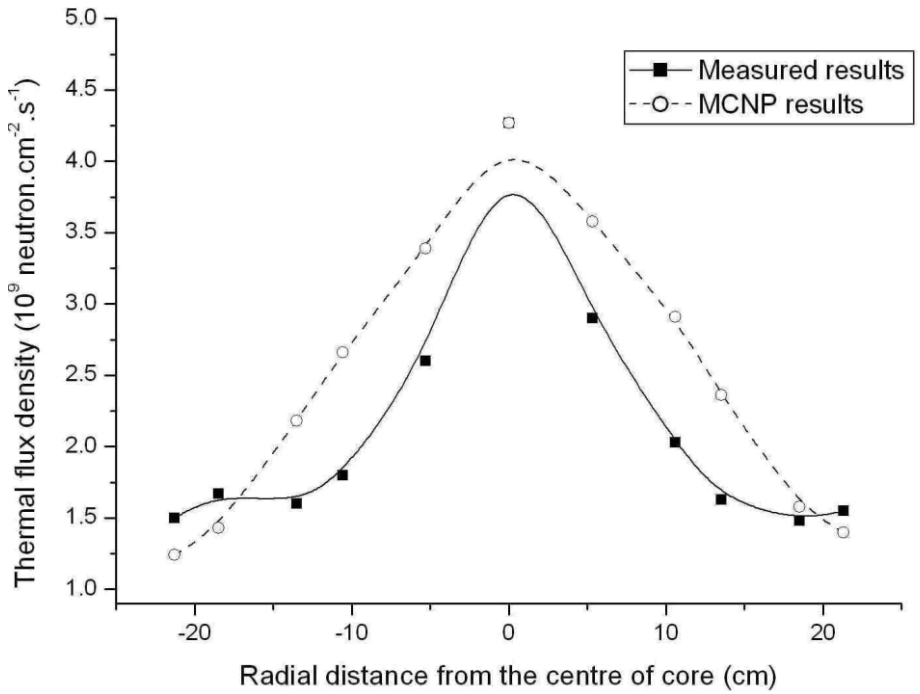
Reactivity Distribution Experiment (12-12-1963)

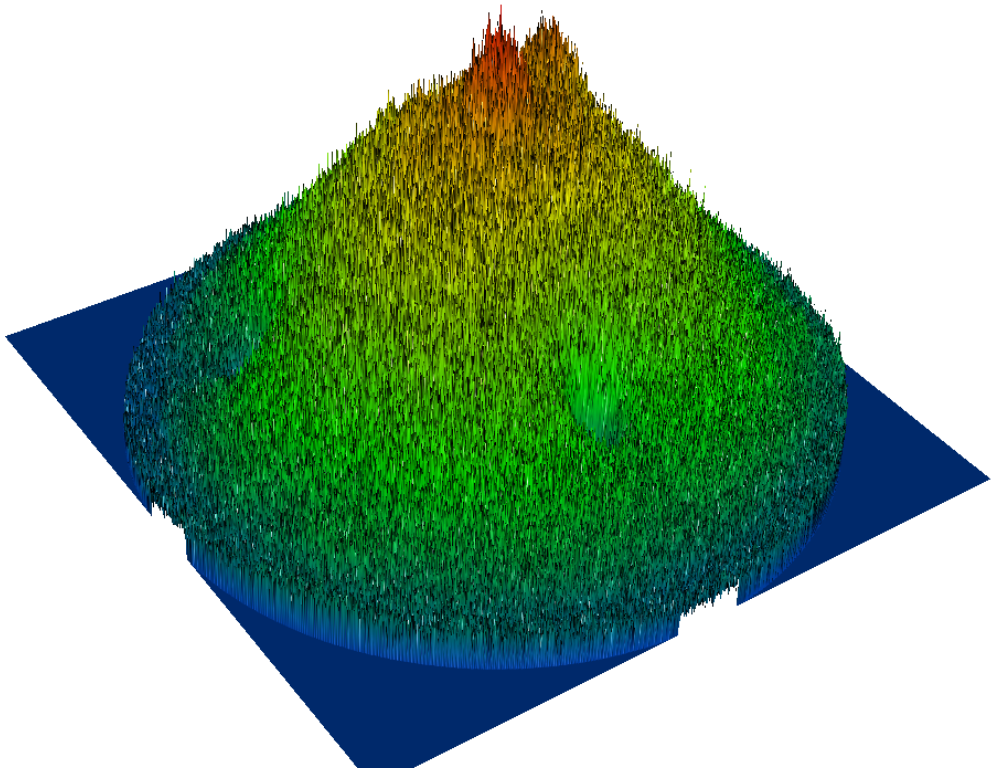
FE No.	Reactivity MCNP (¢)	Reactivity Exp. (¢)	%-diff
GE (F01)	11.9	10.5	8.4
FE (2058)	53.6	56	4.3
FE(2141)	73.4	65	12.9
FE(2164)	102	80	22.5
FE(2172)	153	143	6.9

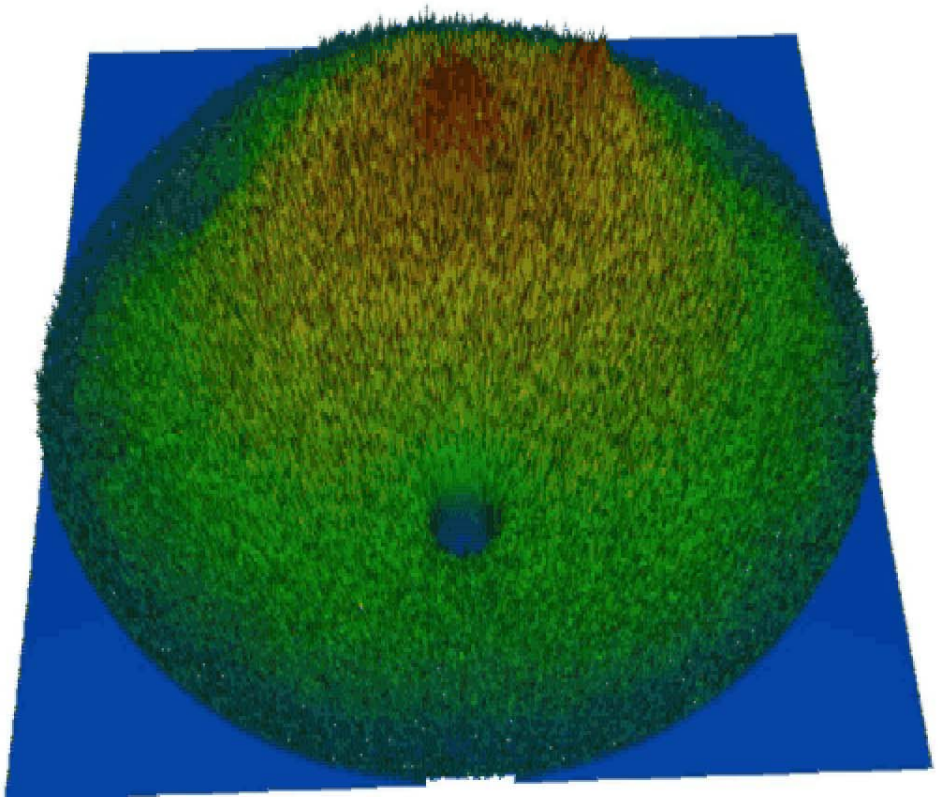


Model Validation (1st core)

Thermal Flux Mapping Experiment (1964)

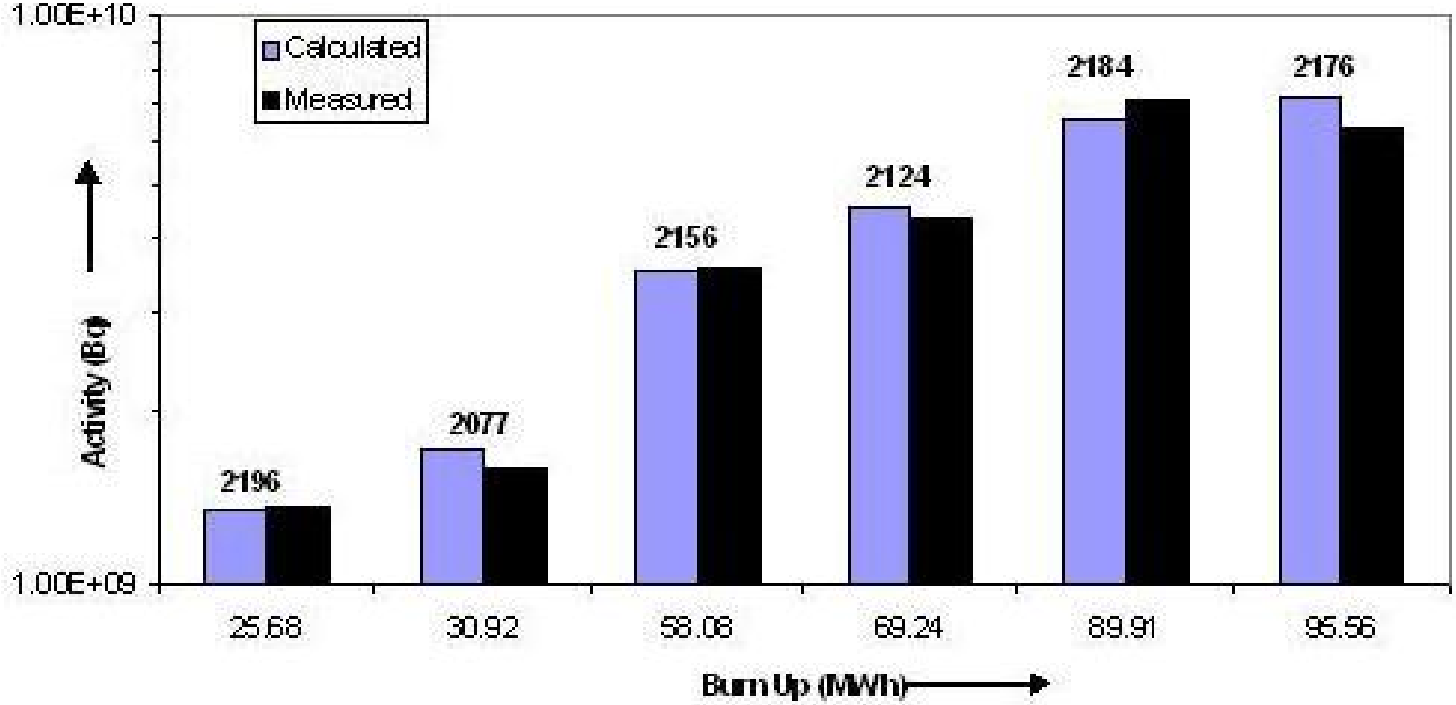






Burn-up Calculations

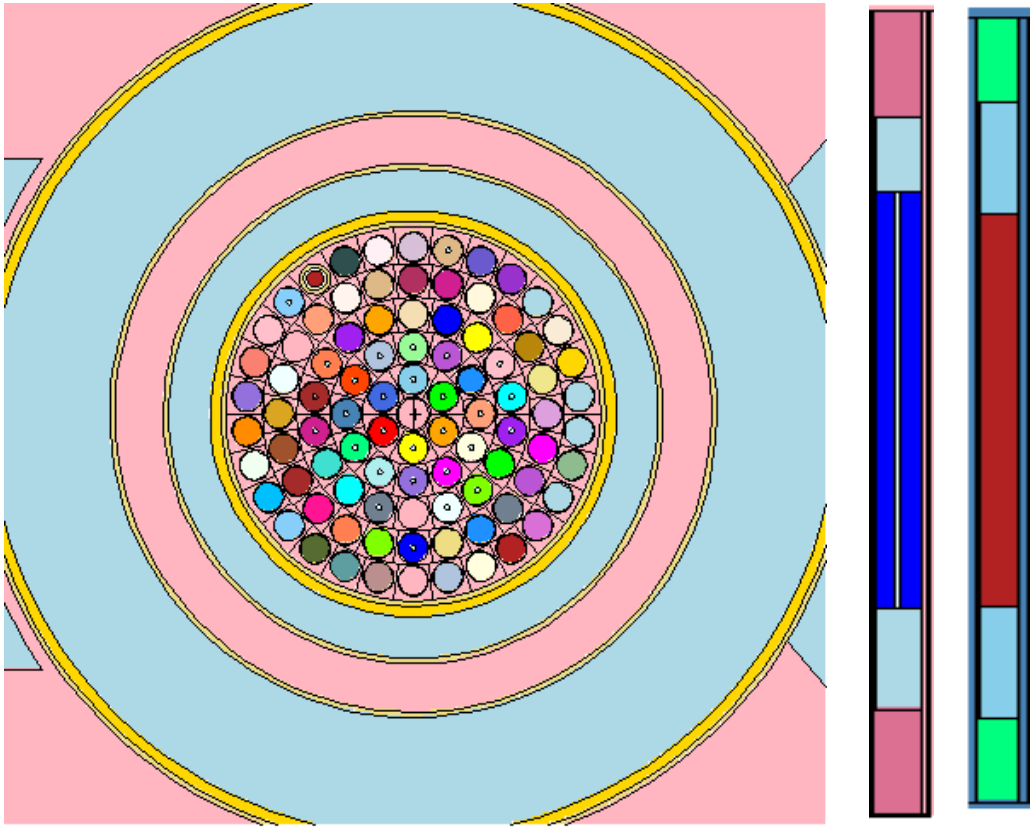
(From 07-03-1962 to 30-06-2009)



i. ORIGEN2 calculations & gamma spectroscopic experiments
ii. Effective material composition applied to the MCNP model

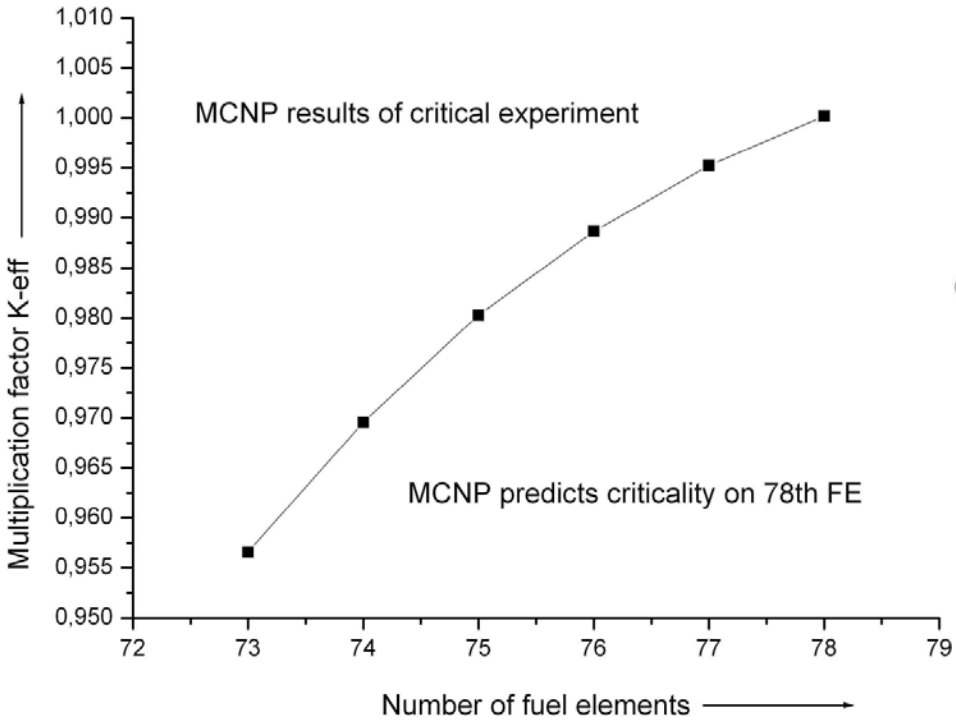
Current Core Model (current core)

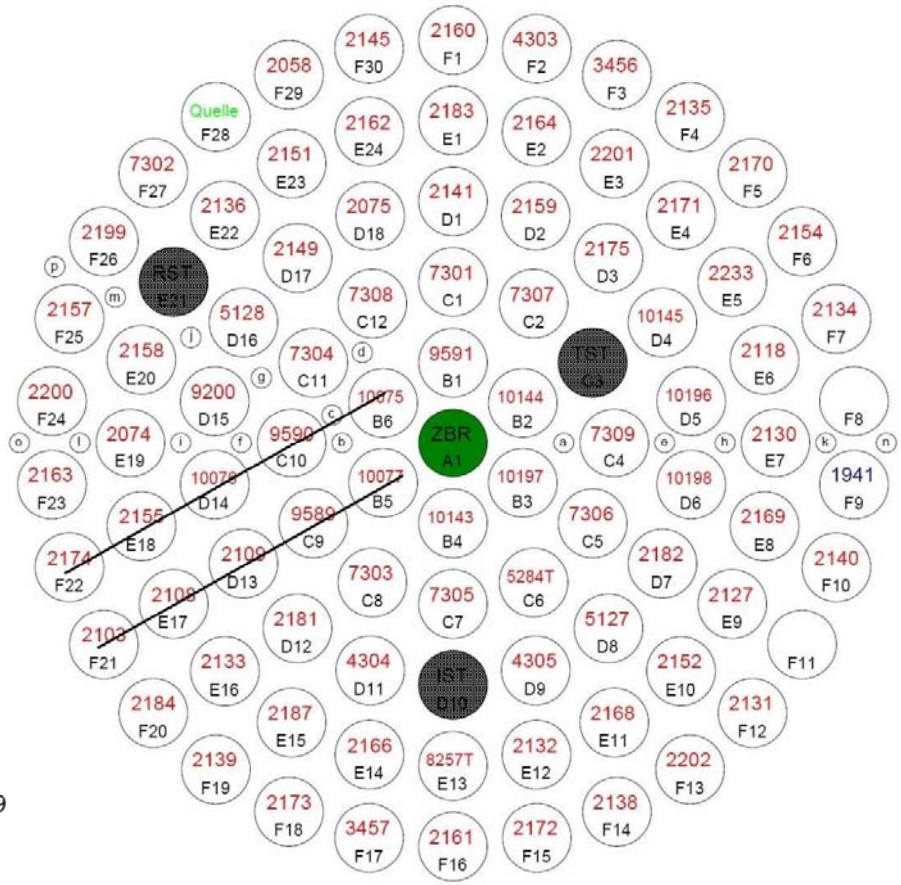
i. Addition of new FE(s), over the history of reactor operation (20% SS clad, 70% FLIP)
ii. Incorporation of effective burned fuel composition
iii. Burn up group approximation
iv. SE (F06 to F28)
v. Only one graphite element left
vi. Change of one pneumatic transfer system from F21 to F08.



Model Validation(current core)

Criticality Experiment
29-06-2009

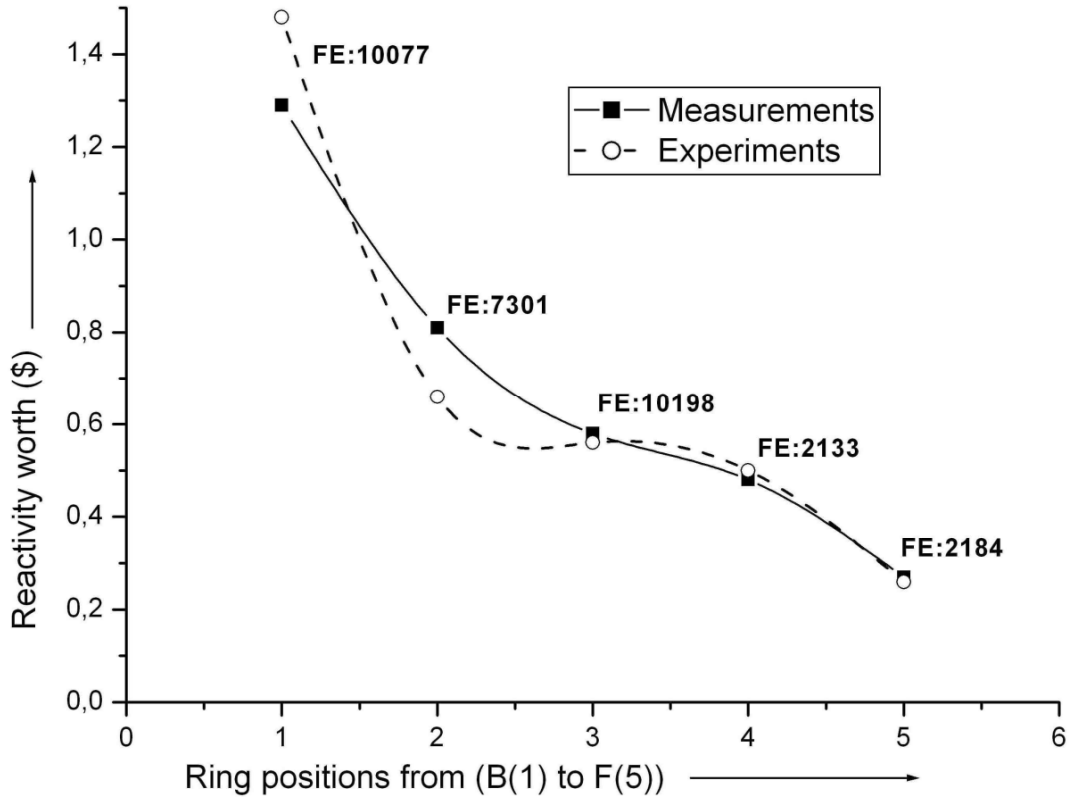




Model Validation (current core)

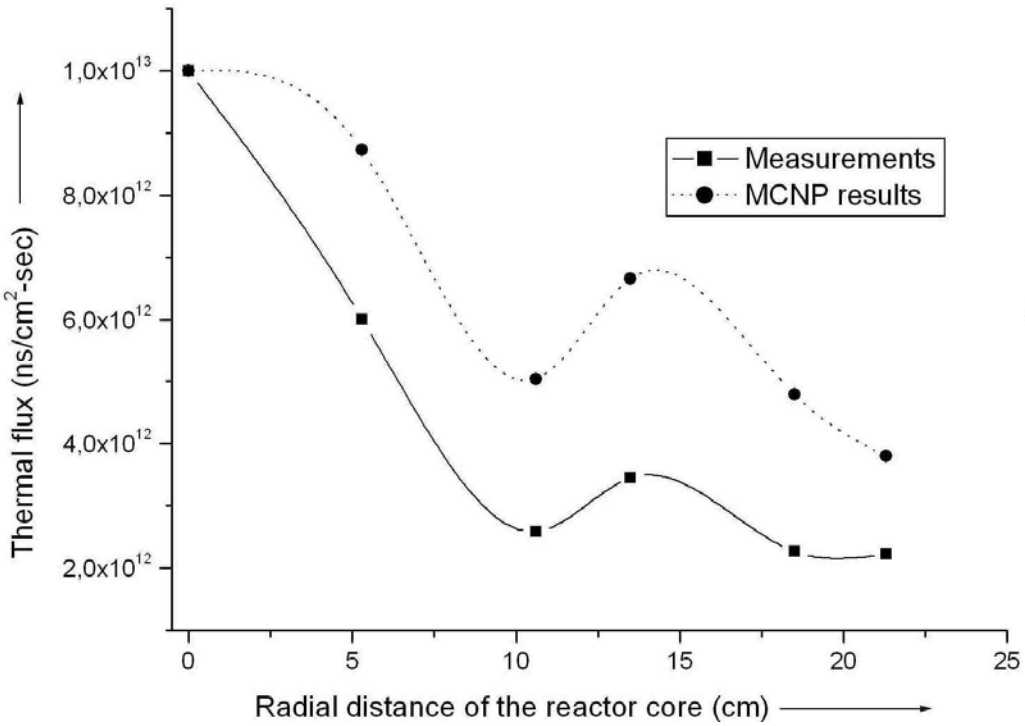
Reactivity Dist. Experiment (02-07-2009)

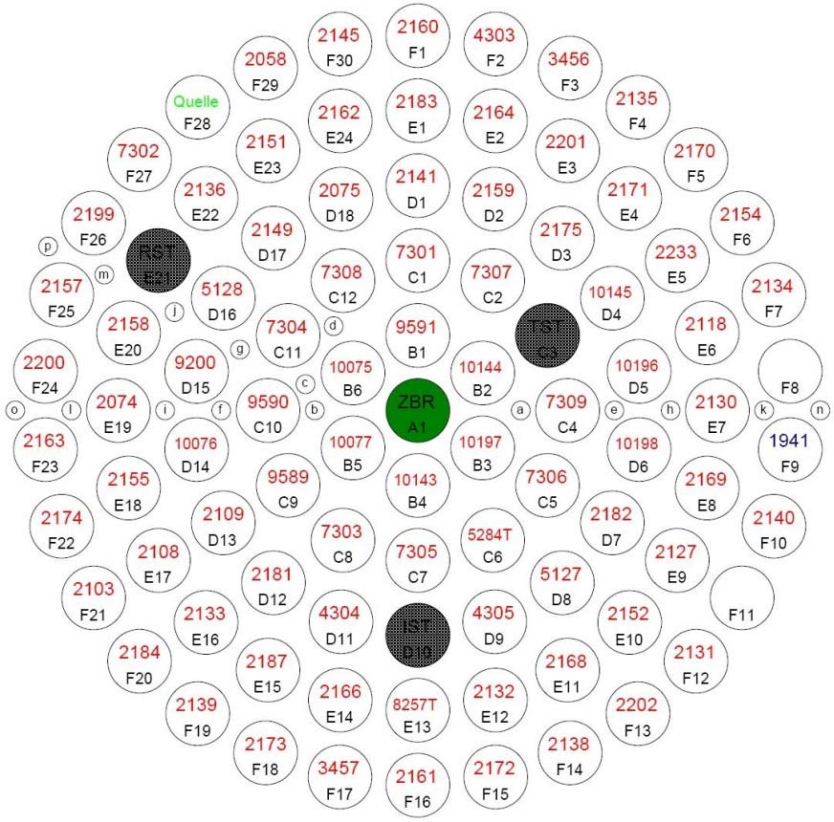
FE no.	MCNP (¢)	Exp. (¢)	%-diff.
10077	129	148	12.8
7301	81	68	19.1
10198	58	56	3.6
2133	48	50	4.0
2184	27	26	3.8

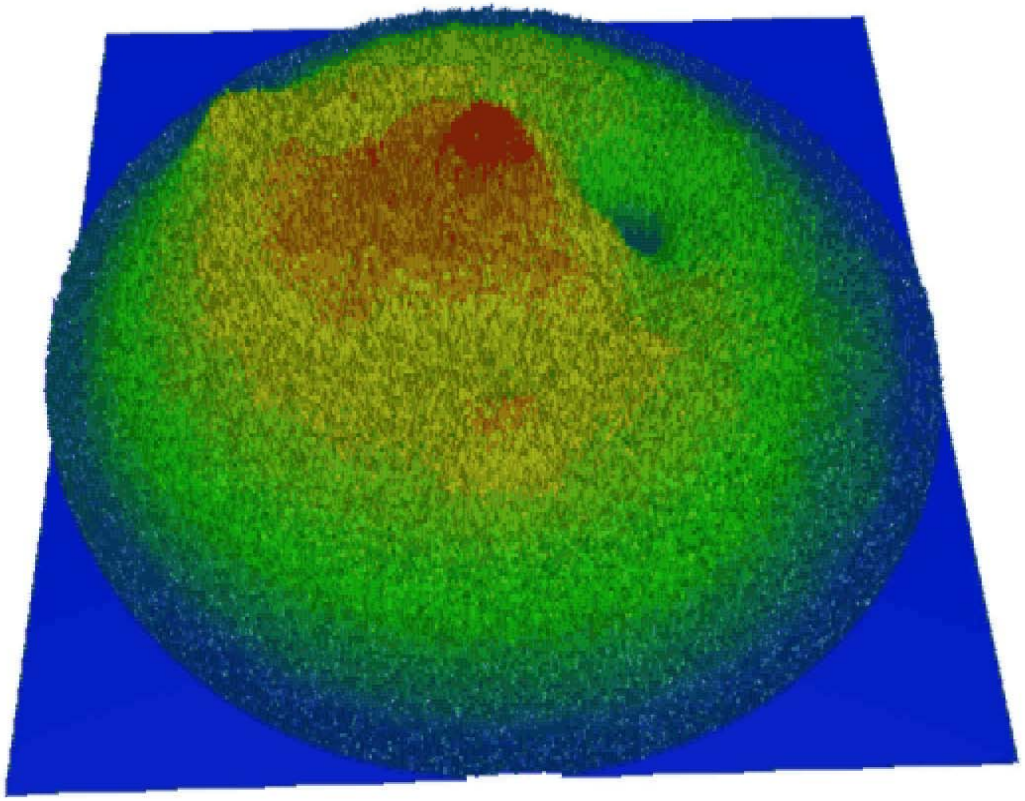


Model Validation (Current core)

Flux mapping experiment
01-07-2009







Conclusion & Outlook

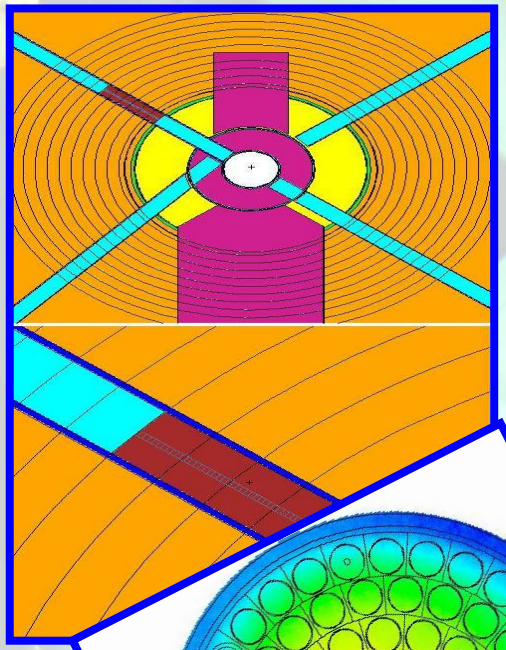
The initial core MCNP model was developed incorporating all geometrical and material information collected from various sources (TRIGA manual, GA, different users and shipment documents). The model was confirmed at both i.e. global and local levels. The developed model was modified to the current core model employing current core conditions. The current core model was completely verified by three different experiments performed in June-July 2009.

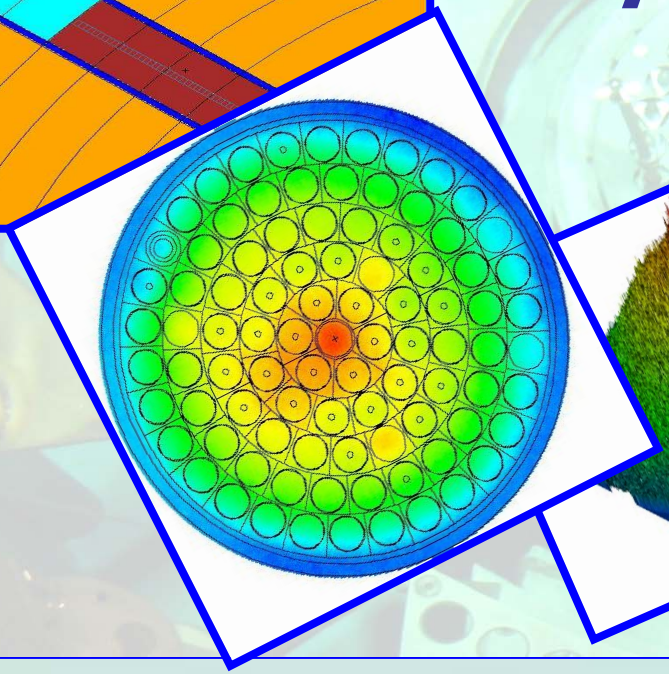
The current core model has been extended to biological shielding including the thermal column, radiographic collimator and 4 beam tubes (BT) and confirmed in the thermal column and BT region.

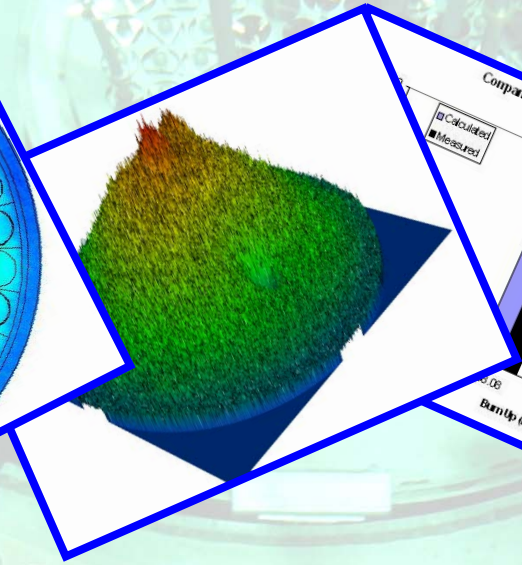
References

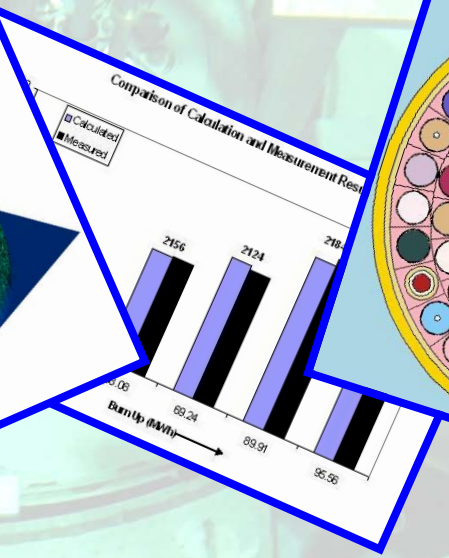
- General Atomic (GA), March 1964. TRIGA Mark II Reactor General Specifications and Description. General Atomic Company, U.S.A.
- Shipment documents from GA, USA.
- Log books of TRIGA Mark II reactor at Atominstitue (from 1962 to 2009)
- Monte Carlo Team, “MCNP5”, LA-UR-03-1987, LANL, April 24, 2003.
- A.G. Croff, 1999. A user’s manual for the ORIGEN2 computer code. OAK RIDGE National Laboratory, USA.
- Robert Jeraj, Tomaz Zagar, Matiaz Ravnik, “Monte Carlo Simulation of the TRIGA Mark II Bench Mark Experiment with Burned Fuel”, Nuclear technology, Vol. 137, September 2001.
- R. Khan, S. Karimzadeh, H. Boeck, TRIGA fuel Burn-up calculations. RRFM 2009, Vienna, Austria.
- R. Khan, S. Karimzadeh, H. Böck, M. Villa. Modelling of TRIGA Mark II biological shielding using MCNP5, Nuclear Energy for new Europe 2009, Sep. 2009.
- R, the environment for statistical computing and graphics http://www.r-project.org/

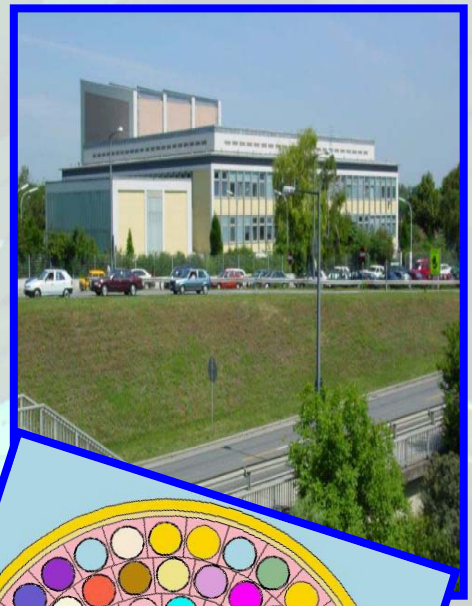
Thanks for Your Attention!

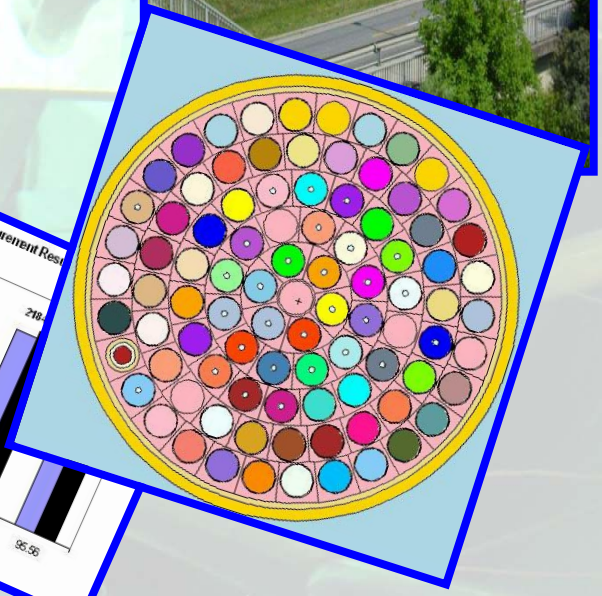




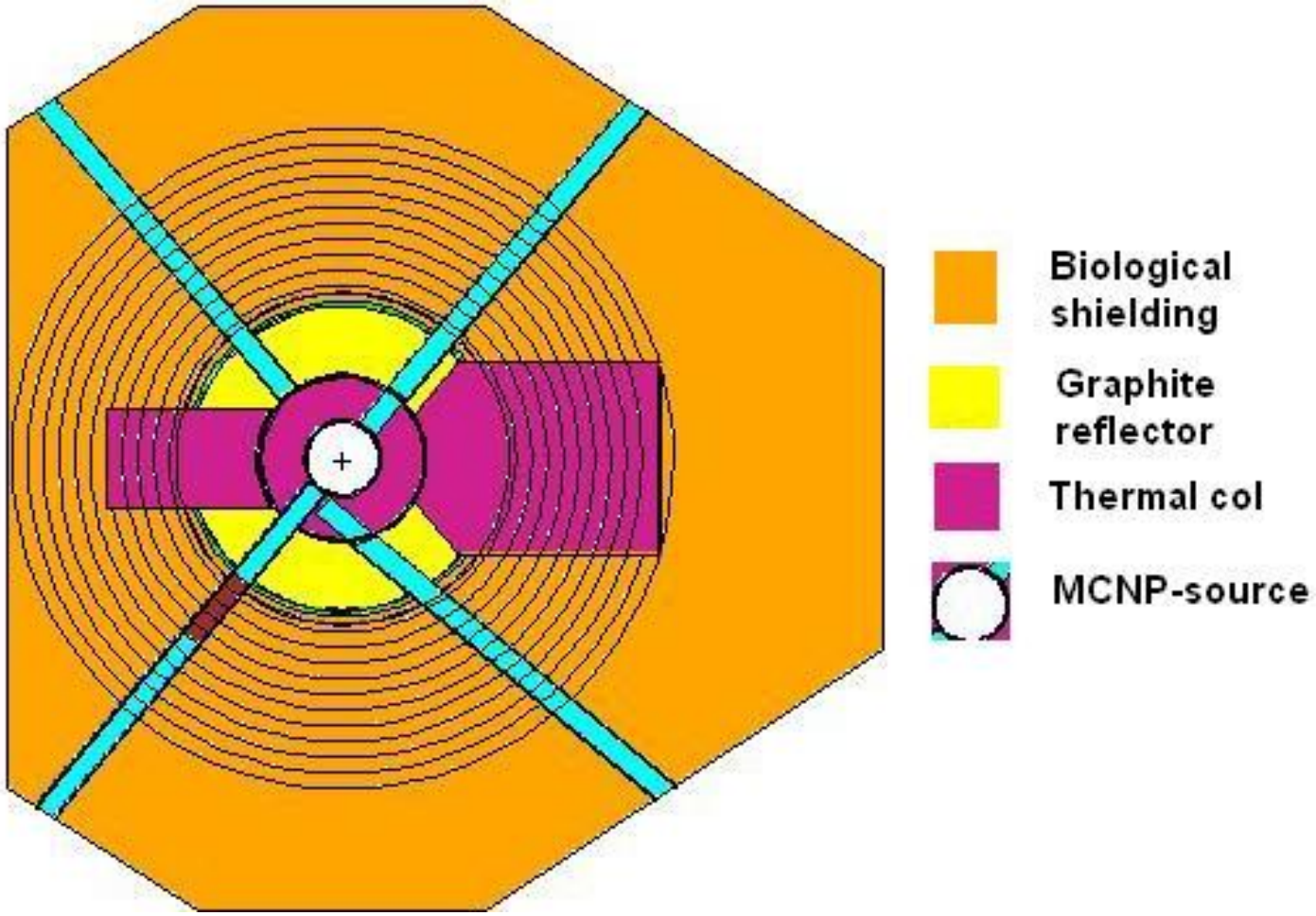








Extended MCNP Model

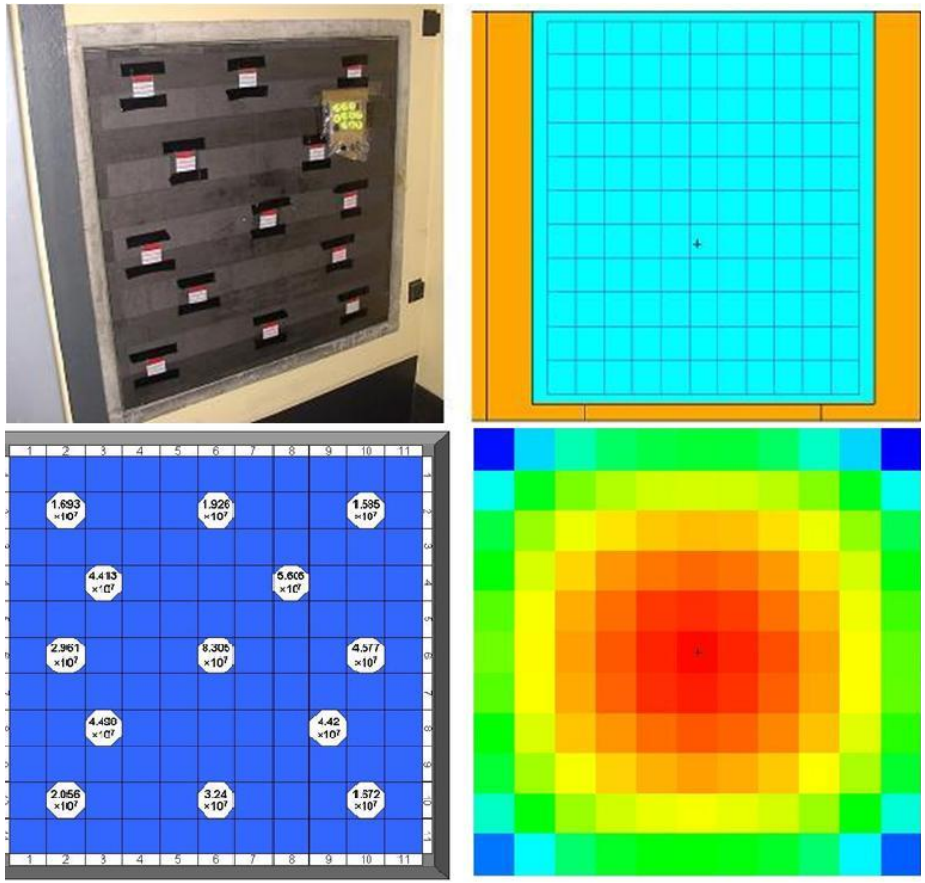


Slide 19

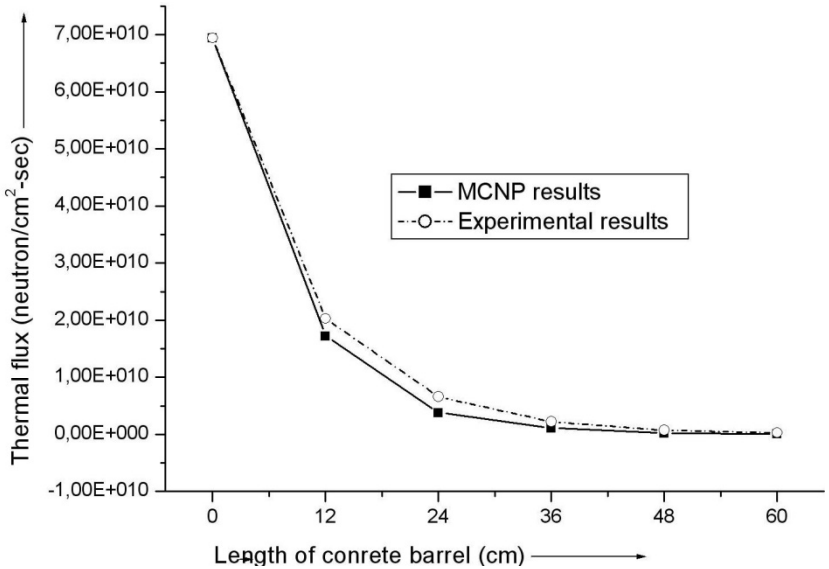
KR1 Khan Rustam; 03.09.2009

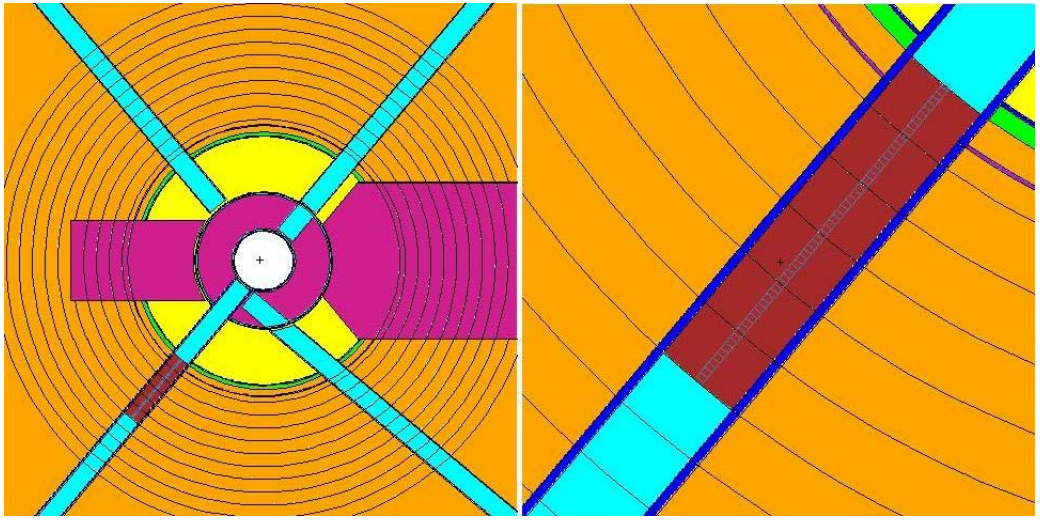
Extended Model Validation

Positions	Exp. flux	Cal. flux	Cal/exp.
(2,2)	1.6932E+07	2.0755E+07	1.226
(2,6)	1.9255E+07	3.7084E+07	1.926
(2,10)	1.5848E+07	2.0693E+07	1.306
(4,3)	4.5127E+07	5.0593E+07	1.121
(4,8)	5.6064E+07	6.0810E+07	1.085
(6,2)	2.9609E+07	4.4650E+07	1.508
(6,6)	8.3050E+07	8.3050E+07	1.000
(6,10)	4.5768E+07	4.4126E+07	0.964
(8,3)	4.4985E+07	5.2957E+07	1.177
(8,9)	4.4196E+07	6.3907E+07	1.446
(10,2)	2.0561E+07	2.2168E+07	1.078
(10,6)	3.2400E+07	4.2623E+07	1.315
(10,10)	1.6723E+07	2.2406E+07	1.340



Extended Model Validation





Exp. diffusion length = 10.77 cm
MCNP diffusion length = 9.36 cm
Difference = 13 %

Effective Material Composition

Nuclide	3% Burnup (pcm)	10% Burnup (pcm)	20% Burnup (pcm)
54-Xe-135	**850**	**899**	**973**
62-Sm-149	**620**	**638**	**645**
62-Sm-151	**101**	**222**	**284**
94-Pu-239	**−95**	**−357**	**−840**
60-Nd-143	**51**	**178**	**384**
92-U-236	25	**84**	**168**
61-Pm-147	24	**65**	**102**
45-Rh-103	20	**82**	**179**
54-Xe-131	16	**56**	**118**
55-Cs-133	14	50	**105**
43-Tc-99	11	38	**79**
60-Nd-145	7	26	55
63-Eu-155	6	14	20
pseudo FP	6	21	47
62-Sm-152	6	26	64
94-Pu-240	5	**57**	**216**
42-Mo-95	5	17	36
36-Kr-83	3	11	24
62-Sm-150	3	13	30
44-Ru-101	3	9	19
55-Cs-135	2	8	17
63-Eu-153	2	8	20
46-Pd-105	1	4	8
62-Sm-147	1	9	31
93-Np-239	1	1	1
93-Np-237	0	3	12
47-Ag-109	0	1	3
44-Ru-103	0	0	0
53-I-127	0	0	1
55-Cs-134	0	0	2
46-Pd-107	0	0	1
46-Pd-108	0	0	1
95-Am-241	0	0	1
62-Sm-148	0	0	0
64-Gd-156	0	0	0
94-Pu-241	0	−2	−17
54-Xe-134	0	0	−1
54-Xe-136	0	0	−1

*The burnups are 3% (approximately experimental burnup), 10%, and 20%. Contributions to the total reactivity ($\Delta k/k$) are shown in relative values as calculated by the WIMSD4 program. Boldfaced numbers represent isotopes that contribute >90% of the total burnup reactivity change.

2072 AL8 0.255
1198 ST8 0.464
9200 ST8 0.499
1197 ST8 0.965

Group No. 2
2196 AL8 1.669
2077 AL8 1.604
1044 ST8 1.931
1045 ST8 1.406
1196 ST8 1.151

Group No. 3 (3)
2177 AL8 2.463
1043 ST8 2.499

Group No. 4
1077 ST8 3.959
1076 ST8 3.631
8257 ST8 3.311
3457 ST8 3.831
2071 AL8 3.067
2085 AL8 3.059
2117 AL8 3.226
2147 AL8 3.727
2156 AL8 3.578

Group No. 5
2124 AL8 4.202
2058 AL8 4.983
2200 AL8 4.951
2036 AL8 4.994
4305 ST8 4.332
9589 ST8 4.175
9590 ST8 4.108
9591 ST8 4.888
1075 ST8 4.469

Group No. 6
2127 AL8 5.162
2172 AL8 5.190
2145 AL8 5.687
2138 AL8 5.556
2202 AL8 5.558
2169 AL8 5.588
2174 AL8 5.592
2168 AL8 5.630
2160 AL8 5.669
2133 AL8 5.690
2176 AL8 5.260
2131 AL8 5.263
5284 ST8 5.372
2139 AL8 5.378
3456 ST8 5.399
2184 AL8 5.406
2173 AL8 5.446
2136 AL8 5.447
2135 AL8 5.497
2103 AL8 5.797
2233 ST8 5.798
2118 AL8 5.804
2201 AL8 5.811
2161 AL8 5.829
2075 AL8 5.845
2154 AL8 5.869
2181 AL8 5.878
2159 AL8 5.881
2183 AL8 5.945
2162 AL8 5.957
2170 AL8 5.969
4303 ST8 5.990

Group No. 7
2152 AL8 6.000
2163 AL8 6.032
2166 AL8 6.053
2157 AL8 6.085
2182 AL8 6.144
2199 AL8 6.154
2158 AL8 6.155
2140 AL8 6.156
2132 AL8 6.213
5128 ST8 6.214
2164 AL8 6.244
2175 AL8 6.248
2130 AL8 6.298
2187 AL8 6.305
2141 AL8 6.336
2151 AL8 6.353
2134 AL8 6.436
2074 AL8 6.446
2171 AL8 6.451
2108 AL8 6.451
2155 AL8 6.733
5127 ST8 6.878
2149 AL8 6.931
2109 AL8 6.949

Group No. 8
4305 ST8 7.222
4304 ST8 7.588

Group No. 9
7302 FLIP 8.130
7306 FLIP 8.140
7309 FLIP 8.337
7308 FLIP 8.648

Group No. 10
7307 FLIP 9.677
7305 FLIP 9.795

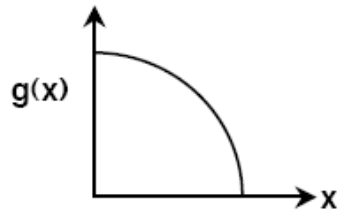
Group No. 11
7304 FLIP 10.408

Group No. 12
7303 FLIP 11.826
7301 FLIP 11.903

Introduction

Simple Monte Carlo Example

Evaluate $G = \int_0^1 g(x)dx$, with $g(x) = \sqrt{1-x^2}$



- **Mathematical approach:**

  For k = 1, …, N: choose $\hat{x}_k$ randomly in (0,1)

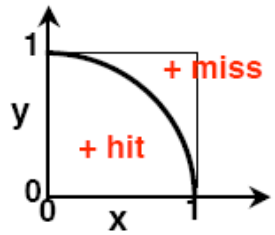
$$G = (1-0)\cdot[\text{average value of } g(x)] \approx \frac{1}{N}\cdot\sum_{k=1}^{N} g(\hat{x}_k) = \frac{1}{N}\cdot\sum_{k=1}^{N}\sqrt{1-x_k^2}$$

- **Simulation approach:**

  "darts game"

  For k = 1, …, N: choose $\hat{x}_k$, $\hat{y}_k$ randomly in (0,1),

  if $\hat{x}_k^2 + \hat{y}_k^2 \le 1$, tally a "hit"



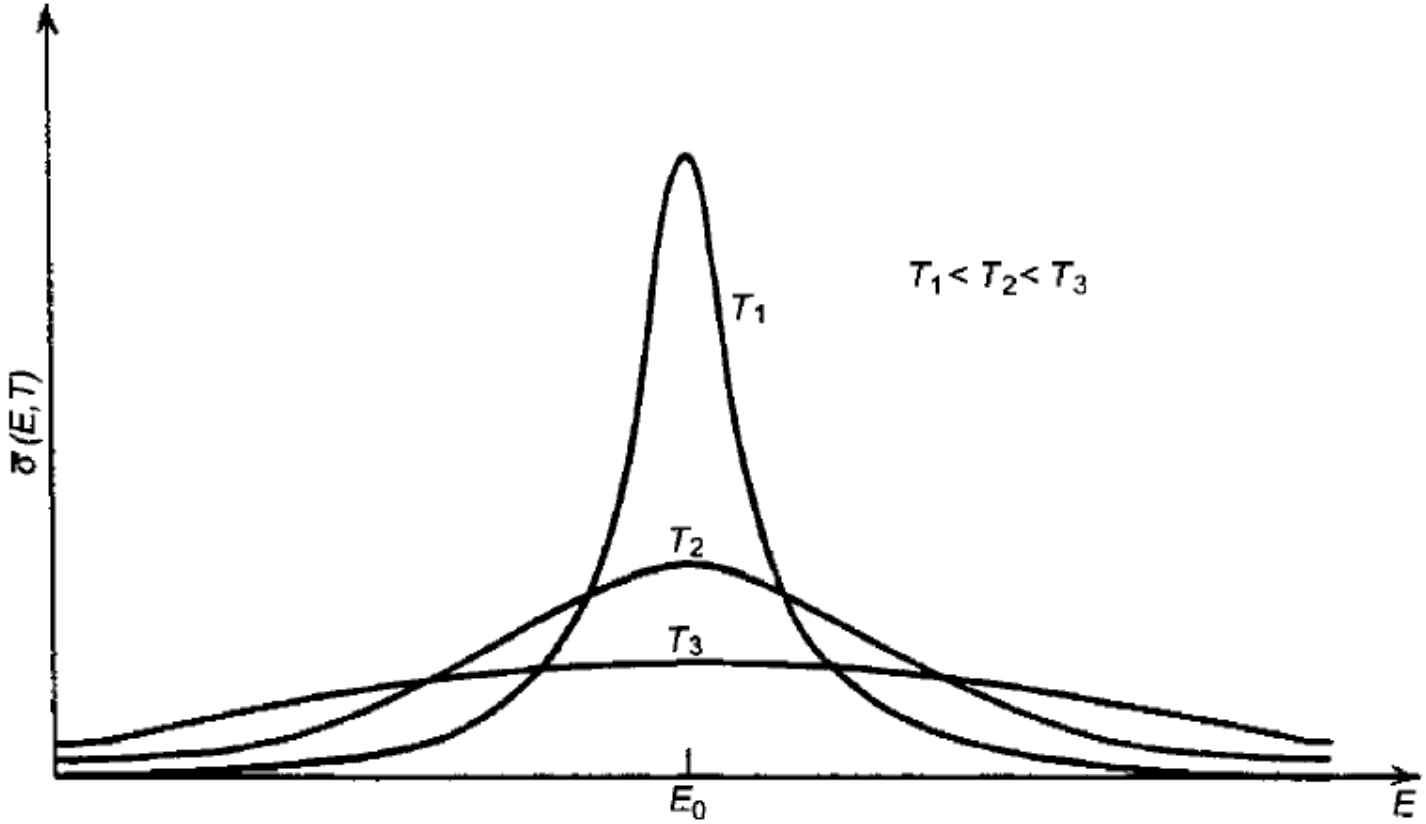
$$G = [\text{area under curve}] \approx (1\cdot 1)\cdot\frac{\text{number of hits}}{N}$$

Why we need Temperature dependent cross sections When MCNP deals with continuos energy distribution only?

Ideally

$$\delta = f\,(E,T)$$

MCNP & Temp Dependent XS



MCNP with resonance

- MCNP versions are equipped with
  - $\delta = \delta(E, T_o)$. [T_o is given Temp.]
- Current MCNP has no module which can create $\delta(E, T)$ from $\delta(E, T_o)$
- Codes like “HELIOS“ can creat $\delta(E, T)$ from $\delta(E, T_o)$
- NJOY generates cross sections having different temp.
- Current MCNP has no module which can create $\delta(E, T)$ from $\delta(E, T_o)$

MCNP - Electric and Magnetic fields

- **Magnetic field tracking with MCNP5**

  J. S. Bull1,*, H. G. Hughes1, P. L. Walstrom1, J. D. Zumbro1 and N. V. Mokhov2

Current Core Model