RA6 REACTOR
MCNP MODEL AND PRELIMINARY RESULTS OF DETAILED SPECTRA CALCULATED ON IRRADIATION ZONES

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1. INTRODUCTION

The inconsistencies in NAA constants between different measurements can be originated from the neutron spectra. Then, it is important to test procedures for more accurate neutron spectrum characterization based on activation measurements, complemented by full scale computational simulations.

On the frame of NAA NDS-IAEA CRP, RA6 reactor calculations and measurements will be included.

An improvement on the conditions of RA6 will be next year (August-September 2006): a new core with all fresh 20 % fuels and maybe also a raise of power from 500 Kw to 3 Mw. It will be the first time that correct comparisons between calculations and measurements will be possible, because from the first start up of the reactor until now we are using old spent fuels from RA3 reactor (CNEA-Ezeiza Atomic Center) and there is an unknown incertitude on the fuel composition.

The scope of CRP work on RA6 has been outlined as:

1. Development of a computational (Monte Carlo) model of the reactor and the irradiation facility for the present core.
2. Verification of the model by comparing induced activities at different irradiation positions with measurements
3. Calculated detailed neutron spectrum.
4. Measurements of specific saturation activities for a number of monitor materials, including threshold reactions for the purpose of spectrum characterization.
5. Update the model for the new core and repeat validation of the model (later).
6. Provide measurements of NAA constants for selected materials.

On this informal report, it is given a schematic diagram of the actual RA6 core layout for Monte Carlo calculation model and results of preliminary calculated neutron spectra at 2 typical irradiation facility positions.

Geometry details of the model of RA6 for Monte Carlo calculations are given in the Annex

Input and Output of Monte Carlo calculations of spectra are given on separate files.

2. BRIEF DESCRIPTION OF RA6 REACTOR MODEL FOR NEUTRON TRANSPORT CALCULATIONS

Figure 1
Cut XY of RA6 Core and Reflector

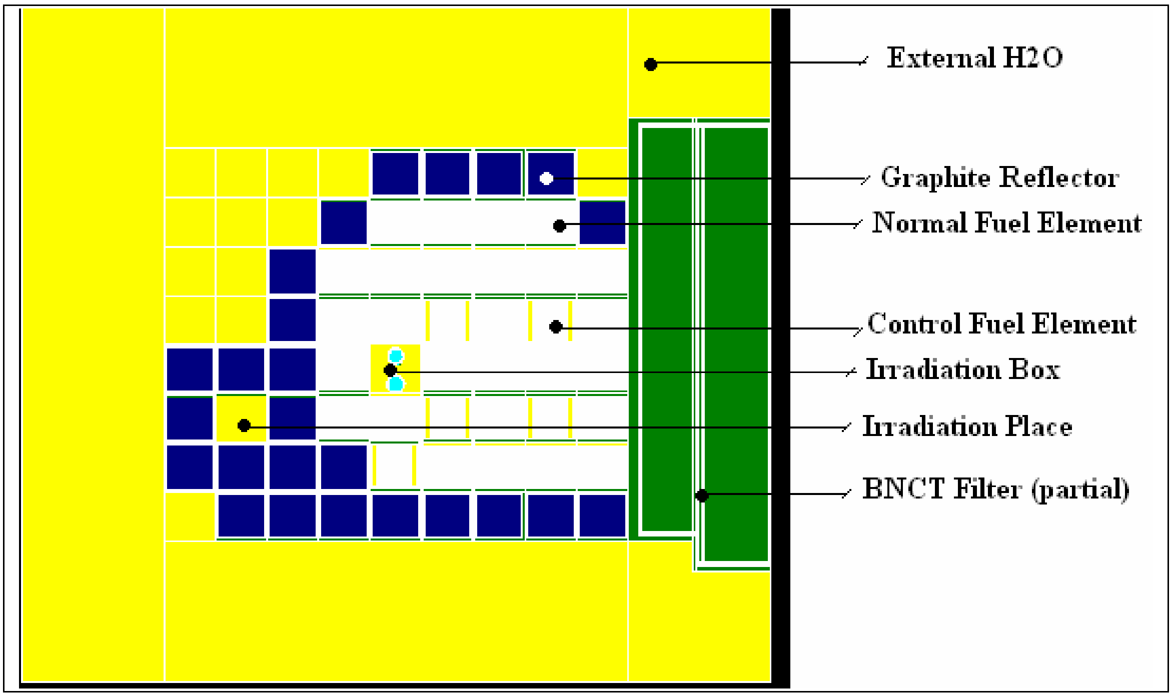


Table 1: General Data of RA6 core

Item	Parameter	Condition
A. POWER	<= 0.5 MW	
B. CORE	**FE (Fuel Elements);**	
	Type	MTR
	Number of plates (normal):	19
	Number of plates (control):	15
	Active width of fuel plates	6 cm
	Total width of fuel plates	7.05 cm
	Depth of fuel plates	0.051 cm
	Material of fuel plates	U-metal(15%w)/Al
	Mass ^{235}U in normal fuel element:	130 gr *
	Enrichment in U-235	80 % isot..*
	Depth of clad	0.040 cm
	Material of clad	Al
	½ active height of fuel plates	30,75cm
	½ total height of fuel plates	32,75cm
	Space between plates (H2O)	0.29 cm
	Depth of marks	0.5 cm
	Width of marks	8.0 cm
	Space between marks	6.6 cm
	Material of marks	Al
	Depth of control plates	0.2 cm
	Material of control plates	Cd
	Depth of clad of control plates	0.05 cm
	Material of clad of control plates	SS
	Width of control plates and clad	6.0 cm
	Depth of guides of control plate	0.12 cm
	Material of guides of control plate	Al
	Distance between centers of control plates	6.345 cm
	Reflector:	Graphite in box of Al walls
	Moderator/Coolant:	demineralized water (H2O)

*: medium value: the old RA6 reactor (up today Sept 2005) uses spent fuel element from RA3 reactor

Calculation Program: MCNP (Ref.1)

Adopted nuclear data library: mainly the .66 series based on ENDF/B-VI.Rev.6

Materials

Temperature of all materials: 20 C

The fuel material contains fission products (remember that these fuel elements are from the spent fuels of RA3 reactor after 10 years of decay (and other 20 years of use on RA6). For MCNP calculation, only the main estimated isotopes are included.

The fuel plates are divided on 5 axial zones with different burnup (different composition).

Previous cell calculations with WIMSD code (Refs.2, 3) were performed for obtaining the fuel composition vs. burnup. A map of burnup vs. position in the core was obtained from typical distributions from previous diffusion calculations. A total of 10 different compositions for normal fuel elements and 6 compositions for control fuel elements were identified and included on the input of Monte Carlo calculations..

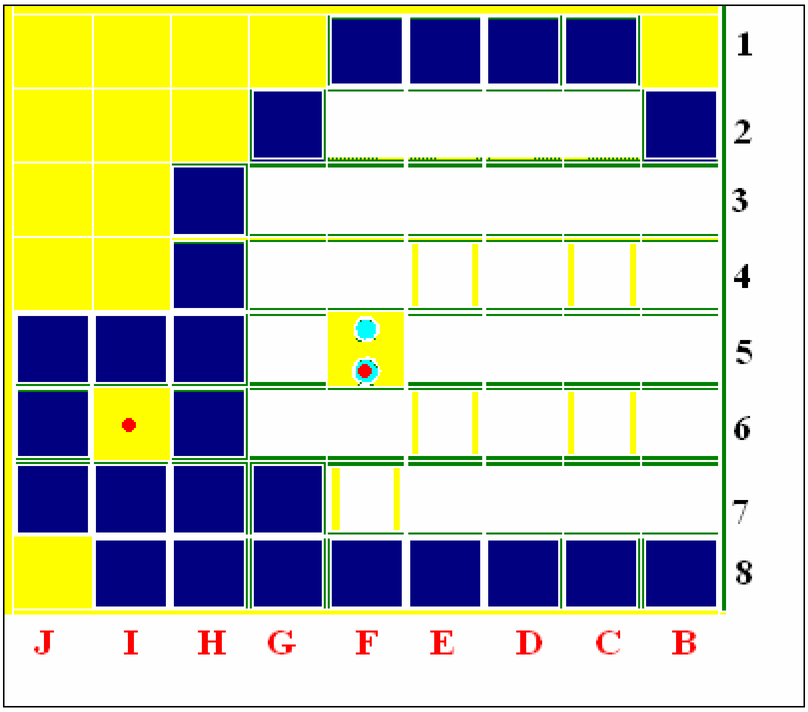
The full MCNP input is included on a separate file.

Other materials included on this input are the following:

```
C     graphite (density=1.80 g/cm3)
M3   6000.66C   1.
MT3  GRPH.60T
C
C     aluminum (density=2.70 g/cm3)
M4   13027.66C   1.
C
C     water (density=1.0 g/cm3)
M5   1001.66C    2.
      8016.66C    1.
MT5  LWTR.60T
C
C     stainless steel (density=7.8 g/cm3)
M7   6000.66C     3.40E-03
      25055.66C    1.93E-02
      14000.60C    1.90E-02
      24000.50C    1.98E-01
      28000.50C    9.13E-02
      26000.50C    6.69E-01
C
C     air (density=0.00121 g/cm3)
M11  7014.66C    .8
       8016.66C    .2
C
C     cadmium (density=8.65)
M12  48000.50C    1.0
```

Geometry: the active part of each fuel element is modeled with all details of plates and marks. Graphite reflector and irradiation boxes were modeled with details also. The lower Al-grid is included, and all the system is rounded by about 25 cm of water reflector (H2O) See the Annex 1 for geometry details of the model for Monte Carlo calculations.

Figure 2
Cut XY of RA6 core with identification of grid positions



The positions of detailed spectrum calculations included on this work are:F5 and I6 (marked with red points on the Figure)

3. PRELIMINARY RESULTS OF SPECTRUM CALCULATIONS ON ACTIVATION ANALYSIS IRRADIATION ZONES

According with the Coordinator of the NAA CRP, an energy distribution of 641 groups (SAND groups) was adopted for calculation of neutron spectra (see Table 2).

Table 2: Energy Distribution (SAND 641 groups)

1.0000E-10	1.0500E-10	1.1000E-10	1.1500E-10	1.2000E-10	1.2750E-10
1.3500E-10	1.4250E-10	1.5000E-10	1.6000E-10	1.7000E-10	1.8000E-10
1.9000E-10	2.0000E-10	2.1000E-10	2.2000E-10	2.3000E-10	2.4000E-10
2.5500E-10	2.7000E-10	2.8000E-10	3.0000E-10	3.2000E-10	3.4000E-10
3.6000E-10	3.8000E-10	4.0000E-10	4.2500E-10	4.5000E-10	4.7500E-10
5.0000E-10	5.2500E-10	5.5000E-10	5.7500E-10	6.0000E-10	6.3000E-10
6.6000E-10	6.9000E-10	7.2000E-10	7.6000E-10	8.0000E-10	8.4000E-10
8.8000E-10	9.2000E-10	9.6000E-10	1.0000E-09	1.0500E-09	1.1000E-09
1.1500E-09	1.2000E-09	1.2750E-09	1.3500E-09	1.4250E-09	1.5000E-09
1.6000E-09	1.7000E-09	1.8000E-09	1.9000E-09	2.0000E-09	2.1000E-09
2.2000E-09	2.3000E-09	2.4000E-09	2.5500E-09	2.7000E-09	2.8000E-09
3.0000E-09	3.2000E-09	3.4000E-09	3.6000E-09	3.8000E-09	4.0000E-09
4.2500E-09	4.5000E-09	4.7500E-09	5.0000E-09	5.2500E-09	5.5000E-09
5.7500E-09	6.0000E-09	6.3000E-09	6.6000E-09	6.9000E-09	7.2000E-09
7.6000E-09	8.0000E-09	8.4000E-09	8.8000E-09	9.2000E-09	9.6000E-09
1.0000E-08	1.0500E-08	1.1000E-08	1.1500E-08	1.2000E-08	1.2750E-08
1.3500E-08	1.4250E-08	1.5000E-08	1.6000E-08	1.7000E-08	1.8000E-08
1.9000E-08	2.0000E-08	2.1000E-08	2.2000E-08	2.3000E-08	2.4000E-08
2.5500E-08	2.7000E-08	2.8000E-08	3.0000E-08	3.2000E-08	3.4000E-08
3.6000E-08	3.8000E-08	4.0000E-08	4.2500E-08	4.5000E-08	4.7500E-08
5.0000E-08	5.2500E-08	5.5000E-08	5.7500E-08	6.0000E-08	6.3000E-08
6.6000E-08	6.9000E-08	7.2000E-08	7.6000E-08	8.0000E-08	8.4000E-08
8.8000E-08	9.2000E-08	9.6000E-08	1.0000E-07	1.0500E-07	1.1000E-07
1.1500E-07	1.2000E-07	1.2750E-07	1.3500E-07	1.4250E-07	1.5000E-07
1.6000E-07	1.7000E-07	1.8000E-07	1.9000E-07	2.0000E-07	2.1000E-07
2.2000E-07	2.3000E-07	2.4000E-07	2.5500E-07	2.7000E-07	2.8000E-07
3.0000E-07	3.2000E-07	3.4000E-07	3.6000E-07	3.8000E-07	4.0000E-07
4.2500E-07	4.5000E-07	4.7500E-07	5.0000E-07	5.2500E-07	5.5000E-07
5.7500E-07	6.0000E-07	6.3000E-07	6.6000E-07	6.9000E-07	7.2000E-07
7.6000E-07	8.0000E-07	8.4000E-07	8.8000E-07	9.2000E-07	9.6000E-07
1.0000E-06	1.0500E-06	1.1000E-06	1.1500E-06	1.2000E-06	1.2750E-06
1.3500E-06	1.4250E-06	1.5000E-06	1.6000E-06	1.7000E-06	1.8000E-06
1.9000E-06	2.0000E-06	2.1000E-06	2.2000E-06	2.3000E-06	2.4000E-06
2.5500E-06	2.7000E-06	2.8000E-06	3.0000E-06	3.2000E-06	3.4000E-06
3.6000E-06	3.8000E-06	4.0000E-06	4.2500E-06	4.5000E-06	4.7500E-06
5.0000E-06	5.2500E-06	5.5000E-06	5.7500E-06	6.0000E-06	6.3000E-06
6.6000E-06	6.9000E-06	7.2000E-06	7.6000E-06	8.0000E-06	8.4000E-06
8.8000E-06	9.2000E-06	9.6000E-06	1.0000E-05	1.0500E-05	1.1000E-05
1.1500E-05	1.2000E-05	1.2750E-05	1.3500E-05	1.4250E-05	1.5000E-05
1.6000E-05	1.7000E-05	1.8000E-05	1.9000E-05	2.0000E-05	2.1000E-05
2.2000E-05	2.3000E-05	2.4000E-05	2.5500E-05	2.7000E-05	2.8000E-05
3.0000E-05	3.2000E-05	3.4000E-05	3.6000E-05	3.8000E-05	4.0000E-05
4.2500E-05	4.5000E-05	4.7500E-05	5.0000E-05	5.2500E-05	5.5000E-05
5.7500E-05	6.0000E-05	6.3000E-05	6.6000E-05	6.9000E-05	7.2000E-05
7.6000E-05	8.0000E-05	8.4000E-05	8.8000E-05	9.2000E-05	9.6000E-05
1.0000E-04	1.0500E-04	1.1000E-04	1.1500E-04	1.2000E-04	1.2750E-04
1.3500E-04	1.4250E-04	1.5000E-04	1.6000E-04	1.7000E-04	1.8000E-04
1.9000E-04	2.0000E-04	2.1000E-04	2.2000E-04	2.3000E-04	2.4000E-04
2.5500E-04	2.7000E-04	2.8000E-04	3.0000E-04	3.2000E-04	3.4000E-04
3.6000E-04	3.8000E-04	4.0000E-04	4.2500E-04	4.5000E-04	4.7500E-04
5.0000E-04	5.2500E-04	5.5000E-04	5.7500E-04	6.0000E-04	6.3000E-04
6.6000E-04	6.9000E-04	7.2000E-04	7.6000E-04	8.0000E-04	8.4000E-04
8.8000E-04	9.2000E-04	9.6000E-04	1.0000E-03	1.0500E-03	1.1000E-03
1.1500E-03	1.2000E-03	1.2750E-03	1.3500E-03	1.4250E-03	1.5000E-03
1.6000E-03	1.7000E-03	1.8000E-03	1.9000E-03	2.0000E-03	2.1000E-03
2.2000E-03	2.3000E-03	2.4000E-03	2.5500E-03	2.7000E-03	2.8000E-03
3.0000E-03	3.2000E-03	3.4000E-03	3.6000E-03	3.8000E-03	4.0000E-03
4.2500E-03	4.5000E-03	4.7500E-03	5.0000E-03	5.2500E-03	5.5000E-03
5.7500E-03	6.0000E-03	6.3000E-03	6.6000E-03	6.9000E-03	7.2000E-03
7.6000E-03	8.0000E-03	8.4000E-03	8.8000E-03	9.2000E-03	9.6000E-03
1.0000E-02	1.0500E-02	1.1000E-02	1.1500E-02	1.2000E-02	1.2750E-02
1.3500E-02	1.4250E-02	1.5000E-02	1.6000E-02	1.7000E-02	1.8000E-02

1.9000E-02	2.0000E-02	2.1000E-02	2.2000E-02	2.3000E-02	2.4000E-02
2.5500E-02	2.7000E-02	2.8000E-02	3.0000E-02	3.2000E-02	3.4000E-02
3.6000E-02	3.8000E-02	4.0000E-02	4.2500E-02	4.5000E-02	4.7500E-02
5.0000E-02	5.2500E-02	5.5000E-02	5.7500E-02	6.0000E-02	6.3000E-02
6.6000E-02	6.9000E-02	7.2000E-02	7.6000E-02	8.0000E-02	8.4000E-02
8.8000E-02	9.2000E-02	9.6000E-02	1.0000E-01	1.0500E-01	1.1000E-01
1.1500E-01	1.2000E-01	1.2750E-01	1.3500E-01	1.4250E-01	1.5000E-01
1.6000E-01	1.7000E-01	1.8000E-01	1.9000E-01	2.0000E-01	2.1000E-01
2.2000E-01	2.3000E-01	2.4000E-01	2.5500E-01	2.7000E-01	2.8000E-01
3.0000E-01	3.2000E-01	3.4000E-01	3.6000E-01	3.8000E-01	4.0000E-01
4.2500E-01	4.5000E-01	4.7500E-01	5.0000E-01	5.2500E-01	5.5000E-01
5.7500E-01	6.0000E-01	6.3000E-01	6.6000E-01	6.9000E-01	7.2000E-01
7.6000E-01	8.0000E-01	8.4000E-01	8.8000E-01	9.2000E-01	9.6000E-01
1.0000E+00	1.1000E+00	1.2000E+00	1.3000E+00	1.4000E+00	1.5000E+00
1.6000E+00	1.7000E+00	1.8000E+00	1.9000E+00	2.0000E+00	2.1000E+00
2.2000E+00	2.3000E+00	2.4000E+00	2.5000E+00	2.6000E+00	2.7000E+00
2.8000E+00	2.9000E+00	3.0000E+00	3.1000E+00	3.2000E+00	3.3000E+00
3.4000E+00	3.5000E+00	3.6000E+00	3.7000E+00	3.8000E+00	3.9000E+00
4.0000E+00	4.1000E+00	4.2000E+00	4.3000E+00	4.4000E+00	4.5000E+00
4.6000E+00	4.7000E+00	4.8000E+00	4.9000E+00	5.0000E+00	5.1000E+00
5.2000E+00	5.3000E+00	5.4000E+00	5.5000E+00	5.6000E+00	5.7000E+00
5.8000E+00	5.9000E+00	6.0000E+00	6.1000E+00	6.2000E+00	6.3000E+00
6.4000E+00	6.5000E+00	6.6000E+00	6.7000E+00	6.8000E+00	6.9000E+00
7.0000E+00	7.1000E+00	7.2000E+00	7.3000E+00	7.4000E+00	7.5000E+00
7.6000E+00	7.7000E+00	7.8000E+00	7.9000E+00	8.0000E+00	8.1000E+00
8.2000E+00	8.3000E+00	8.4000E+00	8.5000E+00	8.6000E+00	8.7000E+00
8.8000E+00	8.9000E+00	9.0000E+00	9.1000E+00	9.2000E+00	9.3000E+00
9.4000E+00	9.5000E+00	9.6000E+00	9.7000E+00	9.8000E+00	9.9000E+00
1.0000E+01	1.0100E+01	1.0200E+01	1.0300E+01	1.0400E+01	1.0500E+01
1.0600E+01	1.0700E+01	1.0800E+01	1.0900E+01	1.1000E+01	1.1100E+01
1.1200E+01	1.1300E+01	1.1400E+01	1.1500E+01	1.1600E+01	1.1700E+01
1.1800E+01	1.1900E+01	1.2000E+01	1.2100E+01	1.2200E+01	1.2300E+01
1.2400E+01	1.2500E+01	1.2600E+01	1.2700E+01	1.2800E+01	1.2900E+01
1.3000E+01	1.3100E+01	1.3200E+01	1.3300E+01	1.3400E+01	1.3500E+01
1.3600E+01	1.3700E+01	1.3800E+01	1.3900E+01	1.4000E+01	1.4100E+01
1.4200E+01	1.4300E+01	1.4400E+01	1.4500E+01	1.4600E+01	1.4700E+01
1.4800E+01	1.4900E+01	1.5000E+01	1.5100E+01	1.5200E+01	1.5300E+01
1.5400E+01	1.5500E+01	1.5600E+01	1.5700E+01	1.5800E+01	1.5900E+01
1.6000E+01	1.6100E+01	1.6200E+01	1.6300E+01	1.6400E+01	1.6500E+01
1.6600E+01	1.6700E+01	1.6800E+01	1.6900E+01	1.7000E+01	1.7100E+01
1.7200E+01	1.7300E+01	1.7400E+01	1.7500E+01	1.7600E+01	1.7700E+01
1.7800E+01	1.7900E+01	1.8000E+01	1.8100E+01	1.8200E+01	1.8300E+01
1.8400E+01	1.8500E+01	1.8600E+01	1.8700E+01	1.8800E+01	1.8900E+01
1.9000E+01	1.9100E+01	1.9200E+01	1.9300E+01	1.9400E+01	1.9500E+01
1.9600E+01	1.9700E+01	1.9800E+01	1.9900E+01	2.0000E+01	

A plot of the preliminary spectra obtained from calculation with MCNP with the tally option of punctual detectors and relative statistical errors are shown in Fig.3.

A comparison of rather approximated measurements of thermal (<0.5 eV, epithermal (>0.5 eV and <0.1 MeV) and fast (>0.1 MeV) neutron flux within the scope of NAA normal activities, with integrated values from MCNP output is shown in Table 3 for F-5 channel and Table 4 for I-6 channel.

The total number of histories on this run was 4.4E+07 (880 cycles of 50000 histories by cycle). The computer time spent for this calculation (on a PC-Pentium-2.8 GHz) was about 14 days.

Full MCNP output and processed file for plot of spectra results are included on separate files.

Figure 3
Neutron Flux at irradiation positions F5 and I6

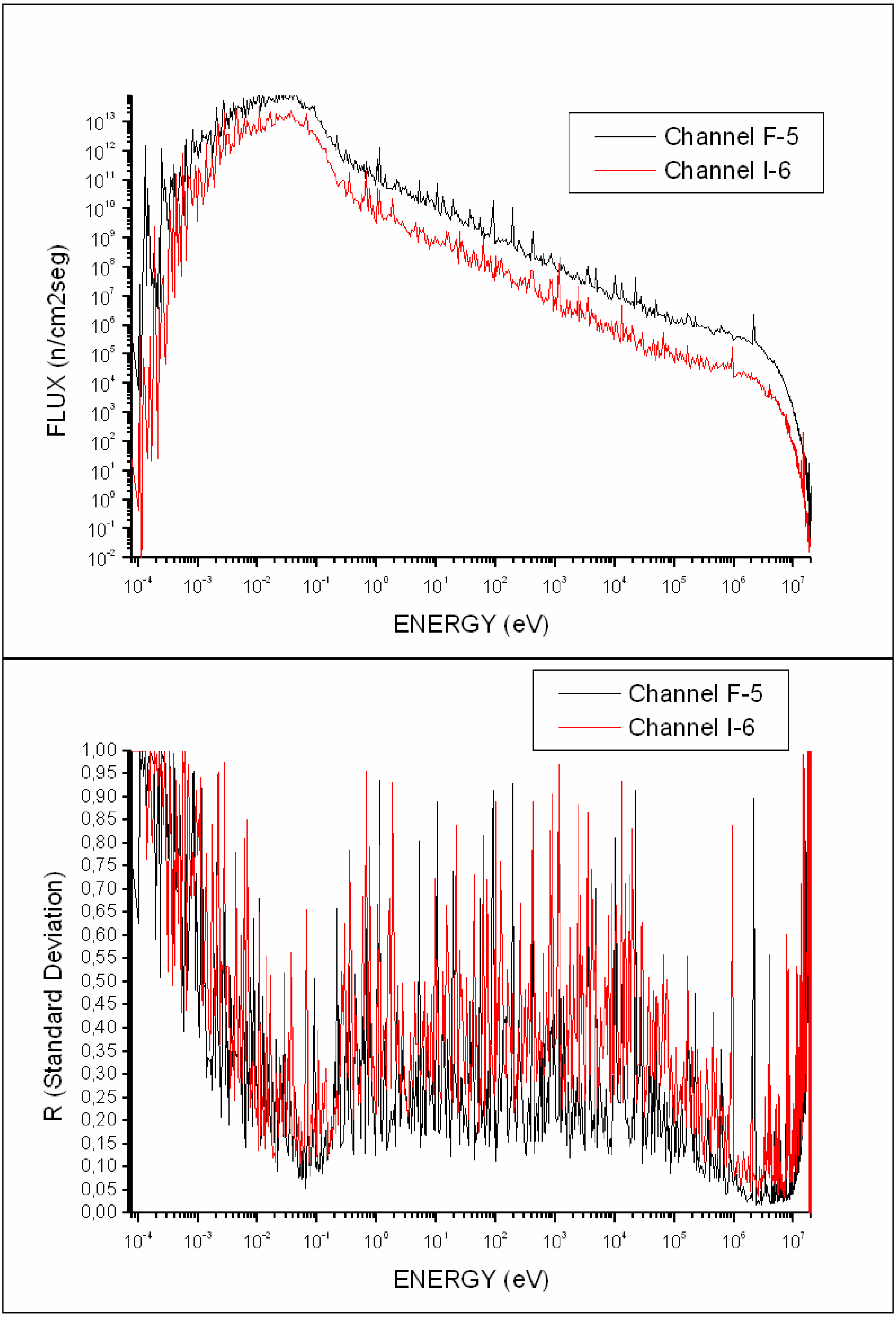


Table 3: Calculated and Experimental Integral Neutron Flux Values at Irradiation Position F5

	THERMAL FLUX n/(cm^2seg) E<0.5 eV	EPITHERMAL FLUX n/(cm^2seg) 0.5 eV<E<0.1 MeV	FAST FLUX n/(cm^2seg) E>0.1 MeV
Experimental Estimation *	6.58E+12	2.95E+12	2.00E+12
MCNP Calculated Result **	5.29E+12	1.97E+12	1.64E+12
((Cal/Exp)-1)*100	-19	-33	-17

* Estimated mean experimental error for all energy ranges: 10 %
** Estimated mean statistical error for all energy ranges: 4 %

Table 4: Calculated and Experimental Integral Neutron Flux Values at Irradiation Position I6

	THERMAL FLUX n/(cm^2seg) E<0.5 eV	EPITHERMAL FLUX n/(cm^2seg) 0.5 eV<E<0.1 MeV	FAST FLUX n/(cm^2seg) E>0.1 MeV
Experimental Estimation *	1.05E+12	1.22E+11	1.00E+11
MCNP Calculated Result**	1.01E+12	1.40E+11	9.16E+10
((Cal/Exp)-1)*100	-4	+14	-8

* Estimated mean experimental error for all energy ranges: 10 %
** Estimated mean statistical error for all energy ranges: 6 %

4. CONCLUSIONS

1) A detailed model for Monte Carlo calculations of RA6 core is ready for use on different applications, including spectra calculations on different special regions.

2) Preliminary calculations in 2 irradiation positions of neutron flux on 641 energy groups were made and the results shown a typical shape of these spectra but the statistical errors are very large for the number of histories calculated

3) Integrated neutron fluxes for fast, epithermal and thermal regions were compared between the calculated values and approximated experimental results with relative good agreement, taking into account the rather crude approximations of both (experimental and calculated) values.

4) A further study is needed of the sensibility of calculated results with details of local and full geometry and with nuclear data used, and the required precision and treatment of the numerical values obtained on calculations.

5) The calculation of spectra with acceptable statistical errors is a very slow process. Then, it is needed to reduce the number of calculation to the really needed with a careful previous study of all the input to be used on the runs.

REFERENCES

1. J.F.Briesmeister, (ed.) “MCNP- A General Monte Carlo N-Particle Transport Code, LA-12625-M (1993).
2. J.R.Askew, F.J.Fayers, P.B.Kemshell, A General Description of the CodeWIMS, J. British Nucl. Energy Soc., Vol. 5, No. 4, p. 564, October 1966.
3. WIMS-D5, NEA Data Bank Documentation, Package ID No. 1507/02, 1998.

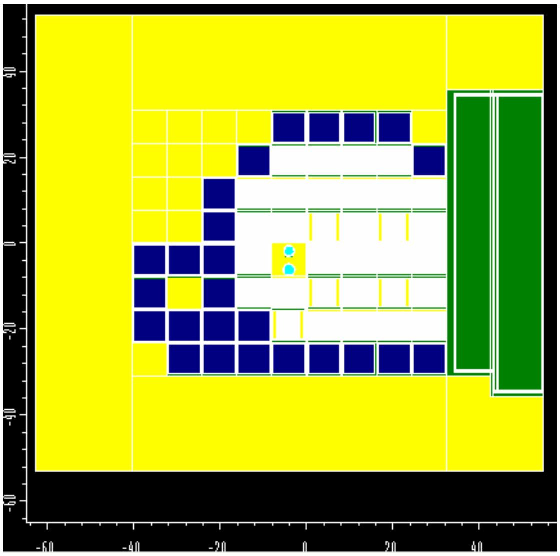
ANNEX

GEOMETRICAL MODEL OF RA6-CORE FOR CALCULATIONS WITH MCNP

The description of the geometrical model of the actual RA6 core (September 2005) is included.

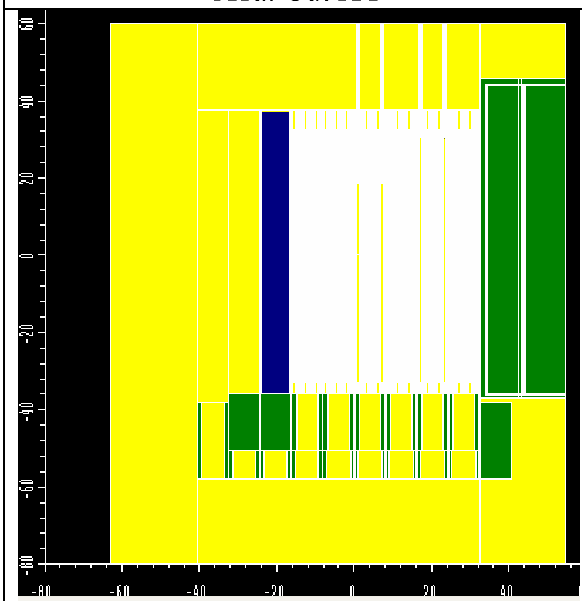
In Figure A1 it is shown cuts in xy, xz e yz at active zone level of the full modeled system.

Figure A1
Cuts of RA6 for MCNP

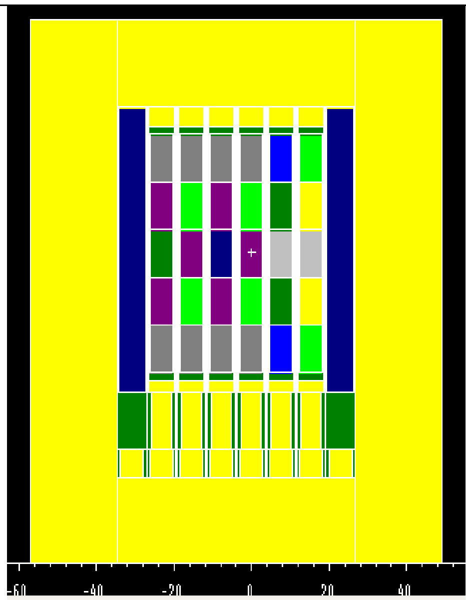


A1a: Cut XY

Remarks:
Yellow zones are of water reflector and irradiation boxes. Blue zones are reflector boxes of graphite. Green zones are parts of BNCT filter (to the right of the plot).
The full system is a parallelepiped of 120 cm en X, 106 cm en Y y 140 cm high Z.
Inside the system 3 main zones are included: the core grid with all the details of its components, the BNCT filter, and the water reflector. Besides, control plates are inserted in the grid and in the upper water reflector zones.
In the YZ cut, the 5 axial sub-zones of fuel active part for each fuel element can be seen.



A1b: Cut XZ



A1c: Cut YZ

Figure A2
Cut XZ of the grid, at the level of the active zone
(dimensions in cm)

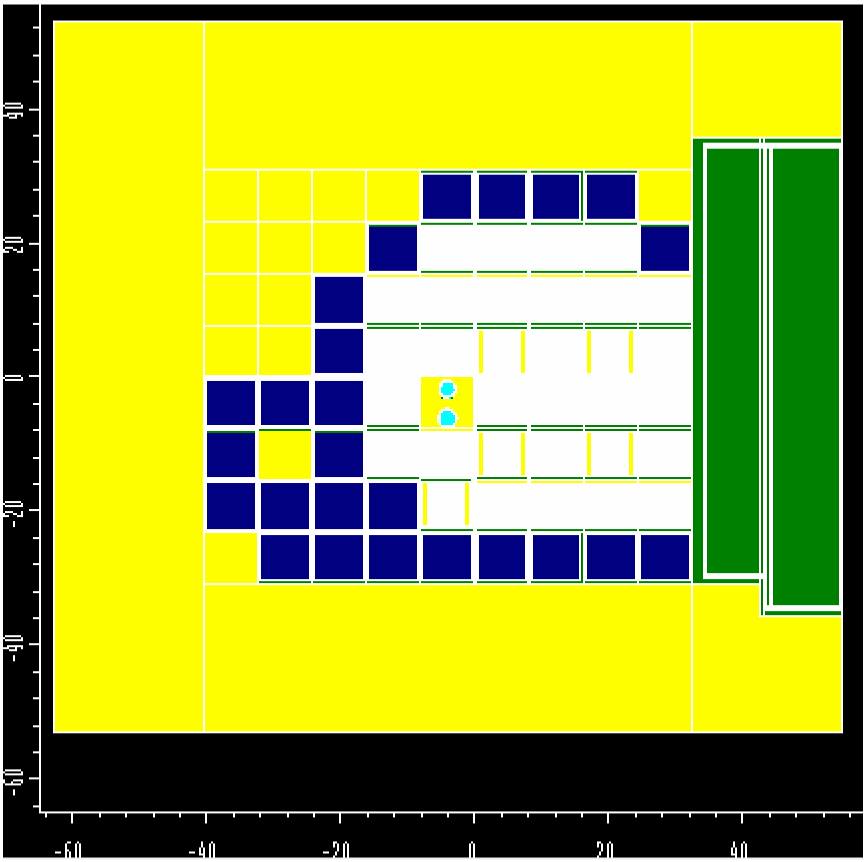


Figure A3
Cut XZ of the grid, at the level of the active zone
(dimensions in cm)

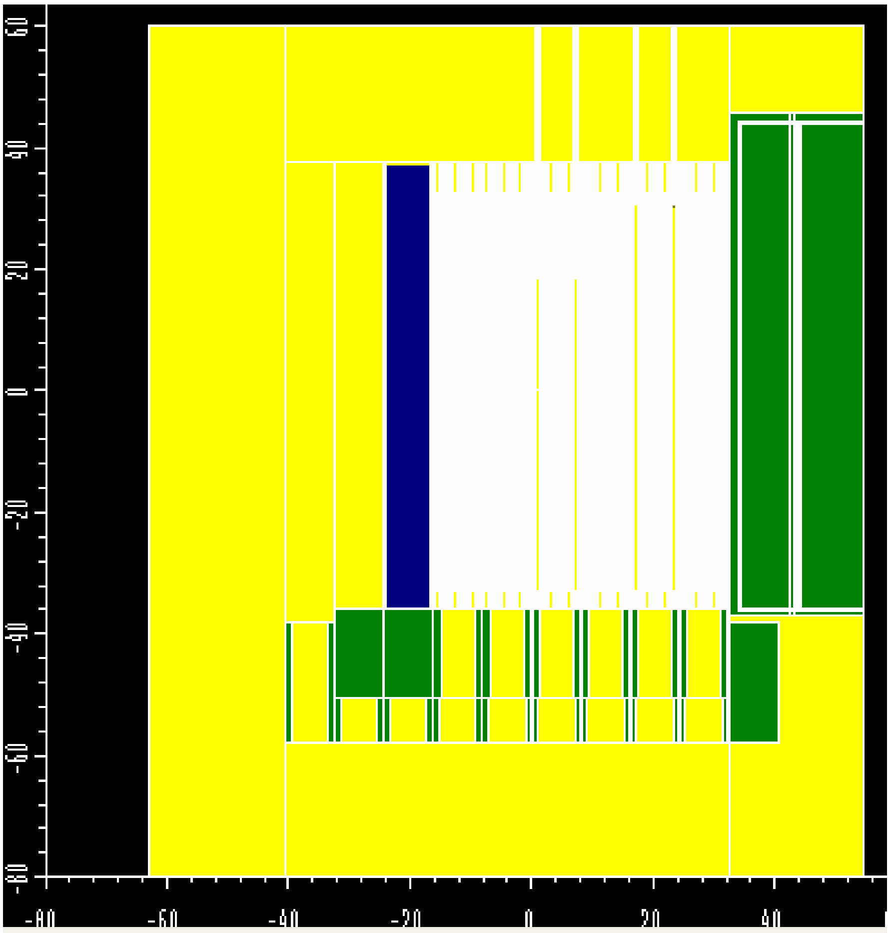
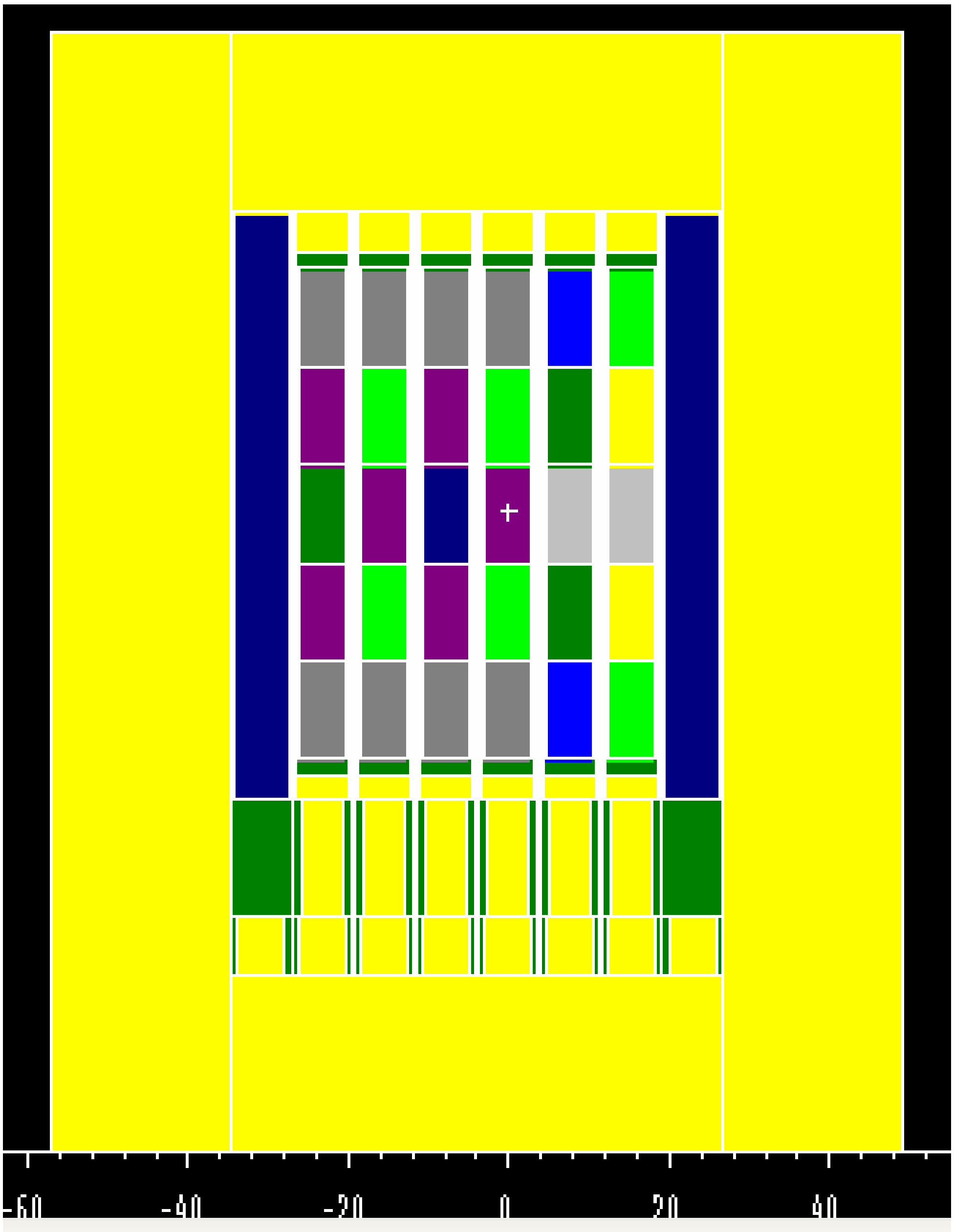


Figure A4
Cut YZ of the grid, at the level of the active zone
(dimensions in cm)



Core grid

The core grid is inside a parallelepiped of 72.9 cm in X, 61.5 cm in Y and 95.5 cm in Z. It is adopted the option of "square lattice" of MCNP, filling each mesh lattice with an universe. Each universe represent to each component of the core, including the lover part of the grid.

The positions of the components of the grid are shown in the following lines, extracted from the MCNP input:

J	I	H	G	F	E	D	C	B	
11	8	8	8	8	8	8	8	8	8
8	8	8	8	132	109	107	105	101	7
8	12	8	101	104	131	101	131	103	6
8	8	8	101	9	108	107	103	103	5
11	12	8	103	102	131	104	131	102	4
11	11	8	110	104	101	102	104	101	3
11	11	11	8	108	104	106	102	8	2
11	11	11	12	8	8	8	8	12	1
J	I	H	G	F	E	D	C	B	

COMPONENTS (UNIVERSES)

8 - GRAPHITE REFLECTOR BOX
9 - IRRADIATION BOX
11 - H2O (EMPTY POSITION)
12 - EXTERNAL SOURCE CONTAINER
101/110 – Normal Fuel Elements
131 – Control Regulation Fuel Element BC5
132 - Control Regulation Fuel Elements -BC1/4

Positions of Control Fuel Elements:
BC1:C4 - BC2:C6 - BC3:E4 - BC4:E6 - BC5:F7
Column A is not included in the grid because it is below BNCT. Filter.

Zones of water reflector, BNCT filter and control plates

Water reflector zone is all the space not filled by the core grid and the BNCT filer. In the upper zone of water reflector, parts of control plates not inserted in the core are included (see Figure A1b). They are modeled as independent components with 10 zones (2 for each control element). The Z planes that limit the absorber zone are positioned according to the percent of extraction of each control plate.

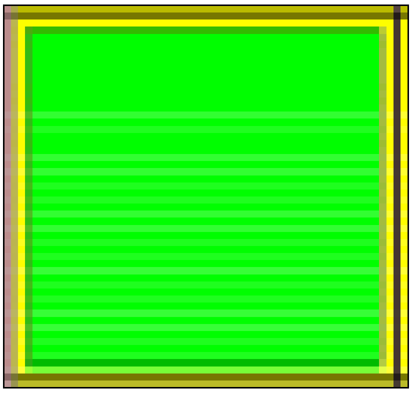
DETAILS OF THE CORE COMPONENTS

Each mesh of the grid is filled with the corresponding component according it position on the grid. All components are parallelepipeds of 8.1 cm in X, 7.7 cm in Y and 96 cm in Z. The cuts on XY of each component, at the level of the active zone (61.5 cm) are modeled without geometric approximations besides the planar form (the original plates present a small curvature). The upper and lower parts respect to the active zone are modeled in simplified form.

Graphite boxes

The graphite boxes are divided in 3 vertical zones.
From high to low:
1) graphite blocs with aluminum walls and space of water around (see Fig.A5). The graphite blocs are parallelepiped of 7.4 cm in X and Y and 71.5 cm in Z (35.75 up to the center of the active zone and 35.75 cm down). The Al walls are of 0.3 cm of depth. The space with water around is of 0.5 cm on depth.
2) aluminum (se Fig.A1b,c) of 14.5 cm height.
3) part of the support table of the grid, of Al, with water hole (see Fig.A1b,c). The hole is of radius 3 cm . The height of this zone is 10 cm.

Figure A5
Cut XY of graphite reflector box at the level of active zone



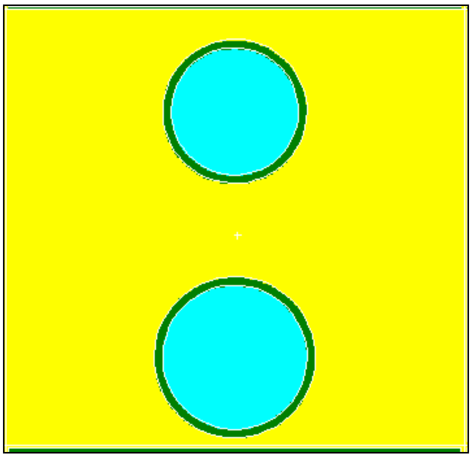
Water (free positons)

The free positions are divided in 2 vertical zones (see Fig.A1b).
From high to low:
1) water in a parallelepiped of 8.1 cm in X, 7.7 cm in Y and 73.5 cm in Z (35.75 up to the center of the active zone and 35.75 cm down).
2) part of the support table of the grid, of Al, with water hole (see Fig.A1b,c). The hole is of radius 3 cm . The height of this zone is 22 cm.

Irradiation boxes

On this model it is adopted the same form and materials that water (free positions) for the I6 position. For F5 position it is included the terminal of the pneumatic tube (see Fig.A6).

Figure A6
Cut XY of Irradiation box with pneumatic tube at the level of active zone



Normal and control fuel elements

The fuel elements are divided in 7 vertical zones (see Figs.A7-11 and A1b,c).
From high to low:
1) upper zone with Al marks (support part) and water, without plates, of 5 cm height,
2) zone above the active part with Al marks, parts of the plates with Al only and water, of 2 cm height,
3) active zone with fuel plates ("meat", clad, Al marks and water. This zone is sub-divided in 5 vertical regions with different burnup. The dimensions in XY of the different parts of this zone are given in Table 1 of this report.
4) zone bellow the active part with Al marks, parts of the plates with Al only and water, of 2 cm height (equal to zone 2)),
5) zone above the fuze with Al marks and water, without plates, of 5 cm height,
6) zone of the inserted fuze in the support table of the Al grid with water hole, 12.5 cm height,
7) part of the support Al gird table, with water hole (3 cm radius). The height of this zone is 5 cm.

Figure A7
Model of the fuel elements

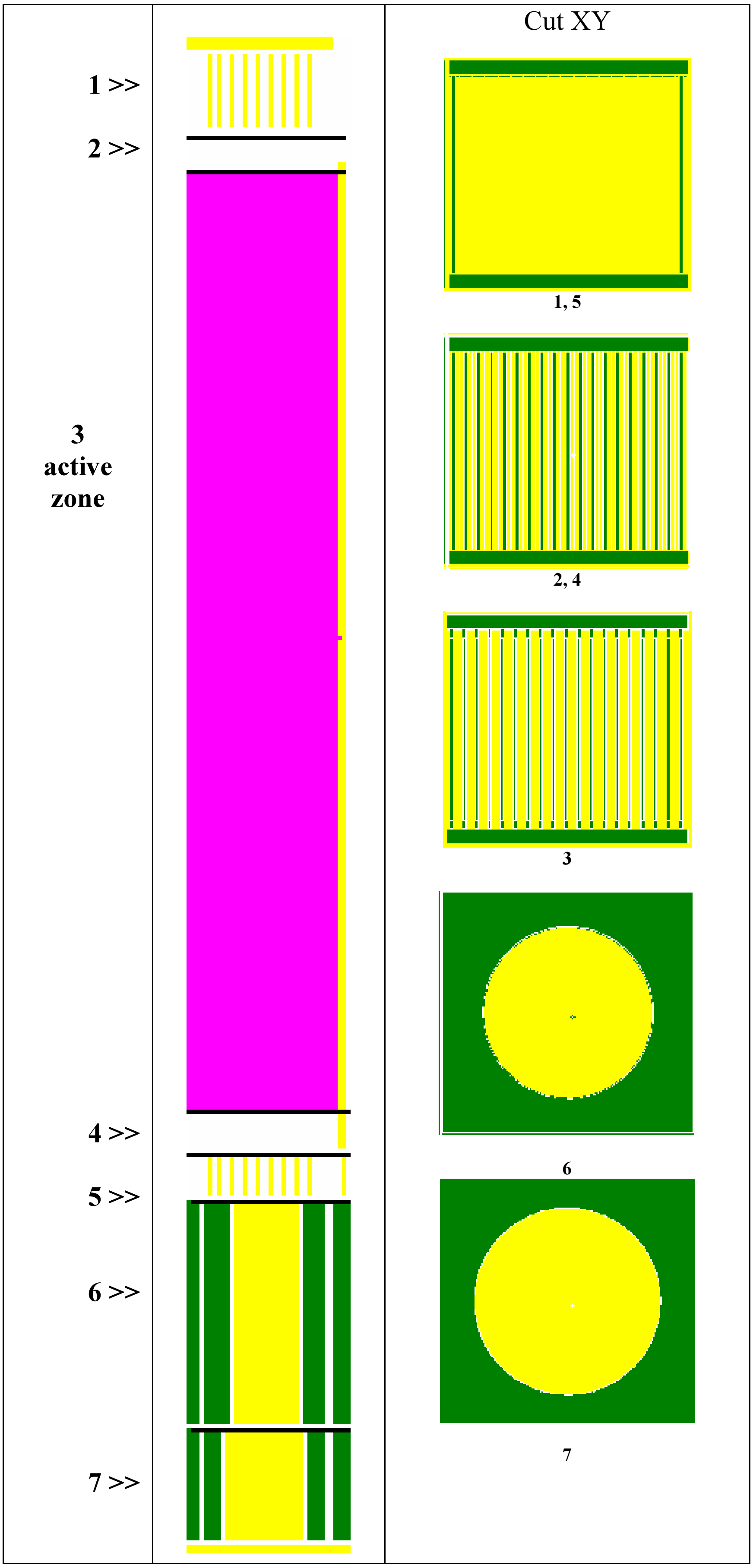


Figure A8
Cut XY of the normal fuel elements at the level of active zone

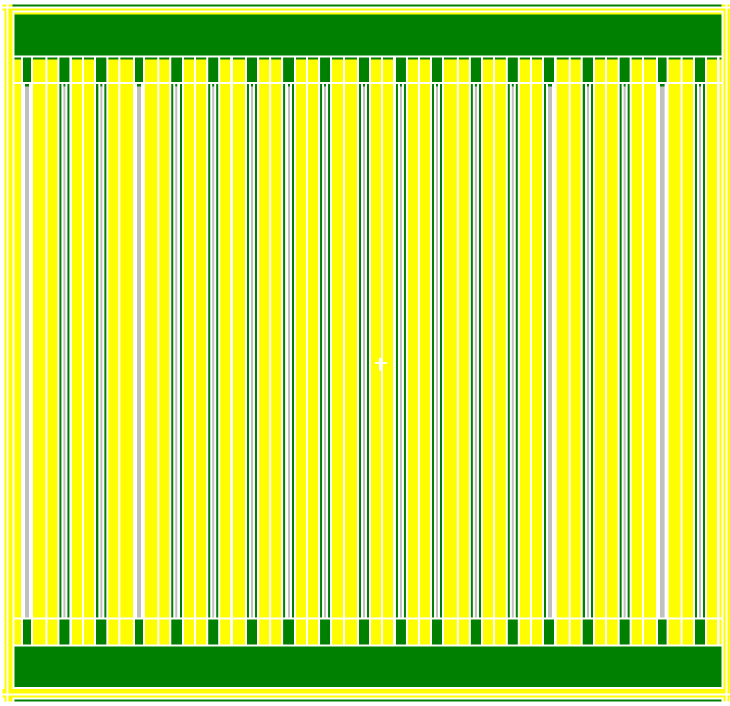


Figure A9
Cut XY of the contol fuel elements at the level of active zone without control plates

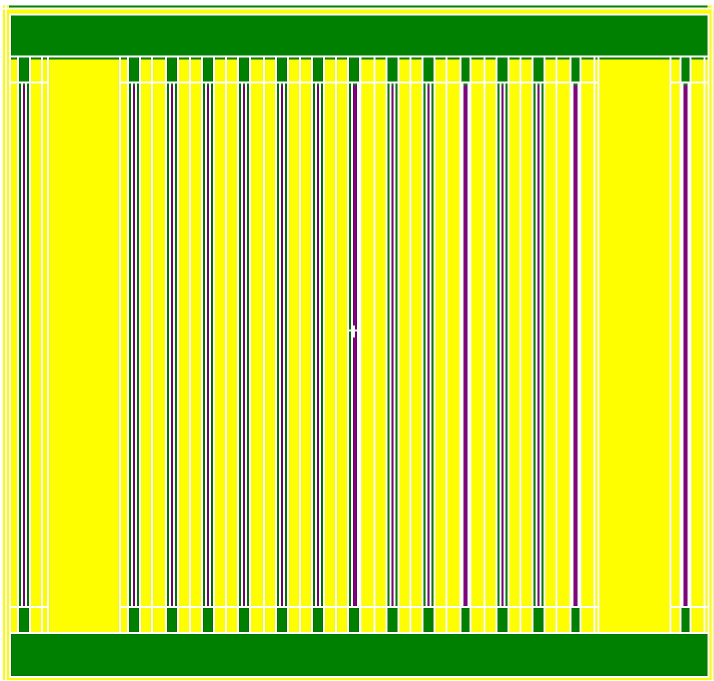


Figure A10
Cut XY of the contol fuel elements at the level of active zone with control plates

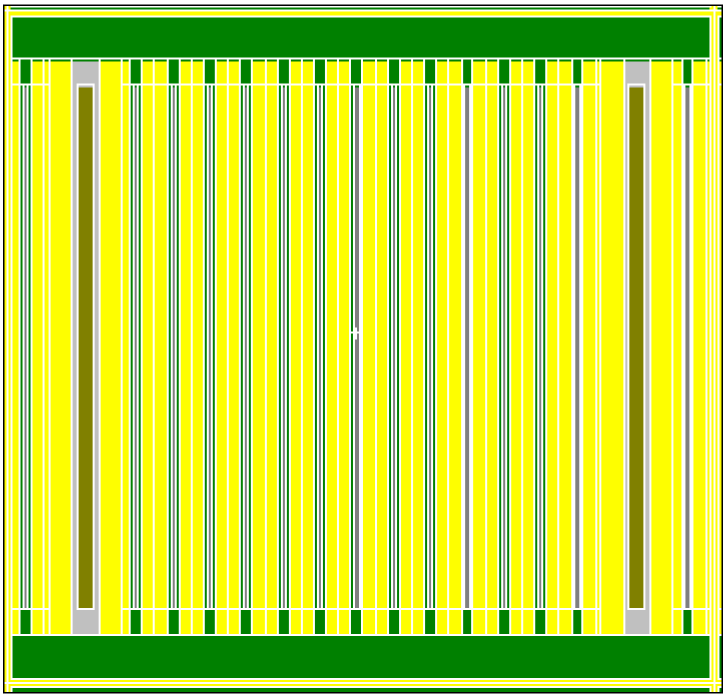
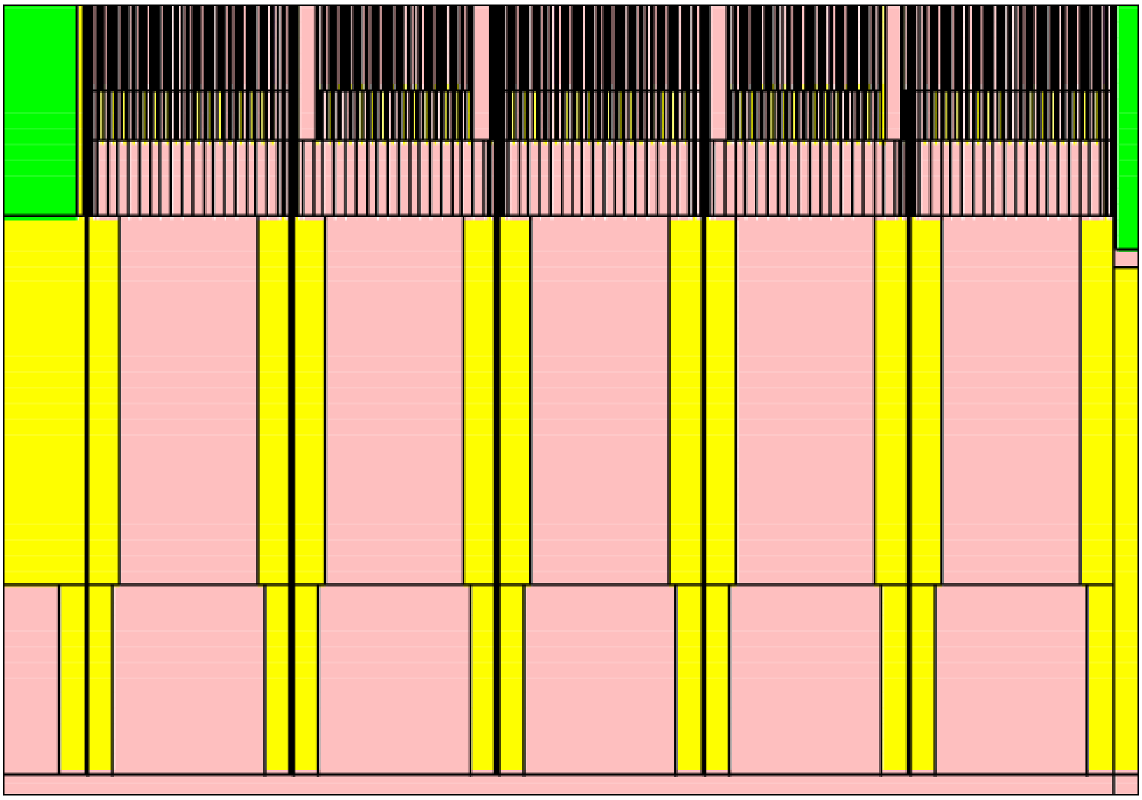


Figure A11
Cut XZ of the lower zones of the fuel elements



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