

CIEMAT simulations for SAD (2004-2005)

E. Gonzalez, M. Embid and F. Alvarez
CIEMAT

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1st SAD/YALINA-B Steering Committee Meeting
2nd SAD/YALINA-B Steering Committee Meeting

July 12-13, 2004 DUBNA
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- Target studies
- System static simulations
- System kinetic simulations
- Reactivity insertion and Dynamic tests
- SAD target decay heat

2nd MEETING on DM2 ECATS: Feasibility Study April 20-21, 2005 SCK-CEN Headquarters, Brussels

SAD TARGET Simulations

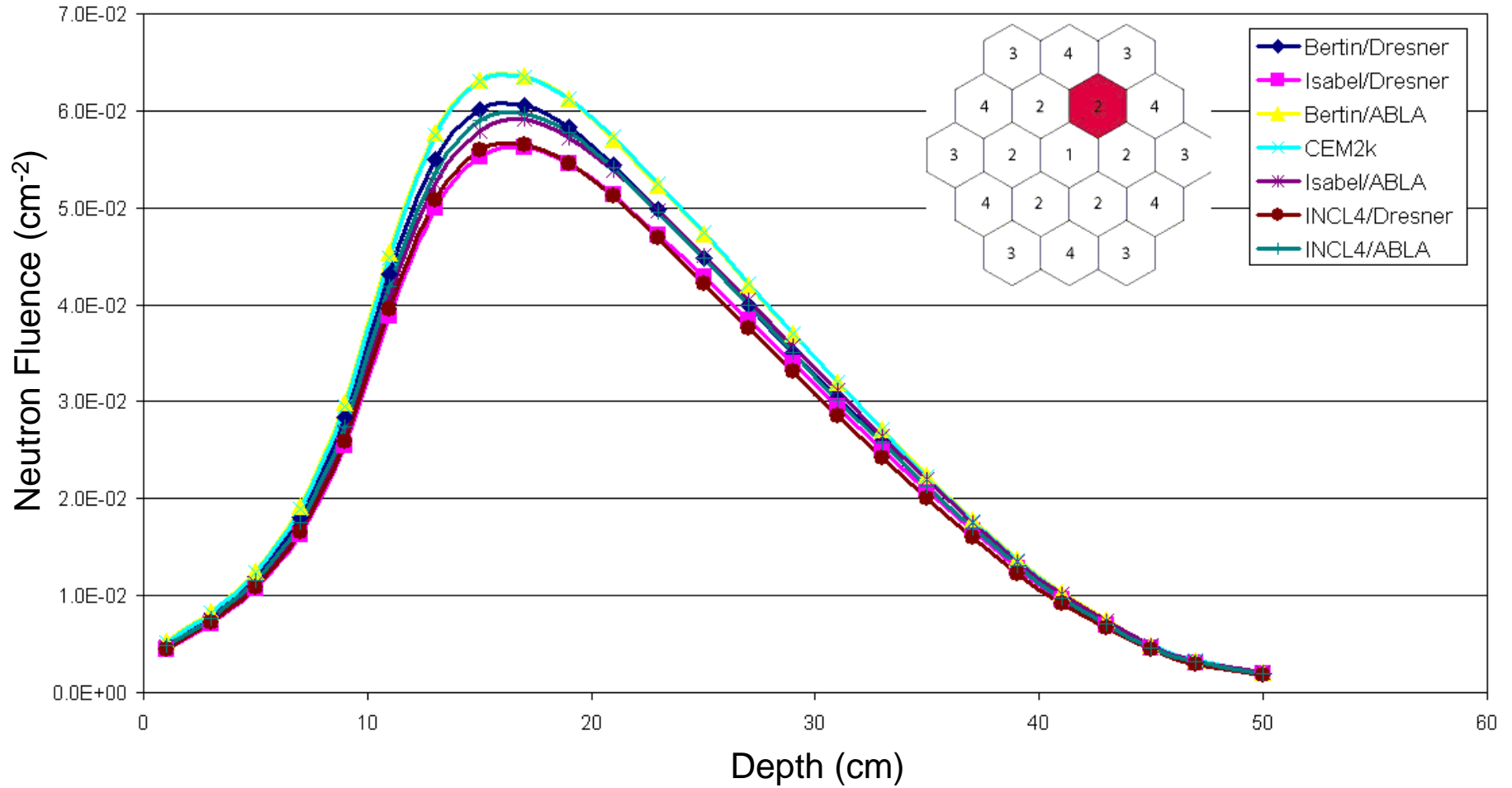
Up to 8 simulations had been performed with different high energy models using always the ENDFB6r6 data library and the MNCPx2.5e code

Computed: Neutron leakage, Neutron fluence, Energy deposition

Integrated number of neutrons per proton escaping from the lead target by the bottom, top and perimeter surfaces.

Surface	Bertin/Dresner	Isabel/Dresner	Bertin/ABLA	CEM2k
Bottom	5.3264E-01	4.8021E-01	5.7017E-01	5.5341E-01
Top	1.9548E-01	1.9345E-01	2.0721E-01	1.9581E-01
Perimeter	1.2595E+01	1.1851E+01	1.3372E+01	1.3212E+01
Surface	Isabel/ABLA	INCL4/Dresner	INCL4/ABLA	INCL4/ABLA updated
Bottom	5.1212E-01	5.1212E-01	4.8130E-01	5.18822E-01
Top	2.0438E-01	2.0438E-01	1.7675E-01	1.88195E-01
Perimeter	1.2552E+01	1.2552E+01	1.1761E+01	1.25800E+01

The deviations between different physics models in both tables range from 13% to 17%.



Neutron flux depth dependence for the cell #2 of the target

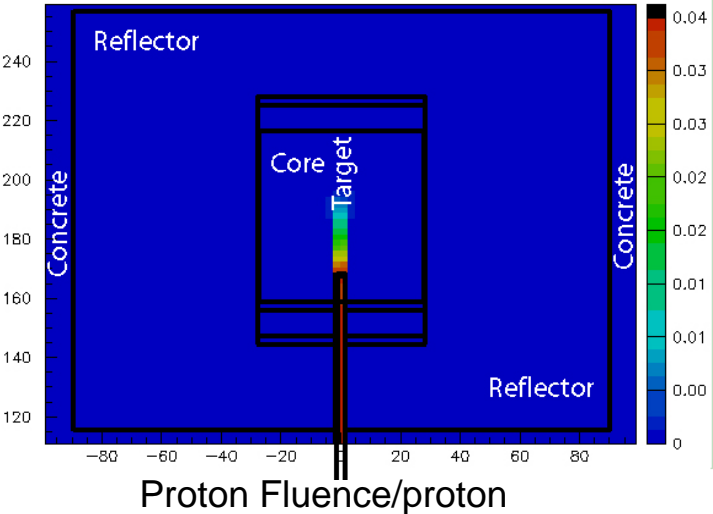
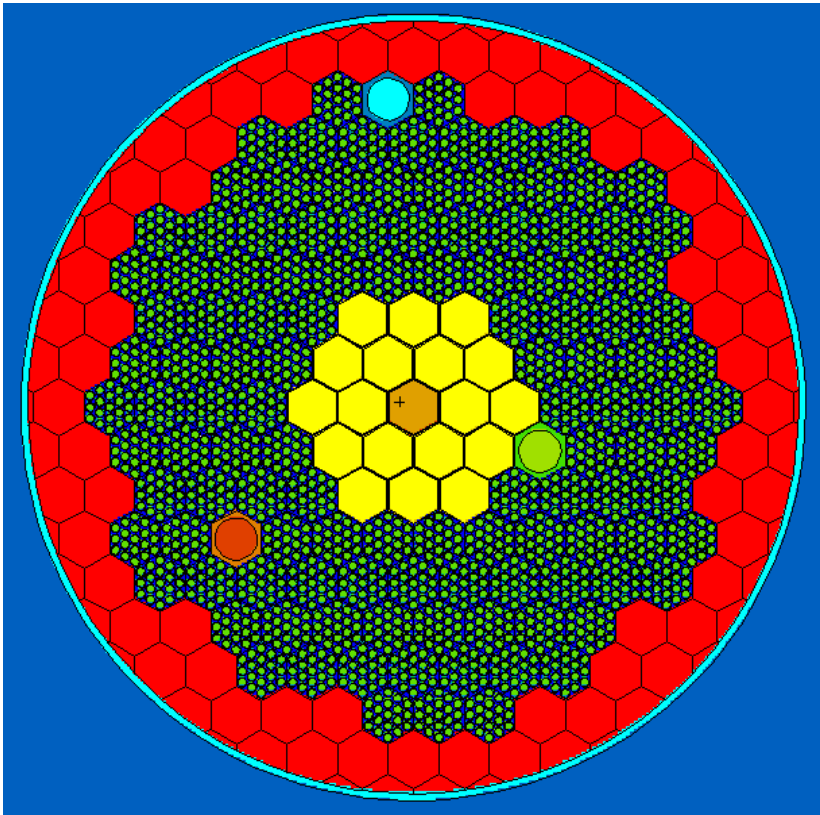
System static simulations

More than 20 simulations

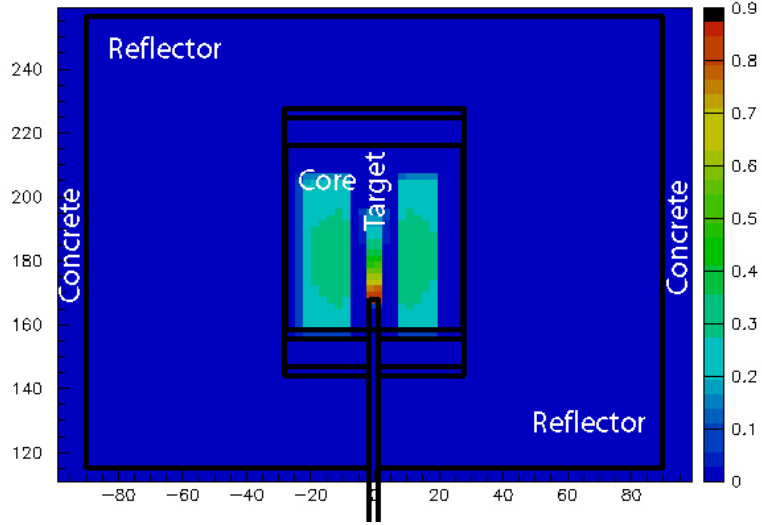
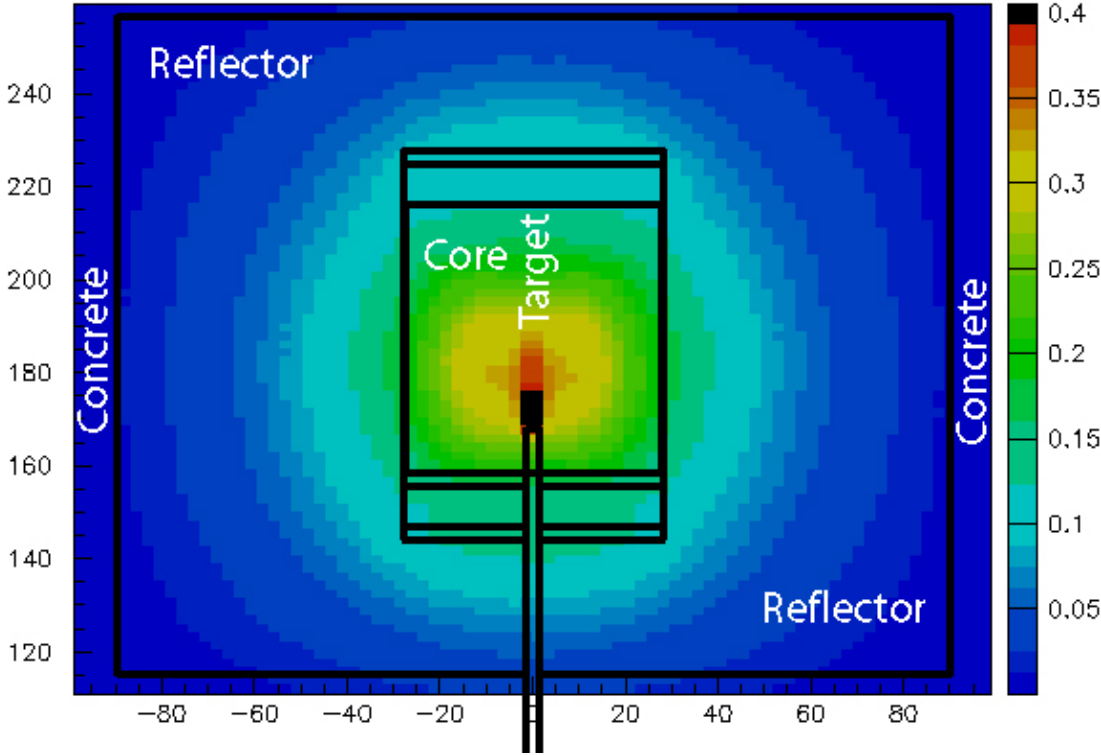
K_{eff} , Spatial distributions of neutron and proton fluence and Energy deposition

Case number	New radius of the lead reflector	Number of fuel assemblies removed/Total	Modification	$K_{\text{eff}} \pm \text{Error}$
1	Without modification	none/145	none	0.94951 ± 0.00036
2	~60cm	none/145	none	1.00726 ± 0.00101
3	~70cm	none/145	none	1.01352 ± 0.00112
4	~80cm	none/145	none	1.01937 ± 0.00120
5	~60cm	4/141	none	1.00177 ± 0.00112
6	~60cm	8/137	none	0.99434 ± 0.00109
7	~60cm	12/133	none	0.98328 ± 0.00105
8	~60cm	16/129	none	0.97541 ± 0.00113
9	~60cm	20/125	none	0.96608 ± 0.00102
10	~60cm	24/121	none	0.95416 ± 0.00110
11	~60cm	28/117	none	0.94386 ± 0.00098
12	~60cm	26/119	none	0.94783 ± 0.00010
13	~70cm	26/119	none	0.95150 ± 0.00010
14	~80cm	26/119	none	0.95425 ± 0.00011
15	~60cm	26/119	10% of B-10 to the first 10 cm of of concrete close to lead reflector	0.94195 ± 0.00011
16	~60cm	24/121	Idem as case #15	0.95027 ± 0.00011
17	~60cm	25/120	Idem as case #15	0.94563 ± 0.00011
18	~60cm	22/123	0.5% of ^{10}B @ internal lead reflector 1.0% of ^{10}B @ bottom and top plates	0.95089 ± 0.000108
19			Latest SAD MCNP Input distributed	0.94627 ± 0.00101

Configuration number #12

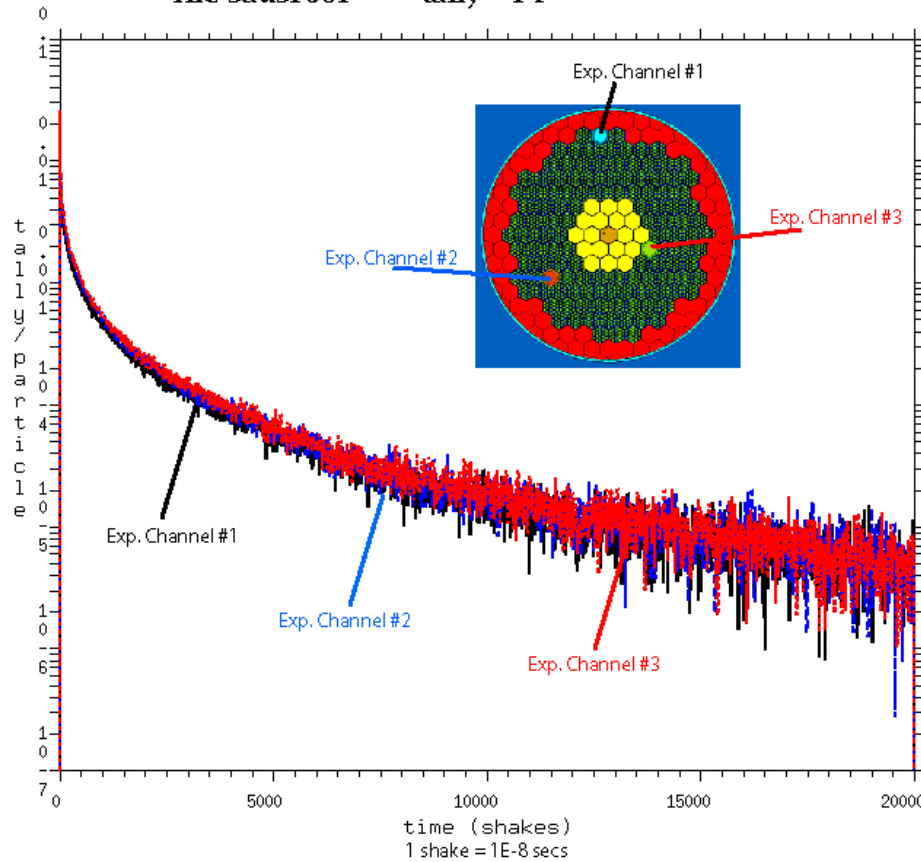


Neutron Fluence/proton



Deposited energy/proton (MeV/cm³/p)

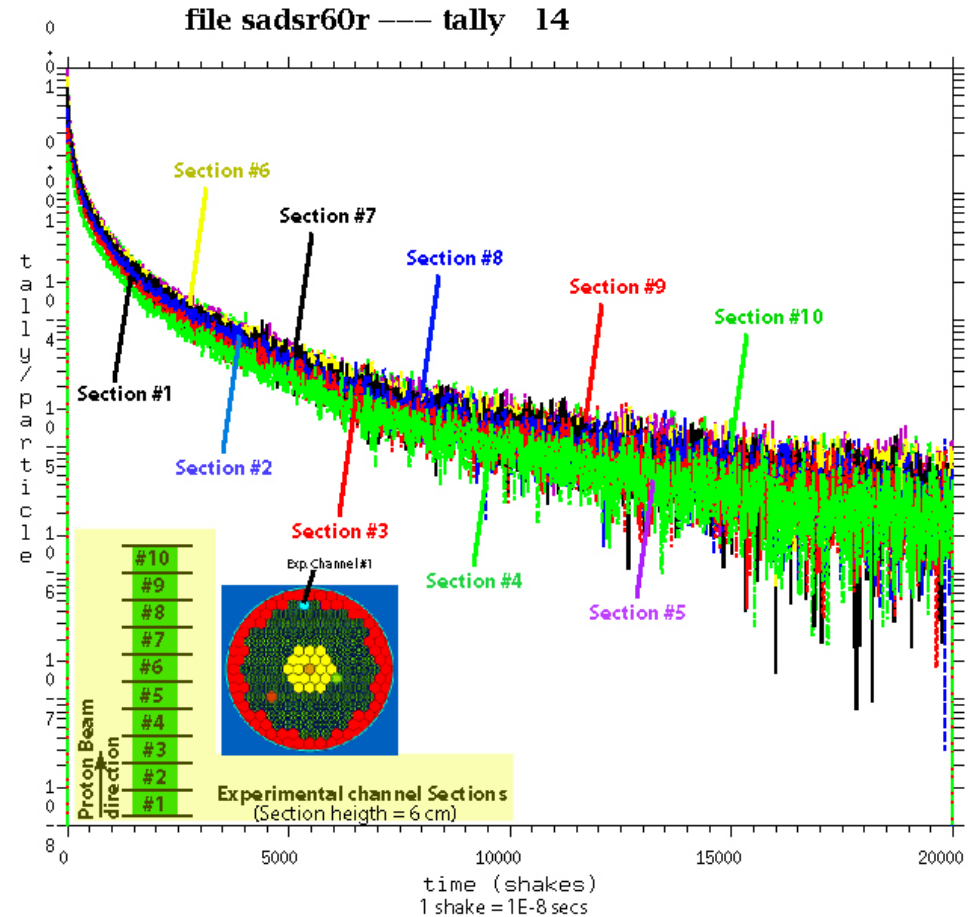
file sadsr60r --- tally 14

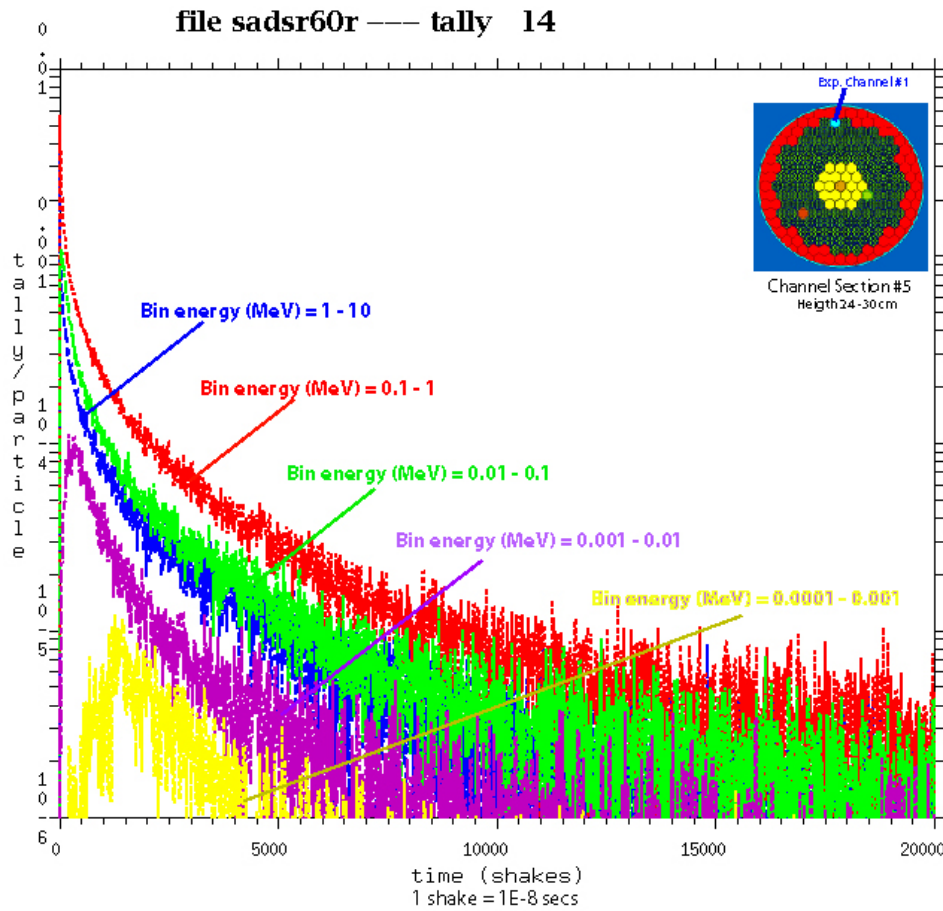


Case #12: Time evolution of ^{235}U fission counting rate. Central height.
Detectors in the 3 experimental channels at the core.

System kinetic simulations

Case #12: Time evolution of ^{235}U fission counting rate. Exp. Channel 1 in the core.
Detectors at 10 different heights.

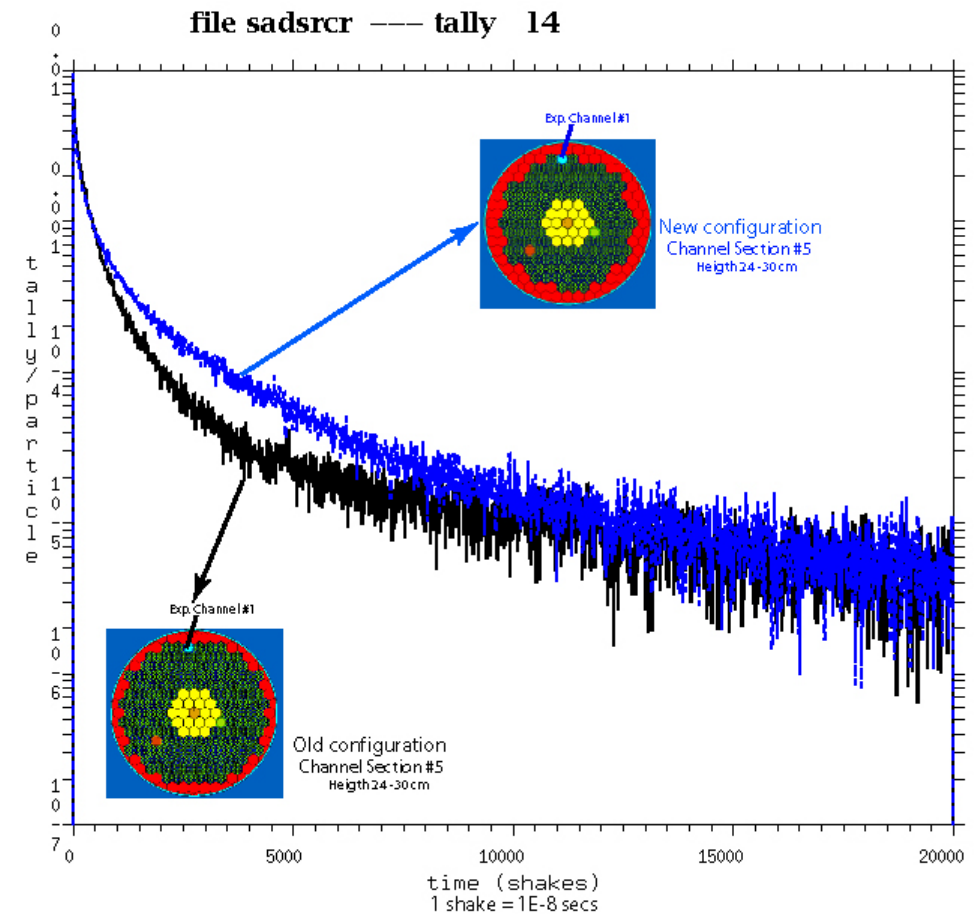


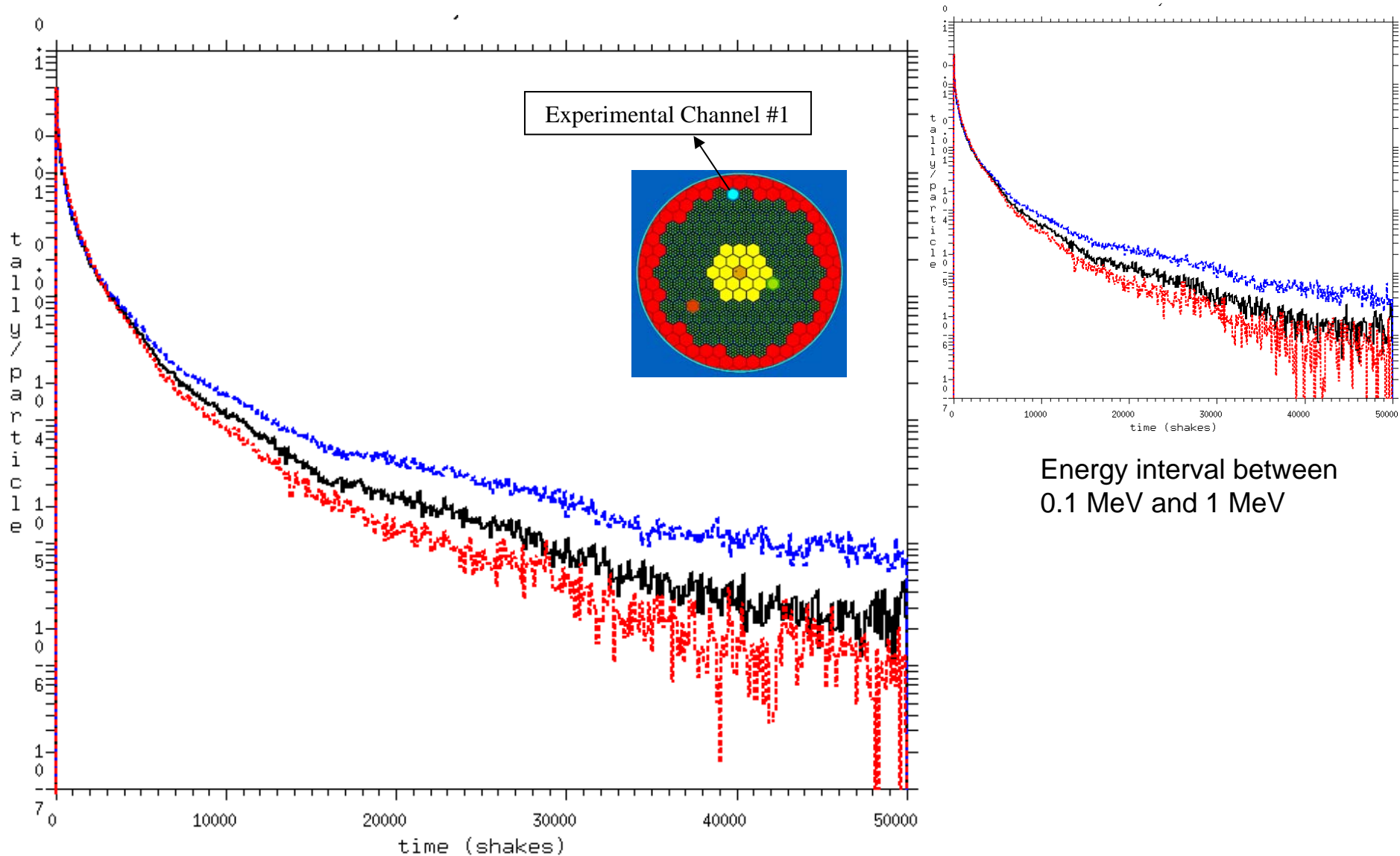


Case #12: Time evolution of ^{235}U fission counting rate. Exp. Channel 1 in the core. Central height.
Contributions from different energy intervals

System kinetic simulations

Time evolution of ^{235}U fission counting rate. Exp. Channel 1 in the core. Central height. Case #1(0.94951) vs. Case #12 (0.94783).

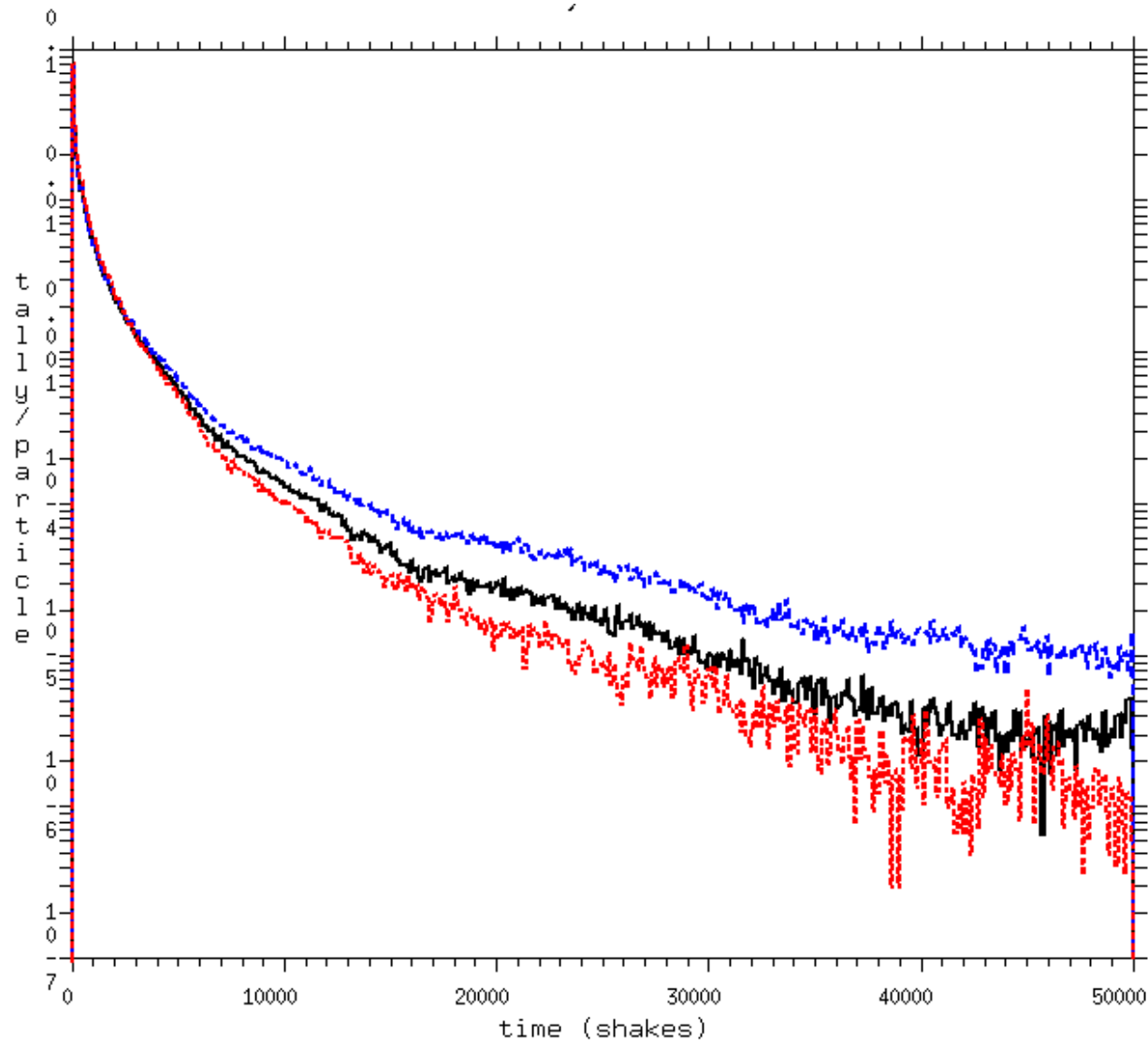




Neutron time response in the **experimental channel #1** at central height.

Virtual ^{235}U fission detectors were placed in the center of the experimental channel.

Blue = Case #12; **Black** =Case #15 (Borated Concrete); **Red**=Case #18 (Borated Pb)



Neutron time response in the external experimental channel placed in the **lead reflector** ($R=40.5\text{cm}$) at central height.

Virtual ^{235}U fission detectors in the center of the experimental channel.

Blue = Case #12; **Black** =Case #15 (Borated Concrete); **Red**=Case #18 (Borated PB)

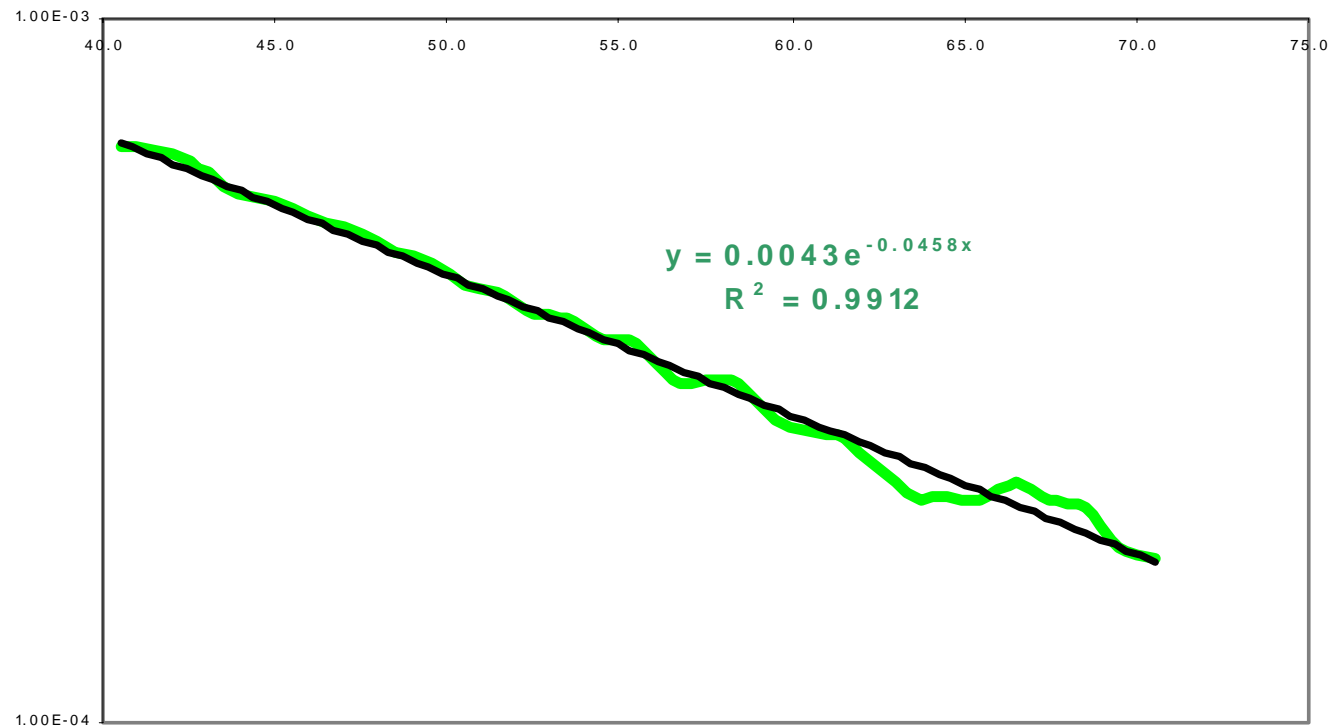
Application of simple point kinetics to case #18:

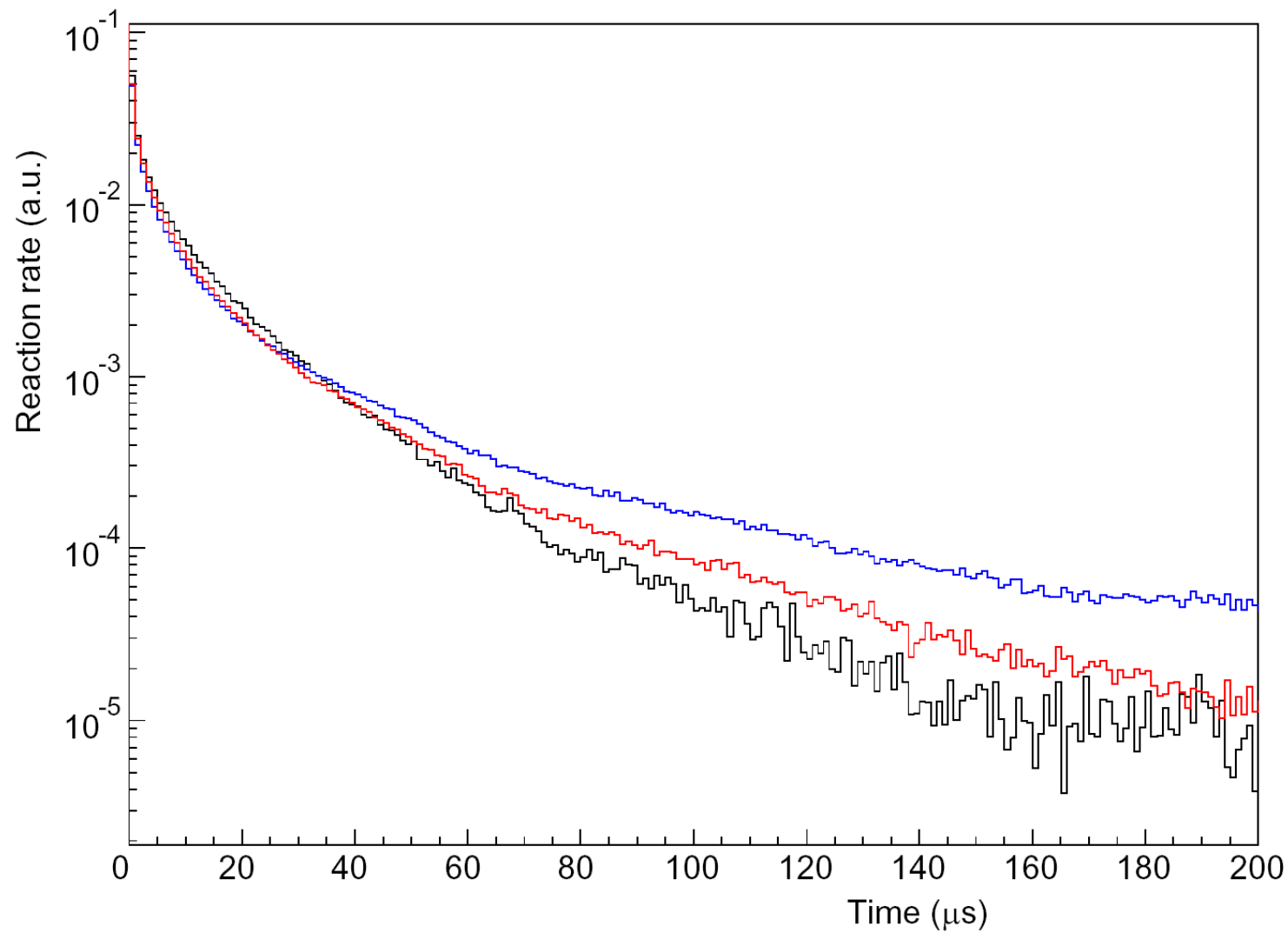
MCNP: $\Lambda=9.543 \cdot 10^{-7}\text{s}$, $\beta=345 \text{ pcm}$;

FIT: $\alpha=45800 \text{ s}^{-1}$

then, $\rho(\$) = 11.6$ so $K_{\text{eff}} = 0.9597$

Note: β_{eff} Case #1 = 368 ± 10 (pcm)
 β_{eff} Case #12 = 350 ± 10 (pcm).





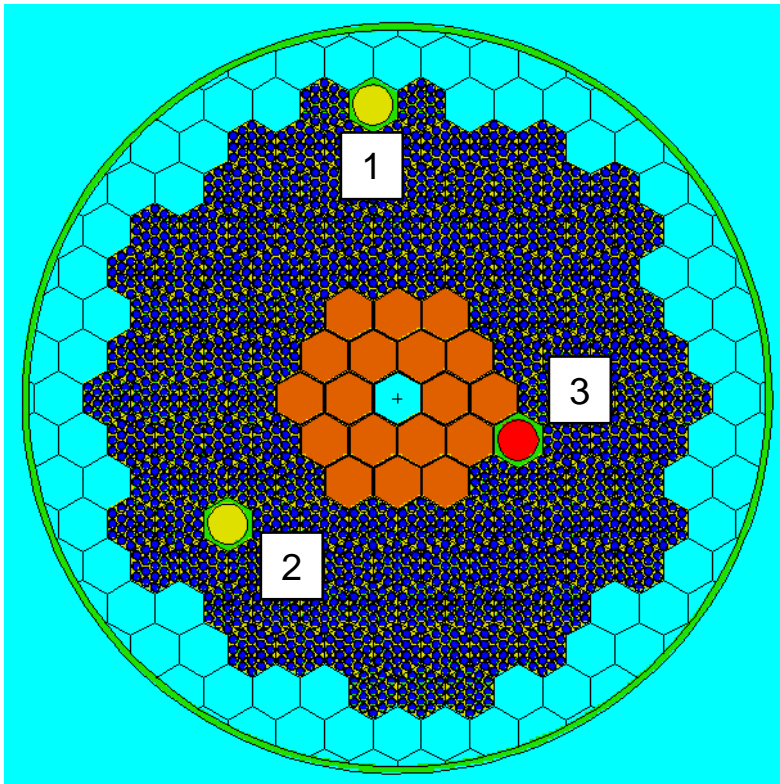
Neutron time response in the **experimental channel #1** at central height.

Virtual ^{235}U fission detectors were placed in the center of the experimental channel.

Blue = Case #12; **Red**=Case #18 (Borated PB); **Black** =Case #19 (Latest SAD Distr. Input file)

Reactivity insertion simulations

Introduction of a B_4C cylinder ($\text{Ø}3 \text{ cm} \times 51 \text{ cm}$ long)
in the core experimental channels



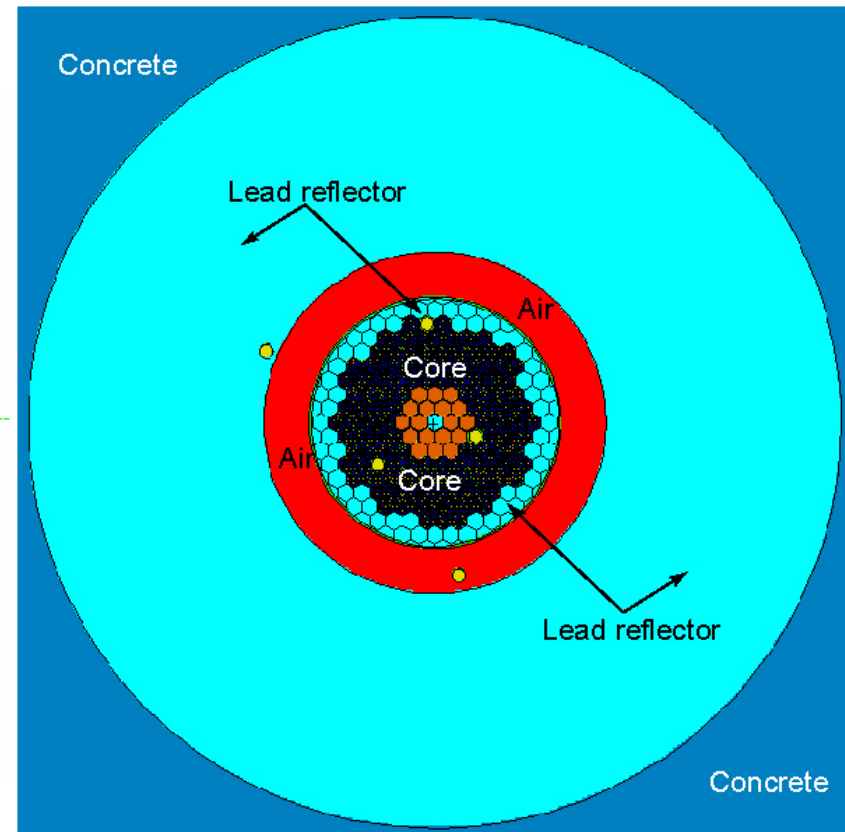
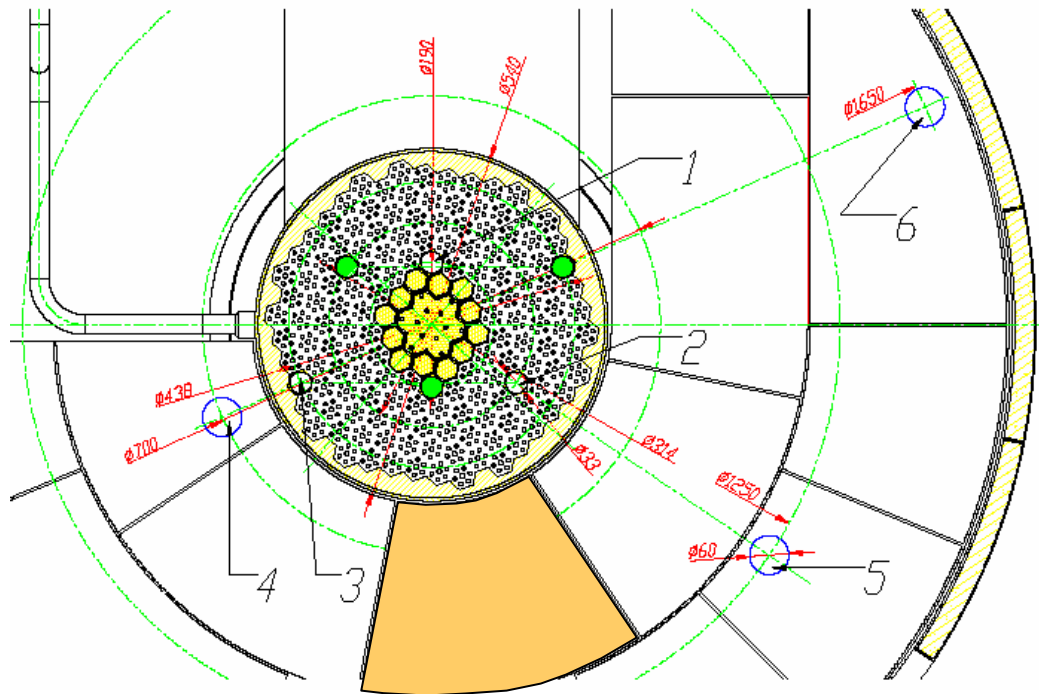
K_{eff} reference = 0.94783		
Exp. Channel	K_{eff}	Δk_{eff}
3	0.92406	-0.02377
2	0.92720	-0.02063
1	0.93063	-0.01720

Reactivity insertion simulations

Reduction of the reflector effect:

- In reality extraction of one of the reflector elements.
- In the simulation reduction of the lead thickness.

K_{eff} reference = 0.94783		
Reduct. of \varnothing cm	K_{eff}	Δk_{eff}
20	0.84882	0.09901
6	0.91437	0.03346



Dynamic tests proposal

In the near future (<7 years) there will be no ADS system that

- Is similar to the proposed transmutation device: Fuel, Coolant, Neutron Spectrum
- and Has sufficient power / heaters as to introduce significant thermal feedbacks

Two complementary approaches:

- 1) Use a different system with significant feedbacks (TRADE-Plus)
- 2) Use a similar ADS system simulating the feedbacks (⇒ **SAD**)

The proposal is to study dynamic feed-backs of ADS systems by artificial introduction of reactivity variations following the pattern of the calculated thermal feedbacks in industrial ADS incidents.

The reactivity (positive/negative) insertions can be obtained by programmed reflector movements (more complicated options possible).

The follow up can be done by neutronic detectors, and actions can be applied by beam actuation or absorbers in the experimental channels.

It would be interesting to study insertions of as much as ± 1000 pcm (from $0.95 \rightarrow 0.96$ and from $0.95 \rightarrow 0.94$).

Targets simulations

- The decay heating and radioactivity in two different targets (**Pb** and **W**) have been calculated. For every target, three high energy models have been used: **INCL4/ABLA**, **Bertini/Dresner** and **CEM2k**.
- Codes **MCNPX**, **EVOLCODE** and **ORIGEN** were used in order to make the proper calculations, using the **ENDF-VI** library.

Target geometry and input data

- Protons energy of 660 MeV and beam power of 1 kW.
- Irradiation time of 1000 hours.
- Diameter of beam cross section of 22 mm.
- Proton guide channel depth of 10 cm and diameter of 5 cm.
- Target length of 60 cm and diameter of 16.5 cm (Pb) and 10 cm (W).

Targets simulations: Solving the problem

- The spallation process produces [spallation products](#) and also a [neutron flux](#) in the target. These quantities have been obtained using [MCNPX](#) version [2.5e](#).
- During the irradiation, the neutron flux can [activate](#) the target by itself. This activation and the spallation products continual production induced activation were obtained separately.
- In order to calculate the required cross sections library for ORIGEN, the code [EVOLCODE](#) has been utilized.
- After the irradiation, the decay heat and the radioactivity have been also obtained using [ORIGEN2.2](#) for fast reactors.
- As many of the spallation products created according to the models are not included in the ORIGEN DECAY library, it has been necessary to extend largely this database. The information of more than 1900 isotopes have been added from the [NuDat2.1](#) database of the [National Nuclear Data Center](#) (Brookhaven, USA).
- Nevertheless, the information of the [average energy per decay](#) has only been added for the [90 isotopes](#) with higher contribution to the radioactivity after irradiation. This should provide a [precision](#) better than [3%](#).
- In addition, some of the non-usual spallation products do not have complete nuclear databases so the nuclear reactions are not considered for them, only radioactive decay.

Targets simulations: Pb

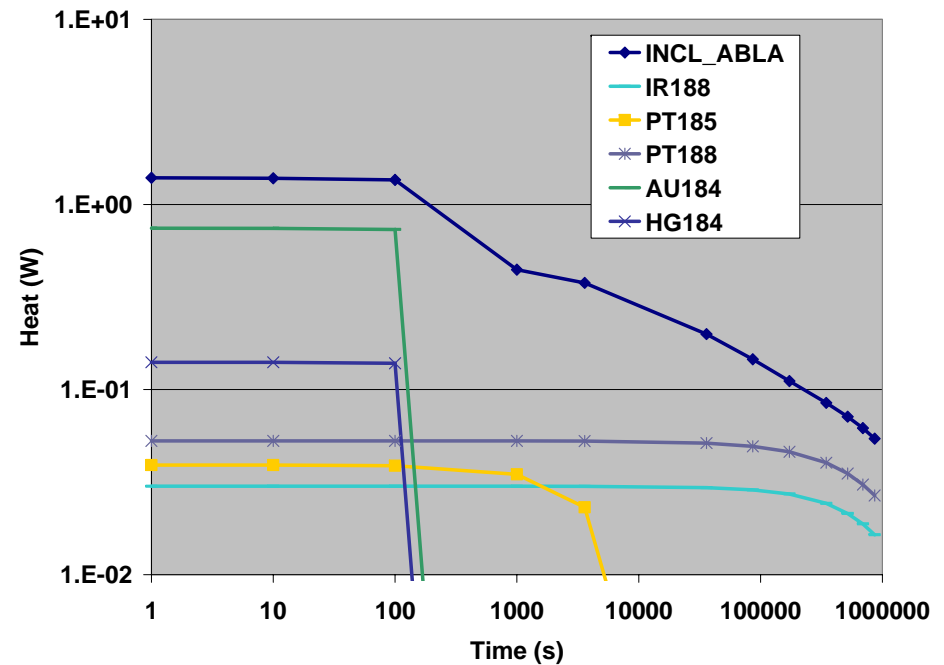
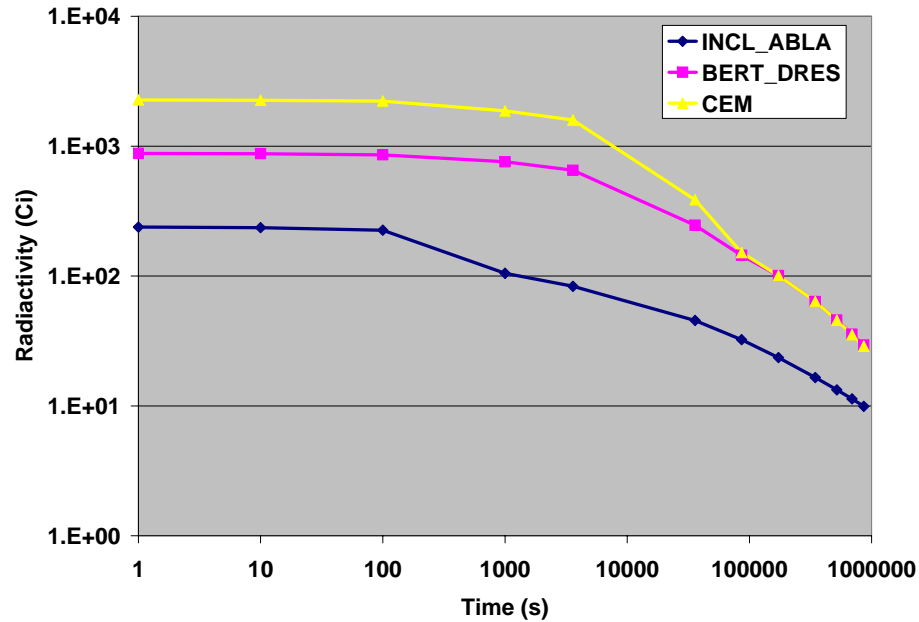
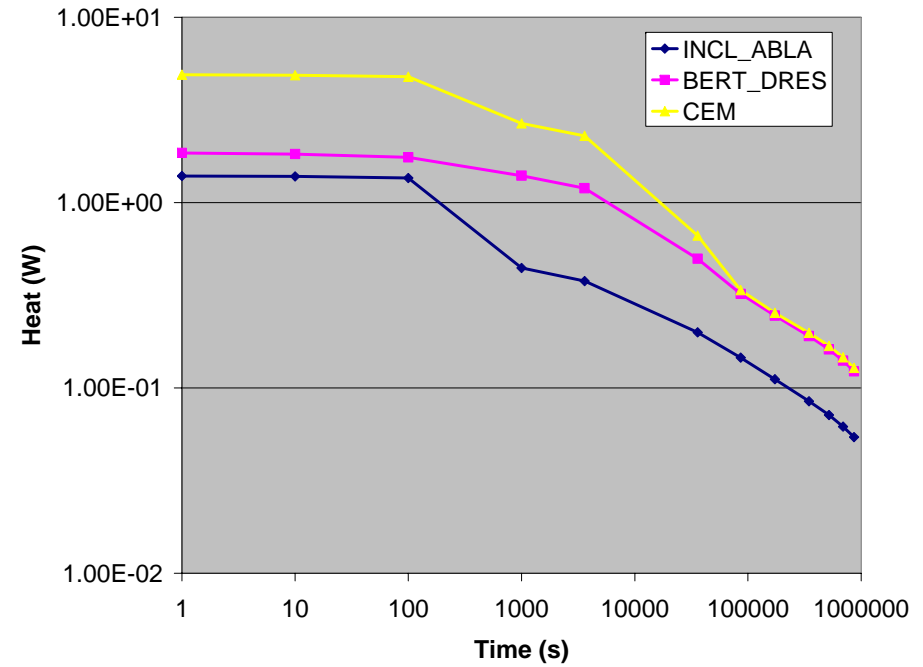
Radioactivity (Ci)

Heat (W)

Heat main contributors

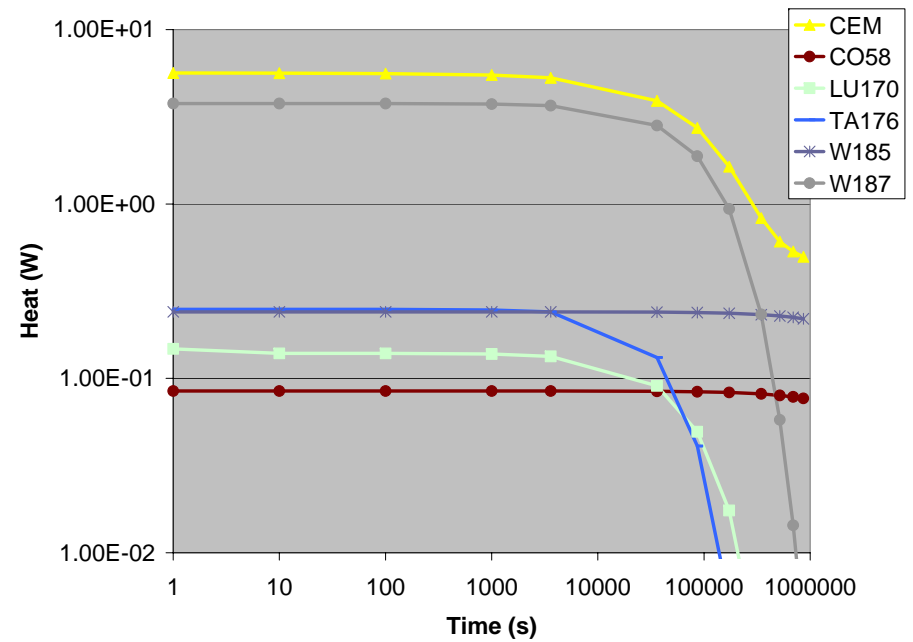
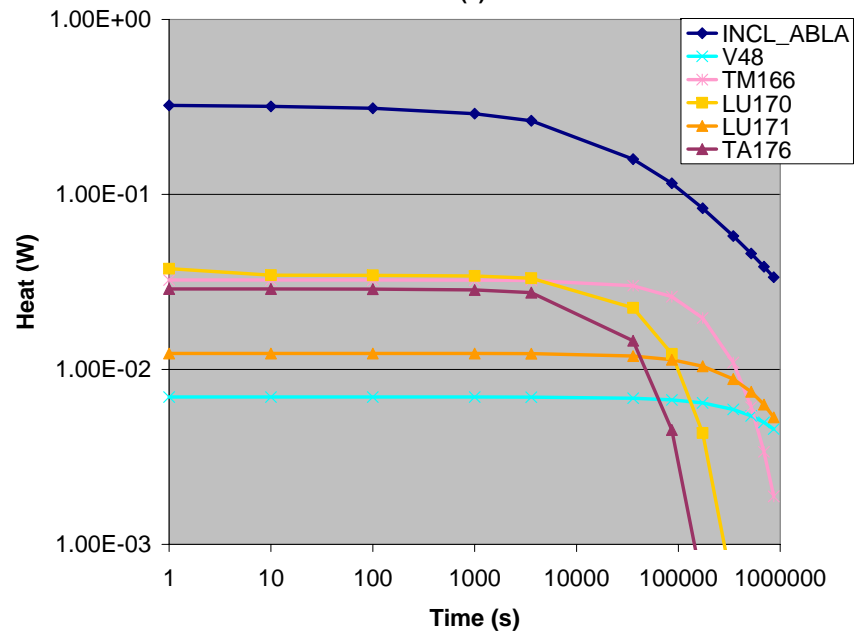
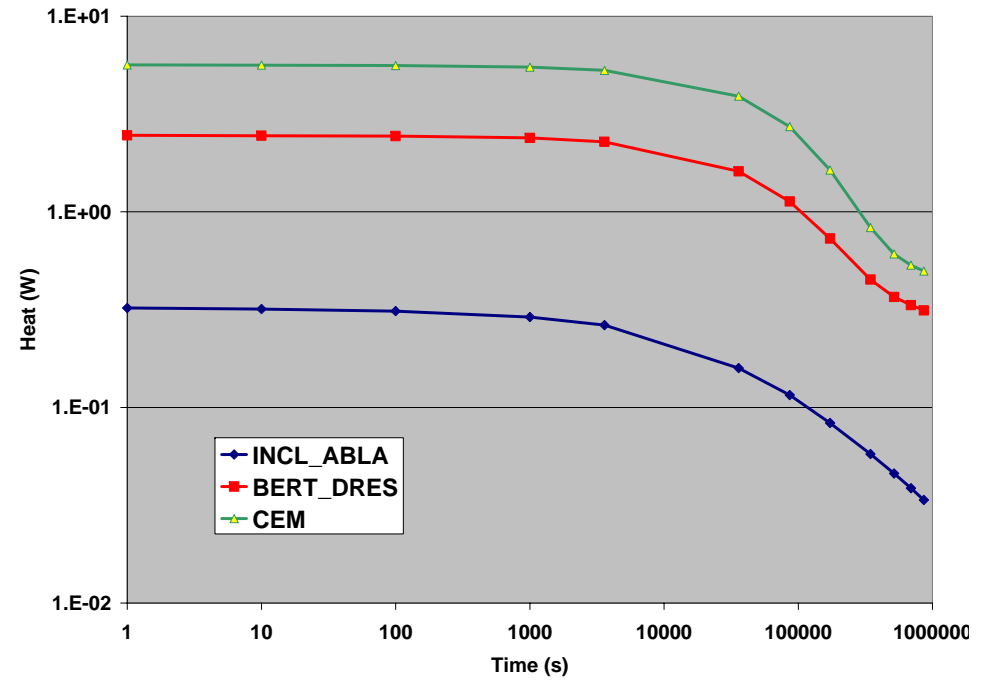
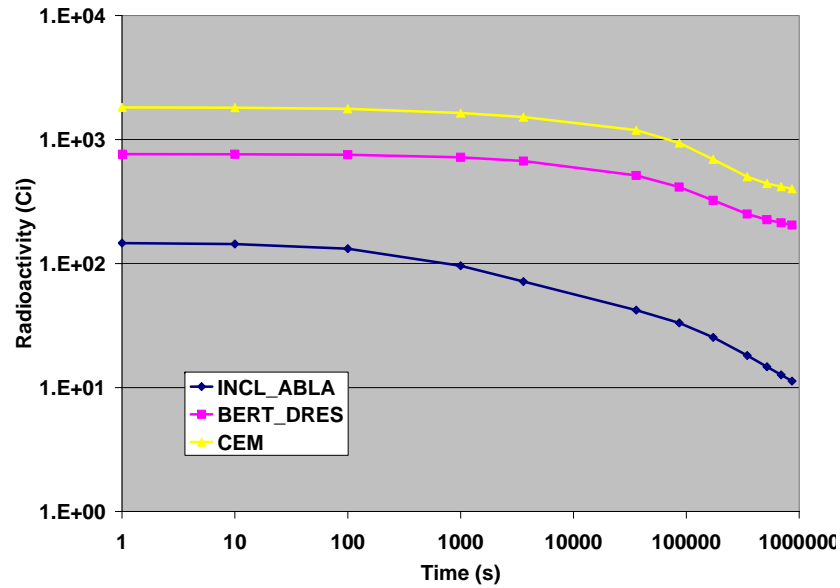
Time range 1s -10 days

After 1000 hours irradiation



Targets simulations: W

Radioactivity (Ci), Heat (W), Heat main contributors
Time range 1s -10 days, After 1000 hours irradiation



Conclusions 1/2

15% differences are observed on the neutron production/proton from different nuclear models in the target simulation

Large lead reflector:

- Reduce the number of fuel elements / fissile material (margin to increase K_{eff})

- Recover a kinetic behavior closer to point kinetics

- Low energy neutron absorber (^{10}B , ^6Li , Cd) around core improve kinetic response

- Attention to absorbing materials in the reflector

Kinetic techniques might be usable at SAD for reactivity determination

Large reactivity insertions can be obtained by:

- Reflector modification

- Absorber rods (B_4C) on the experimental channels

- Need of electromechanical fast actuators

These options might allow investigation of ADS dynamic behavior

SAD might allow to study: Source multiplication, source importance, Shielding aspects, and other static effects but probably also **kinetic and dynamic ADS aspects**

Conclusions 2/2

Radioactivity and heat calculations

- **For Pb:** The contribution to the decay heat and radioactivity of the neutron flux activation of the target looks to be negligible in comparison with the spallation products.
- **For W:** The contribution to the decay heat is small (factor 1/10 to 1/3) in comparison with the spallation products, but the radioactivity is comparable and even larger in the INC model (lower by factor 100 in the CEM model). Production of W185 (75d) and W187(24h).
- The decay heat and the radioactivity from spallation products vary considerably with the model used in MCNP.
- Results presented by CIEMAT are not very reliable, shortly after the irradiation, because the average energy per decay data is not complete for all the “*non-usual*” spallation products (being improved).
- Even the list of isotopes with higher contribution depend on the model, at least in the W target case.
- In all models and both for the Pb or the W targets the decay heat is lower than 10W, few minutes after beam shut down.

A benchmark with experimental data in preparation by U.Cracow + CIEMAT