

Computacional

Episodio I



The Abdus Salam
International Centre
for Theoretical Physics
Physics Without Frontiers



Aplicaciones del método de Monte Carlo en el transporte de radiación a través de la materia

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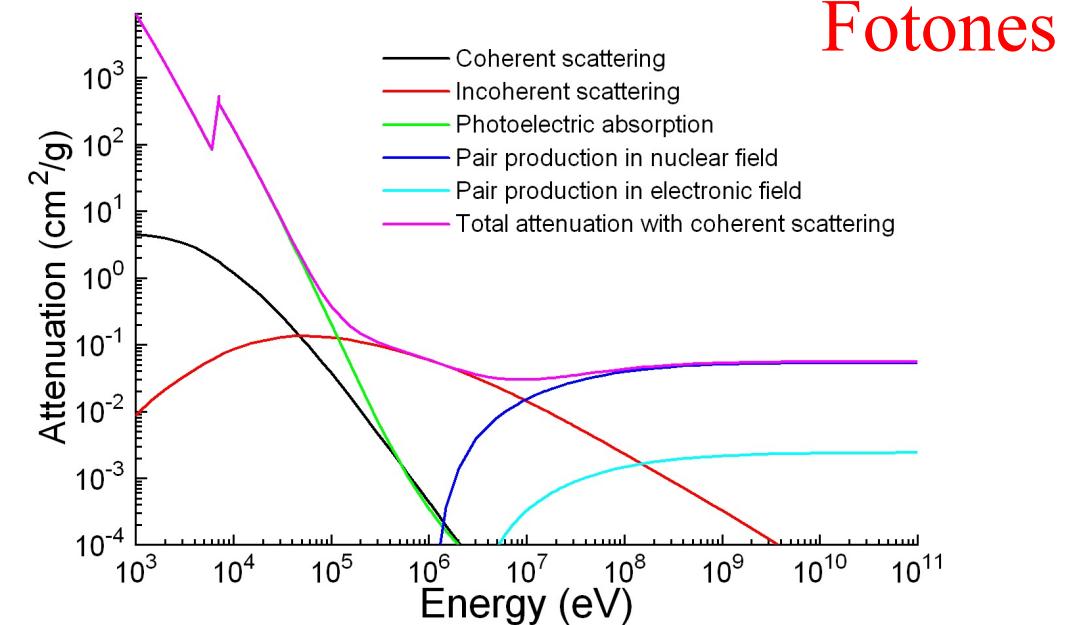
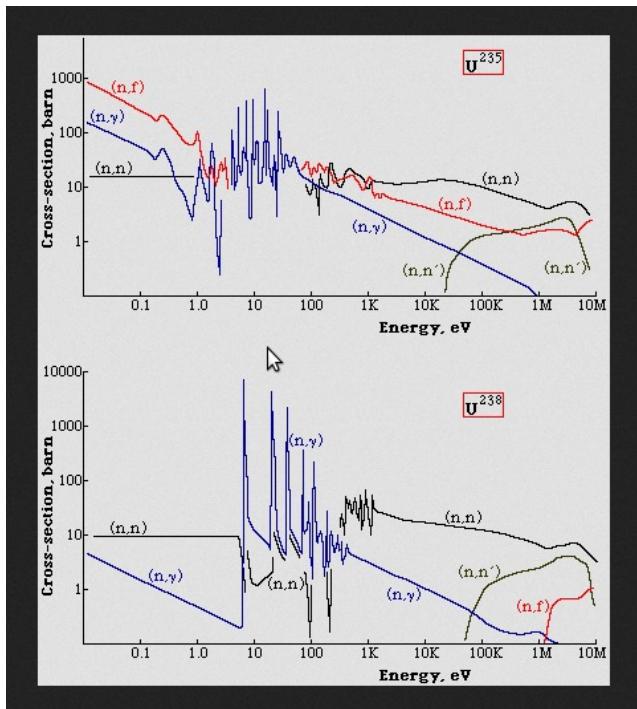
Método de Monte Carlo

- “Numerical solution to a problem that models objects interacting with other objects or their environment based upon simple object-object or object environment relationships” (Bielajew, 1998).

Transporte de radiación (MC)

- La interacción de partículas es un proceso “estocástico”, es decir, sigue una distribución de probabilidades.

Neutrones



Transporte de radiación (MC)

- DCS → Define the Probability Distribution Functions (PDF) of the random variables that characterizes the all particle path.
 - Mean free path
 - Kind of interaction
 - Energy lost and change of direction
- PDF → Sampling methods

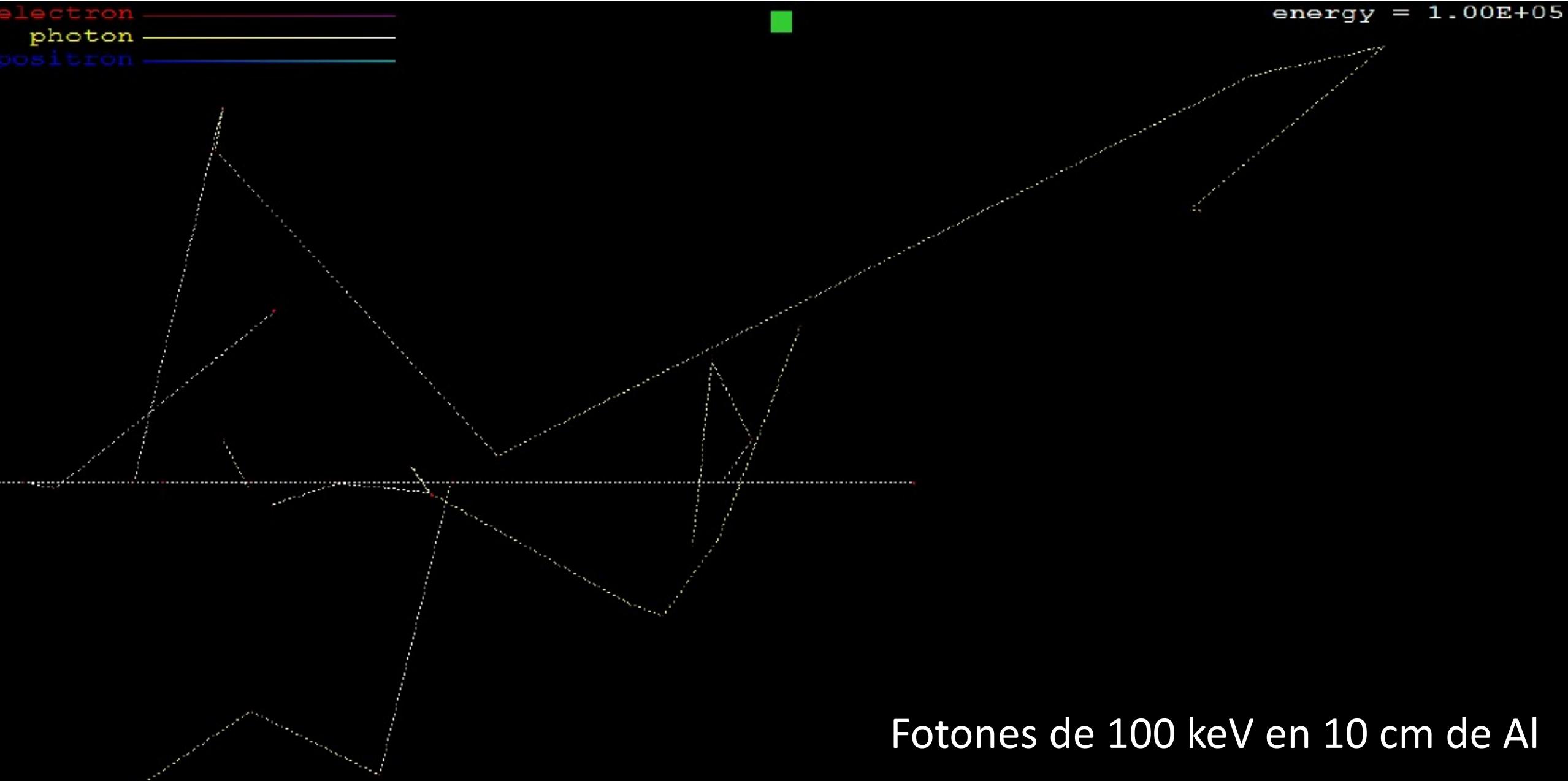
Transporte de radiación (MC)

- Particle history is seen as a sequence of steps ending with one interaction
- After the interaction → Change of direction, lost of energy, creation of secondary particles, etc.
- Simulation of an experiment → generate a lot of histories (run).

electron
photon
positron



energy = 1.00E+05



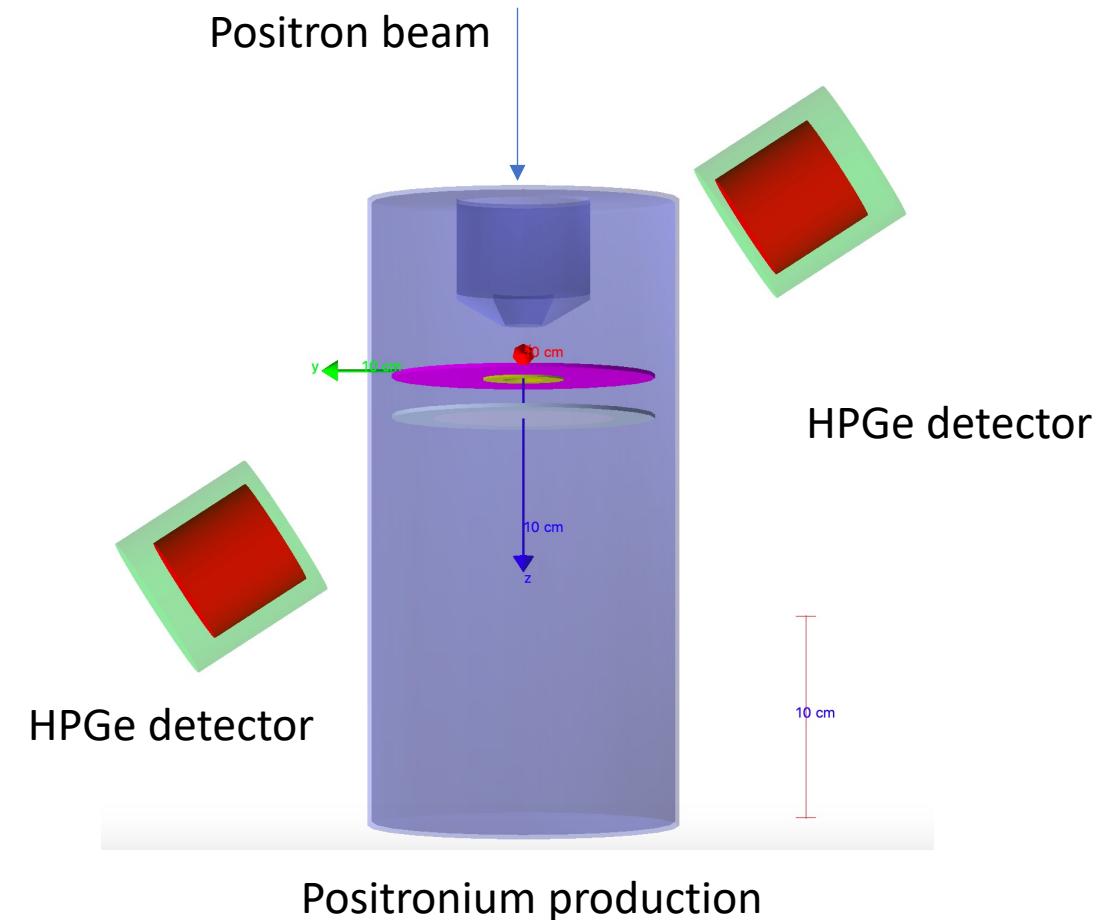
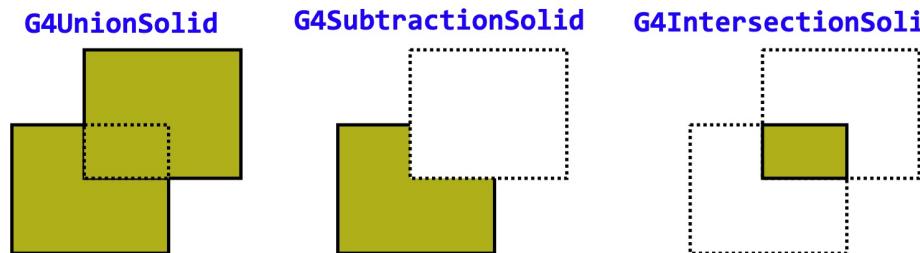
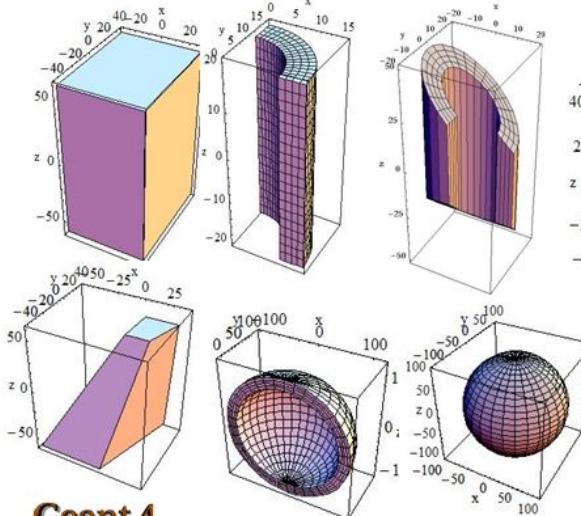
Fotones de 100 keV en 10 cm de Al

¿Qué se necesita para simular?

- Ambiente: Geometría con cuerpos compuestos de un material homogéneo.
- Partícula primaria: tipo (gamma, neutrón, electrón, positrón, etc.), energía, distribución espacial, angular, etc.
- Física: secciones eficaces. (Experimentales, analíticas)
- Especificar que cantidad quiero determinar.
- Construyo el código o uso alguno (PENELOPE, GEANT4, MCNP, OpenMC, FLUKA, etc.)

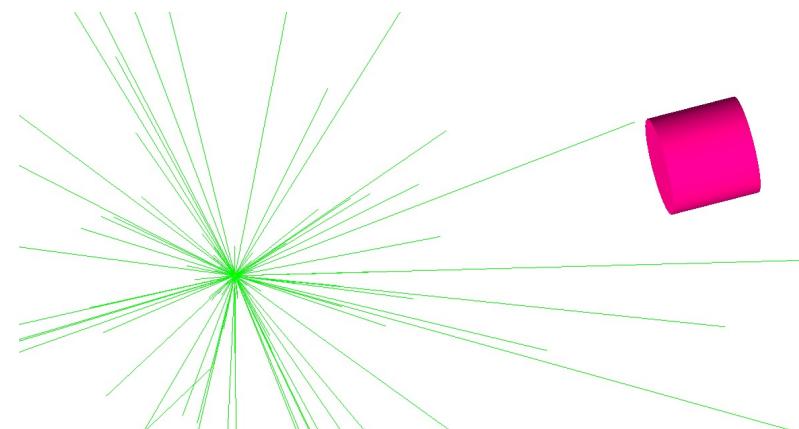
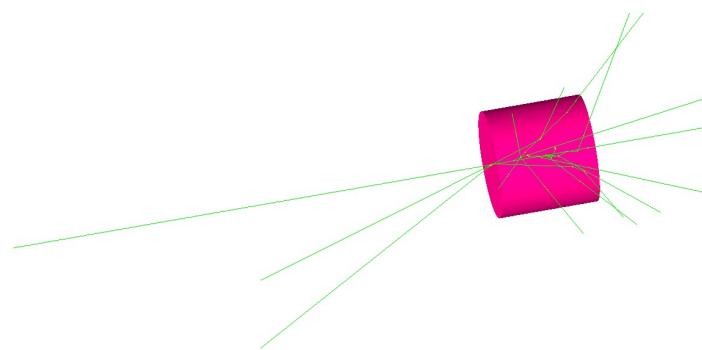
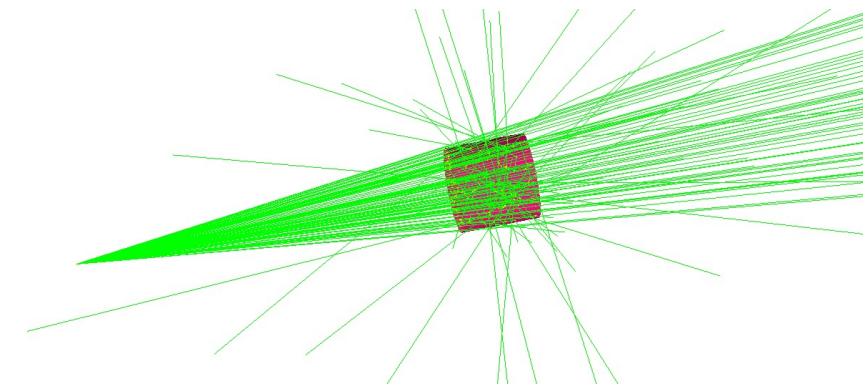
¿Qué se necesita para simular? Ambiente

- Superficies cuadráticas + operaciones booleanas.
- En algunos casos se puede importar CAD files.



¿Qué se necesita para simular? **partícula primaria**

- Tipo: neutrón, fotón, protón, ion(Z,A)
- Posición: en el S.C. del ambiente
- Energía cinética
- Dirección de emisión: iso, colimado, etc.



¿Qué se necesita para simular? **Física, resultados**

- **Física**

- Incluir mecanismos de interacción de interés para el problema.
- Atención! Es diferente en cada código.

- **Resultados**

- Espectro en energía depositada
- Dosis absorbida
- Flujos de partículas secundarias
- Espectros en tiempo
- Actividad de un radionucleido
- ...

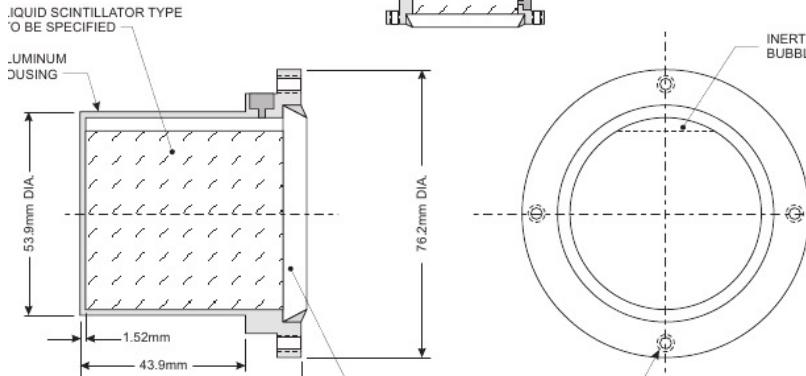
Transporte de radiación (MC)

- Se simula la historia de cada partícula una por una hasta que se absorbe por completo.
- Es un proceso estadístico, mientras más partículas se simulen, se determinarán con mayor precisión y exactitud cantidades de interés (espectros, dosis, eficiencia, etc.)
- Ejemplo:
 - 10^7 gamma se simulan en 5-10 min en una geometría relativamente simple.
 - 10^8 neutrones en geometría extensa → algunos días

Aplicaciones

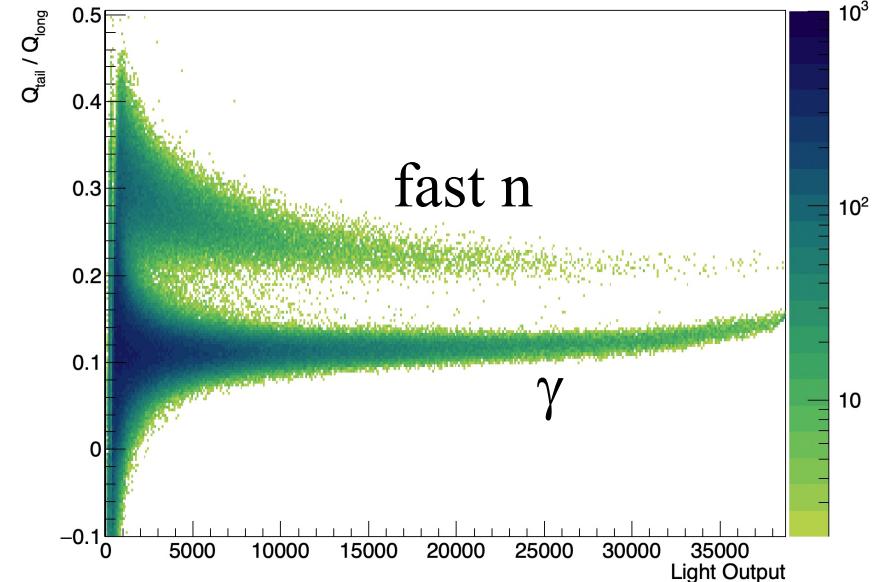
- Proyecto DRAGON (INFN-Italia)
 - Caracterización de detectores: centelladores orgánicos e inorgánicos sensibles a fotones y a neutrones: respuesta, eficiencia, dect. Limits.
- Proyecto C-BORD (Euroatom H2020)
 - Tagged Neutron Inspection System: Inspección de cargo containers
- Compton densitometer: densidad del pavimento

Centelladores orgánicos



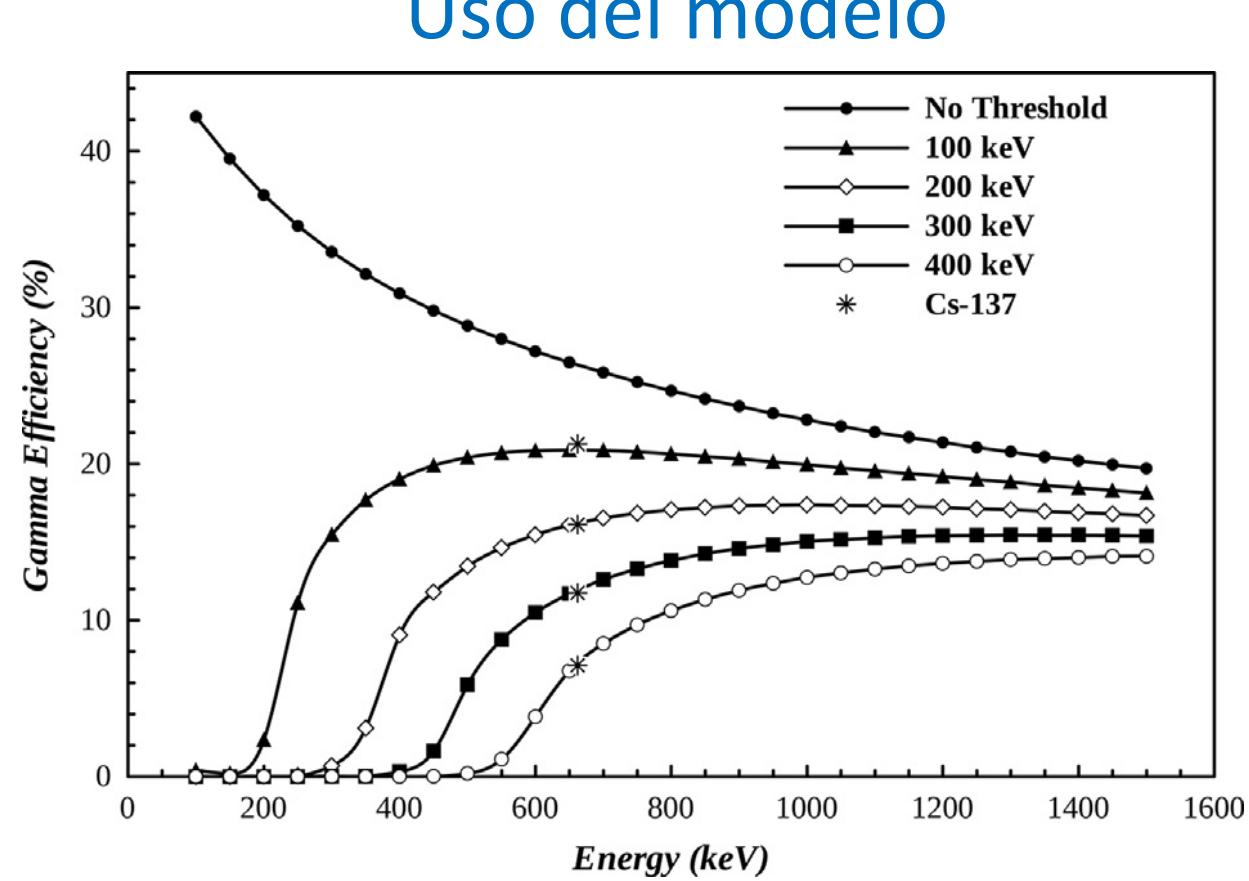
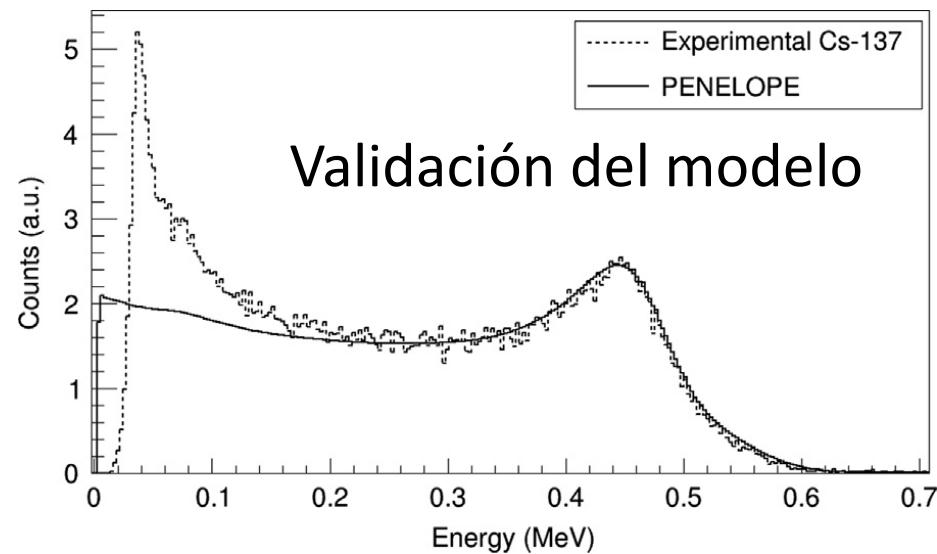
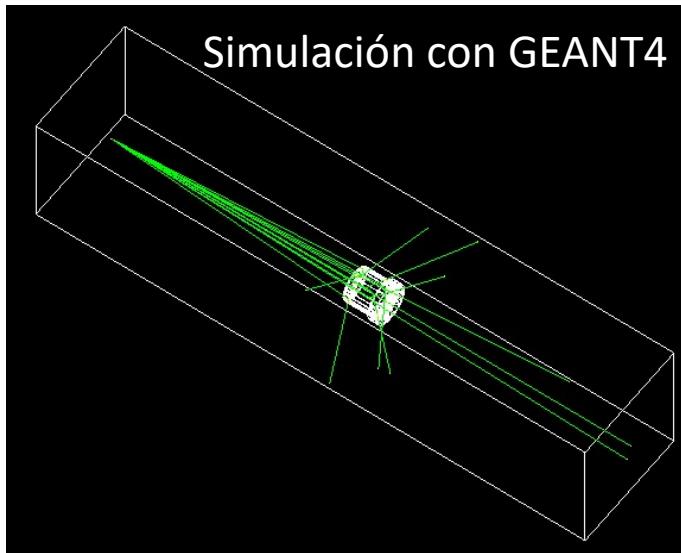
Líquidos

Plásticos



- Aplicaciones: experimentos en física nuclear, física de partículas, física médica, monitoreo de radiación (homeland security), ...
- Económicos, incluso con un gran volumen
- Composición elemental -> H, C
- Densidad -> 0.8 – 1.1 g/cm³

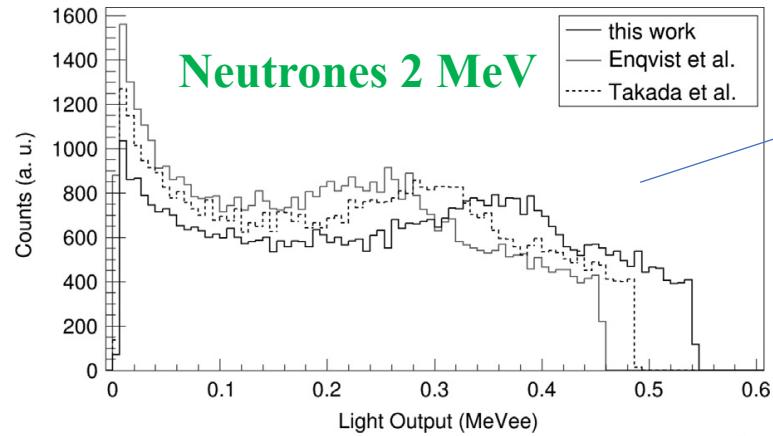
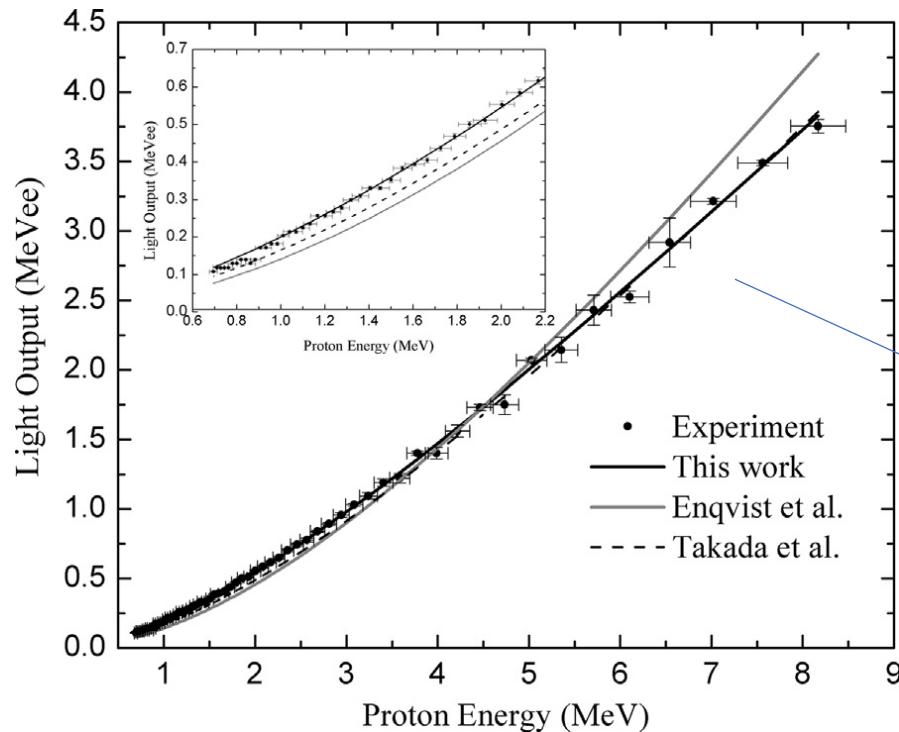
Centellador orgánico líquido 2"x2": EJ-309 respuesta a fotones



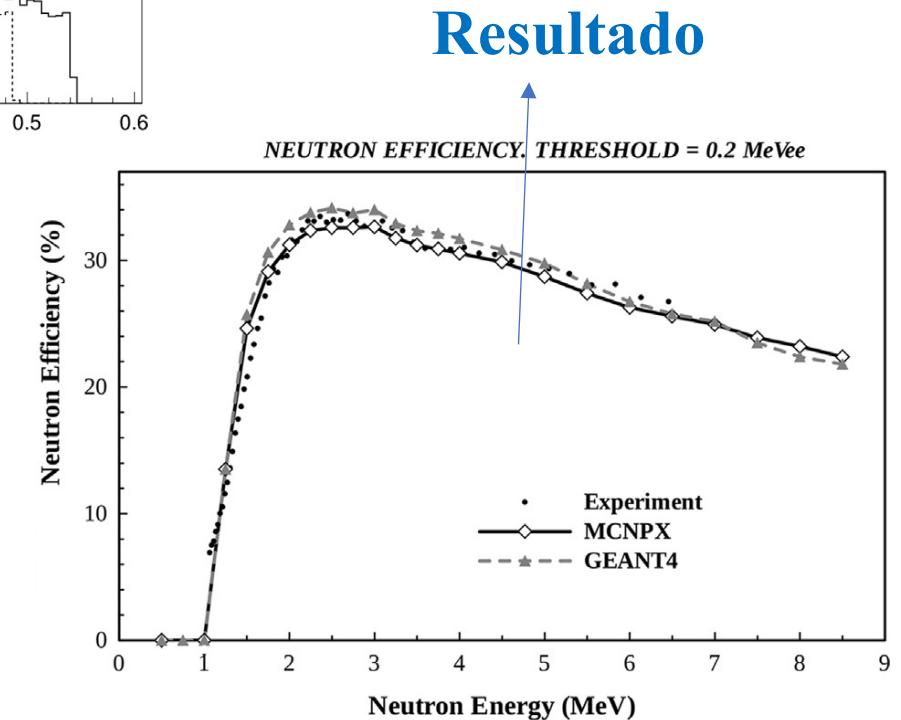
Centellador orgánico líquido 2"x2": EJ-309 respuesta a neutrones rápidos

- Scattering elásticos con atomos de H

Light output



Experimento

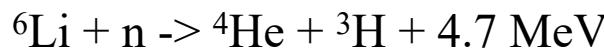


Simulación

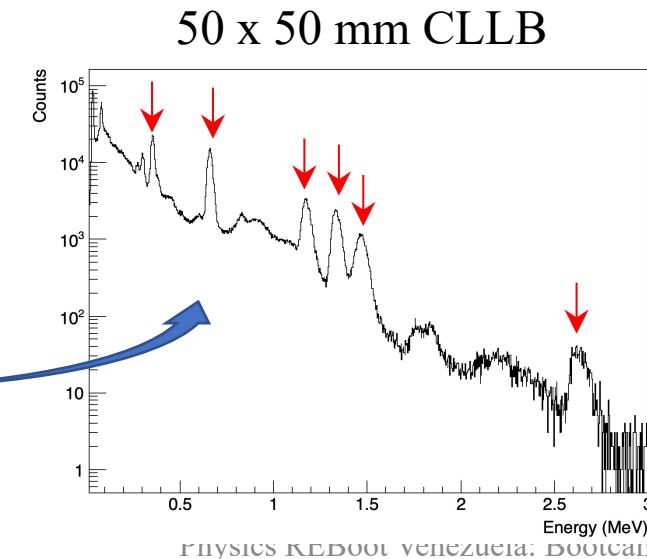
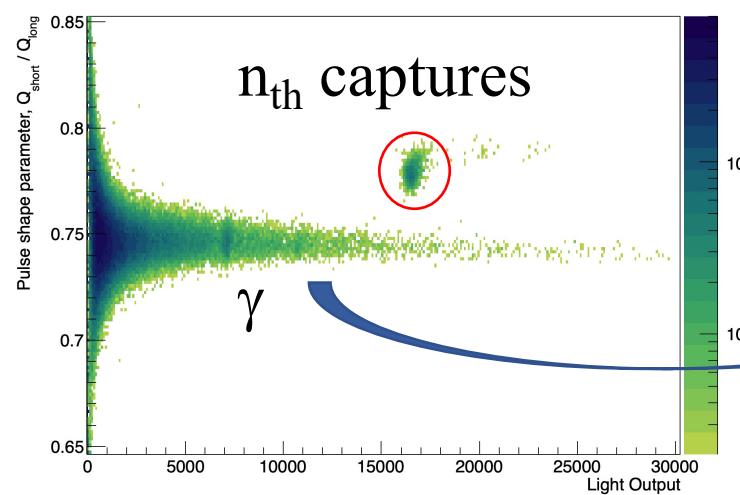
Resultado

Centellador inorgánico 2" x 2": CLLB

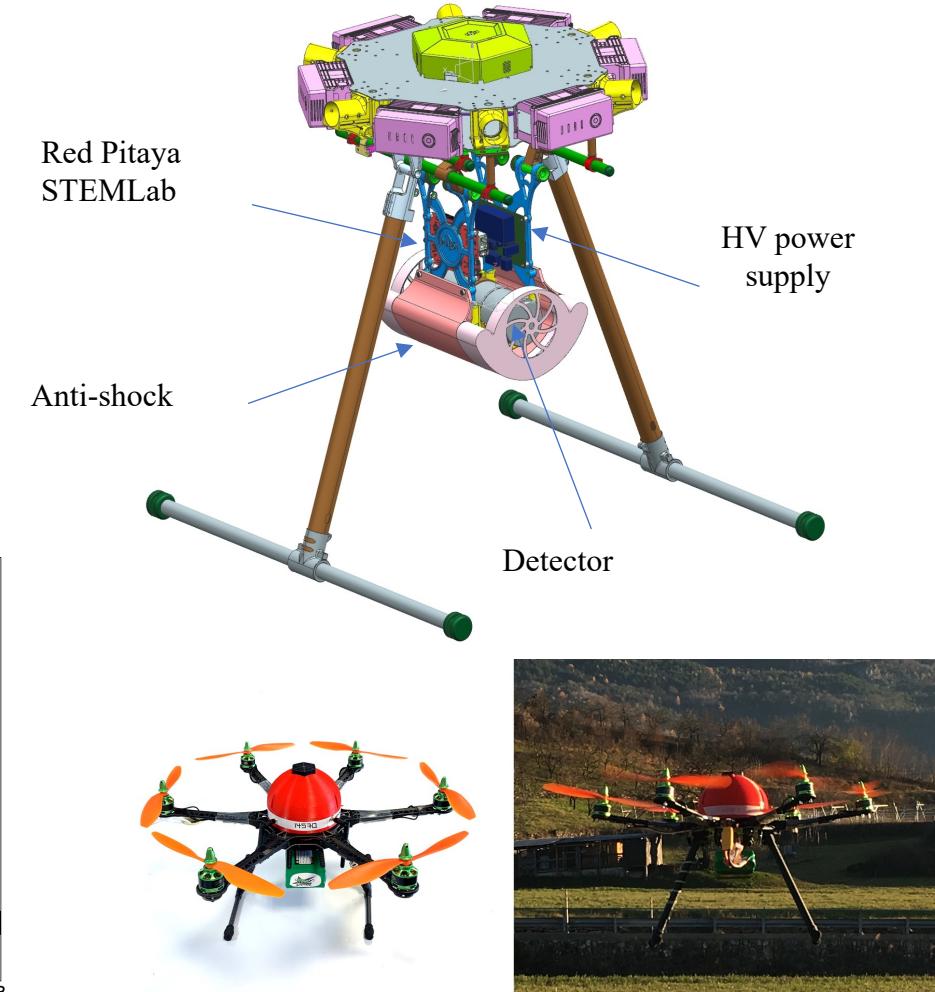
CLLB
Cs₂ Li La Br₆ (Ce)



CLLB Typical Data	Value
Energy Resolution (Cs137)	<4.0%
Density	4.2g/cc
Light Output	40,000 ph/MeV



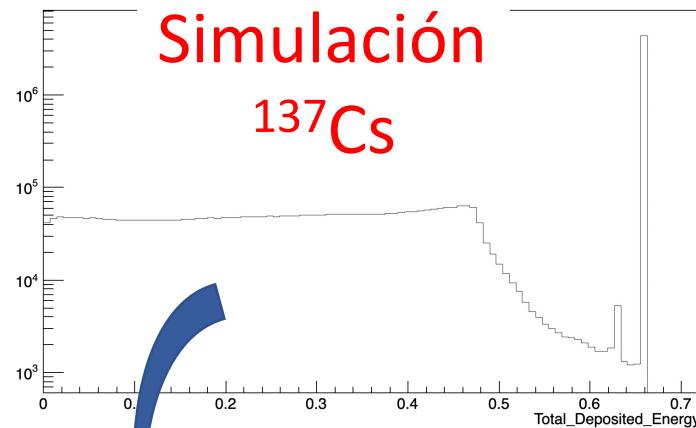
DRAGoN – Drone for RAdiation detection of Gammas and Neutrons



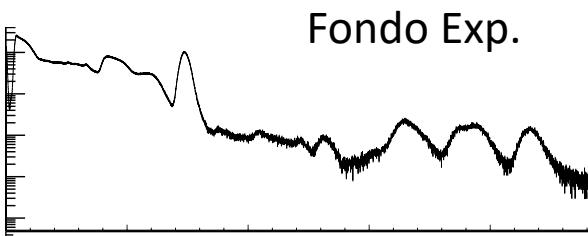
Centellador inorgánico 2" x 2": CLLB respuesta a fotones

Simulación

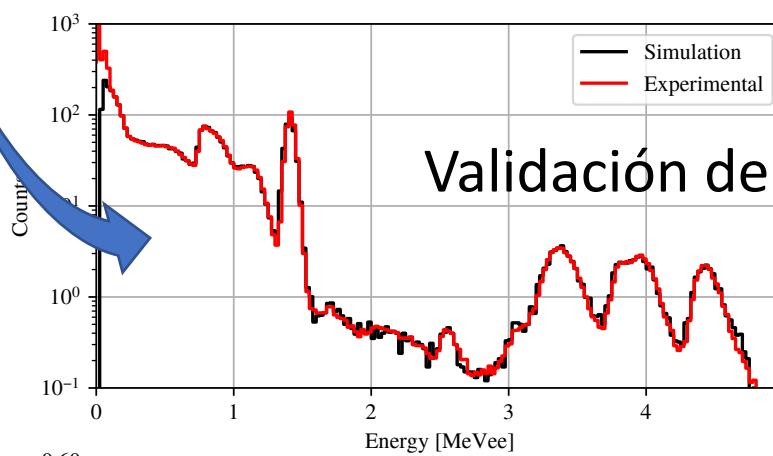
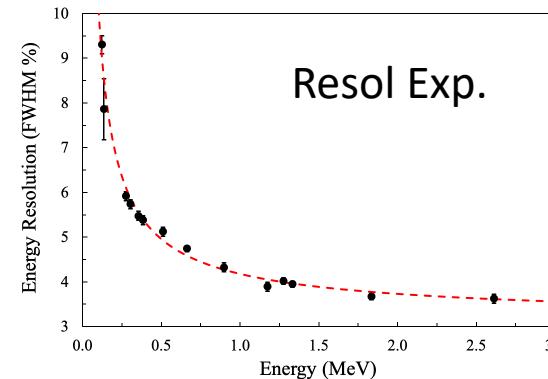
^{137}Cs



Fondo Exp.



Resol Exp.



Validación del modelo

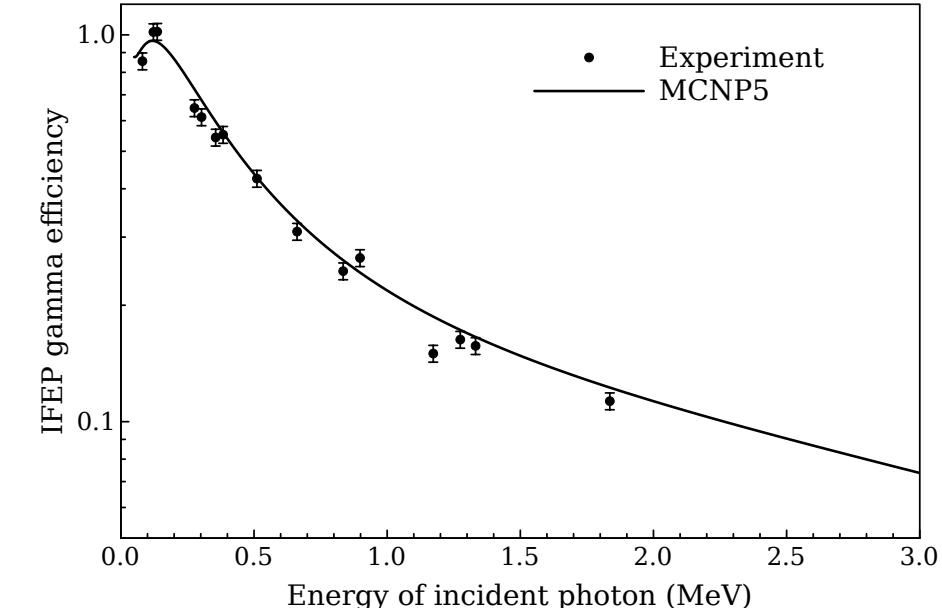
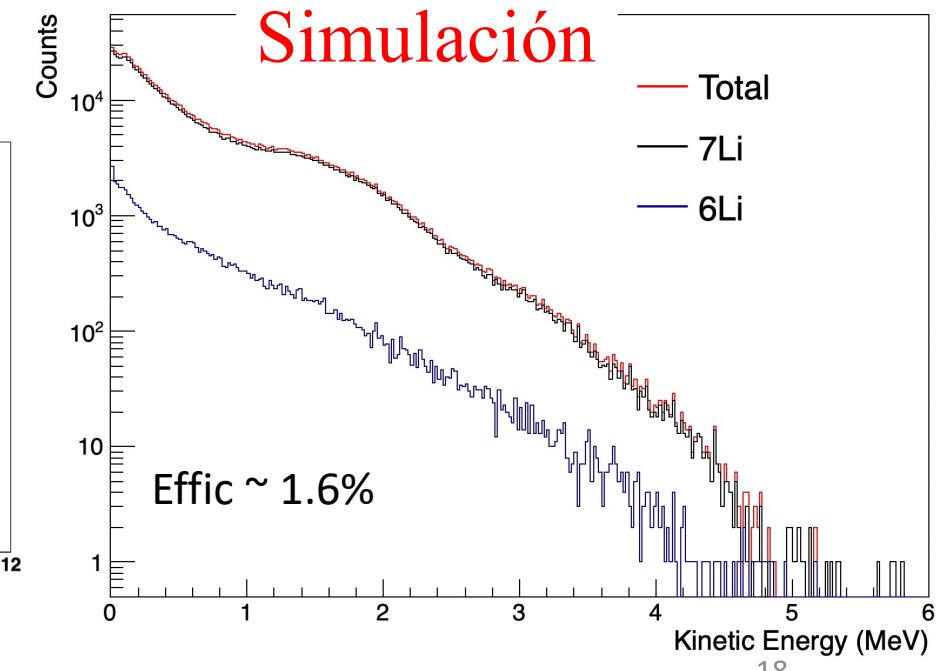
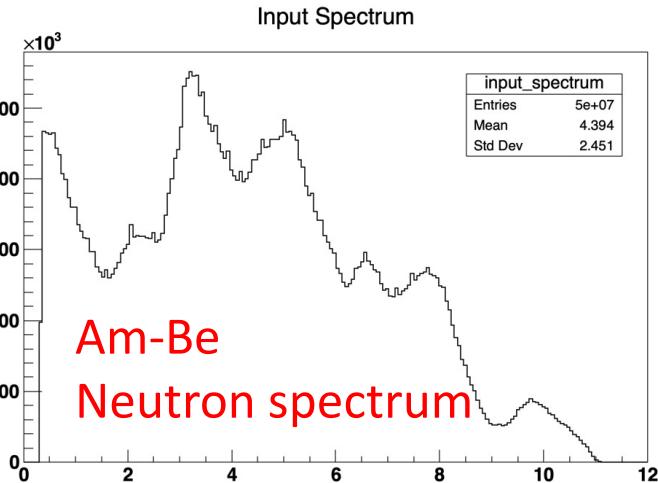
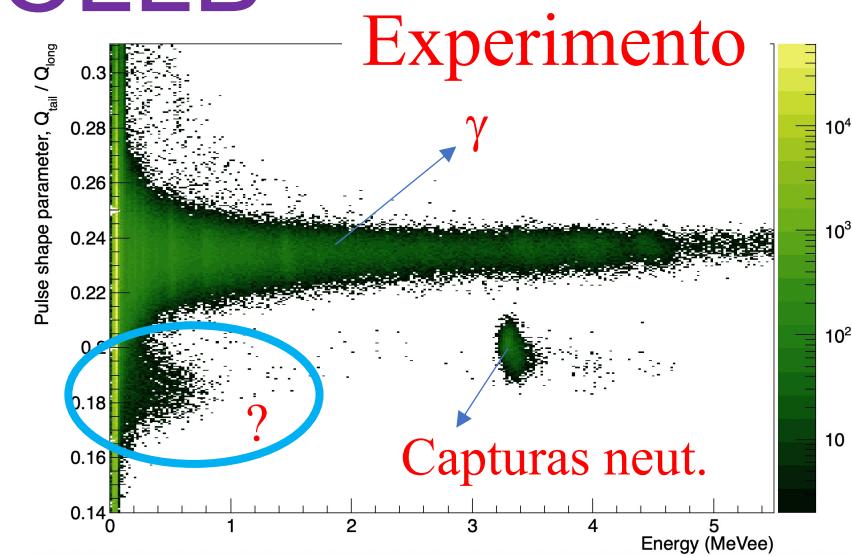
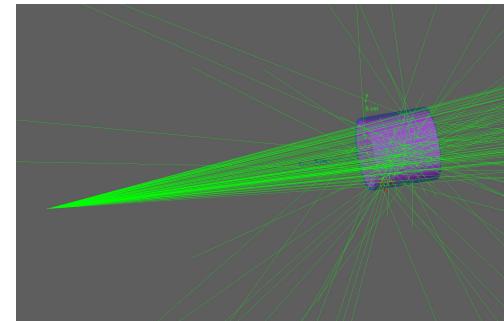
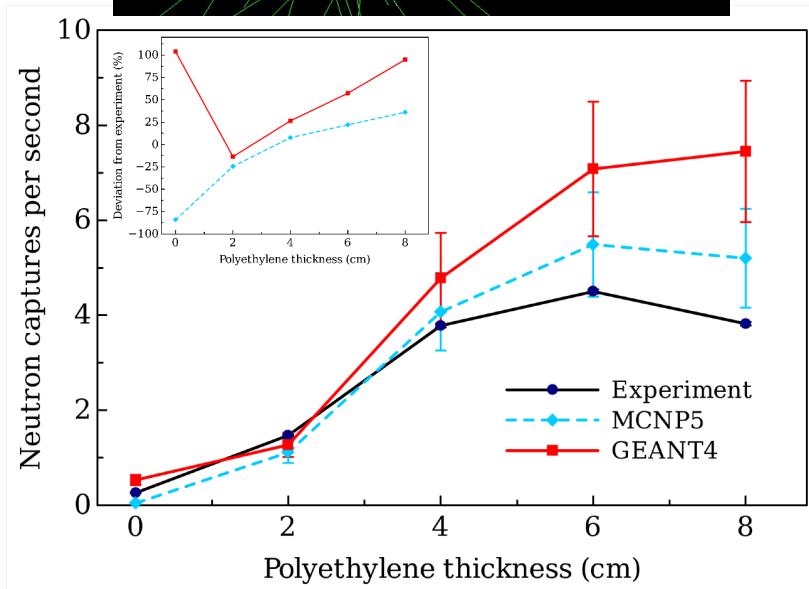
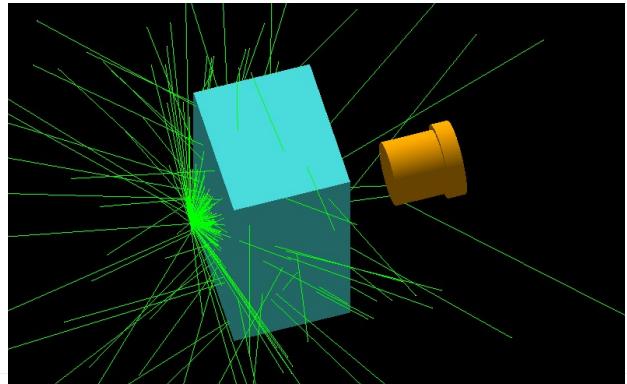


Table 4. Minimum detectable neutron emission rates ($I_{n,min}$) for a ^{252}Cf source (naked and shielded with 4 cm of polyethylene) at 25 cm from detector's face considering the PSD and energy methods. $\epsilon_n[\text{naked}] = 5.0 \times 10^{-6}$, $\epsilon_n[4\text{cm}, \text{poly.}] = 7.3 \times 10^{-5}$.

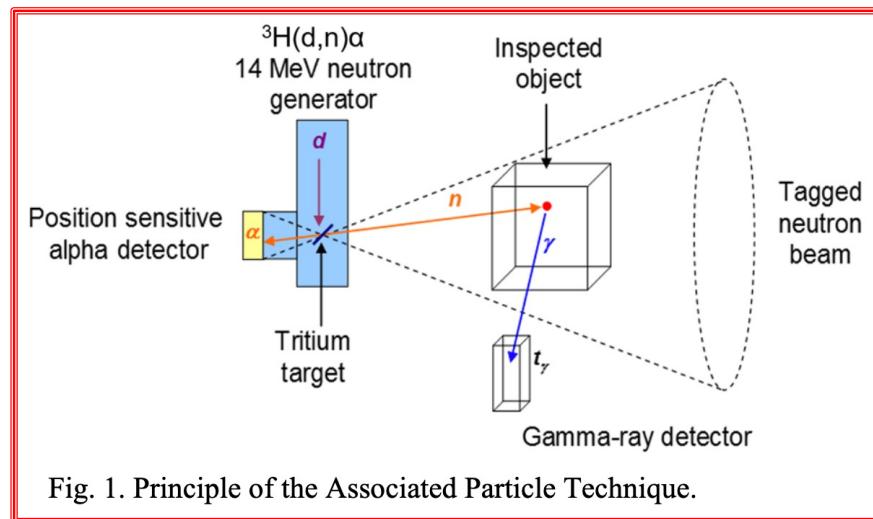
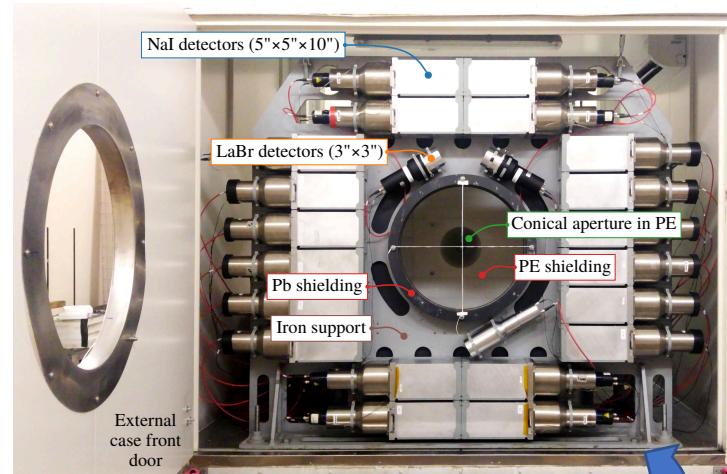
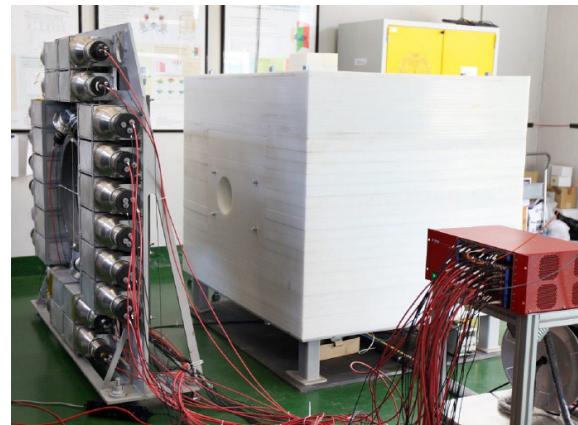
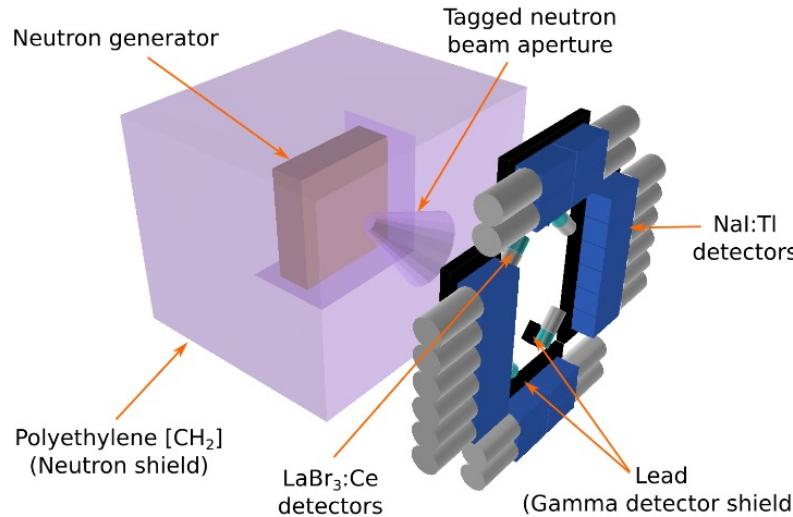
Measurement time (s)	$I_{n,min} (\text{s}^{-1}), \pm 20 \%$		$A_{min} (\text{kBq}), \pm 5 \%$ Point-like ^{137}Cs
	^{252}Cf , naked	$^{252}\text{Cf} + 4 \text{ cm poly.}$	
5	2.4×10^5	1.7×10^4	4.9
10	1.5×10^5	1.0×10^4	3.3
30	7.2×10^4	5.0×10^3	1.8
60	4.7×10^4	3.3×10^3	1.3

Centellador inorgánico 2" x 2": CLLB respuesta a neutrones

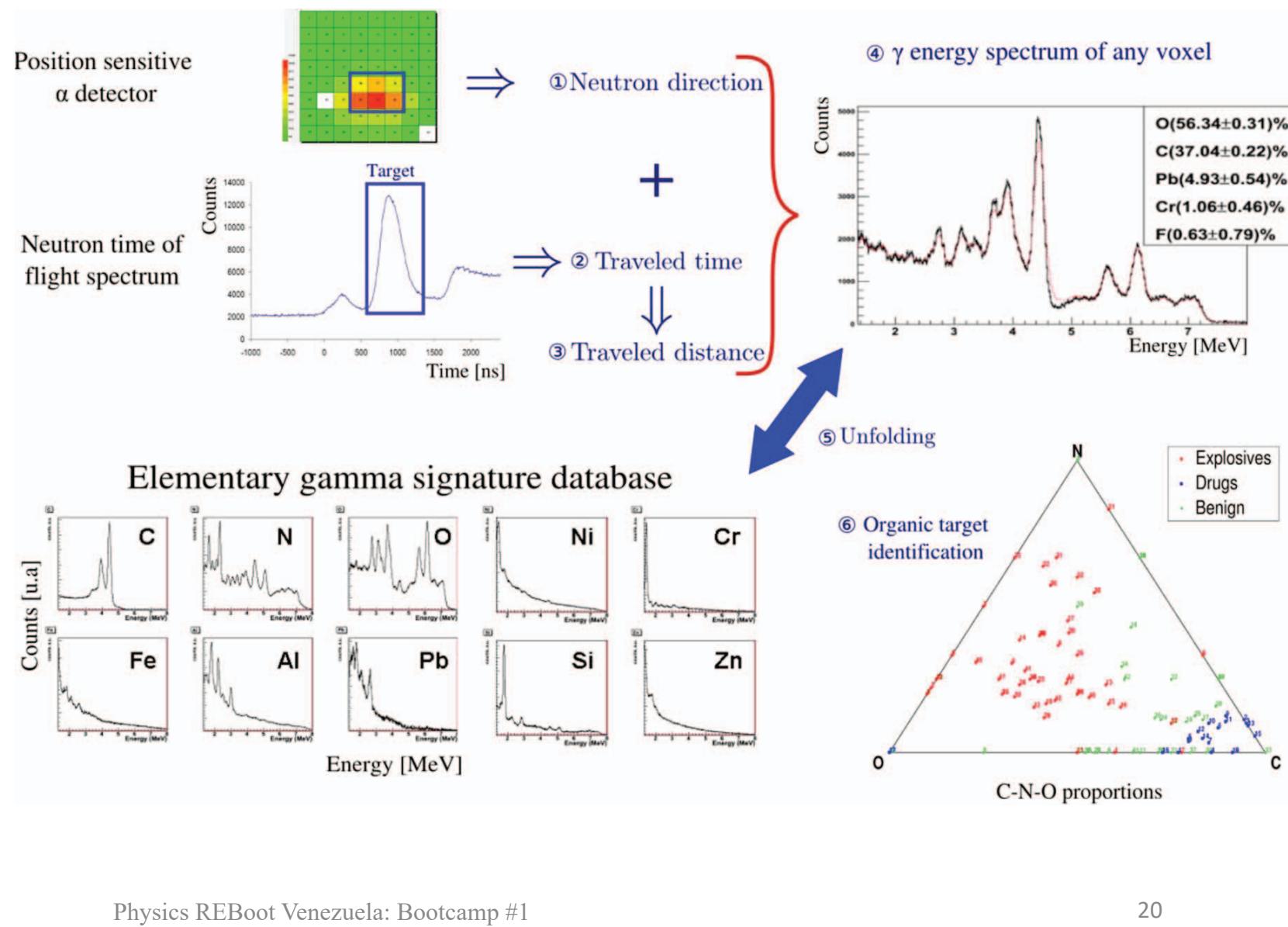
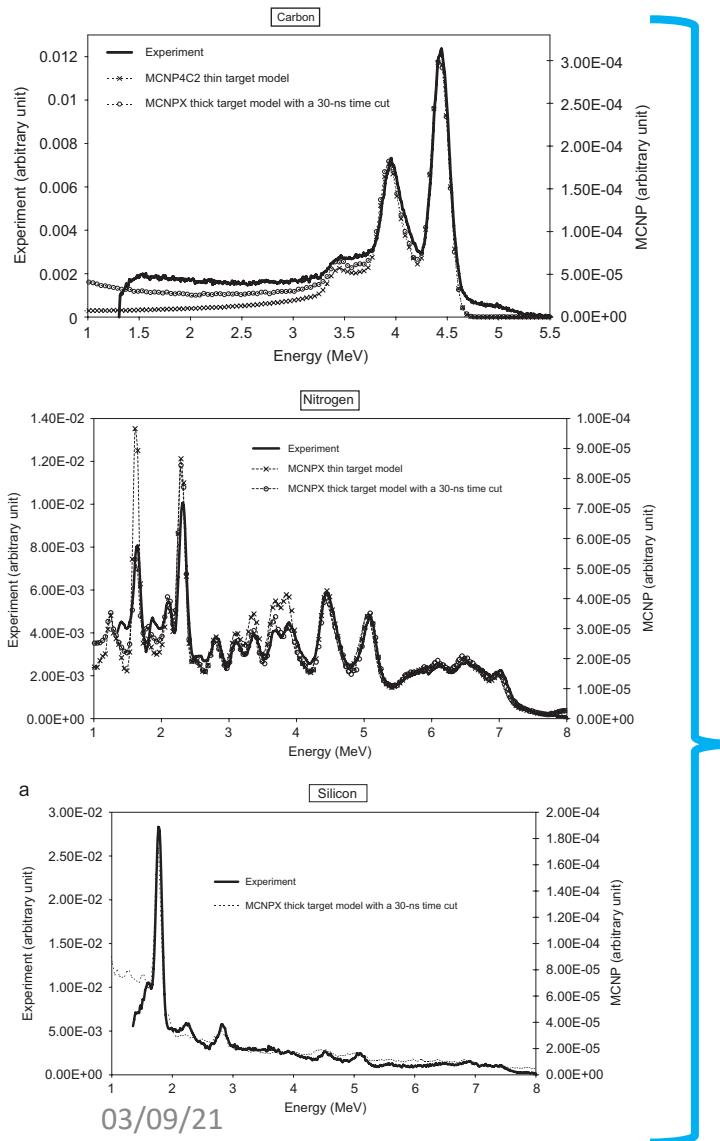
Capturas neut. de ${}^6\text{Li}$



Tagged Neutron Inspection System



Tagged Neutron Inspection System



Tagged Neutron Inspection System: Monte Carlo en el diseño

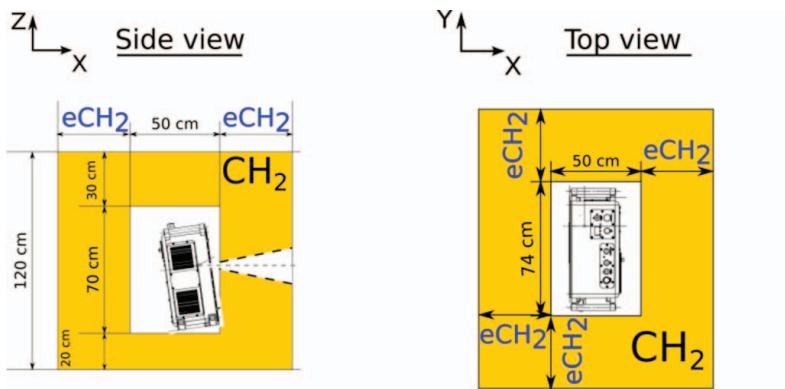


Fig. 3. Geometry of the neutron shield. The lateral thickness of the shield eCH_2 is used as a variable parameter in the simulations.

CH_2 thickness (cm)	CH_2 dimensions (cm^3)	Total weight (tons)	Distance at which $1 \mu\text{Sv}/\text{h}$ is reached (m)
35	120 x 144 x 120	≈ 3.0	16.6
40	130 x 154 x 120	≈ 3.3	14
45	140 x 164 x 120	≈ 3.6	11.9
50	150 x 174 x 120	≈ 3.9	10

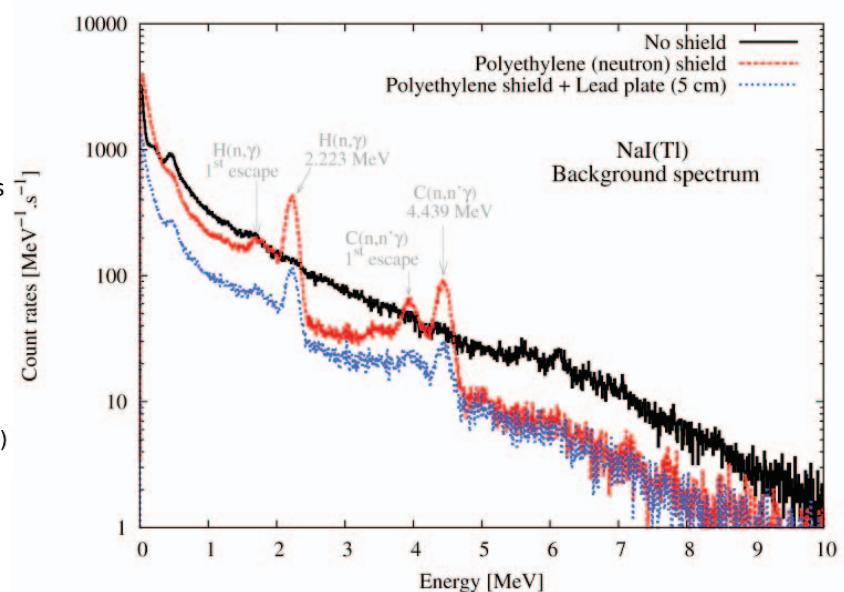
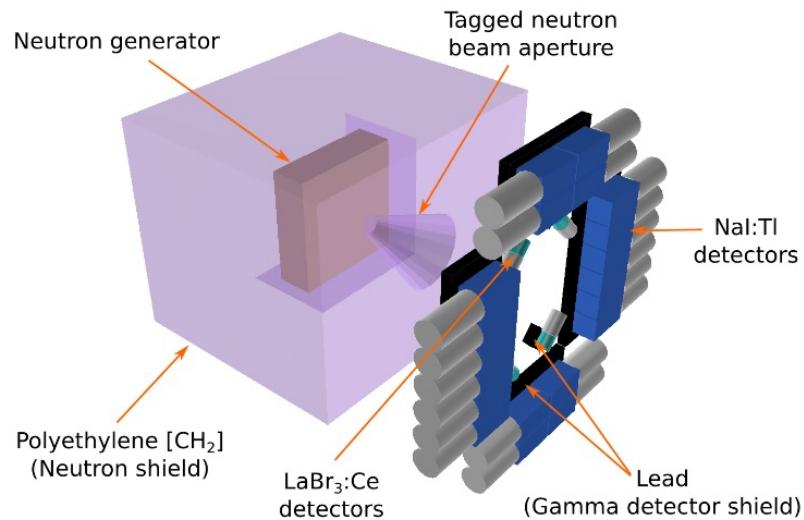
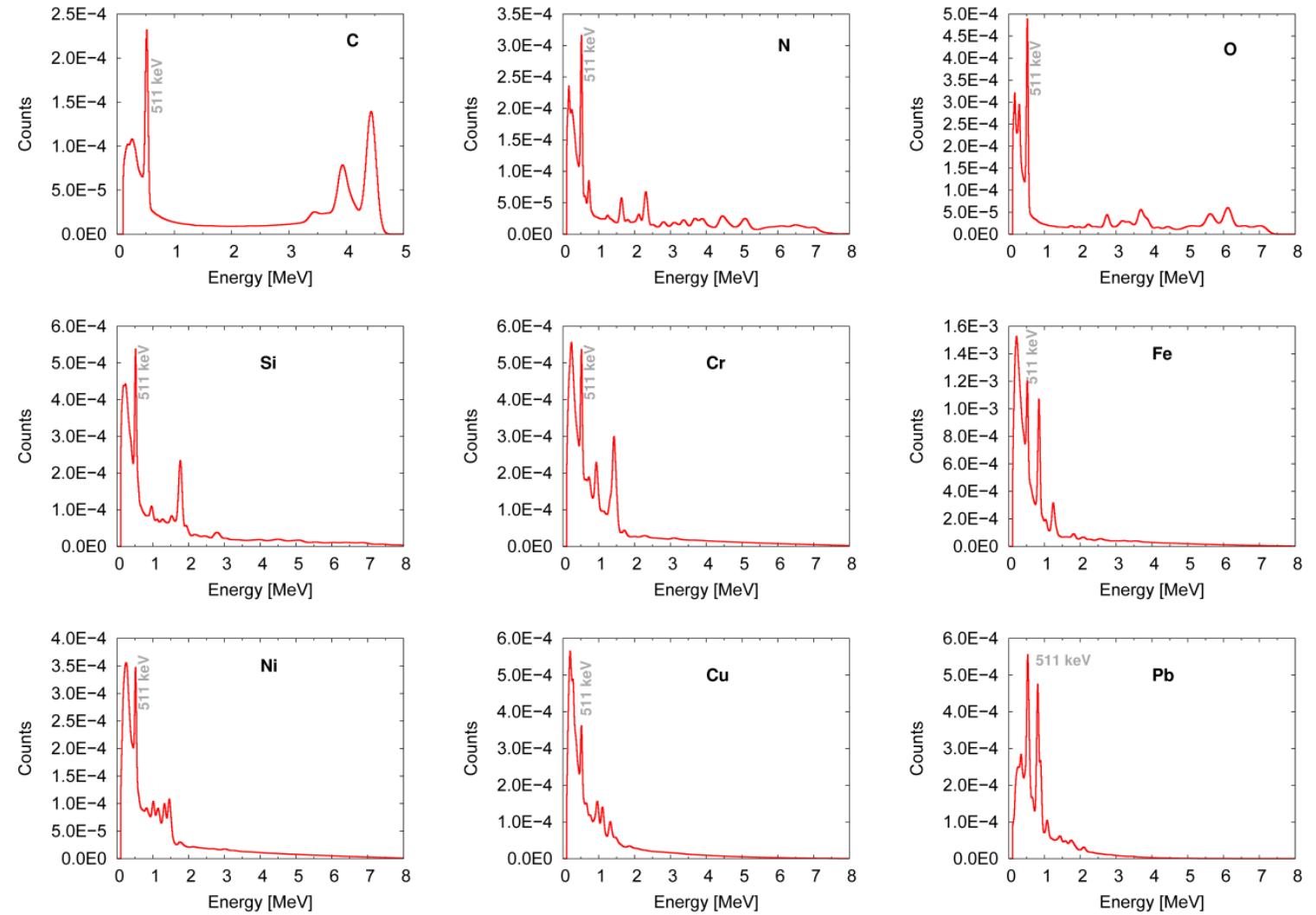
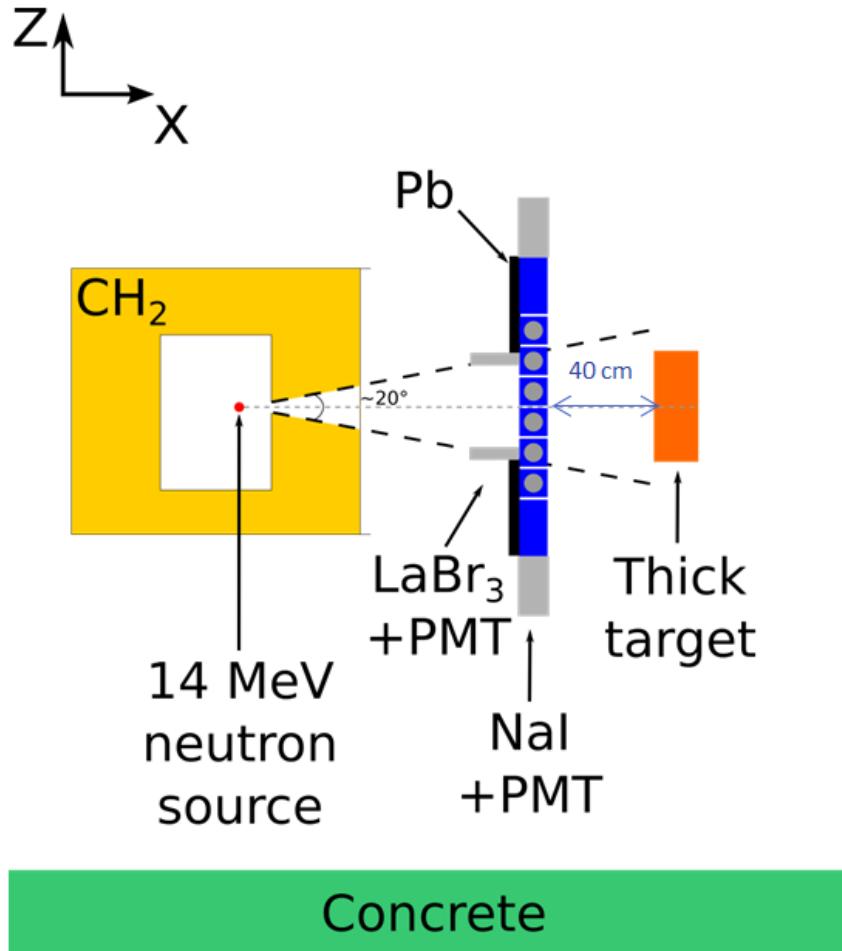


Fig. 5: Background gamma ray spectrum simulated with the MCNP6 pulse height tally on a NaI detector.

- Espesor y composición del NG shielding -> Polietileno de alta densidad (0.94 g/cm^3)
- Espesor y composición del gamma shielding -> 5 cm de Pb

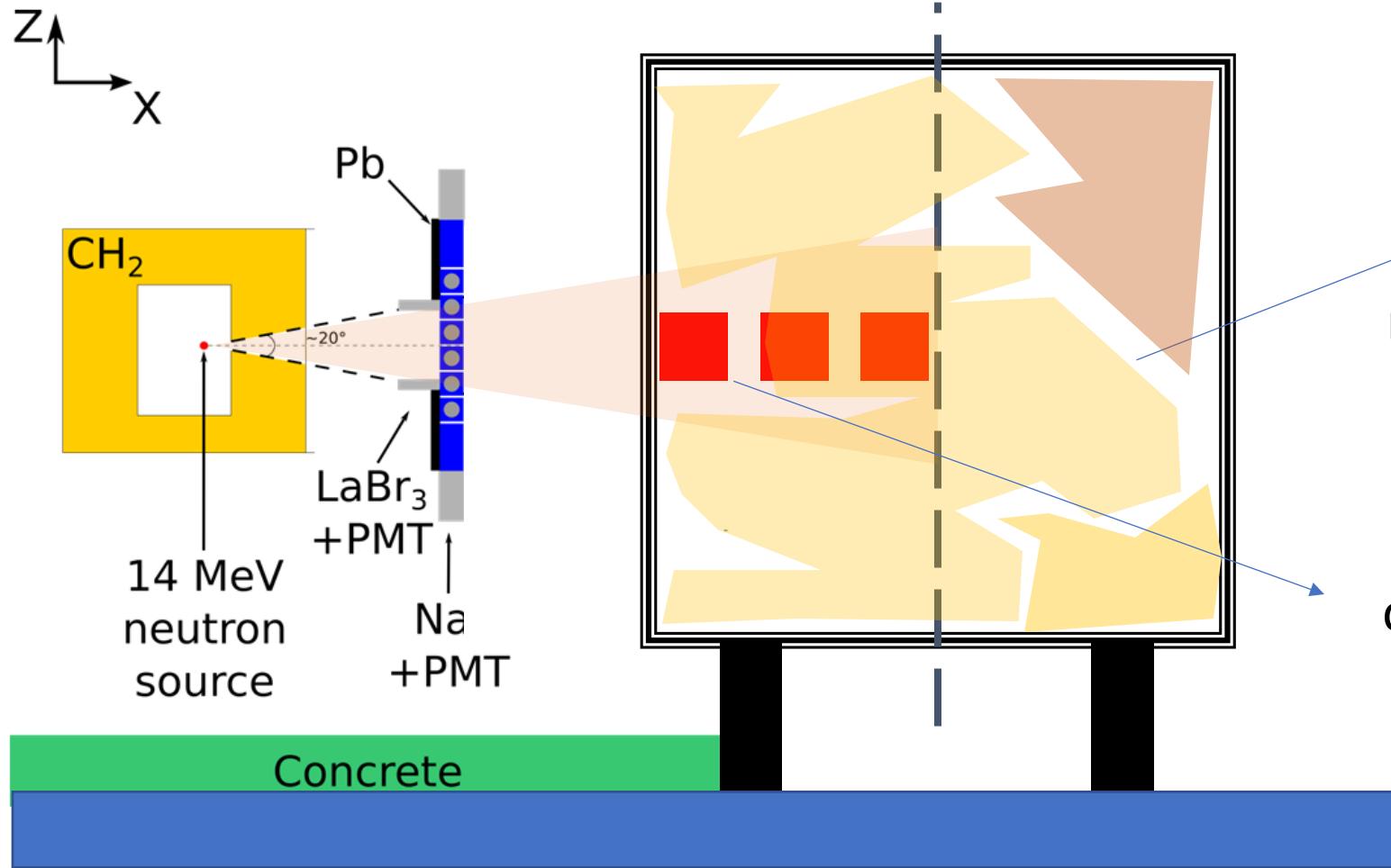
Tagged Neutron Inspection System

simulación de espectros γ , elementos puros



Tagged Neutron Inspection System

Factores de corrección por atenuación



Neutrones no tienen suficiente energía para producir reacciones de interés.

Se necesita tener en cuenta atenuación de neutrones y fotones

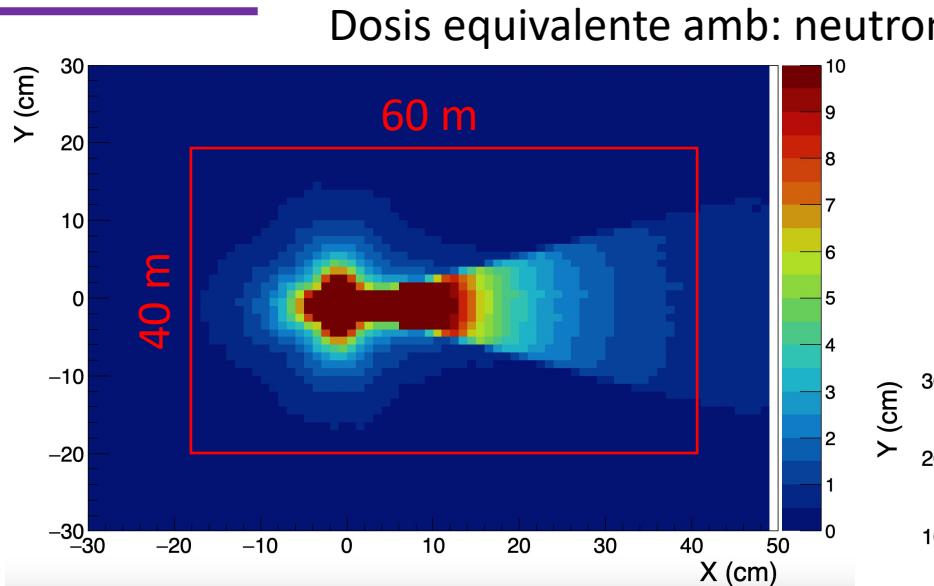
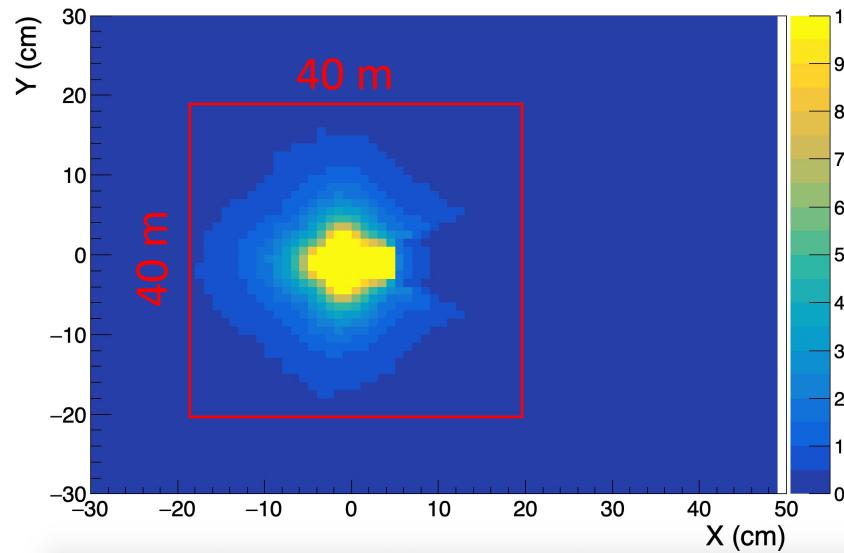
Tagged Neutron Inspection System

Mapa de dosis eq. amb.

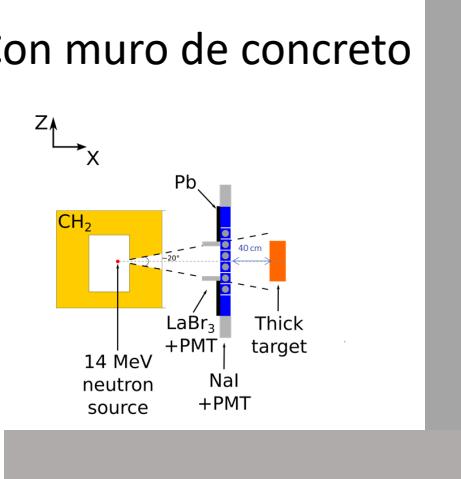
Flujo en una red[mesh]

+

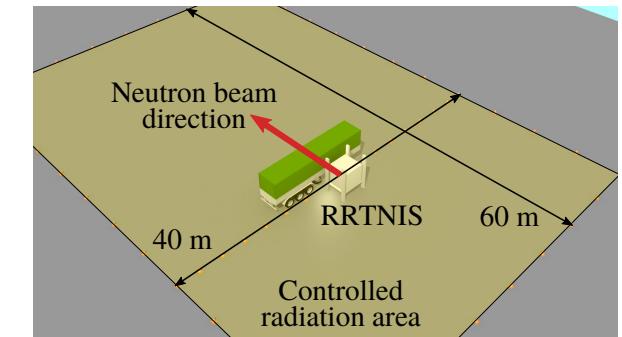
Factores de conversión
ICRP 74



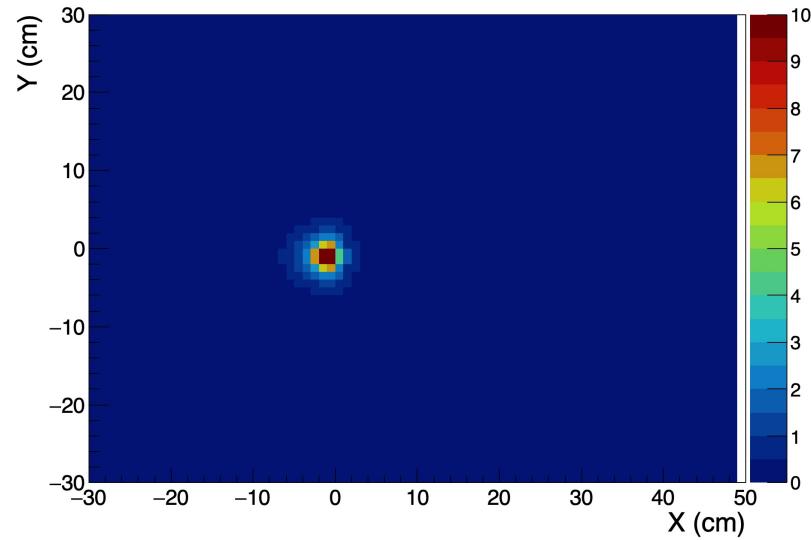
Con muro de concreto



Physics REBoot Venezuela: Bootcamp #1

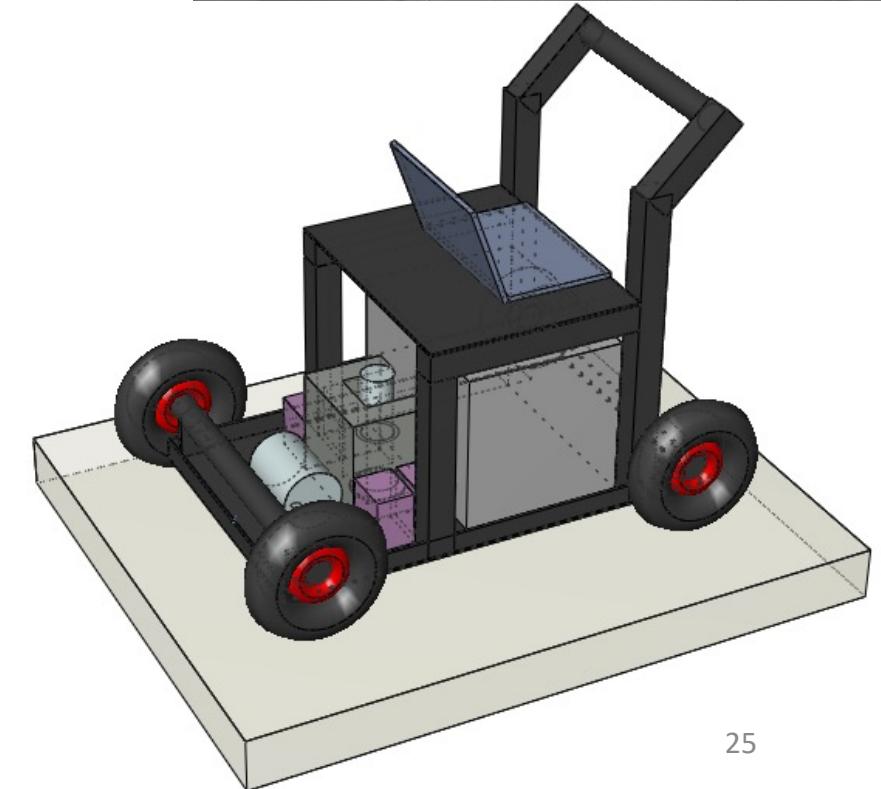
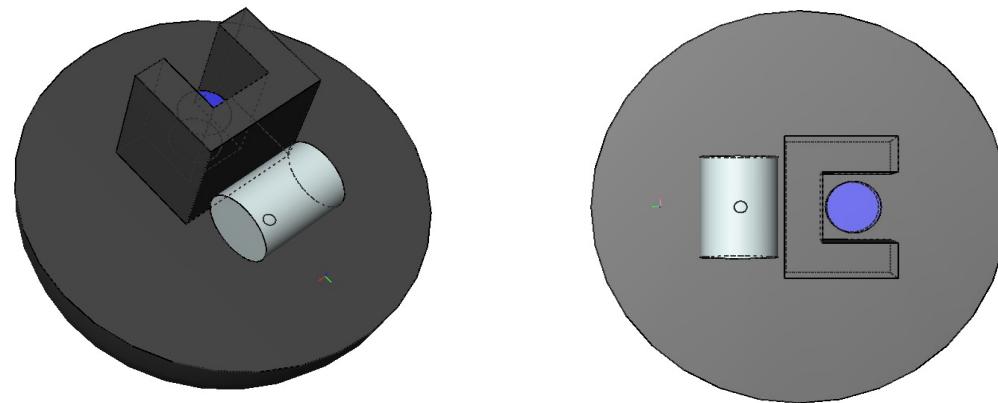
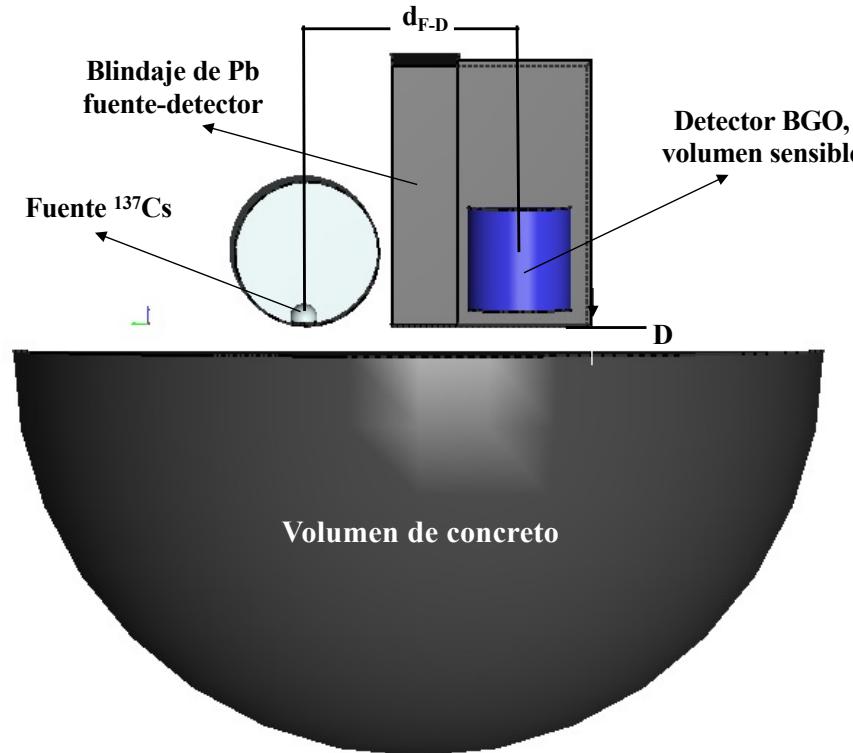


Dosis equivalente amb: fotones



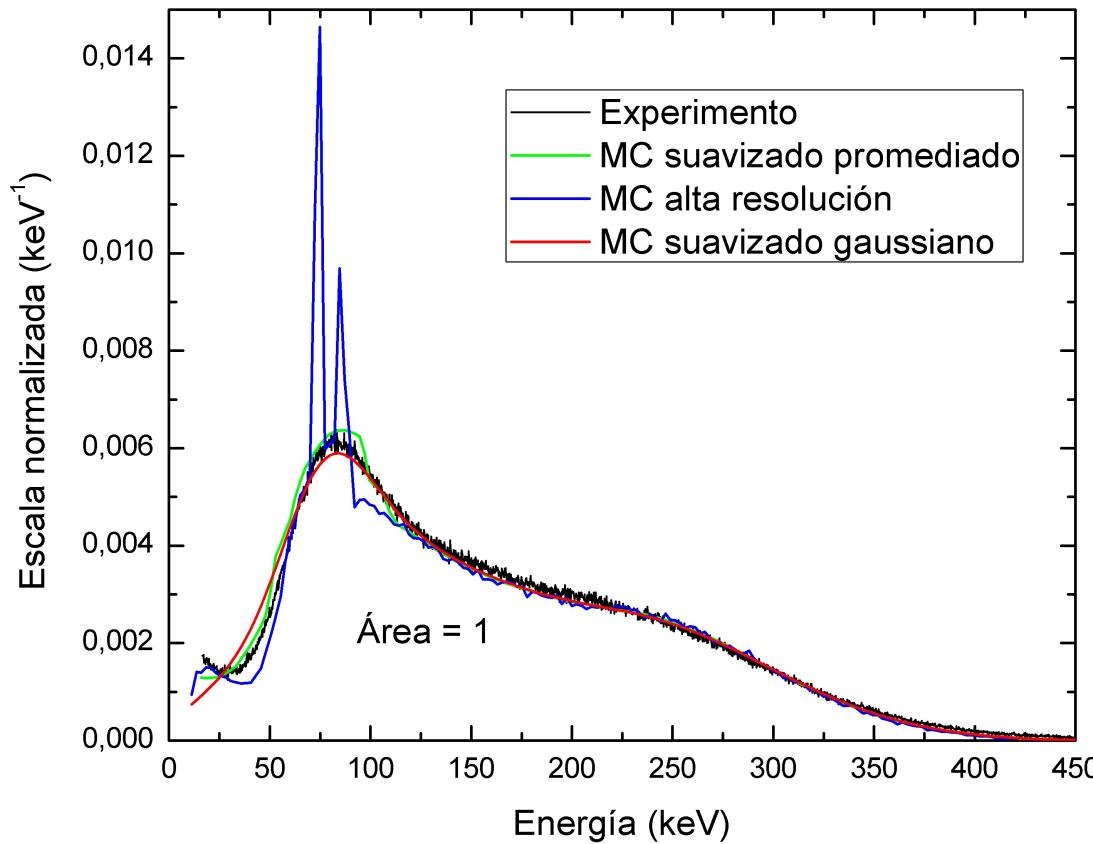
Contribución principal:
2.2 MeV \rightarrow H
4.4 MeV \rightarrow C

Compton Densitometer

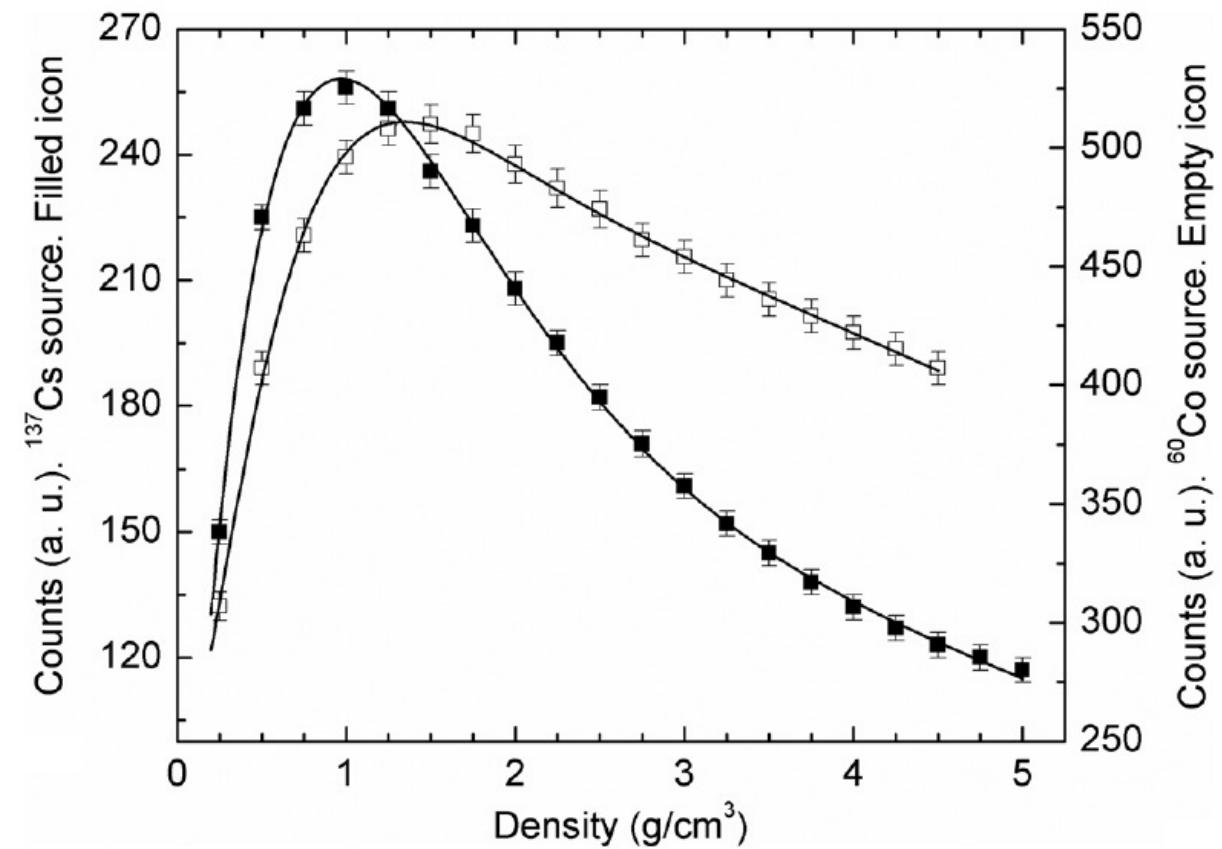


Compton Densitometer

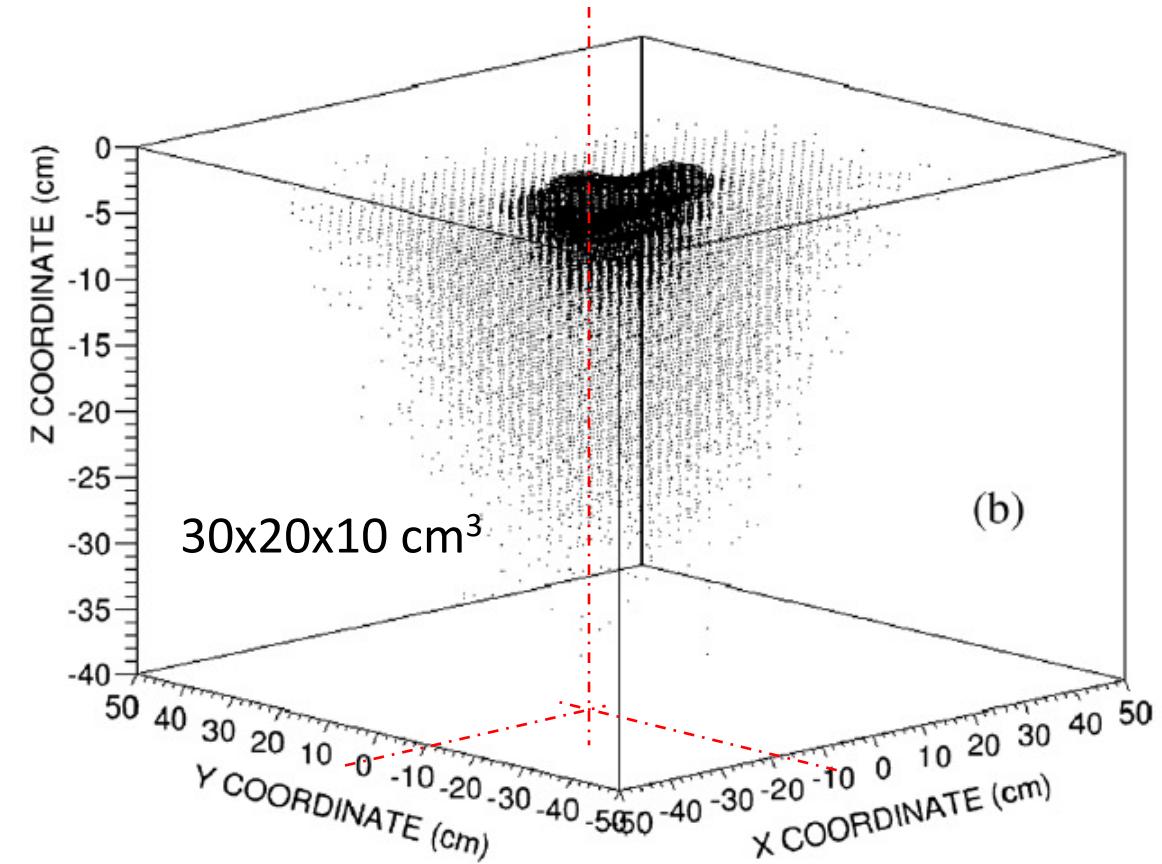
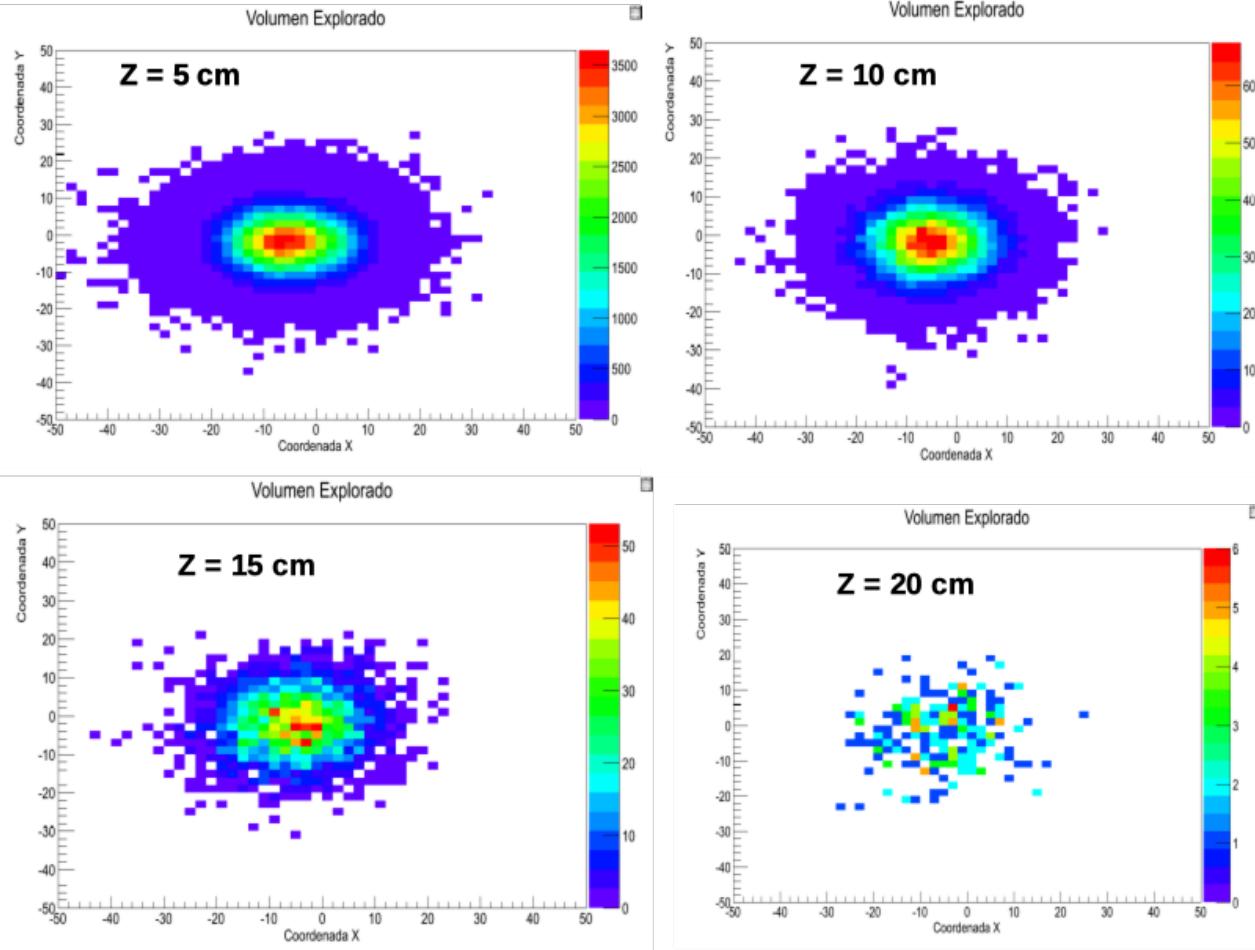
Respuesta del detector



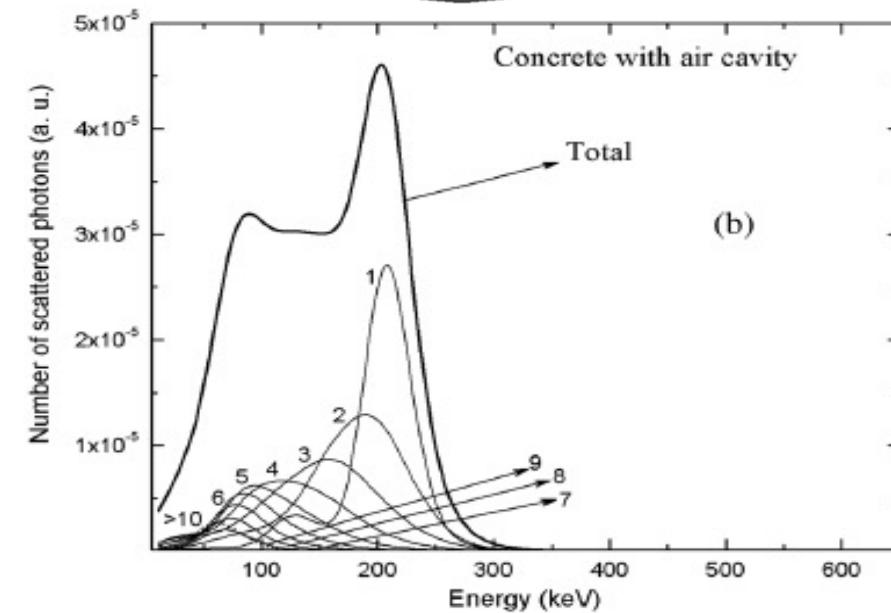
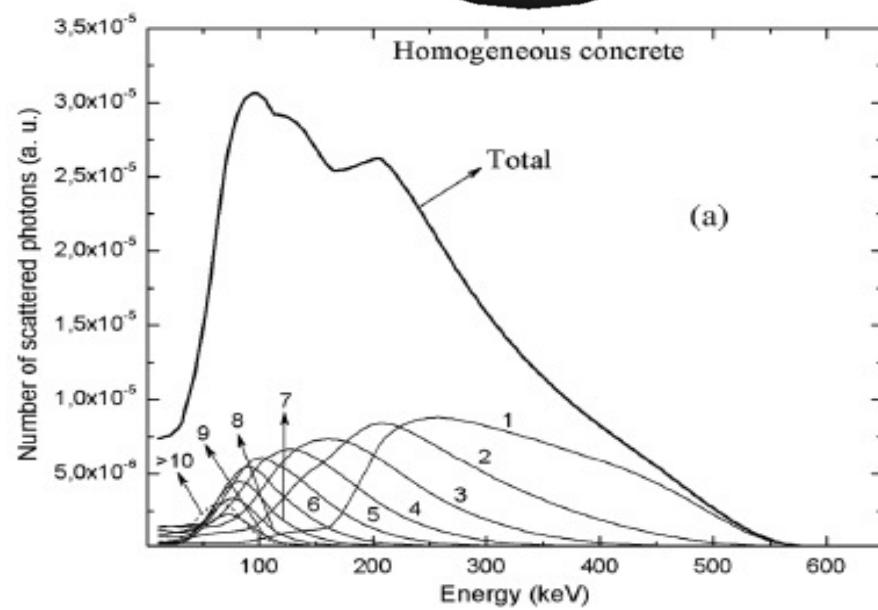
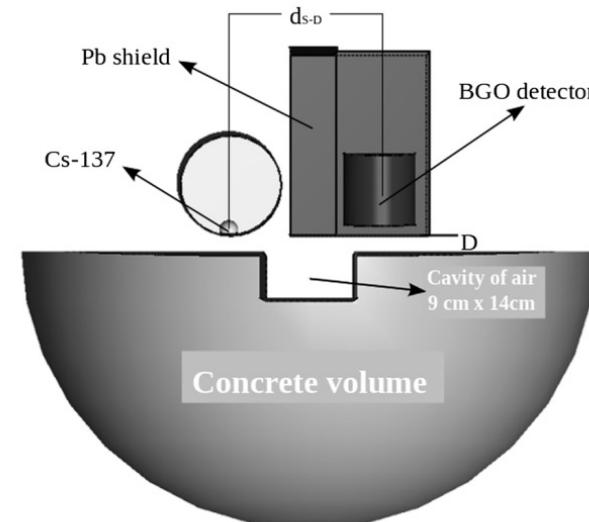
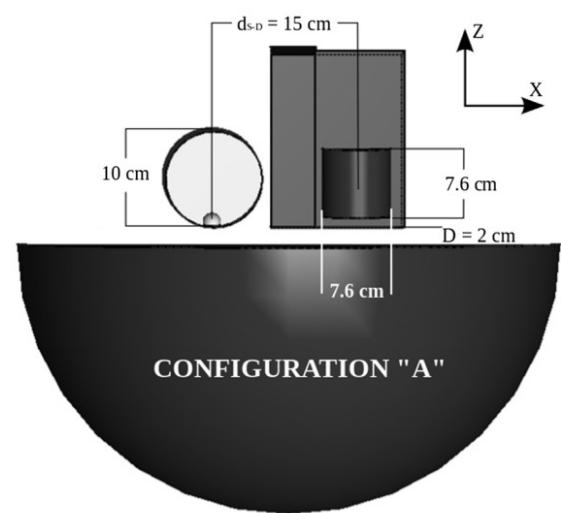
Curva de calibración, cps / densidad



Compton Densitometer: Volumen explorado



Compton Densitometer: Volumen no homogéneo



Algunos códigos

Free download:

- GEANT4: <https://geant4.web.cern.ch/>
- GATE: <http://www.opengatecollaboration.org/>
- OpenMC: <https://docs.openmc.org/en/stable/>
- Fluka: <http://www.fluka.org/>

Others (request, fees, etc.)

- MCNP6: <https://rsicc.ornl.gov/codes/ccc/ccc8/ccc-850.html>
- PENELOPE 2018 : <https://www.oecd-nea.org/>