The Replacement of Cadmium as a Thermal Neutron Filter

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Introduction

- Cadmium widely used to absorb thermal neutrons due to cross section properties.
- Cadmium is highly toxic causing many symptoms such as;
  - Kidney dysfunction,
  - Lung cancer,
  - High blood pressure.
- European directives now limit the use and discharge of cadmium.
- Ministry of Defence ban cadmium from on-board ships.

The RoHS Directive

European Union Directive EU 2002/95/EC, *(RoHS)*, states in article 4;

> Member States shall ensure that, from 1 July 2006, new electrical and electronic equipment put on the market does not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE).

Some exceptions do apply but efforts are being made to remove these exceptions.

Possible Alternatives

Flex-boron A flexible sheet of silicone elastomer which contains 25.3 weight-percent of boron. The ^{10}B isotope has a large neutron cross-section which decreases linearly with neutron energy.

Possible Alternatives

Flex-boron

Gadolinium A member of the lanthanide group, two of the seven isotopes in the natural form have a large thermal-neuton cross-section. ^{155}Gd and ^{157}Gd have a sharp cut-off transition but a major resonance is apparent in the pass-band.

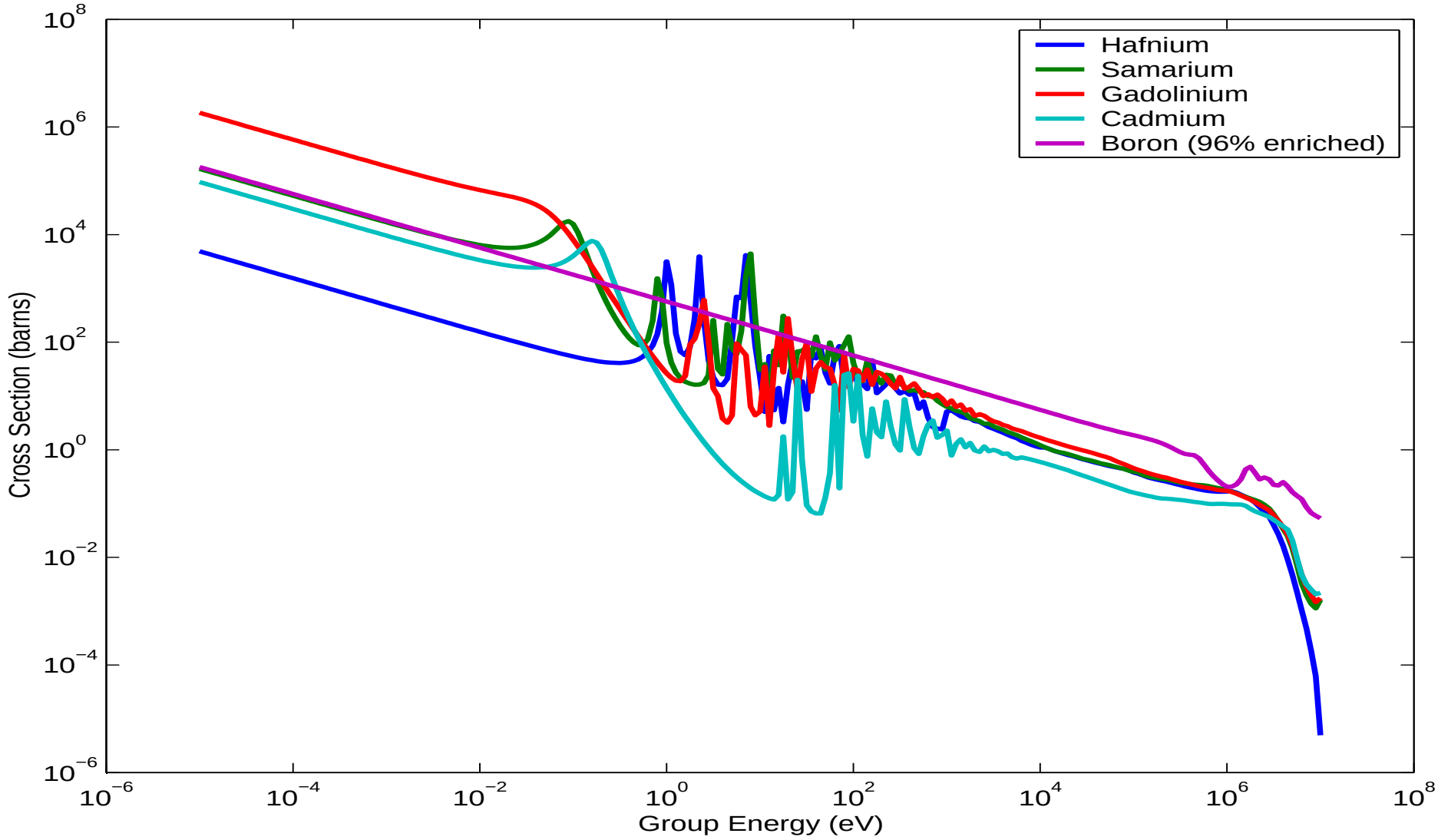
Possible Alternatives

Flex-boron

Gadolinium

Samarium A member of the lanthanide group with similar properties to gadolinium and two noteworthy isotopes, ^{149}Sm and ^{152}Sm, but with several major resonances in the pass-band.

Cross-Sections



MCNP Calculations

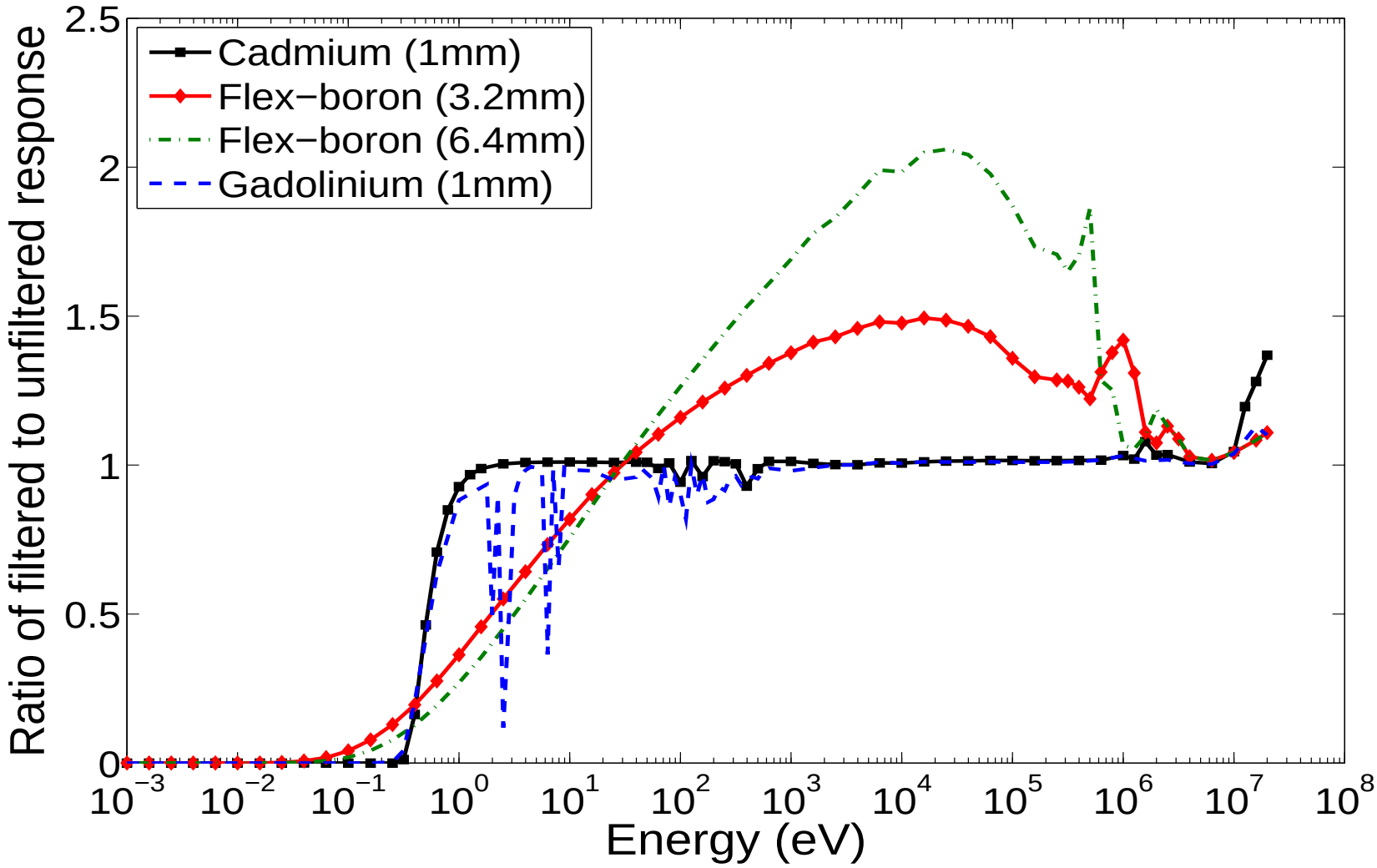
Two sets of calculations were performed to;

- Find the response of a BF_3 counter with and without filters at various point energies.
- Repeat the first set but using a simulation of the NPL thermal column.

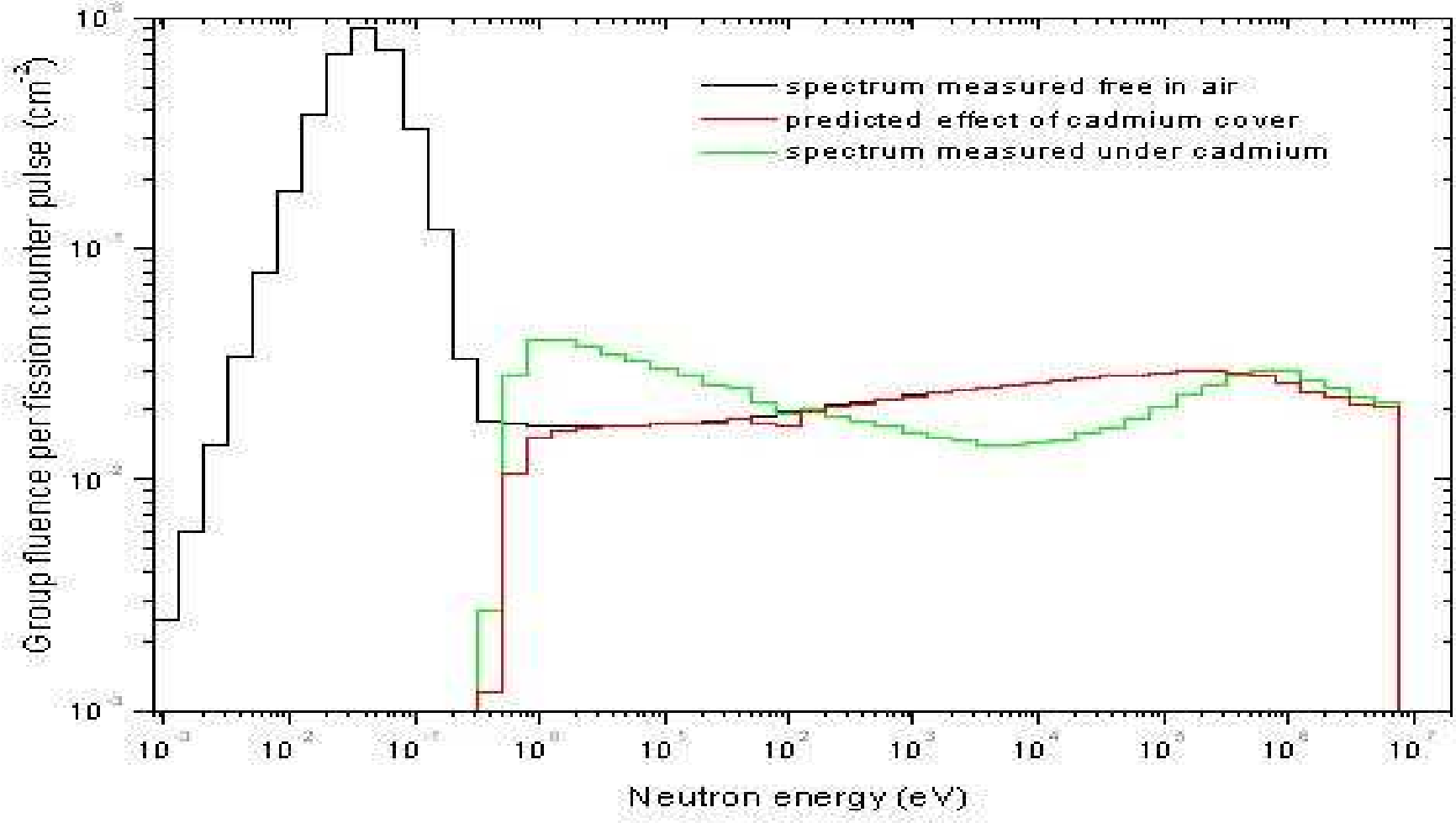
The calculations were performed on;

- Cadmium (reference)
- Gadolinium (best cross-section)
- Flex-boron (cheapest)

Calculation results – 1



Calculation results – 2

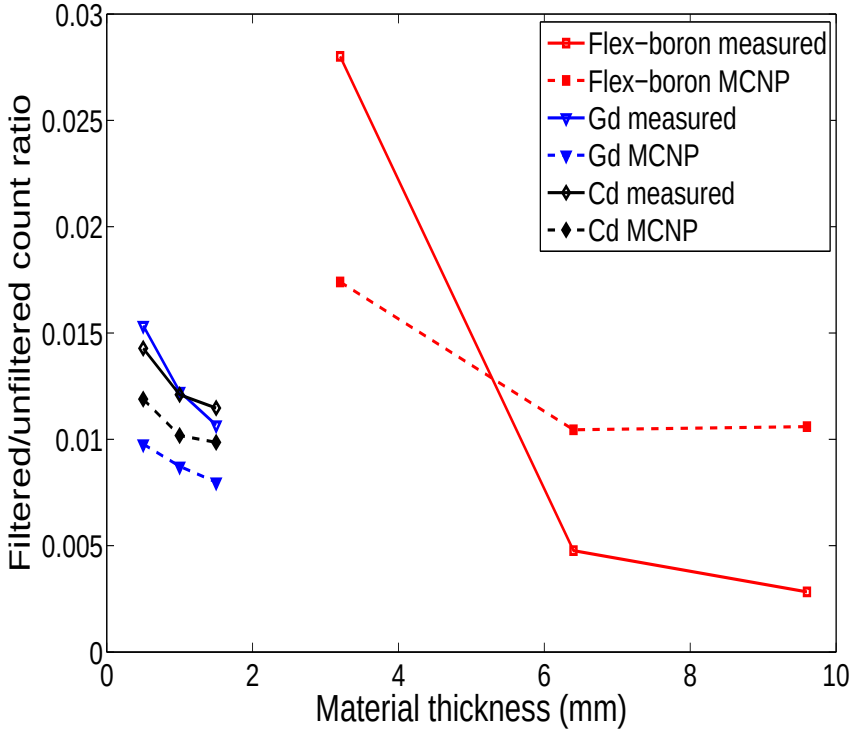


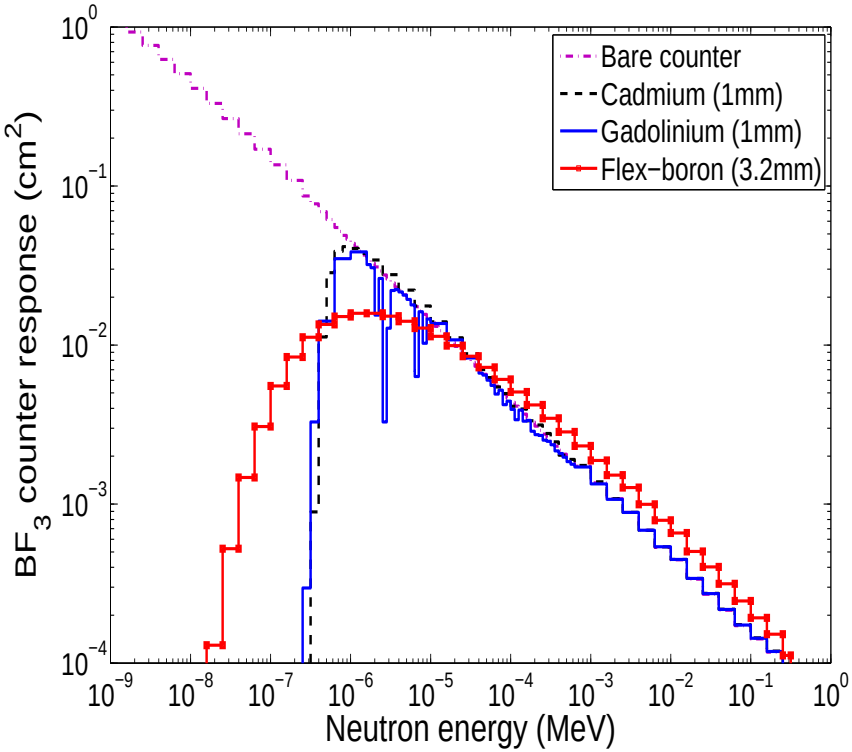
Experimental Validation

Material	Sleeve thickness (mm)
Cadmium	0.5, 1.0, 1.0 + 0.5
Flex-boron	3.2, 2×3.2
Gadolinium	0.5, 2×0.5, 3×0.5

- Tests carried out ot 1.5 m reference of NPL thermal column.
- Noise and γ-ray events gated out.
- Counter tested bare and with listed filters.

Results


Flex−boron measured
Flex−boron MCNP
Gd measured
Gd MCNP
Cd measured
Cd MCNP
Filtered/unfiltered count ratio
Material thickness (mm)
0.03
0.025
0.02
0.015
0.01
0.005
0
0
2
4
6
8
10


Bare counter
Cadmium (1mm)
Gadolinium (1mm)
Flex−boron (3.2mm)
BF3 counter response (cm2)
Neutron energy (MeV)
10^0
10^−1
10^−2
10^−3
10^−4
10^−9
10^−8
10^−7
10^−6
10^−5
10^−4
10^−3
10^−2
10^−1
10^0

Summary

- RoHS Directive restrict the use of cadmium.
- Neutron cross-sections of possible alternatives examined.
- MCNP calculations evaluated candidate materials.
- Experimental work at NPL verified calculations.
- Gadolinium is a very good substitute. Flex-boron can be used in some situations.

Publications

- D.J. Thomas, P. Kolkowski, N.J. Roberts, B. D'Mellow, M.J. Joyce. *Investigation of a possible replacement for cadmium as a thermal neutron absorbing material in neutron instruments*. NPL REPORT DQL-RN 017 (2006).
- B. D'Mellow, D.J. Thomas, M.J. Joyce, P. Kolkowski, N.J. Roberts, S.D. Monk. *The replacement of cadmium as a thermal neutron filter*. NIM A 577 (2007) 690 – 695.

Questions

- Introduction
- RoHS Directive
- Alternatives
- Cross-sections
- MCNP Calculations
- Calculation Results – 1
- Calculation Results – 2
- Experimental Work
- Results
- Summary
- Publications