Proposal for the (n,γ) cross section measurements of ^{244}Cm and ^{246}Cm at n_TOF EAR-2

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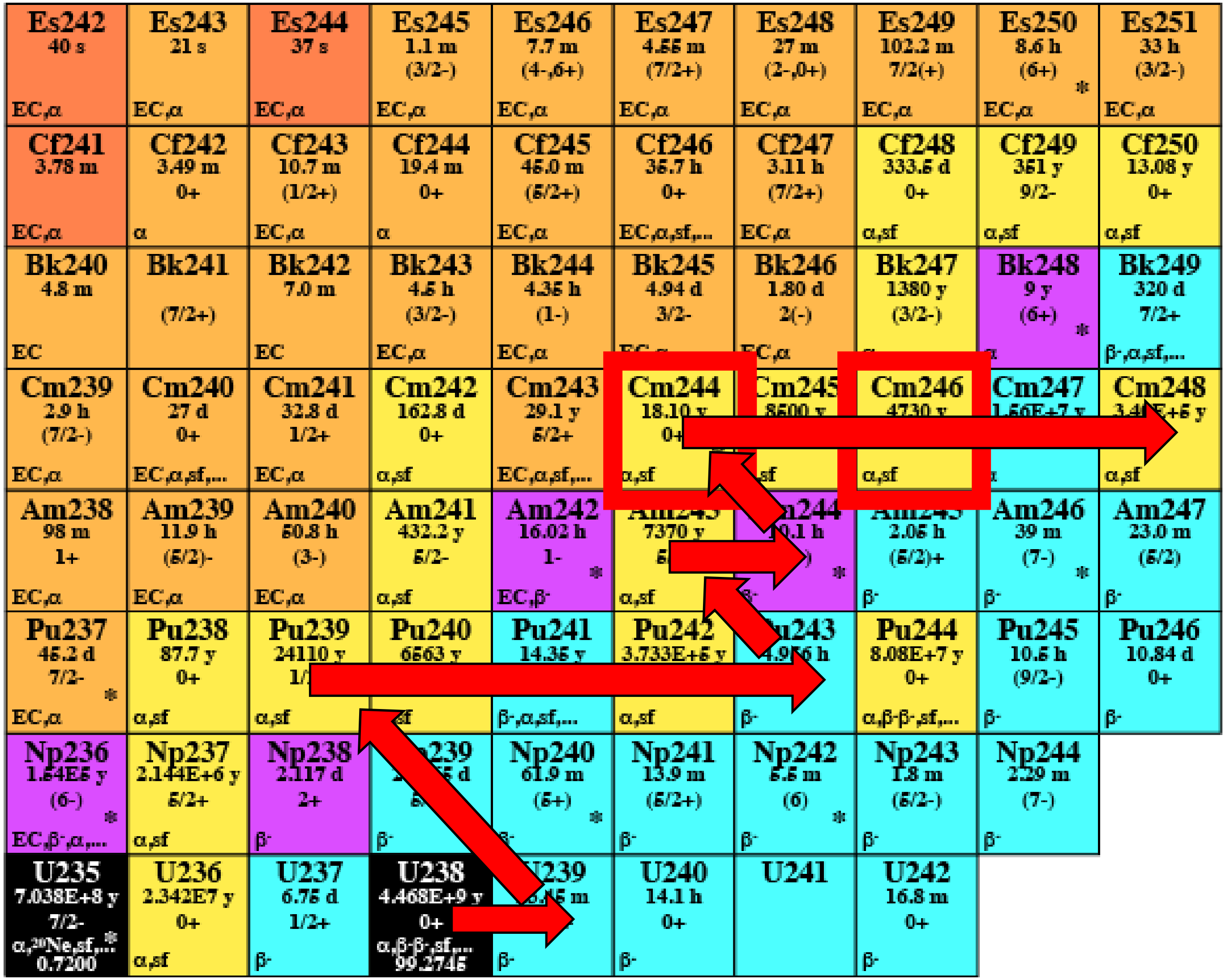
Motivation

nTOF



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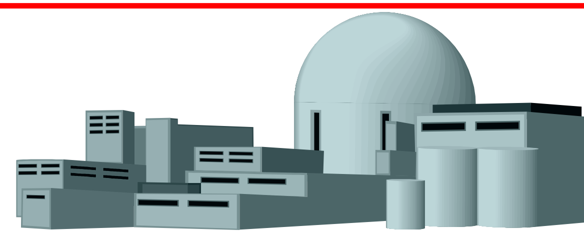
Motivation

Neutron Capture Cross Sections of

- **minor actinides (MAs) and**
- **long-lived fission products (LLFPs)**

are important.



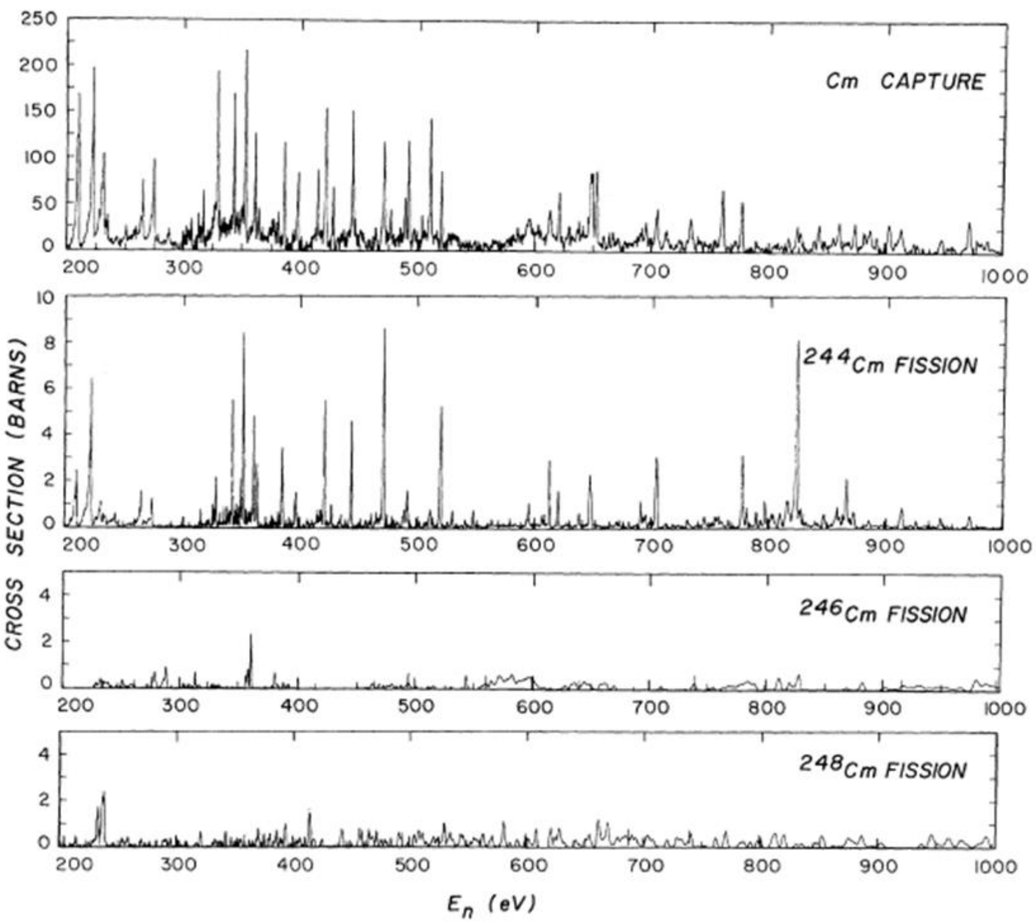
- for improving the performance and safety of our actual reactors,
- for designing new types of reactors,
  for reducing the high-level radioactive Waste (transmutation),

The reported uncertainties of c.s. Libraries are (too) often questionable!

Especially, ^{244}Cm and ^{246}Cm are **very important**:

- Share nearly 50% of the total actinide decay heat in spent reactor fuels even after three years of cooling.
- ^{244}Cm is one of the main neutron emitters in the irradiated nuclear fuel (fuel safety).
- Both capture and fission cross sections (transmutation) are known poorly.
- Cm isotopes open the path to the production of higher Z elements: Bk, Cf…
- Only two previous measurements available (extreme difficulties).

Experiment by Moore et al.



This experiment was performed with the neutron time-of-flight (TOF) method in 1969 **using a under-ground nuclear explosion (one single pulse)** as a pulsed neutron source and Moxon-Rae detectors operated in current mode.

The data had to be corrected with some assumptions, because the **sample** had been **shifted from the correct position** in their experiment.

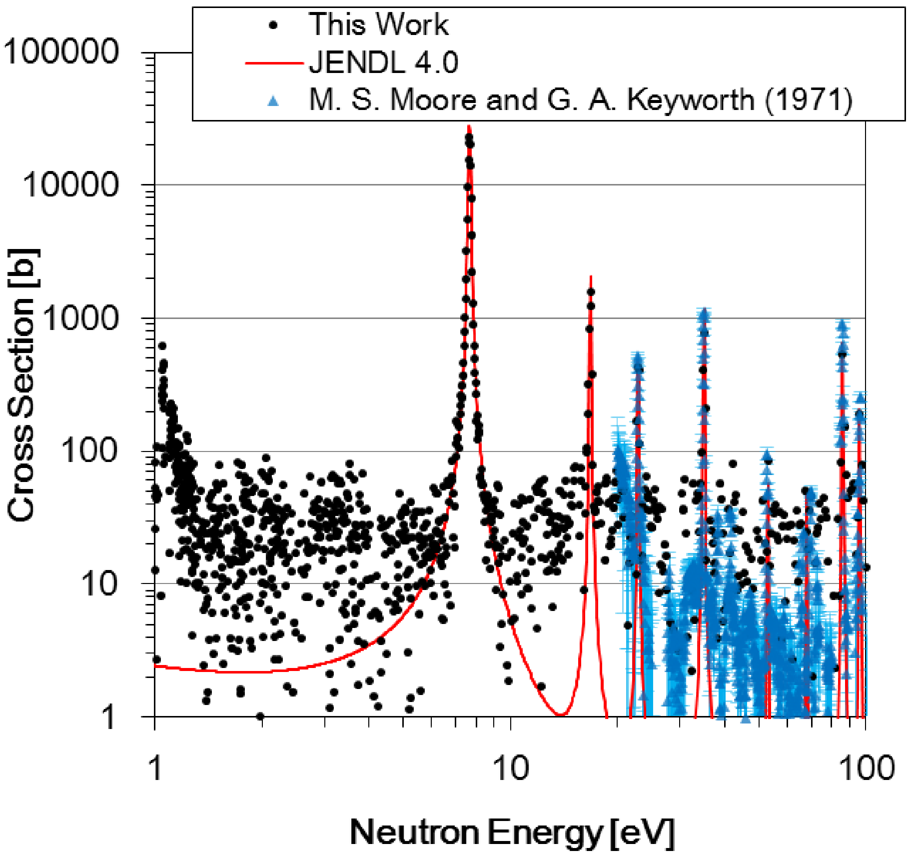
→Accuracy questionable due to systematic uncertainties

[1] M. S. Moore and G. A. Keyworth, Physical Review C, 3, 1656 -1667 (1971)

Experiment by Kimura et al.

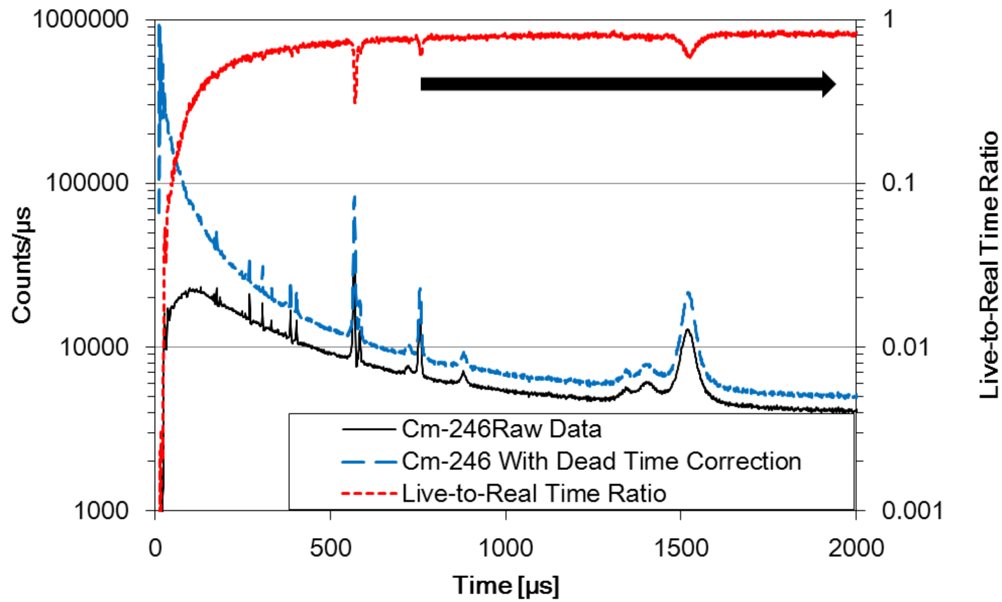
In the experiment at J-PARC Ge detectors were used for detecting the (n,γ) cascades.

- In the neutron energy range **above 100 eV**, the measurement at J-PARC required severe **dead time corrections (up to 90%)** due to the high counting rates and the long decay times of the detectors.
- Dependence on the electromagnetic de-excitation pattern.



As a result the upper-limits of the measured neutron energy range were restricted to 100 eV.

A. Kimura et al., J. Nucl. Sci. Tech. 49, 708 (2012).



The experiment proposed at EAR-2

The uncertainties of the reported data sets are much larger than the required accuracy of 4.1–25.7% especially in the neutron energy range over 100eV.

Avdantages/improvementes of the experiment proposed at n_TOF EAR-2:

- The EAR-2 neutron rate is 250 times larger than at EAR-1 (25 time more fluence in 10 times less time) which permits to reduce to reduce the influence of background due to decay γ-rays (i.e. smaller time windows). The n_TOF EAR-2 was built for the measurement of highly radioactive samples.
- The use of a high performance digital acquisition system (12/14 bits resolution, 1 Gsample/s)
- The use of the total energy detector technique based on very fast (40 ns vs ~100 μs) C_6D_6 detectors.

We expect as well to be able to obtain results in the range up to 300 eV.

The Cm samples

Two sealed ^{244}Cm samples and one ^{246}Cm sample are available and will be provided by JAEA.

Outside
9mmΦ 1.5mmt

Inside
5mmΦ 0.5mmt

	^{244}Cm sample (mole %)	^{246}Cm sample (mole %)
^{244}Cm	88.5±1.7 (0.46 mg)	24.1±0.4 (0.50mg)
^{245}Cm	3.14±0.40 (0.02 mg)	1.11±0.29 (0.02 mg)
^{246}Cm	8.36±0.39 (0.04 mg)	62.3±1.4 (1.30mg)
^{247}Cm	-----	2.99±0.37 (0.06mg)
^{248}Cm	-----	9.53±0.25 (0.20mg)
^{240}Pu	32.1±0.8 (0.17mg)	7.42±0.15 (0.15mg)

Samples:

^{244}Cm ($T_{1/2}$=18.1y: MA)
- **Net weight = 0.6 mg**
- **Activity = 1.8 GBq (x2)**

^{246}Cm ($T_{1/2}$=4753y: MA)
- **Net weight = 2.1 mg**
- **Activity = 12.1 MBq (^{244}Cm: 1.7GBq)**

Both of the samples
- **Chemical form = CmO_2**
- **Container = Al capsule**

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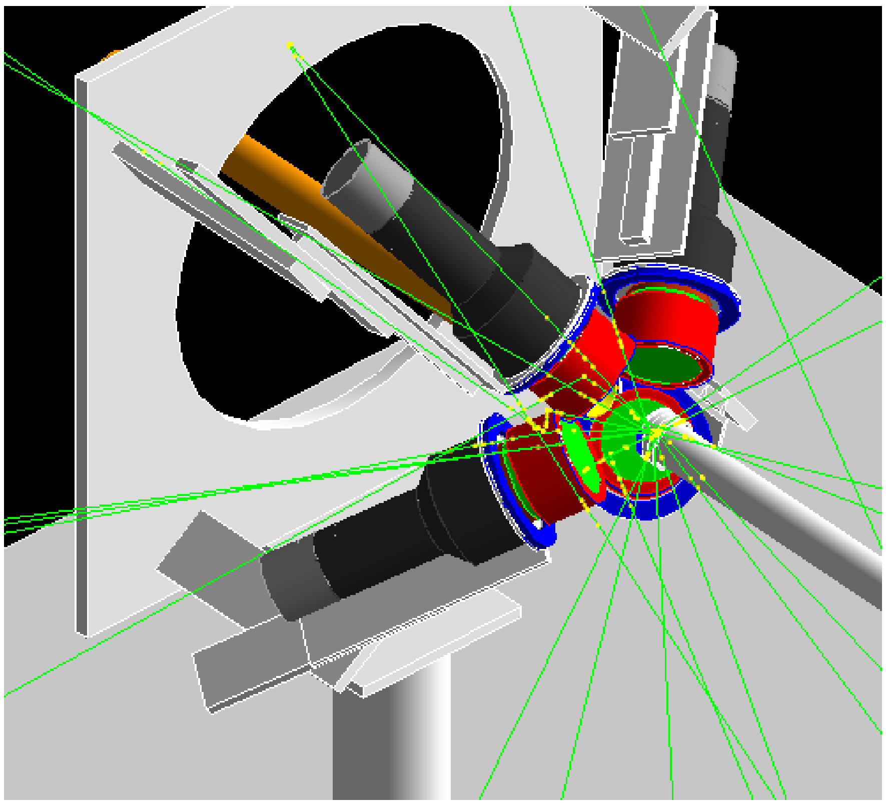
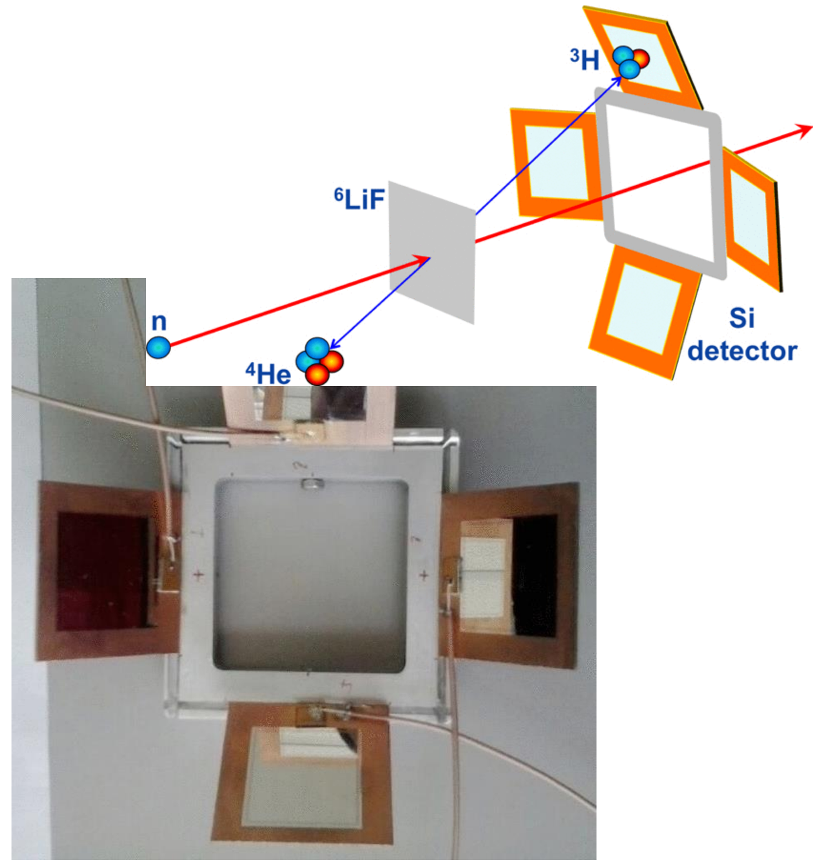
The detector setup

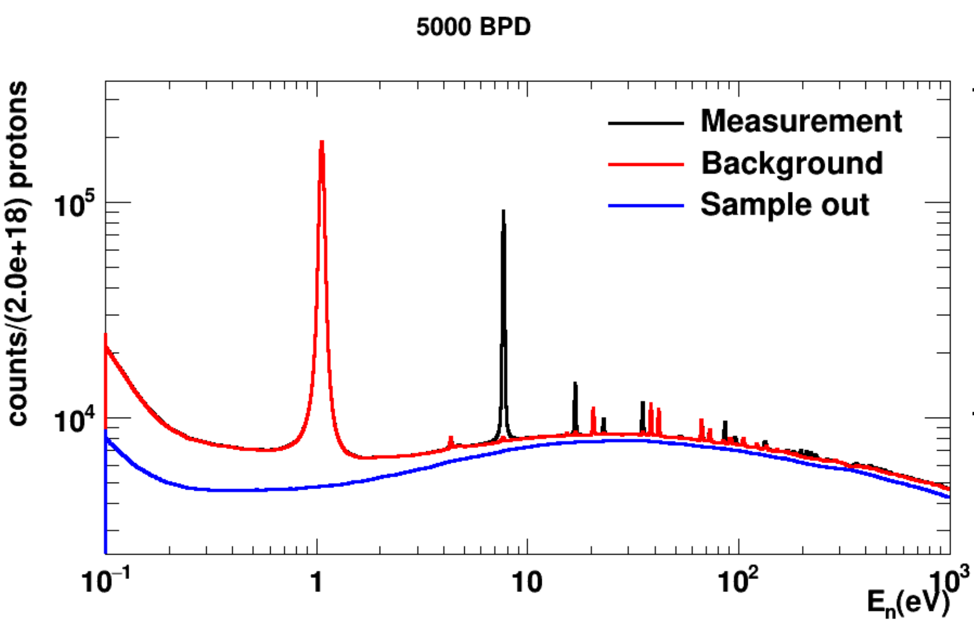
- We will use a set of four C_6D_6 detectors (20% efficiency). These detectors have been used successfully during the first (n,γ) cross measurements performed at EAR-2 in 2015.
- The neutron beam intensity will be monitored with a neutron transparent silicon flux monitor.



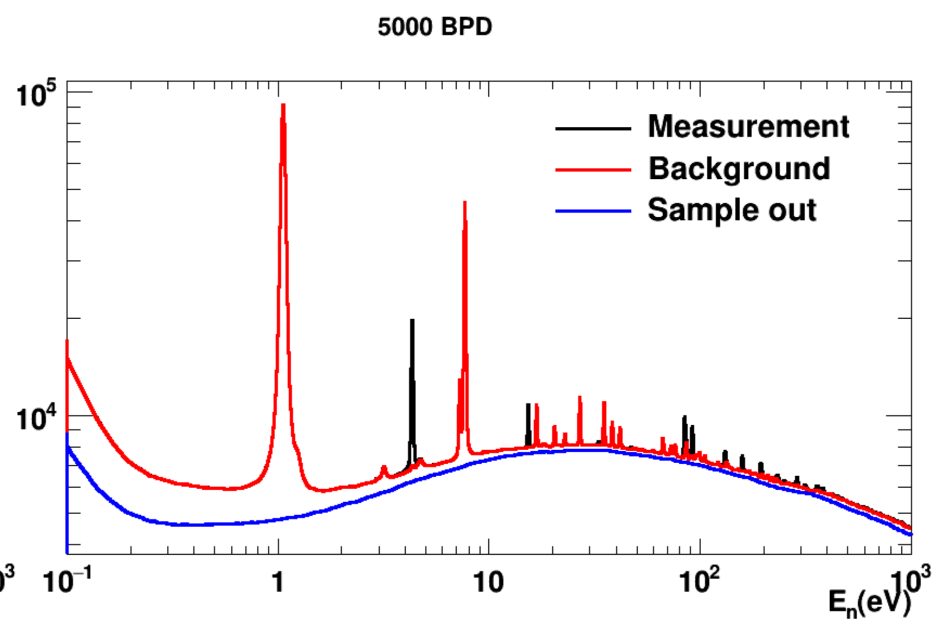


Rate estimates for the proposal

- A 20% total detection efficiency for the setup with 4 x C_6D_6 detectors
- The EAR-2 background has been determined experimentally (in 2015). An attempt for optimising the C_6D_6 setup for reducing the background (with active/passive shielding) is currently in progress.
- The background due to elastic (and fission) reactions has been estimated with a 0.1% neutron sensitivity of the C_6D_6 detectors.
- An efficiency for detecting fission reactions 2 times larger as the efficiency for capture.

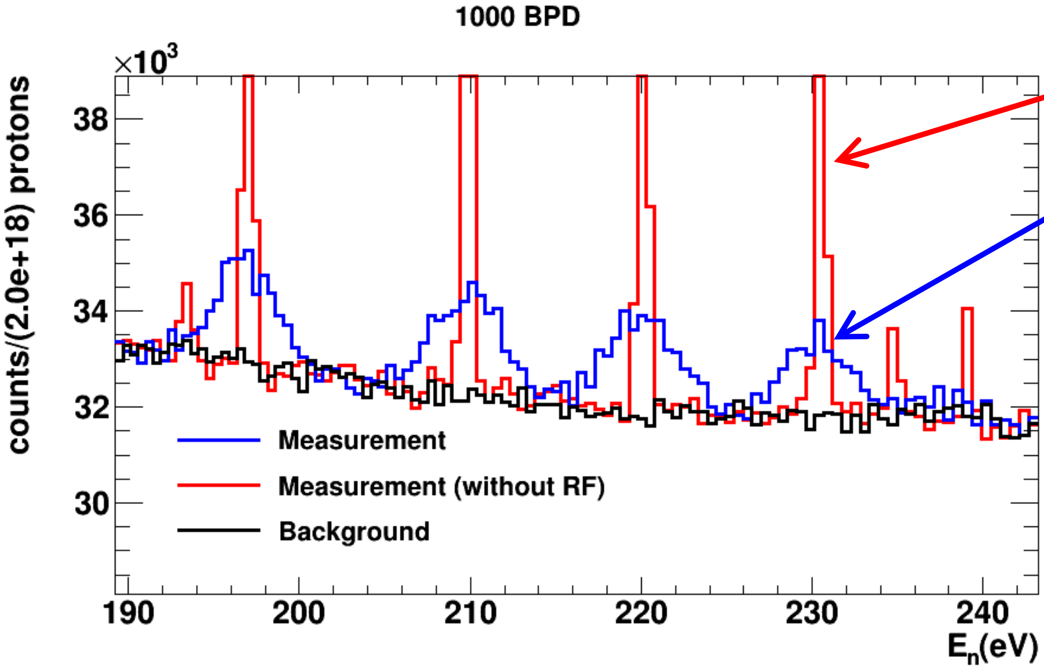


^{244}Cm



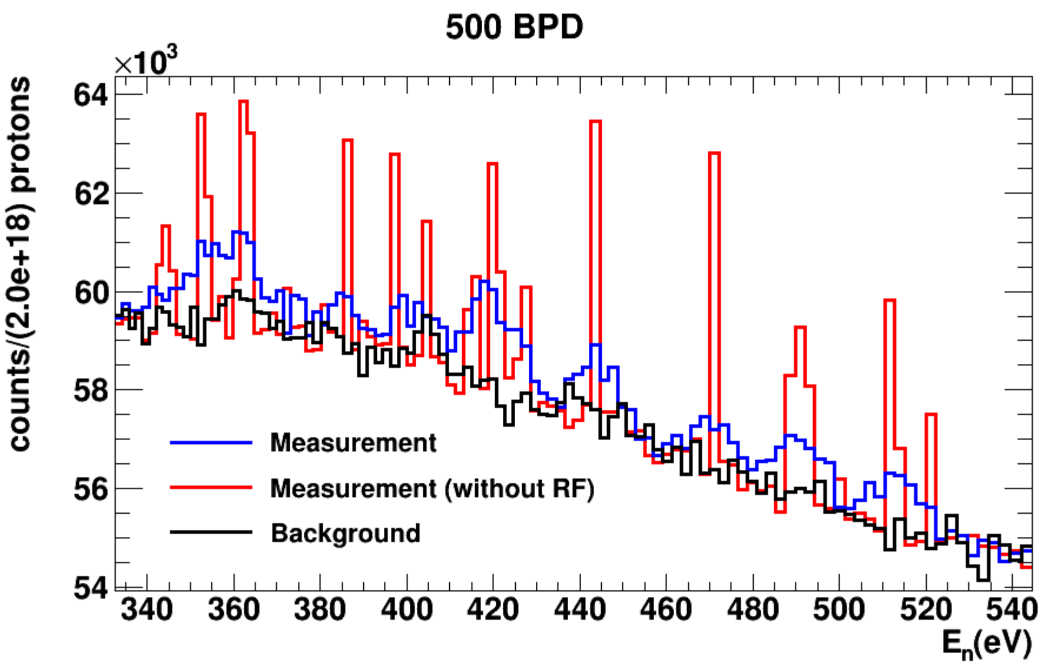
^{246}Cm

The effect of the resolution function



Doppler broadening

Doppler + R.F. broadening



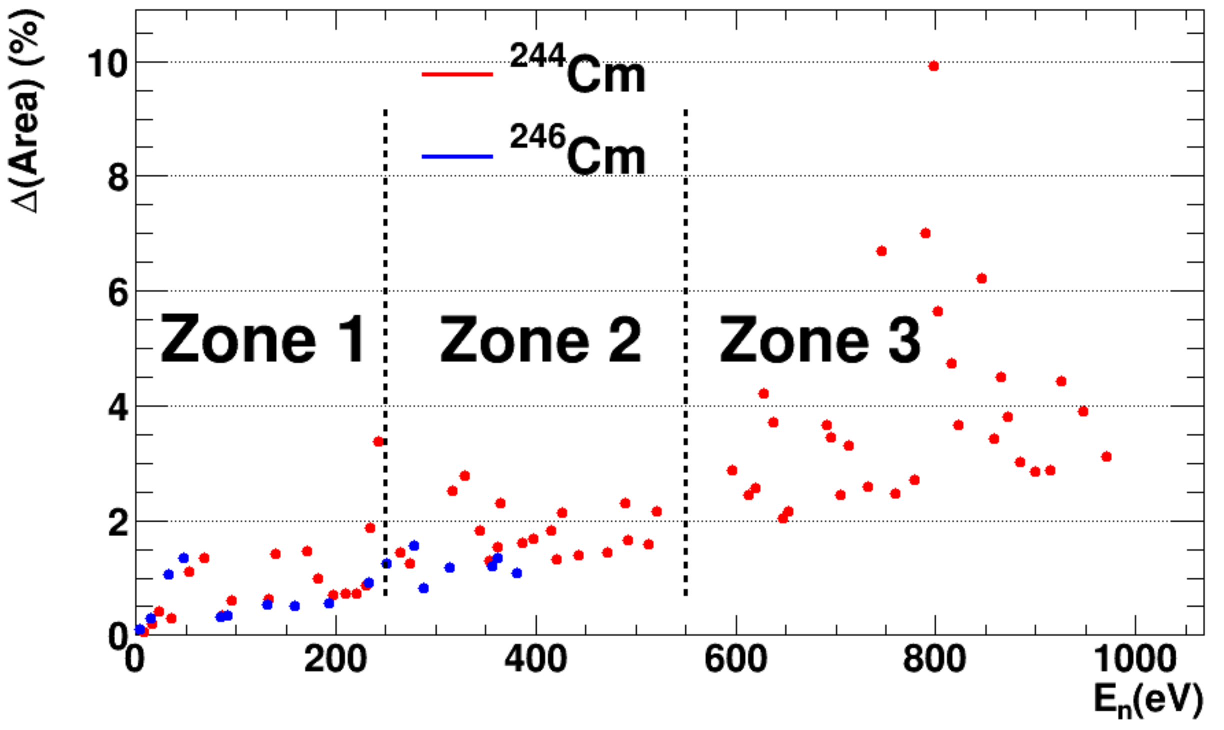
Good statistics is required because:

- The resolution function worsens the peak to background ratio.
- The background will have to be subtracted.

(*) expected number of counts per $2\text{x}10^{18}$ protons in the ^{244}Cm measurement, using 500 bins per decade.

Estimated statistical uncertainties

Estimated statistical uncertainties in the area of the resonances with $2x10^{18}$ protons.



- **Zone1**, between 1 eV and 200 eV. The measurement proposed at EAR-2 will allow to get resonance integrals with an overall uncertainty below 5%.
- **Zone2**, between 200 eV and 550 eV. The uncertainty in the results in this region will depend largely on the real cross section values and background.
- **Zone3**, between 550 eV and 1 keV. If the experimental conditions are much better than expected, this region could be analysed as well.

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Proton request

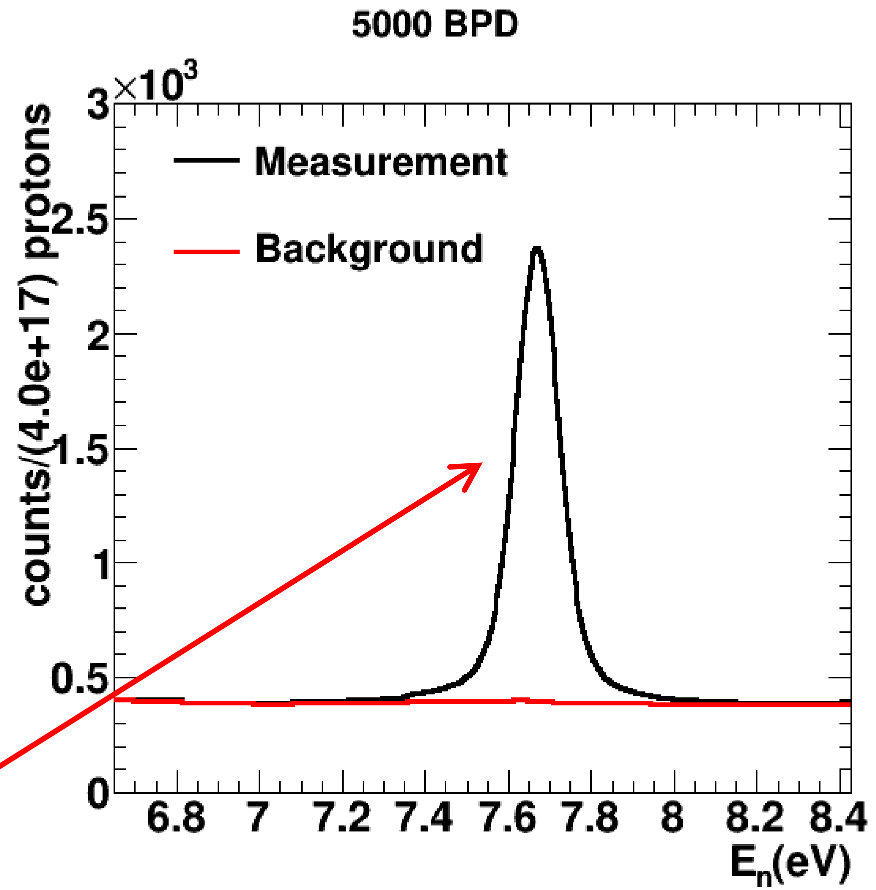
Number of protons requested for each measurement in EAR-2.

Sample	Purpose	Protons
$^{244}Cm(n,\gamma)$	capture cross section measurement	2.0×10^{18}
$^{246}Cm(n,\gamma)$	capture cross section measurement	2.0×10^{18}
Dummy – ^{244}Cm	Canning related background	1.0×10^{18}
Dummy – ^{246}Cm	Canning related background	1.0×10^{18}
Sample out	Beam related background	1.0×10^{18}
Graphite	Neutron Sensitivity	0.5×10^{18}
$^{197}Au(n,\gamma)$	Validation of the capture measurement	0.5×10^{18}
$^{244}Cm/^{246}Cm/-$	No beam related background	0
Total		8.0×10^{18}

Additional Measurement at EAR-1

Short measurement with the TAC in EAR-1:

- To have an alternative (total absorption) normalization to the ^{240}Pu 1 eV resonance. The systematic uncertainty in the normalization is the largest contribution in the overall uncertainty.
- To obtain spectroscopic information about the γ-ray cascades following the $^{244}Cm(n,\gamma)$ and $^{240}Pu(n,\gamma)$ reactions.



Number of expected counts in the TAC in strongest resonance in the $^{244}Cm(n,\gamma)$ c.s. for 4.0×10^{17} protons.

Sample	Purpose	Protons
$^{244}Cm(n,\gamma)$	Capture cascades of the strongest ^{240}Pu and ^{244}Cm resonances	0.4×10^{18}
Dummy – ^{244}Cm	Beam related background	0.1×10^{18}
^{244}Cm	Background with no correlation with the beam	0
Total		0.5×10^{18}

Summary and conclusions

- We propose to measure the capture cross sections of ^{244}Cm and ^{246}Cm at the n_TOF EAR-2 and perform a short measurement at EAR-1 for getting an addition normalization and spectroscopic information (statistical de-excitation models of the nucleus, photon strength functions).

- Both measurements have to be performed with the same systematics since the two isotopes appear in the two samples with different weights.

- Both ^{244}Cm and ^{246}Cm cross sections are required to estimate the production and transmutation Cm and heavier isotopes.

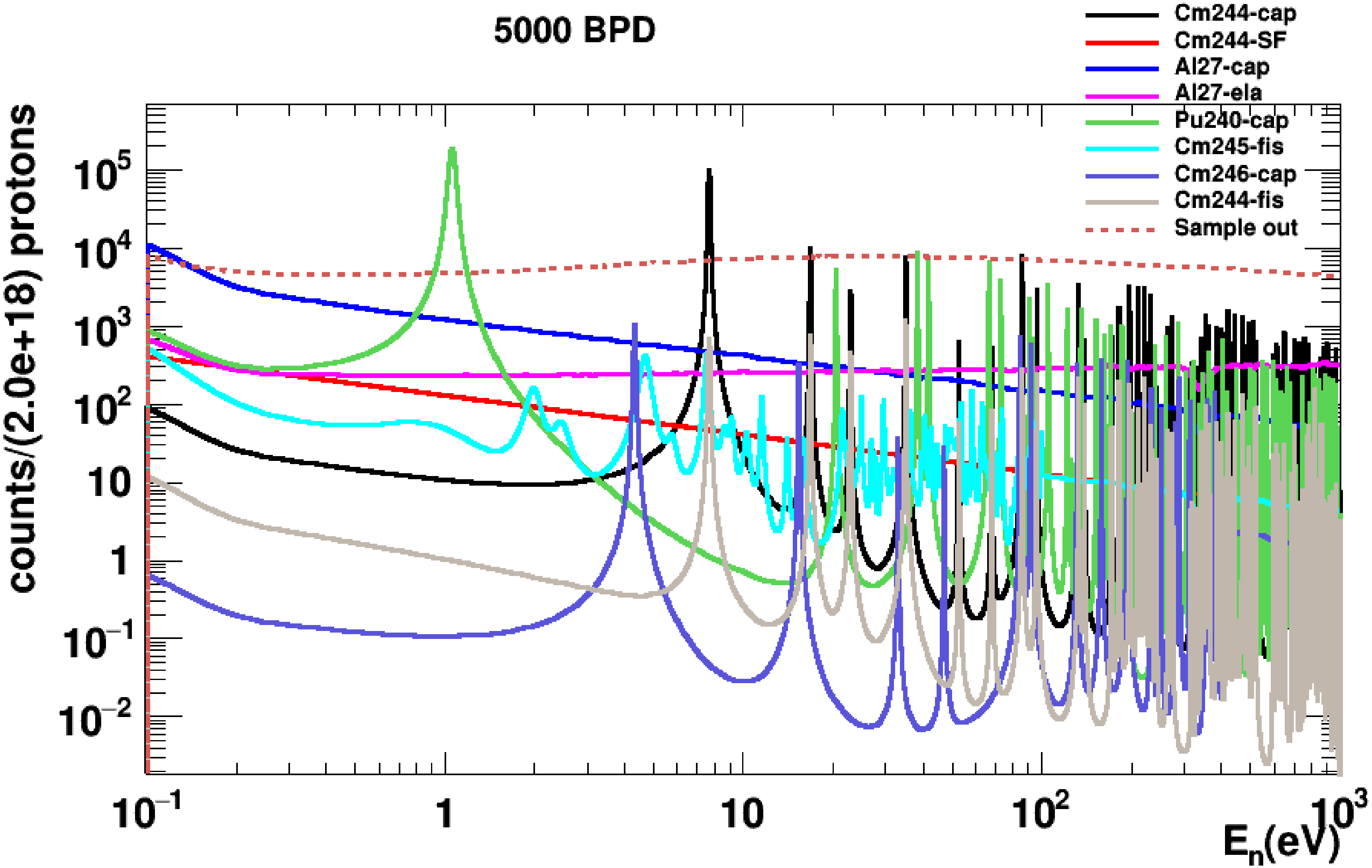
- This is the type of measurements for which EAR-2 was built (250 times more neutron rate than at EAR-1) and will have a large impact/visibility in the nuclear data for nuclear technologies community.

We request a total of:

- 8×10^{18} protons for the measurement at EAR-2
- 0.5×10^{18} protons at EAR-1.

SPARE SLIDES

Background components in the ^{244}Cm experiment



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Background components in the ^{246}Cm experiment