Day 1 SPIRAL2 Phase 1 Experiment Template		Dead-line for submission : **July 20th, 2009**

Title: Fragment angular distributions in neutron-induced fission of actinides

Spokespersons (if several, please use capital letters to indicate the name of the contact person):

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Brief summary of the physics goal (detailed description and counting rates should be given on separate pages) max. 1/2 a page:

The fission angular distributions are an ingredient in the efficiency corrections for the measurement of fission cross sections. They also carry information on the (J,K) distributions of the states involved in the fission process. Although the angular distributions of several actinides have been measured up to a few MeV, we have very little knowledge beyond this limit: measurements are scarce and often inconsistent. Experiments carried on ^{232}Th and ^{238}U fission indicate that the neutron-induced anisotropy of angular distributions is much higher than for proton-induced ones, which is not easily explained and should be confirmed. Generally the angular distributions change suddenly through the multi-chance thresholds reflecting the properties of the different fissionning nuclei.

We intend to measure the angular distributions of some actinides for which the angular distribution is significantly changing with the energy (^{232}Th, ^{238}U) or is an important ingredient in the cross section measurements (^{237}Np, ^{235} U, ^{234}U). Significant countings can be achieved only with large targets and this requires a detection system able to track the fission trajectory. We will detect the 2 fission fragments in coincidence by 2 position sensitive PPACs placed on each side of a target. Our detection system is made of 10 detectors with 9 targets.

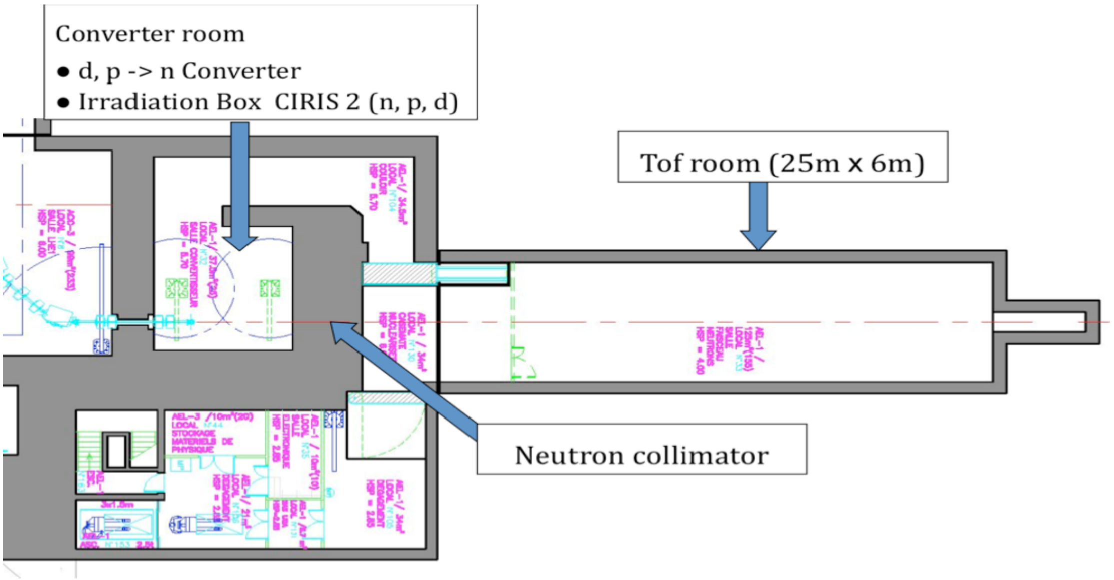
LINAC Primary Beam(s) ***(see beam parameter table at the end of template)***	Ion(s)	Energy (MeV/nucl.)	Intensity (pμA)	Number of beam UT (1UT=8hours) per beam	Requested time structure (if different from parameters given in the attached table) Δ t(ns): Beam on: Beam off:
	$^{2}H^{1+}$	**20**	**8**	**90**	**1 burst every 600**

Total estimated number of beam UTs (1 UT=8hours): **90**	Approximate time for setting up the apparatus: 3 days Approximate time required for off-beam calibration and dismounting: 1 day
When the experiment might be ready to run (month, year): January 2012	

Beam Line (NFS or S3):
Detectors to be used (provide a sketch of the setup): **The chamber is an horizontal chamber approximately 77 cm in diameter and 160 cm in length. The chamber contains a stack of 10 detectors and 9 targets in the neutron path, all bent at 45 degrees from the beam axis to maximize the available angular range (see figure in the attached text).**

NFS parameters *(for the experiments using the NFS beam line):*

Type of neutron converter (Li, Be, C)	Neutron collimator (diameter in cm)	Distance collimator - target (m)	Use of irradiation Box CIRIS 2 (Y/N)
Be	8cm right before the experimental setup	25-30 m	N

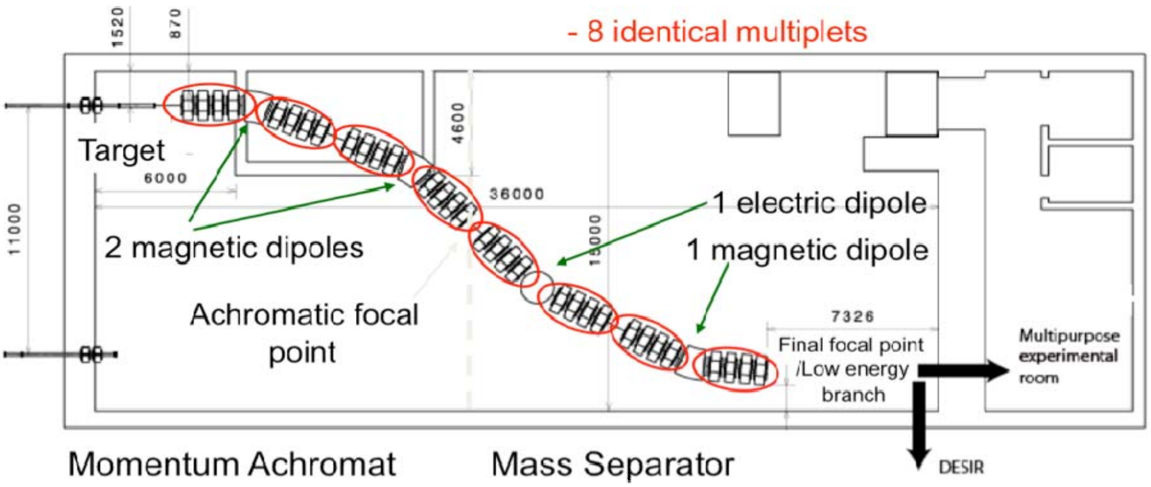


Schematic layout of the NFS facility

More information on the NFS facility can be found at:
http://www.ganil.fr/research/developments/spiral2/collaborations.html
For further questions on NFS please contact spokesperson of the collaboration:
xavier.ledoux@cea.fr

S3 parameters *(for the experiments using the S3 beam line)* **:**

	Material	Thickness	
Primary target(s)			
Stripper(s)			
Devices needed Mark with X	Momentum achromat	Mass separator	Low energy branch
Setup at achromatic point	Secondary target	Ancillary detectors (specify)	
Setup at Mass separator Focal Plane	Implantation decay station	Gas cell	Other devices (specify)



Schematic layout of the S3 spectrometer/separator

More information on the S3 spectrometer/separator can be found at:
http://www.ganil.fr/research/developments/spiral2/collaborations.html
For further questions on S3 please contact spokesperson of the collaboration:
savajols@ganil.fr

Acquisition system (present GANIL or specific one if yes specify): Ganil DAQ: 50 ADCs or QDCs, and 50 TDCs

Electronics system (type of electronics - provide a reference if possible, estimated number of racks, necessary electric power, other requirements) and its location (ex. located close to the detector/spectrometer or in a separate room) : 5 NIM crates in a separate room

Security, use of hazardous equipment :
(Radioactive target, liquid nitrogen, explosive gas etc.) Use of radioactive targets (typically 10 MBq of alpha radioactivity). Open circuit of non-flamable gas (C_3F_8) sweeping the fission chamber.

Remarks : Need of a neutron collimator 2 or 3 meters before the chamber to define the neutron beam spot. A shielding wall between this collimator and the chamber should set to stop the neutrons scattered by the collimator.

LINAC beams available for the Day 1 SPIRAL2 Phase 1 experiments*$^{)}$

Ion(s)	Energy Range (MeV/nucleon)	Maximum Intensity (pμA)	Approximate date of availability***$^{)}$	Remarks
$^{1}H^{1+}$	20-33	2-10	December 2012	NFS beam line; Intensity with fast chopper 1/100
$^{2}H^{1+}$	10-20	2-10	December 2012	NFS beam line; Intensity with fast chopper 1/100
$^{4}He^{2+}$	10-20	2-10	December 2012	NFS beam line; Intensity with fast chopper 1/100
$^{18}O^{6+}$	4-14	80-160$^{**)}$	February 2013	S3 beam line
$^{20}Ne^{7+}$	4-14	25-140$^{**)}$	February 2013	S3 beam line
$^{36}Ar^{12+}$	4-14	15-50$^{**)}$	February 2013	S3 beam line
$^{40}Ca^{14+}$	4-14	10-40$^{**)}$	February 2013	S3 beam line
$^{48}Ca^{16+}$	4-14	2-10$^{**)}$	February 2013	S3 beam line
$^{58}Ni^{18+}$	4-14	1-2$^{**)}$	February 2013	S3 beam line

Remarks:
Beam time structure: acceleration (or bunch) frequency 88 MHz, Δt for each bunch typically 1 ns (depends on beam energy and target position)

*$^{)}$ The parameters indicated in this table are the first and the best approximations that can be done today. They may be different from those available in reality at the beginning of operation of SPIRAL2. User's request of different beams and specifications supported by recommendations of the Scientific Advisory Committee for the Day 1 SPIRAL2 Phase 1 experiments might be taken into account. The SPIRAL2 project will update the list of parameters periodically.

**$^{)}$ Based on the order of magnitude of the expected best currents extracted from a high performance, fully operational, 28 GHz ECR Ion source.

***$^{)}$ These dates assume that: installation of equipment in the NFS and S3 areas can start in July 2011, commissioning of the LINAC can begin in the first quarter of 2012 and commissioning of the instrumentation in the S3 and/or NFS halls with the LINAC beam(s) would begin in September 2012.

Fragment angular distributions in neutron-induced fission of actinides

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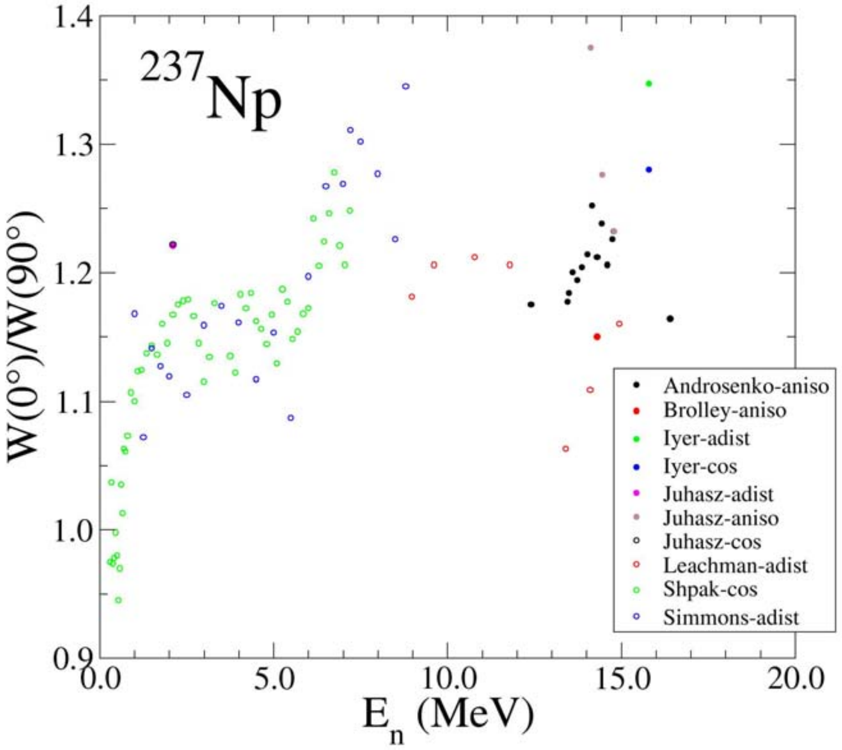
Motivation

The fission angular distributions of fission fragments have often been measured in the past and consistent data exist for isotopes as ^{233}U, ^{234}U, ^{235}U, ^{238}U, ^{237}Np, below a few MeV. However, the measurements are very scarce or discordant above this limit, with a situation of almost unknown data above 20 MeV. This is illustrated by existing measurements for ^{237}Np in Figure 1, which displays the energy variation of



the anisotropy, defined as the ratio of differential cross sections at 0° to 90°.

Below 10 MeV the results are consistent and show clearly the variation occurring at the first (1 MeV) and second (7 MeV) chance fission, corresponding to transition states of given J and K (total spin and its projection on the fission axis) in ^{238}Np for the first chance and ^{237}Np for the second chance. In the vicinity of 14 MeV several measurements have been performed and they are significantly discrepant from each other. This observation is not specific to this isotope, and the same can be seen for ^{238}U, ^{235}U, ^{233}U, ^{232}Th. Such discrepancies could come from a combination of quick

variations of the angular anisotropy, due to the onset of the third chance fission, and an inaccurate knowledge of the neutron energy. In this respect NFS is the best facility to solve this problem, because of its high neutron flux in this domain and the continuous energy spectrum allowing to show the variations of anisotropy.
Above 20 MeV, only one measurement has been carried out for ^{232}Th and ^{238}U [1], and no data exist for the other isotopes. The results from [1] show that a forward anisotropy is persistent up to 150 MeV with an amplitude (1.5 ratio at 70 MeV for ^{232}Th) much higher than in proton-induced fission, as shown

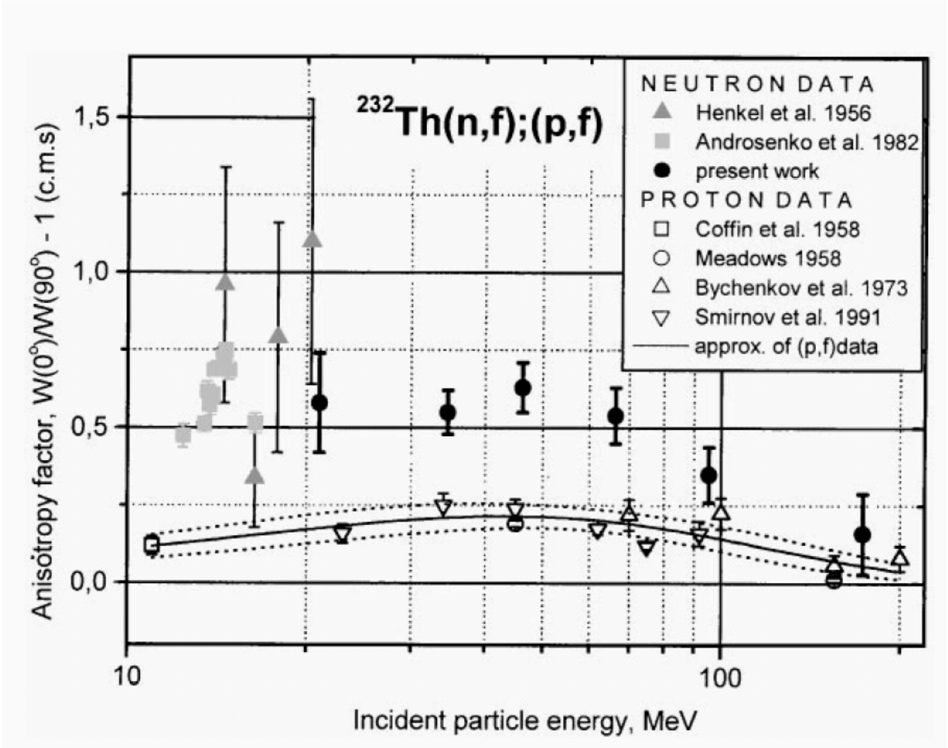


Figure 2 : Anisotropy for neutron- and proton-induced fission of ^{232}Th, from

in figure 2. Such findings are difficult to explain in the framework of statistical model calculations, peculiarly for the neutron/proton difference in the high energy range. Therefore the high anisotropies that have been reported should be confirmed and NFS is well suited to cover the 4MeV to 40 MeV range.

To summarise, the fission fragment angular distribution of actinides is not well-known above a few MeV. This is an important information to understand the fission mechanism, in particular to specify the few transition states which are the path to fission. In addition, this angular distribution has an effect on the detection efficiency in the fission cross section measurements due to the angular limitation of detectors.

Experimental setup

To get reasonable countings we use targets of large areas: disks of diameter 8 cm. As a consequence both fission fragments have to be detected to track the fission trajectory and the detectors have to be position sensitive, and the thicknesses of a detectors and target backings have to be thin to allow the fission fragments to pass through.

Our experimental setup is a stack of 10 Parallel Plate Avalanche Counters (PPAC) interleaved with 9 targets tilted at 45° on the beam axis, as illustrated in figure 3. Figure 4 shows a realistic view of the chamber. In the true experiment 2 ^{232}Th targets would be replaced by ^{237}Np targets, and 2 others by ^{234}U targets. The measuring configuration would be ^{237}Np (2), ^{234}U (2), ^{232}Th (3), ^{235}U (1), ^{238}U (1). The PPACs are made of 3 electrodes defining 2 gaps for the X and Y localisations (stripped cathodes for position recognition).

The tilt angle allows a better efficiency over the full angle range and disentangles the variation of counting rates due to the angular distribution and to the efficiency.

We intend to set the reaction chamber at 25 or 30 m downstream from the converter to benefit from the best energy accuracy, especially if the buncher is not used. In addition a collimator of diameter 8 cm should be placed before the reaction chamber to define the beam spot on the targets. A too wide beam spot would produce a lot of background by reactions on frames, flanges, etc… A neutron shieldind should be inserted between this collimator and the chamber to avoid the presence of scattered neutrons which are harmful for fissile isotopes.

The required electronics are standard. Each detector delivers 5 signals: 1 fast anode signal and 4 localisation signals coming from the ends of the 2 delay lines for X and Y localisations. Therefore 50 channels are needed with CFDs, ADCs (or QDCs) and TDCs. If FADC are used their sampling rate should be at least 500 MHz to allow accurate time determination (0.4 ns) for the anode signals which are very short (10 ns).

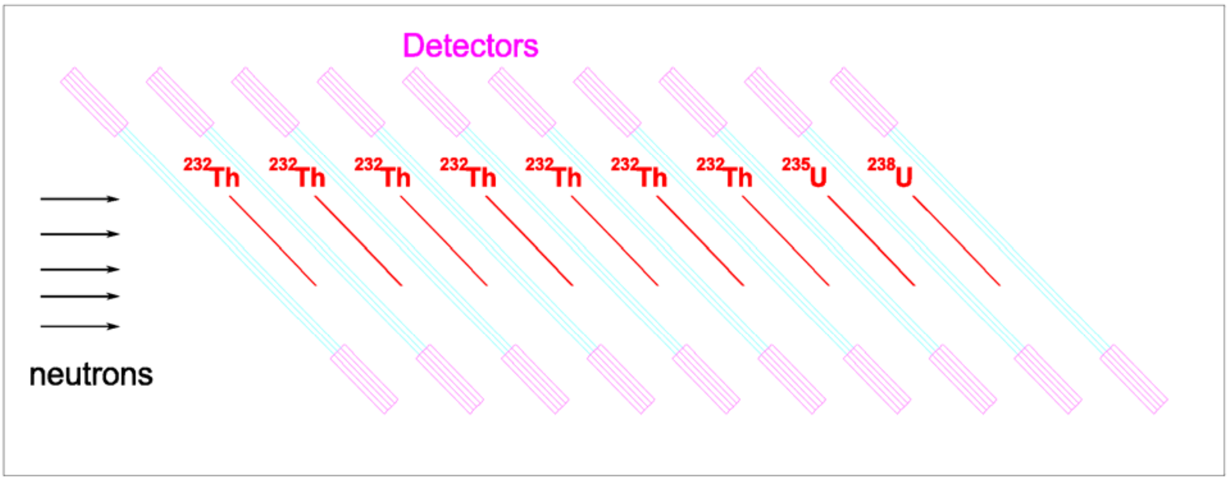


Figure 3 : Top view of the experimental arrangement. The scale is given by the size of the target layer which is 8cm in diameter.

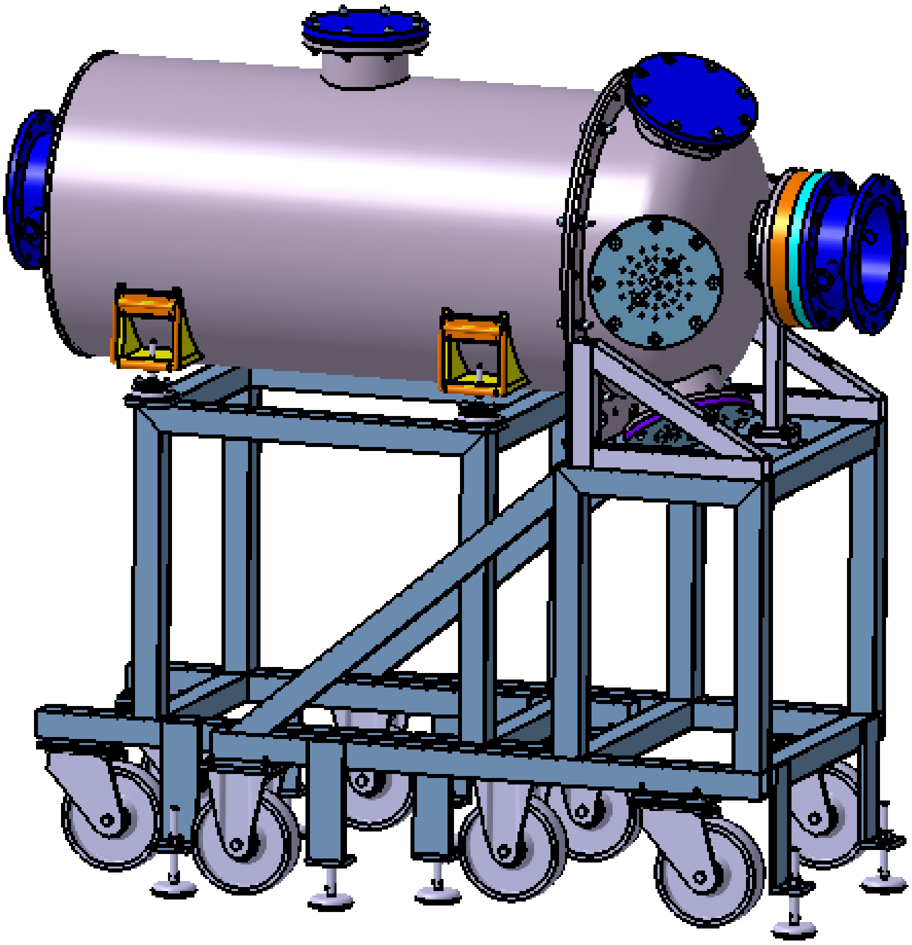


Figure 4: Reaction/detection chamber. The length is 160 cm and the diameter 77 cm

Beam request

We estimate the counting rate by defining an energy binning of 0.01 in energy log scale, corresponding to increments of 2.3% (0.23 MeV at 10 MeV). Figure 5 shows the expected counting rate expected for a ^{237}Np target and a ^{232}Th target, assuming a total efficiency of 0.3 for an average current of 8 μA (1 burst over 600). The total counting rates, integrated over energy, are 8 and 2 counts/s respectively.

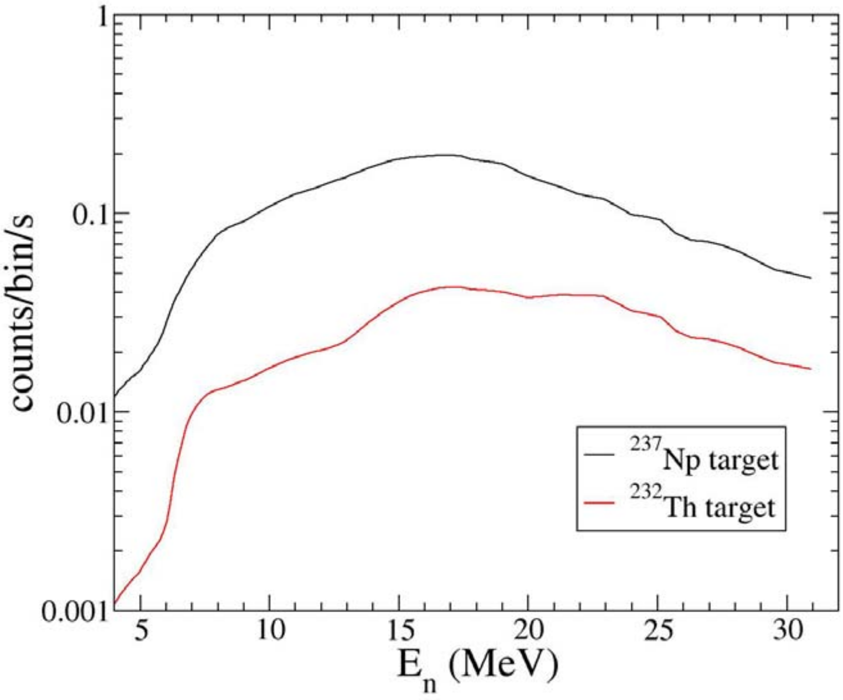


Figure 5: Counting rate per bin including efficiency

A good determination of angular distributions can be obtained by dividing the (cosθ,φ) plane into 20x20 cells with at least 100 counts per cell (40000 for the total angular distribution). In the case of ^{237}Np (2 targets) this can be achieved in 1 month for all bins of the energy domain and a total number of counts of 4 10^7 would be recorded. In the case of ^{232}Th (3 targets) the total number of counts would be 1.5 10^7, and the above specified good conditions would hold beyond 6 MeV.

References

[1] Tutin et al., NIM A457 (2001) 646