HORIZON 2020

HORIZON 2020 RESEARCH AND INNOVATION FRAMEWORK PROGRAMME OF THE EUROPEAN ATOMIC ENERGY COMMUNITY

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Introduction

BELEN (BEta-deLayEd Neutron detector) is a detector-design aiming at measuring beta-delayed neutrons emission probabilities of nuclides of interest in nuclear technology and nuclear physics.

In a very simplistic way, it consists in a set of rings made of thermal neutron detectors (He-3) embedded in a High-Density Polyethylene (moderator) matrix. All BELEN versions have been used with a digital electronic trigger-less data acquisition system (Gasific).

So far, the BELEN concept has been used in several experimental campaigns at GSI[1], JYFL[2], and RIKEN[3]. In all cases the main design criteria have been a) attain the largest neutron detection efficiency compatible with, b) a flat energy-response in a predefine range of neutron energies.

Neutron spectrometry

A wide-spread technique for neutron energy measurement is the so called "Bonner spheres spectrometer". It consists in a set of polyethylene spheres of different diameters with a thermal neutron detector in their center. Due to the different moderator depths, each sphere is sensitive to a different neutron energy range. Sets of 5-14 spheres of different diameter are usually used to determine the energy spectrum of neutron fields up to a few hundreds of MeV.

As a first approximation, each ring of BELEN can be considered as equivalent to a Bonner sphere. Therefore, one would expect to extract spectrometric information from BELEN.

BRIKEN neutron energy sensitivity

BELEN for RIKEN (BRIKEN) is the most advanced beta-delayed neutron detector built so far. It is being used in a long-lasting experimental campaign at RIKEN. BRIKEN is made of 140 He-3 detectors embedded in polyethylene using a seven-ring geometry (see Figure 1).

Several radionuclides and a neutron source where used for testing the neutron energy sensitivity per ring. These nuclides were selected due to the differences in their neutron energy spectrum (see Table 1).

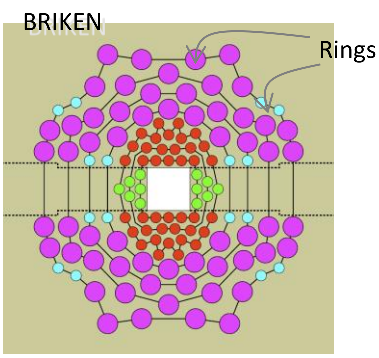

Figure 1. BRIKEN detector geometry

Nuclide	$Q_{\beta 1}$, MeV	Mean Energy, MeV
Ge-85	4.66	0.69
Cu-77	5.61	0.79
Cu-78	6.22	0.80
Ga-83	8.09	1.01
Cf-252	-	2.13

Table 1. BRIKEN. Magnitudes of neutron spectra of selected nuclides

Each ring has a different response to the neutron spectrum's mean and end-point (~$Q_{\beta 1}$) energies (see Figure 2). Rings are ordered using its radius, ring number 1 Is the one located closest to the center of the

[1] GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

[2] Accelerator Laboratory, University of Jyväskylä, Finland

[3] Radioactive Isotope Beam Factory (RIBF), Nishina Center for Accelerator-Based Science, Wako, Japan

detector). One can conclude that, even though BRIKEN has not been designed with spectrometric response in mind, it shows sensitivity to the neutron energy spectrum.

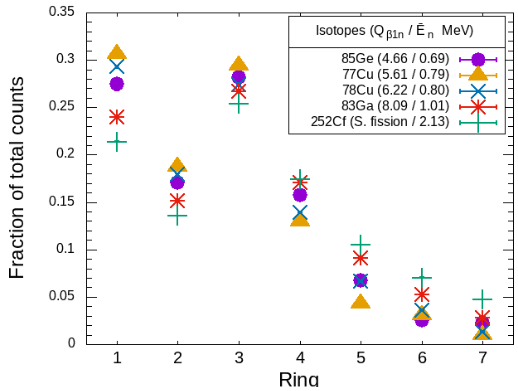

Figure 2. BRIKEN energy sensitivity per ring for selected radionuclides

BELEN design with spectrometric capacity

In order to design a new version of BELEN with spectrometric response, a basic criterium was imposed: attain a neutron detection efficiency of at least 50% for energies up to 5 MeV using the minimum number He-3 tubes.

Based on previous experiences, we have used He-3 tubes of 60 cm length, 2.54 cm diameter and a pressure of 8 atm. Additionally, the polyethylene matrix was set to have a cross-section of 90x90 cm^2 with a central hole of a radius of 4.5 cm.

A new BELEN design, BELEN-62, was made using sixty-two He-3 detectors distributed in six rings (See Figure 3 and Table 2).

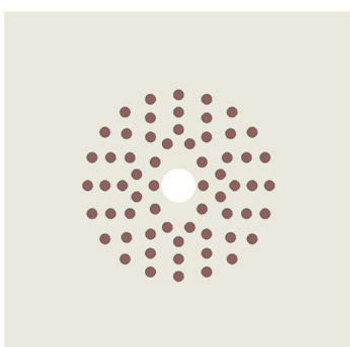

Figure 3. BELEN-62 detector geometry

Ring	Tubes	R, cm
1	2	6.38
2	4	8.58
3	8	11.20
4	12	14.50
5	16	19.00
6	20	23.50

Table 2. BELEN-62 rings properties

A set of selected radionuclides and a neutron source (see Table 2) were used to test energy response of the new design. The energy spectra of each radionuclide were taken from ENDF. The Manhart evaluation was used for the Cf-252 neutron source. The detector response was obtained using Geant4.

The new design presents a good energy sensitivity per ring (see Figure 5).

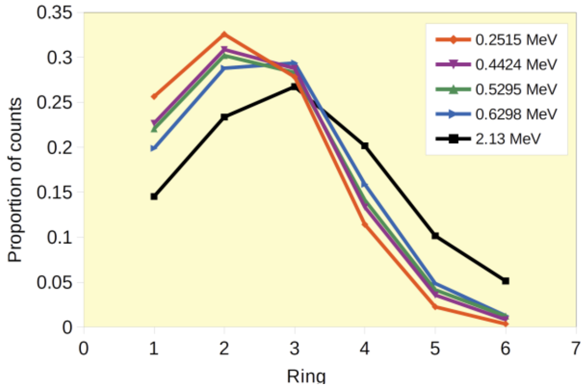

Figure 4. BELEN-62 energy sensitivity per ring for selected radionuclides

Nuclide	$Q_{\beta n}$, MeV	<E>, MeV
Cf-252	---	2.13
Br-88	1.922	0.2515
Rb-94	3.452	0.4424
Rb-95	4.883	0.5295
I-137	2.001	0.6298

Table 2. BELEN-62. Neutron spectrum magnitudes of selected nuclides

An iterative unfolding method was used to obtain the “measured” spectra. As initial guesses, a Maxwellian spectrum was used for Cf-252, while for the beta-delayed neutron emitters a simple constant beta-strength was used to generate the neutron energy spectra.

A good agreement is found between the unfolded spectra and the expected ones (see Figures 5 to 9, and Table 3).

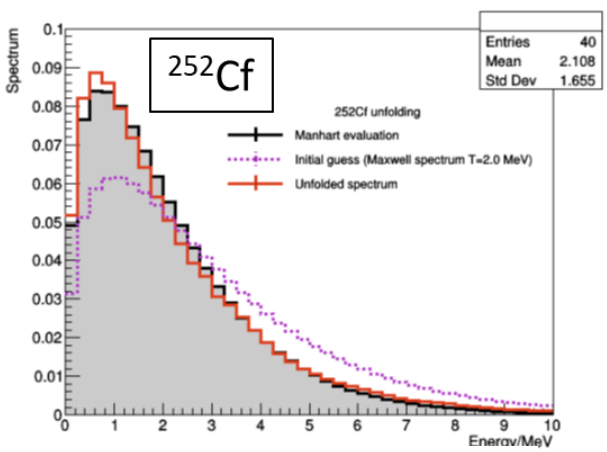

Figure 5. BELEN-62. Cf-252 spectrum

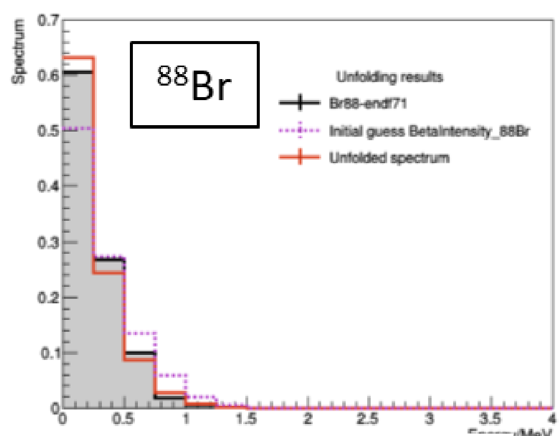

Figure 6. BELEN-62. Br-88 unfolded spectrum

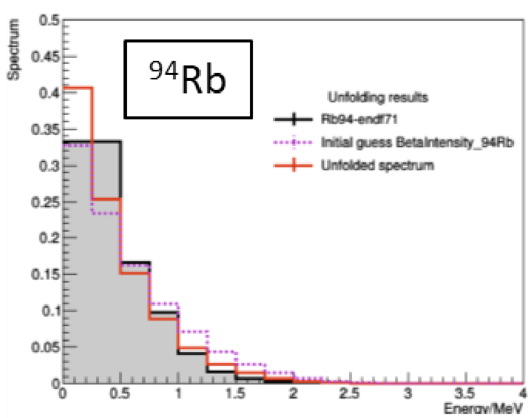

Figure 7. BELEN-62. Rb-94 unfolded spectrum

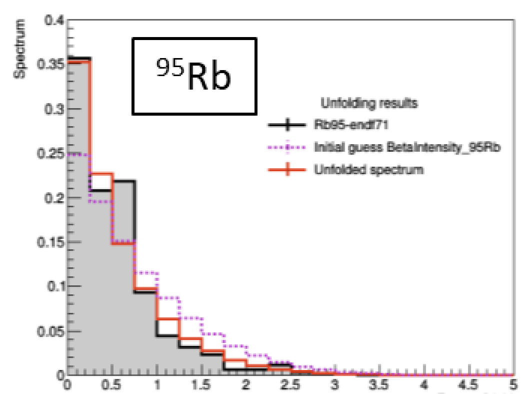

Figure 8. BELEN-62. Rb-94 unfolded spectrum

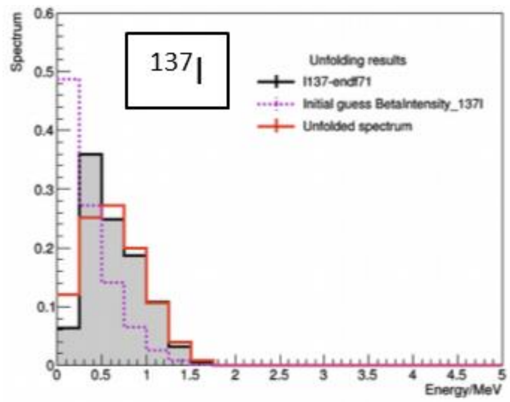

Figure 9. BELEN-62. I-137 unfolded spectrum

Nuclide	Ratio <E>
Cf-252	1.019
Br-88	1.033
Rb-94	1.032
Rb-95	1.091
I-137	1.023

Table 3. Ratio of expected to unfolded mean energies

Concluding remarks

A new design of BELEN with neutron spectrometric capabilities has been achieved.

The unfolded spectra are a good smoothed representation of the expected ones.

Further investigation are ongoing in order to optimize neutron detection efficiencies and spectrometric response.