NEUTRON MONITORS FOR HIGH ENERGY ACCELERATORS

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Abstract

Thermal neutron counters inside moderating shell are used widely at high energy accelerators. Response of these detectors to neutrons of different energy depends on material, size and shape of moderator. Radiators and absorbers can also modify this response significantly. The main application of counters in moderators is neutron dosimetry. Some dedicated sets of these detectors (Bonner spheres) are even used sometimes to estimate neutron spectra. Monitoring of fast neutrons at modern accelerator and experimental facilities is very important to keep radiation damage of electronic components under control.

One more step towards fast neutron measurements with thermal neutron counters in moderators is reported here. A set of neutron transport simulations is done to optimize moderator/radiator/absorber assemblies for higher sensitivity to neutrons with energies above 100 keV along with much lower sensitivity at lower energies. The resulting pair of the main and complementary monitors is designed.

INTRODUCTION

Early neutron detectors based on thermal neutron counters surrounded by moderators and radiators can be found in physics of cosmic rays [1]. Further a lot of attention was paid to the energy response of these detectors and therefore to the moderator shape and size. The famous neutron spectrometer [2] consisted of a set of spherical moderators with different diameters providing a set of different energy response functions. Adjusting the energy response of a single detector to the energy dependence of the dose equivalent let to use this detector as a neutron dosemeter [3]. Since that time many tens of developments and improvements of the Bonner spectrometer and the Andersson-Braun dosemeter have been published. This type of neutron dosemeters is used at high energy accelerators worldwide.

Enclosures of modern accelerator facilities contain a very large amount of complicated and expensive electronic equipment. Radiation monitoring is necessary there to evaluate performance degradation of electronics under irradiation [4].

Neutron component of radiation fields in these enclosures dominates in most cases. Neutron energy spectra stretch from the thermal region to high energies of a few GeV. Fast neutrons with energy above 100 keV are known to be responsible for the radiation damage of electronic components. Measurement of fast neutron fluences can add significantly to the existing radiation monitoring. Neutron counters in moderators with the specially adjusted energy response functions can be used for this goal.

Such a monitor must not be too large (say the overall dimension less than 30 cm) or too heavy (say the weight below 20 kg). Along with that its response curve must be significantly lower at energies below 100 keV than at higher energies. Figure 1 from [5] gives a detailed view of the response functions in a wide range of moderator sizes. The response curves of the type we need are observed for the 8 inch and larger spheres. In other words the moderator thickness must be greater than 7 cm.

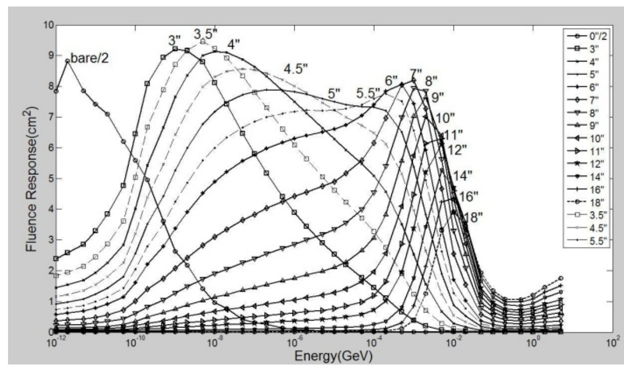

Figure 1: Borrowed from [5]: Energy response functions of Bonner spheres with different diameters. The bare counter diameter is equal to 2 inches.

DETECTOR CONFIGURATION

The thermal neutron counter SNM-14 combines a relatively high sensitivity with reasonable dimensions. Mechanically it is a 154 mm high thin-walled tube with the 18.5 mm outer diameter. These dimensions suggest the shape of the detector as an assembly of cylindrical layers of moderator, absorber and radiator around the counter.

A set of preliminary simulations of the response function was done varying the layers thickness. The materials of the moderator, radiator and absorber were polypropylene (CH_2), lead (Pb) and cadmium (Cd) respectively. The well-known code systems MARS [6] and FLUKA [7] were used for the simulations. More or less acceptable configuration of the detector has been found but the sensitivity to low energy neutrons remained non-negligible.

Most likely a single detector of the reasonable size and weight cannot solve the problem of the low energy tail considerably. A pair of detectors can be more efficient provided the response curve of the second (complementary) detector will be close to the response curve of the main detector below 100 keV and much lower at higher energies. Another set of simulations allowed finding the

ISBN 978-3-95450-197-7

configuration of the complementary detector with the same outer dimensions as the main one. Both configurations are shown in Fig. 2. The complementary detector does not contain any radiator and the moderator material is polystyrene (CH). The weights of the main and complementary detectors were estimated roughly as 16.5 kg and 8.5 kg respectively. Both configurations were found reasonable for the further mechanical design and computer simulations of their response functions.

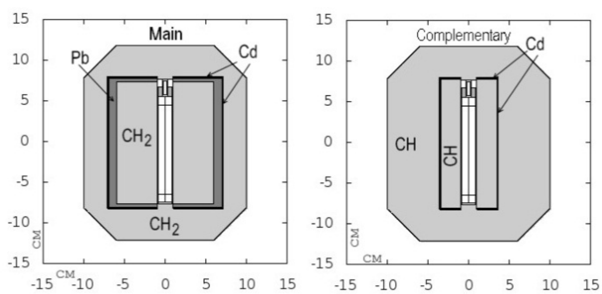

Figure 2: Transverse cross-sections of the main and complementary detectors. Thermal neutron counter SNM-14 is shown schematically in the central area of each cross-section.

RESPONSE FUNCTIONS

The basic set of simulations was done to define the energy response functions of both detectors. Each function consisted of 36 points in the energy range from 0.06 eV to 1 GeV. In addition the response of each of the two detectors to neutrons of the Pu-α-Be isotopic source was simulated for the normalization purposes.

Results of MARS and FLUKA simulations are compared in Fig. 3 for the case of normal lateral incidence of a wide unidirectional beam. The two codes agree very

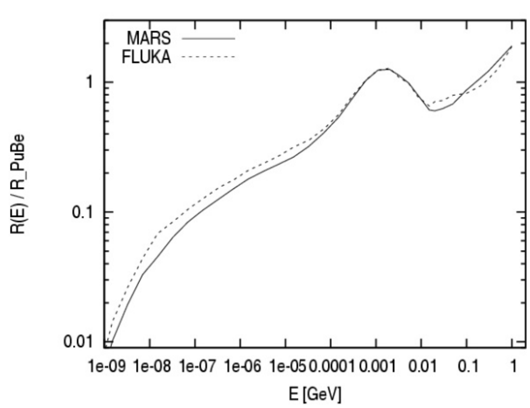

Figure 3: Energy response function of the main detector resulting from simulations by MARS and FLUKA codes.

well despite of their very different systems of neutron constants: 28 energy groups in MARS and 260 groups in FLUKA. It is seen that the response to slow neutrons is significantly lower than to the fast ones but this low energy tail is not negligible. The softer will be the neutron spectrum the larger will be the overestimation of the fast neutron fluence by the main detector. In practice unidirectional wide beam conditions occur mostly at a relatively large distance from a single small sized isotropic source. Neutron fields in the enclosures of the accelerator facilities are rather omnidirectional. The response functions of both the main and complementary detectors in the case of omnidirectional incidence are shown in Fig. 4.

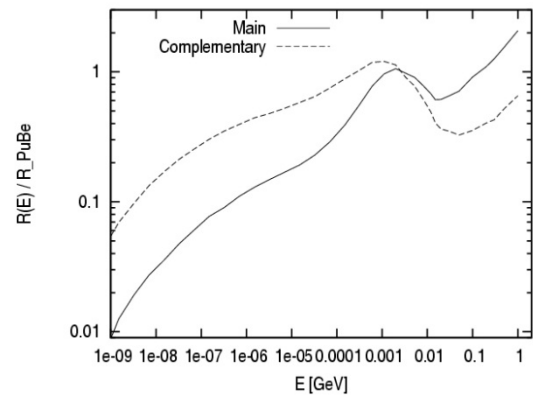

Figure 4: Energy response functions of the main and complementary detectors simulated by MARS. Each curve has its own Pu-α-Be normalization.

If these curves had one and the same normalization they would be almost identical at the energies below several tens of keV. This means that the difference between the responses of the main and complementary detectors will be almost free of the low energy contribution. The difference between the two properly normalized response functions along with the response function of the main detector is shown in Fig. 5. Obviously this difference curve does not make any practical sense. It just demonstrates the advantage of our pair of the main and complementary detectors for the fast neutrons measurements.

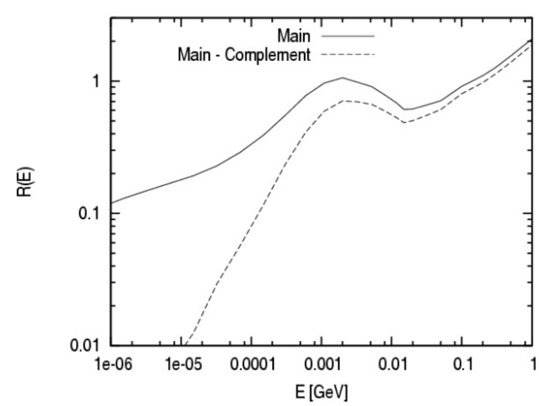

Figure 5: The solid curve is the energy response function of the main detector. The dashed curve represents the difference between the main and complementary response functions normalized both to the Pu-α-Be response of the main detector.

ISBN 978-3-95450-197-7

PROTOTYPING

The work on the detectors mechanical design and on the on-board electronics was carried out along with the response functions simulations. The on-board electronic unit includes the power converter, the signal amplifier and the signal amplitude discriminator. Both the detector and electronics box have 1.5 mm thick aluminium outer shells. These shells provide mechanical stability and electromagnetic screening of the detectors. The first pair of the prototype detectors has been manufactured recently. Figure 6 shows their appearance.

Figure 6: The first prototypes of the main and complementary detectors. Both have the same outer layout. The main detector on the photo is supplied with the removable handle.

The electronic box on the top and the support on the bottom of each detector are clearly seen. The overall weight of the main and complementary detectors without the removable handle is 17.2 kg and 9.1 kg respectively.

Some preliminary measurements have been done very recently with the low intensity Am-α-Be isotopic source which spectrum is very close to the spectrum of Pu-α-Be source. The resulting sensitivities to the source neutrons are estimated as approximately one count per unit of fluence for the main detector and approximately one count per three units of fluence for the complementary detector.

CONCLUSION

Two monitors of fast neutrons have been configured, optimized and designed. The first prototypes have been manufactured. The main monitor can be used to estimate the fluence of fast neutrons with some not too large but unknown overestimation. This overestimation can be corrected with use of the complementary monitor. The work on the monitors calibration and their readings interpretation in the various radiation fields of high energy accelerators is planned for the closest future.

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ISBN 978-3-95450-197-7