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General use of low-dimensional moderators in neutron sources

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Abstract.

The European Spallation Source (ESS) will use low-dimensional moderators for cold and thermal neutron production. Low-dimensional moderators deliver higher slow neutron brightness compared to conventional volume moderators. The concepts developed at ESS could be used in reactors and compact neutron sources to reach large increases in neutron flux to the experiments, compared to common practice. For reactors, the smaller volume of the moderators allows positioning them at the optimum flux region. For compact neutron sources, the reduced heat deposition and lower radiation environment allows for particularly efficient implementation of the ESS concepts. Using tube moderators in a compact source would allow reaching a higher brightness per unit yield at least a factor of 4, with respect to a spallation source.

1. Introduction

High-brightness low-dimensional moderators are the baseline choice at the European Spallation Source [1, 2, 3, 4]. The figure of merit used in the design of the neutron moderators was the brightness of the source. Compared to conventional volume moderators, low-dimensional moderators have higher brightness; by carefully designing the optics system for neutron transport, this will usually result in large gains in flux at samples [5].

One of the reasons for the higher brightness of low-dimensional moderators is the fact that thermal neutrons are effectively moderated in about 1 cm of liquid hydrogen; the optimal thickness of a moderator is of the same order [3]. Another key aspect is the directionality of neutron emission of low-dimensional moderators, which can be flat (quasi 2D) or tube (quasi 1D) shaped: in such moderators, neutrons that are not going in the "right" direction along the moderator walls have a chance to be scattered back into the flat or tube moderator and have a second possibility to exit the moderator. This works particularly well in a tube moderator because of the long extension of the tube, comparable to the mean free path of cold neutrons in pure parahydrogen, which is about 10 cm. Therefore, while low-dimensional moderators can be made of any hydrogenous material, they work particularly well if pure parahydrogen is used, due to the moderator-shape determined directionality of the cold neutron escape in this particular case. Other aspects that contribute to the increased brightness of low-dimensional moderators are: *i*) the lower parasitic neutron absorption from the hydrogen itself, due to the lower amount of moderator material used; *ii*) the fact that less reflector material is removed; *iii*) the closer

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position of the moderator to the target. The latter aspect can be of particular interest for compact sources.

Besides the use of low-dimensional moderators for ESS, in Ref. [2] we suggested the application of low-dimensional moderators at reactors, and suggested in this case the possible use of tube moderators. Beam extraction channels at reactors are commonly spread over a small angular range, which is the ideal application for the very directional tube moderators. Moreover, the compact size of these moderators, with respect to the large D_2 moderators, allows for placing them in the position of maximum thermal flux in the reflector. Tube moderators are also considered for the Jülich high-brilliance neutron source project [6].

In this paper we focus on applications of low-dimensional moderators to compact sources, giving some examples of possible configurations.

2. Application to compact sources

2.1. Possible configurations

Low-energy proton and deuteron beams can be used for fast neutron production in compact sources. For energies below about 30 MeV, proton and deuteron reactions in lithium and beryllium are the most efficient for neutron production [7]. Compared to spallation, these reactions are much less efficient, with yields per accelerated particle of the order of 10^{-2} n/p compared to typical yields achieved in spallation sources, of 30 n/p or more. Of course, with up to 3 orders of magnitude difference in particle energies, there is much less difference between yields per unit beam energy. Despite this large difference in neutron production, compact sources are of interest for reasons of cost; the lower energy of the proton beam minimizes the activation of the target system, and lowers the shielding and cooling requirements. The cost per useful slow neutron produced is optimal for high power spallation sources, in particular for ESS. The low facility costs make compact sources attractive for a host of applications which only require moderate neutron beam flux. The reduced sizes of the targets and incoming beams in compact sources are expected to add more flexibility to the design of the target-moderator-reflector system with respect to spallation sources. We considered two possible configurations using Be targets and proton beams of 13 MeV.

The first configuration is shown in Fig. 1. It consists of a two-target system, with two Be targets, 2 mm thick, 5×5 cm^2 area, cooled by a flow of water. Having two separate proton beams would allow reducing the heat load in each of the targets. Moreover, a configuration with the moderator placed between the targets, can increase the neutron flux at the moderator, with respect to a configuration with only one target and the moderator on its side. The cold moderator consists of a tube-shaped Al container filled with pure parahydrogen. It is wider at the center to allow for an increased angular range of directional emission [2] in the beam extraction channels. The length of the moderator is of 20 cm. On the side, a water moderator has been placed, which can deliver thermal neutrons, and also serve as premoderator for the cold moderator. Neutrons are extracted from the moderator faces with an area 1.5 cm wide and 3 cm high. A Be reflector surrounds the moderators.

An alternative configuration is shown in Fig. 2 [9]. In this second configuration, a proton beam is hitting the Be target from the top. The cold moderator consists of three tubes, of 3 cm height and 3 cm width, surrounding the target and forming a triangular shape. Three openings in the Be reflectors of 60° would allow providing cold beams to more beam lines than in the previous example.

2.2. Performance

The calculated neutron yield for a 2 mm thick Be target, for a 13 MeV proton beam, using MCNPX [8] with ENDF-B/VII proton libraries, is of 6.2×10^{-3} n/p.

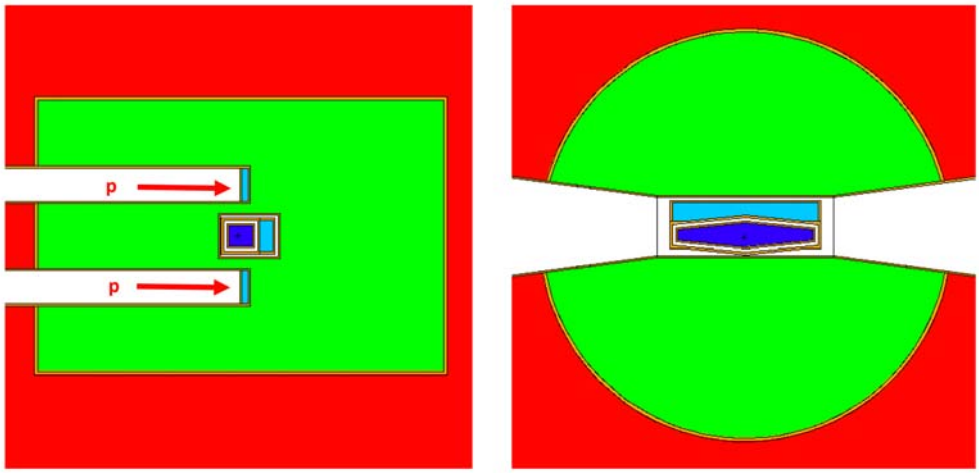

Figure 1. Geometry of the first proposed configuration of compact source using tube moderators [9]. Cold moderator (blue), and thermal moderator (light blue) are surrounded by the Be reflector (green) and outer steel reflector (red). *Left*: side view showing the two proton beam channels, with proton beams hitting the thin, water-cooled Be targets. *Right*: top view, showing cold and thermal moderators, with neutron beam extraction channels.

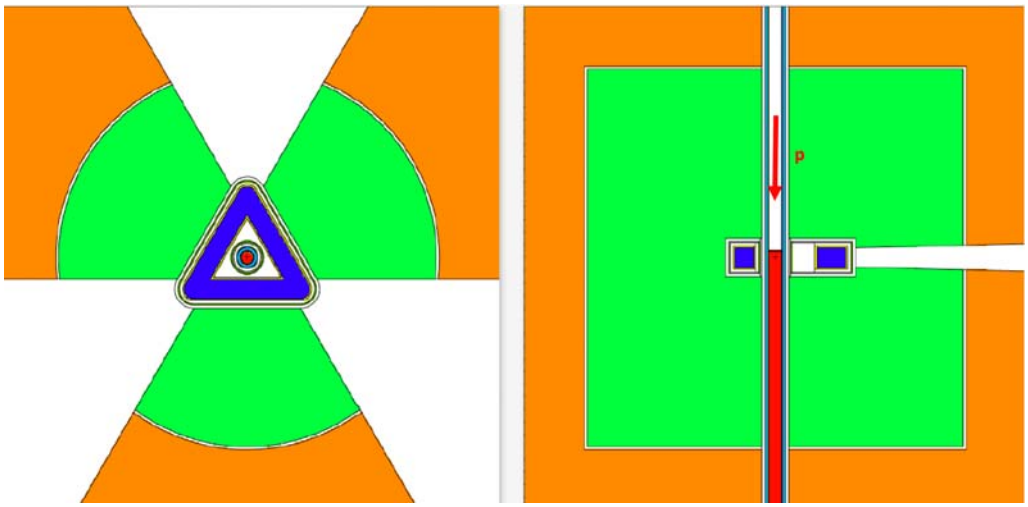

Figure 2. Geometry of the second proposed configuration of compact source using tube moderators. The cold moderator (blue) consists of three tubes filled with parahydrogen, surrounding the Be target (red). The Be reflector is in green, outer steel reflector/shielding in orange. *Left*: top view (proton beam is perpendicular to the figure), showing neutron beam extraction openings in the reflector. *Right*: side view, showing proton beam channel, with protons entering vertically from the top.

Time-average, integrated (between 0 and 5 meV) cold brightness was calculated using F5 tallies, for the configurations of Fig. 1 and 2. Only basic optimizations of the geometry were performed in this preliminary study. The cold neutron brightness delivered by both designs is

similar. For the first configuration, the integrated time-average cold brightness for 100 kW power is of about 3.2×10^{10} n/cm^2/s/sr. An integrated (between 20 meV and 100 meV) time-average thermal brightness of 3.3×10^{10} n/cm^2/s/sr was calculated for the thermal moderator.

The second configuration (Fig. 2) was ran with two different proton beam energies: 13 MeV and 40 MeV. At 13 MeV the performance is very similar to the first case. With 40 MeV protons, a time-average brightness of about 1×10^{11} n/cm^2/s/sr at 100 kW is obtained. The integrated cold brightness below 5 meV from the ILL yellow book is of 3.3×10^{12} n/cm^2/s/sr. This gives an indication that in a pulsed compact source with the same duty cycle of ESS (4%), the peak brightness could reach values comparable to high-flux research reactors.

2.3. Comparison with spallation reactions

In any neutron source, the brightness of the source (moderator) is proportional to the yield of neutrons produced by the primary reaction (e.g. spallation of protons on target, nuclear fission, proton or deuteron reaction on Li/Be targets). These reactions produce fast neutrons with rather similar center of gravity around a few MeV. Therefore, a possible figure of merit to determine how efficient is a neutron source, is the ratio between the moderator brightness and the neutron yield. The neutron yield Y of 2 GeV protons in tungsten is of about 38 n/p, according to the semi-empirical formula in [7]. The ESS brightness per proton (always integrated between 0 and 5 meV) is B=1×10^{-3} n/cm^2/s/sr/p. For a 13 MeV proton on Be, the calculated neutron yield is Y=6.2×10^{-3} n/p. The cold brightness for the model in Fig. 1 is of 6.7×10^{-7} n/cm^2/s/sr/p. Therefore, by considering as figure of merit for slow neutron production efficiency the ratio B/Y, we get a B/Y ratio four times higher in the case of the small source. This gain is probably due in part to the use of tube moderators, in part to the advantages given by the more compact geometry of a small neutron source.

3. Conclusions

We have shown two examples of application of low-dimensional moderators to compact neutron sources. The above results are preliminary, and more in-depth studies are needed for a better exploitation of the properties of these moderators to the case of compact sources. More calculations should be performed with optimization of the modelled sources, including engineering details. Nevertheless, these results indicate that low-dimensional moderators can be used at compact sources to deliver cold neutron beams, perhaps even more efficiently than at spallation sources.

References

[1] K. Batkov, A. Takibayev, L. Zanini and F. Mezei, *Unperturbed moderator brightness in pulsed neutron sources*, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 729 (2013) 500 - 505. http://dx.doi.org/10.1016/j.nima.2013.07.031.
[2] F. Mezei, L. Zanini, A. Takibayev, K. Batkov, E. Klinkby, E. Pitcher, and T. Schönfeldt, *Low dimensional neutron moderators for enhanced source brightness*, Journal of Neutron Research 17 (2014) 101 − 105.
[3] L. Zanini, K. Batkov, E. Klinkby, F. Mezei, T. Schönfeldt, and A. Takibayev, *The neutron moderators for the European Spallation Source*, these proceedings.
[4] L. Zanini, K. Andersen, K. Batkov, E. Klinkby, F. Mezei, T. Schönfeldt, and A. Takibayev, *Design of the cold and thermal neutron moderators for the European Spallation Source*, in course of publication, 2017.
[5] K. Andersen, M. Bertelsen, L. Zanini, E. Klinkby, T.Schönfeldt, P. Bentley, J. Saroun, *Optimisation of moderators and beam extraction at ESS*, in course of publication, 2017.
[6] U. Rücker, T. Cronert, J. Voigt *et al.* Eur. Phys. J. Plus (2016) 131: 19. https://doi.org/10.1140/epjp/i2016-16019-5.
[7] J. M. Carpenter, C.-K. Loong, *Elements of slow-neutron scattering*, Cambridge University Press, 2015, and references therein.
[8] D. Pelowitz, editor, MCNPX Users Manual, Version 2.7.0, Number LA-CP-11-0438, 2011.
[9] A. Takibayev, Presentation at the UCANS-VI conference, Xian, China, 2016.