European network
for developing new horizons for RIs

Project information

Project full title	European network for developing new horizons for RIs
Project acronym	EURIZON
Grant agreement no.	871072
Instrument	Research and Innovation Action (RIA)
Duration	01/02/2020 – 31/01/2024
Website	https://www.eurizon-project.eu/

Deliverable information

Deliverable no.	D3.9
Deliverabe title	Final conceptual design of the high brilliance cold source
Deliverable responsible	MTA EK
Related Work-Package/Task	WP3
Type (e.g. Report; other)	Report
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Dissemination level	Public
Document Version	1.0
Date	20.02.2024
Download page	

Document information

Version no.	Date	Author(s)	Comment
1.0	20.02.2024	A. Ioffe	

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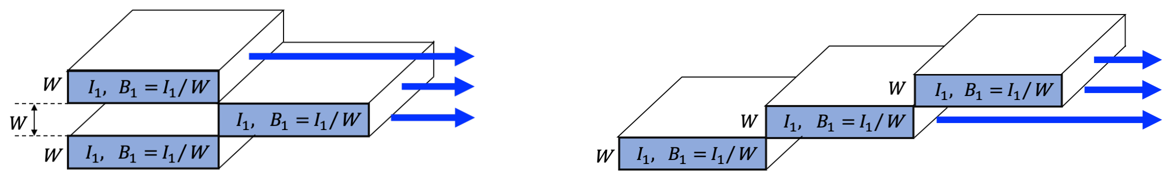
D3.9 Final conceptual design of high-brilliance cold source

We have developed a novel cold neutron source employing chess-board or staircase assemblies of high-aspect ratio rectangular para-hydrogen moderators (Figure. 1).



(a) Chessboard assembly.

(b) Staircase assembly.

Figure 1: Assemblies of narrow moderators. Blue arrows depict the outgoing cold neutron beam.

Two limiting factors for this gain are identified: the limited volume of the high-density thermal neutron region surrounding the reactor core or spallation target, which imposes constraints on the total length of the moderator assembly, and the finite width of moderator walls.

As the para-hydrogen in the moderator should be under a high pressure of around 20 bar, that is necessary for the liquefaction of H2 gas at cryogenic temperatures, the thickness of the moderator walls should be sufficient for safely operation of such moderators. One of the factors decreasing the potentially achievable assembly brightness is the finite wall thickness in each individual moderator, which causes a reduction in the effective emitting area of the assembled cold neutron source. The losses can be minimized when the horizontal walls of neighboring moderators overlap with each other, as depicted in Figure 2a. In this case, the geometrical factor of losses can be calculated as $W/(W+a)$ where a is the wall thickness. By multiplying this factor with the brightness gain dependence on the single moderator width W, we can determine the reduced brightness gain for different wall thicknesses, which is presented in Figure 2b for the moderator height of 10 cm.

While the brightness gain for a single moderator increases monotonically as its size decreases, considering the changes in wall thickness alters this dependence. For a given wall thickness, there exists a maximum achievable brightness gain, and this value increases as the walls become thinner. Consequently, using thinner walls proves to be advantageous. The intensity (the total number of emitted neutrons) delivered by a single moderator is calculated as the product of brightness and the moderator width, as shown in Figure 2b.

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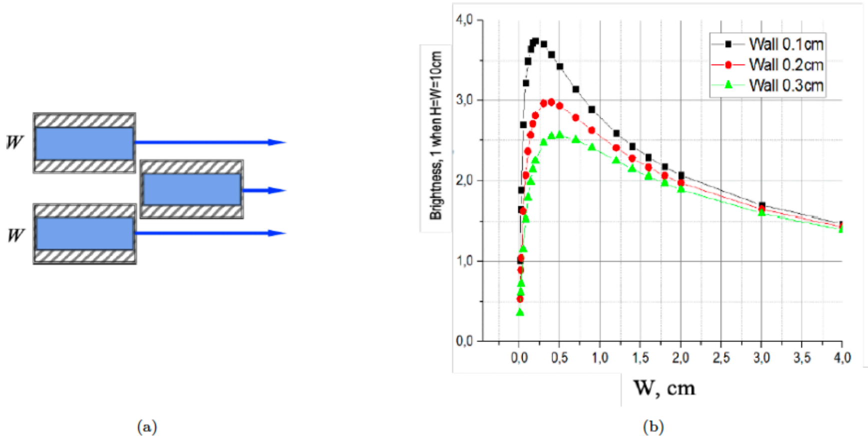

Figure. 2. (a) Overlap of horizontal walls of neighboring moderators; (b) reduced brightness gain for different moderator wall thicknesses.

Certainly, minimizing the wall thickness poses a significant challenge and engineering efforts are needed to address it. One potential approach is to manufacture the single moderator from a single aluminum piece with internal ribs as shown in *Figure 3*. These ribs serve the dual purpose of facilitating the proper flow of liquid hydrogen and acting as connectors between the large area surfaces of the moderator (approximately (10 x 15) cm^2). This design enables the desired flow characteristics while potentially reducing the wall thickness to around 1mm, thereby minimizing the impact on brilliance gain.

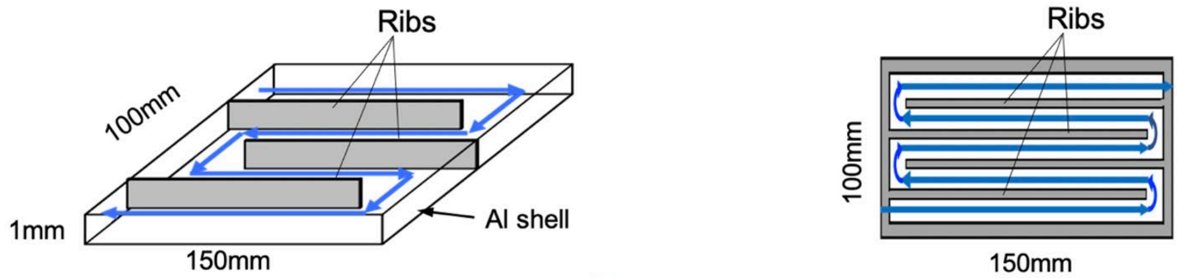

Figure 3. Conceptual drawing of thin narrow elongated cold moderator made of a single aluminum piece with vertical ribs connecting the thin upper and down large area surfaces (3-D (a) and top view (b).

Finally, the design shown in Figure 1 can generate neutron beams with higher intensity and brightness, up to approximately 2.5 times more than any para-hydrogen-based cold neutron source with an equal cold neutron beam cross-section made of a single moderator (flat or voluminous). For instance (Figure 4), the intensity gain for a 10 cm wide assembly consisting of 6 single 1.6 cm wide moderators is approximately 2.5 relative to the 10 cm wide voluminous moderator, and for a 6 cm wide assembly consisting of 4 single 1.5 cm wide moderators, the intensity gain is about 2 relative to

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the 6 cm wide voluminous moderator. Thus, such moderator assemblies provide a significant gain both in brilliance and in intensity.

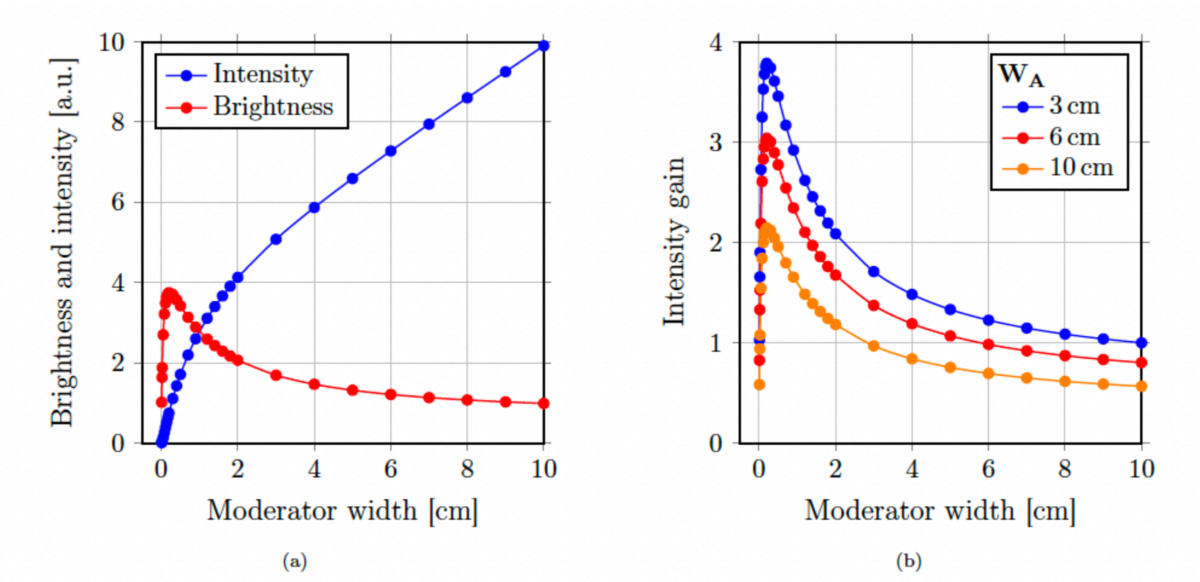

Fig. 4: (a) Brightness and intensity gains delivered by individual moderator as a function of its width; (b) Intensity gains achieved by moderator assemblies in comparison to intensity of voluminous moderators with the same width W_A, as a function of single moderator width. Solid lines are indicative.

However, it is important to note that the aforementioned brilliance gain results are obtained under the assumption of homogeneous illumination of the moderator assembly. In reality, thermal neutron flux distributions from both reactor and pulsed neutron sources follow Gaussian-like profiles with typical FWHM values of approximately 60 cm (e.g., at ILL) and 25 cm (e.g., at ESS) respectively (Figure 5). This fact imposes a limitation for the suggested moderator geometries, as the lower thermal neutron illumination at the periphery of the moderator assembly restricts its feasible overall length (Figure 5a). Because the length of each individual moderator is typically around 15 cm (as the MFP for cold neutrons is approximately 20 cm), there is a restriction on the number of individual moderators that can be used in the assembly. Consequently, this constraint results in a decrease in the potential brilliance gain that could be achieved. This limitation can be, to some degree, overcome using 'zigzag' or parallel staircase assemblies, as depicted in Figure 6. These configurations maintain the same width, *W*, for the cold neutron beam as the single staircase arrangement (see Figure 4a). However, their shorter overall length ensures a more uniform thermal flux illumination, resulting in a higher average intensity throughout the moderator assembly.

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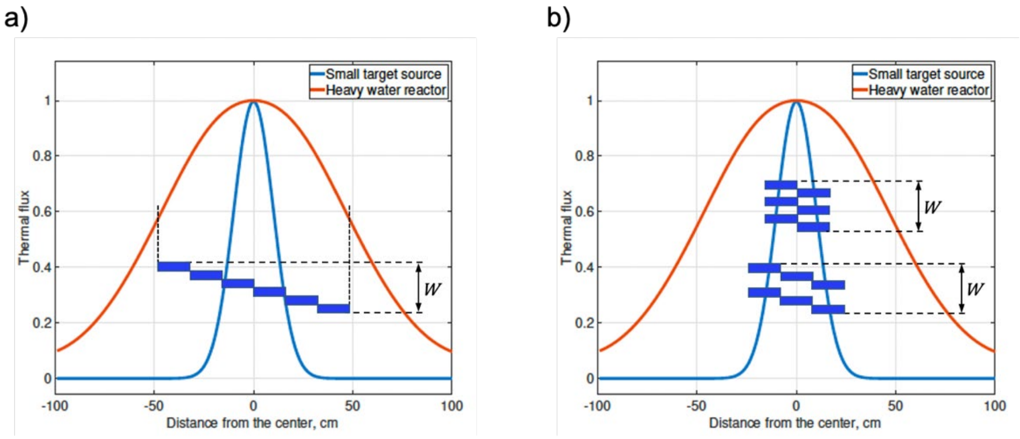

Figure 5. a) Limitations on the overall length of the staircase moderator assembly due to the typical thermal neutron flux distributions in a reactor (red curve) and pulsed neutron sources (blue curve); b) ' 'Zigzag' or parallel staircase assemblies with smaller overall length, providing a closer match to the narrow thermal neutron flux distributions.

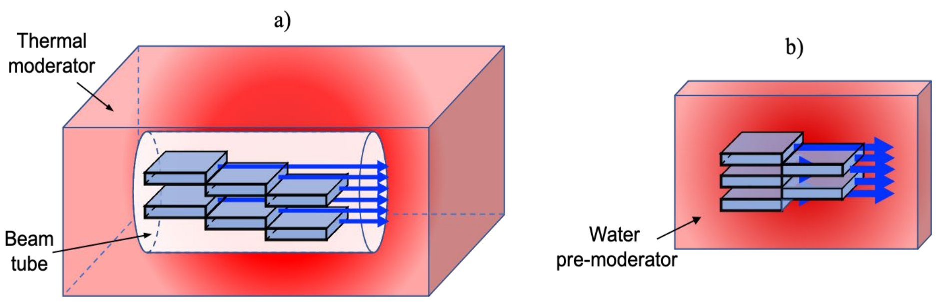

Figure 61. Cold neutron moderator assemblies in thermal moderators of reactor (a) and spallation (b) sources. The gradient coloring of the thermal moderators illustrates inhomogeneous thermal neutron field.

The choice of the width of individual moderators determines the number of moderators in an assembly of a given width and, in turn, its overall length. Decreasing the width of individual moderators increases the brightness gain of each of them, but it also reduces the thermal neutron illumination of peripheral moderators. The interplay of these factors leads to the existence of optimal conditions for each assembly. As an illustration, Figure 7 presents brightness and intensity gain plots for moderator assemblies with overall width of W_A = 10 cm placed at reactor source with inhomogeneous thermal neutron flux distribution shown by the red curve in Figure 5). The gains are calculated as the brightness of moderator assemblies normalized to the brightness of single flat moderators of the same width W_A and a length of 26 cm. Similar plots for compact/spallation sources with inhomogeneous thermal neutron flux distribution shown in Figure 8. Figure 9 presents brightness and intensity gain plots for moderator assemblies with overall width of W_A = 3 cm placed at reactor source.

It can be observed that both brightness and intensity can increase by a factor of up to 3. Notably, even relatively simple moderator assemblies composed of 4 individual moderator yield significant enhancements in brightness and intensity of about 2 times.

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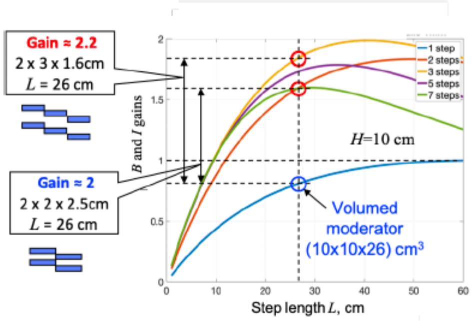
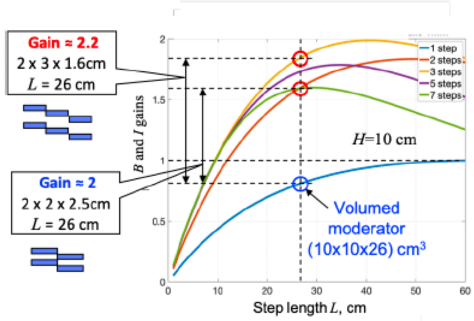
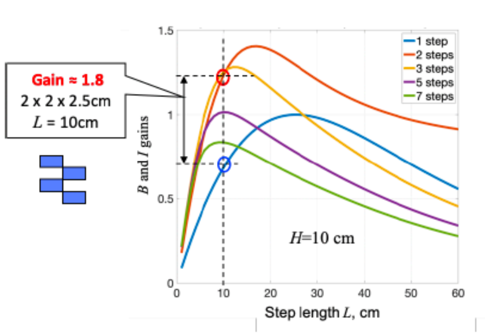


(a) Two parallel stairs configuration.

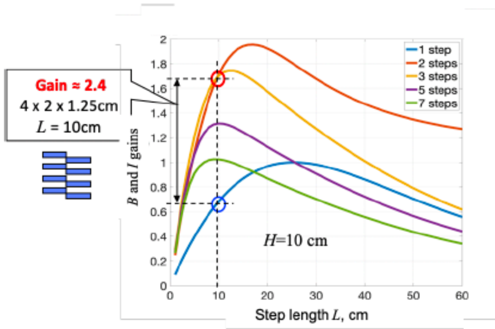


(b) Four parallel stairs configuration.

Figure 7: Brightness and intensity gain plots for various assemblies of low-dimensional moderators with total width W_A = 10 cm at reactor source.

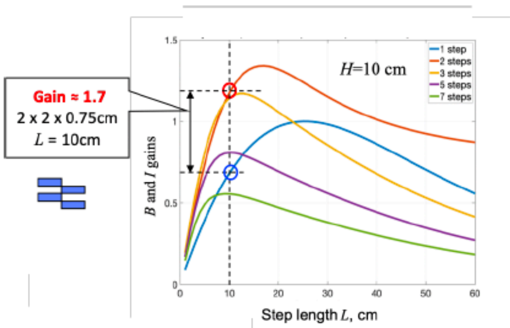


(a) Two parallel stairs configuration.

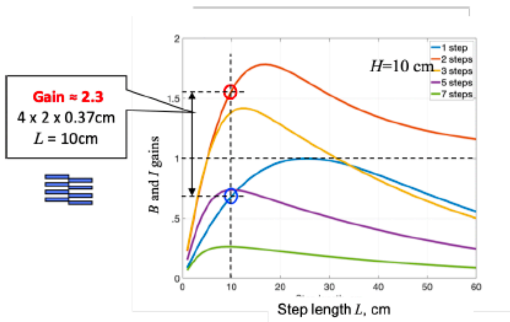


(b) Four parallel stairs configuration.

Figure 8: Brightness and intensity gain plots for various assemblies of low-dimensional moderators with total width W_A = 10 cm at spallation/compact source.



(a) Two parallel stairs configuration.



(b) Four parallel stairs configuration.

Figure 9: Brightness and intensity gain plots for various assemblies of low-dimensional moderators with total width W_A = 3 cm at reactor source.

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