JOINT INSTITUTE FOR NUCLEAR RESEARCH

Final report

START programme

Optimization of the cold neutron source (CNS) reflector material and thickness.

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Abstract

Cold Neutron Sources (CNS), with neutron flux 10^9 – 10^{10} n/cm^2.sec has a continues growing interest around the world, as it does not require a high capital and opereating cost and leaves less nuclear waste compared to nuclear reactors. CNS are promising in new fields such as material science or biology and much more. The results of neutronics calculations are presented to determine the optimal configuration of various materials that can be used as a neutronic reflector.

1. Introduction

Compact neutron sources are a modern trend in the development of research techniques using neutron scattering. A compact neutron source is understood as a low-power neutron source based on pulsed ion or electron accelerators equipped with a target, a neutron moderator and a neutron guide system that allows several neutron devices to be placed on one target. There are currently several compact neutron sources operating in the world for example SARAF, HUNS, n-ELBE, RANS, RANS, LENS and GELINA. Neutron centers are actively developing compact sources based on pulsed accelerators, which make it possible to achieve a pulsed neutron beam intensity of up to 10^{15} n/cm2.sec. The target of the compact source is equipped with moderators of various types for thermalization of the resulting neutrons, which provides, at the output of the target assembly, a flux in a beam of thermal neutrons for research in the physics of condensed matter at a level of about 10^{12} n/s.cm2. The development of compact neutron sources for condensed matter physics began at the end of the 2000s, but only a few, for example, LENS in the USA, CPHS in China, RIKEN in Japan, have reached the stage of constructing neutron stations. Three facilities have been built at LENS: small-angle neutron scattering (SANS), spin-echo SANS and neutron radiography. Two instruments (out of six announced) have been launched at the CPHS compact source in China: the SANS station and the neutron radiography installation. The RIKEN compact source operates a stress diffractometer and a neutron radiography installation.

SANS, SANS spin-echo, neutron radiography and tomography installations use a wide spectral range of the beam and a relatively low wavelength resolution (about 10%), which ensures sufficient experimental luminosity under conditions of relatively low source intensity. It is precisely because of the low intensity that the method of neutron diffraction from compact sources has not been actively developed. In world practice, there is only one neutron device - a stress diffractometer at the RANS source, which has been operating very successfully for several years. This means that the time-of-flight diffraction method can be successfully implemented on other compact neutron sources. This work discusses the concept model of a compact DARIA neutron source as an example to optimizing both the material and thickness of CNS. The source by the Monte Carlo method using the MCNP-6 software package, and the neutron data library of ENDF-6 and JEFF-3.3.

1.1 Background and concepts

1.1.1 The most common neutron sources.

1- **Fission reactors:** Light- and heavy-water research reactors are used for neutron scattering purposes. Most of them are steady state sources, but there are pulsed reactors too, such as IBR-2 at JINR, Dubna, Russian Federation, also the beam from a steady state reactor can be 'chopped' into pulses for a particular beam line for conducting calculations at certain time.

2- **Accelerator systems:** They can be steady state or pulsed too, highest flux sources are based on the spallation process, they are not widely used due to their expenses, but for lower energy accelerator systems producing neutrons they are called **Compact Accelerator based Neutron Sources (CANS),** Most accelerator systems are pulsed , for most neutron scattering techniques, neutrons with energies from the lower epithermal, thermal, or cold range are required, and their energy and wavelengths ranges are shown below in **table1.**

Table 1. Neutrons energy groups

Neutron group	Energy	Wavelength, Å
Fast	> 10 keV	$\lesssim$ 0.03
Epithermal	0.5 eV–10 keV	0.4–0.03
Hot	0.1 eV–1 eV	0.3–0.9
Thermal	< 0.5 eV	$\gtrsim$ 0.4
Cold	< 5 meV	$\gtrsim$ 4
Very cold	0.3 □eV–0.1 meV	28–50
Ultracold	$\lesssim$ 0.3 □eV	$\gtrsim$ 500

1.2 Neutron wavelength.

At neutron energies of 0.02 eV (T_n :237 K), the de Broglie wavelength of a neutron becomes comparable to the size of an atom (10-8 fm). With their longer wavelengths, cold neutrons are particularly adapted for studying ‘soft' excitations, such as those associated with gradual molecule reorientation, etc., as well as elastic neutron scattering from objects with large characteristic dimensions., neutron wavelength eq is shown below.

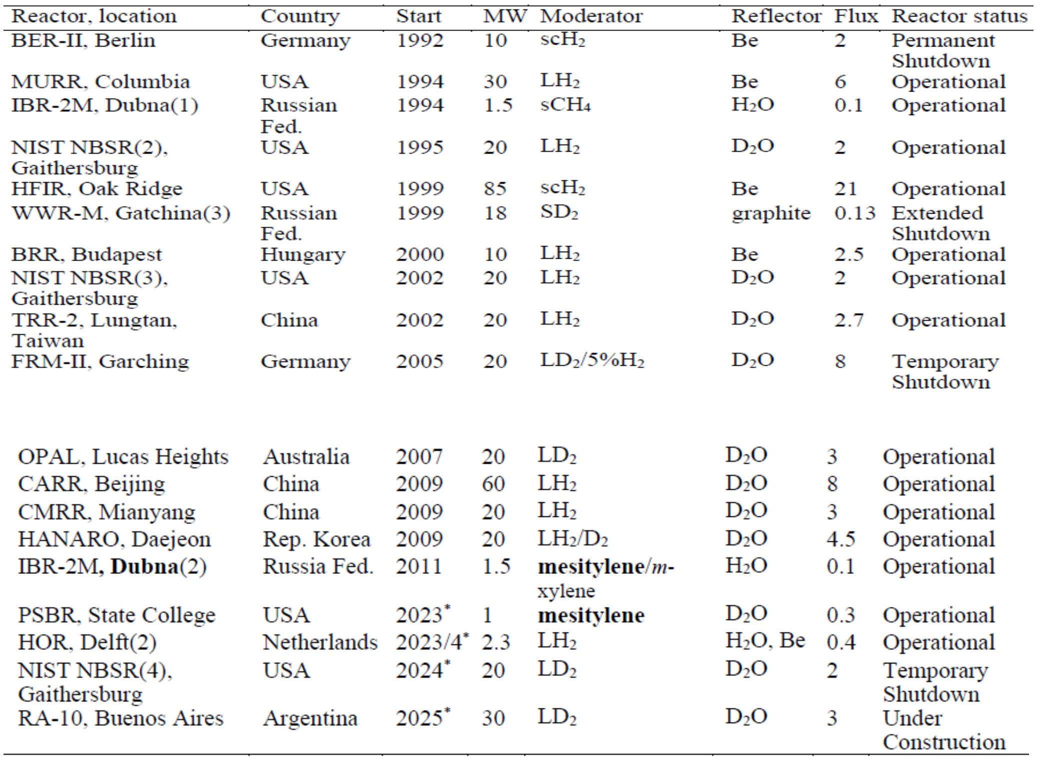
$$\lambda(\mathrm{cm}) = \frac{h}{\sqrt{m_n T_n}} = \frac{4.5 \times 10^{-10}}{\sqrt{T_{n\,(\mathrm{eV})}}}$$

2. The history of cold neutron sources and an overview

2.1. History of development

Cold neutron and hot neutron sources are called "secondary" neutron sources, while reactors and accelerators are called "primary" neutron sources. Over the past few decades ~ sixty (CNSs) have been established at various reactors and accelerators. Most of them were initially developed within steady-state reactors. During the 1960s and 70s, second-generation reactors were constructed with the dual purpose of conducting radiation research and research involving cold neutron beams. The 1980s marked a significant period of growth in CNS development, primarily driven by the introduction of third-generation reactors and the utilization of accelerators for neutron beam research The subsequent decline in the production of Cold Neutron Sources (CNSs) during the 1990s and the first decade of the new century can be attributed to several factors such as the rate of commissioning new reactors was slower compared to the rate of decommissioning old-ones.

table 2. historical list of cold neutron sources at research reactors



Reactor, location	Country	Start	MW	Moderator	Reflector	Flux	Reactor status
BER-II, Berlin	Germany	1992	10	scH_2	Be	2	Permanent Shutdown
MURR, Columbia	USA	1994	30	LH_2	Be	6	Operational
IBR-2M, Dubna(1)	Russian Fed.	1994	1.5	sCH_4	H_2O	0.1	Operational
NIST NBSR(2), Gaithersburg	USA	1995	20	LH_2	D_2O	2	Operational
HFIR, Oak Ridge	USA	1999	85	scH_2	Be	21	Operational
WWR-M, Gatchina(3)	Russian Fed.	1999	18	SD_2	graphite	0.13	Extended Shutdown
BRR, Budapest	Hungary	2000	10	LH_2	Be	2.5	Operational
NIST NBSR(3), Gaithersburg	USA	2002	20	LH_2	D_2O	2	Operational
TRR-2, Lungtan, Taiwan	China	2002	20	LH_2	D_2O	2.7	Operational
FRM-II, Garching	Germany	2005	20	$LD_2/5\%H_2$	D_2O	8	Temporary Shutdown
OPAL, Lucas Heights	Australia	2007	20	LD_2	D_2O	3	Operational
CARR, Beijing	China	2009	60	LH_2	D_2O	8	Operational
CMRR, Mianyang	China	2009	20	LH_2	D_2O	3	Operational
HANARO, Daejeon	Rep. Korea	2009	20	LH_2/D_2	D_2O	4.5	Operational
IBR-2M**, Dubna**(2)	Russia Fed.	2011	1.5	**mesitylene**/*m*-xylene	H_2O	0.1	Operational
PSBR, State College	USA	2023*	1	**mesitylene**	D_2O	0.3	Operational
HOR, Delft(2)	Netherlands	2023/4*	2.3	LH_2	H_2O, Be	0.4	Operational
NIST NBSR(4), Gaithersburg	USA	2024*	20	LD_2	D_2O	2	Temporary Shutdown
RA-10, Buenos Aires	Argentina	2025*	30	LD_2	D_2O	3	Under Construction

3. Moderator material

Effective moderator materials for Cold Neutron Sources (CNSs) require specific characteristics, including a high hydrogen (H or D) content and a substantial vibrational density of states within the molecular excitations of the compound. These features should fall within the energy range suitable for efficiently transferring kinetic energy from incoming neutrons to the moderator material, leading to lowering the neutron temperatures to the levels required.

3.1 The ideal moderator properties

A significant scattering cross-section**,** minimal absorption cross-section, and a low boiling point (approximately 20.4 K at atmospheric pressure)**.** These materials encompass liquid hydrogen and deuterium, especially in high-power research reactors, solid or liquid hydrocarbons, are used in accelerators and lower-powered research reactors, and when selecting a moderator material, it's crucial to potential consequences of radiation exposure.

The moderating efficiency: average loss of neutron energy per unit length.

At lower neutron energy the cross sections become less dependent on the moderator material's and more responsive to the material's structure (such as through neutron diffraction and small angle scattering). The 'density of states' of low-energy excitations becomes crucial in determining cold moderator efficiency.

- Very cold and ultracold neutrons have extremely short wavelengths, very cold neutrons have the ability to see through distinct groupings of atoms and their aggregates.
- Cold neutrons increase in size in proportion to these oscillations.
- Ultra-cold neutrons are the name given to the slowest neutrons
- Ultracold neutrons experience mirror reflection at any angle of incidence from the surfaces of a medium with a positive scattering amplitude due to the wavelengths corresponding to these energies are larger than the critical wavelength for total reflection

3.2 Liquid hydrogen and liquid deuterium moderators

Hydrogen and deuterium have a clear advantage over hydrocarbon moderators because they are less likely to polymerization caused by radiolysis. However, to achieve the most efficient neutron source, hydrogen (deuterium) molecule exists in two distinct nuclear spin isomers, as shown at **Fig1.** These isomers exhibit significant variations as one of these isomers, known as "para (p-)," corresponds to the spin-0 singlet state ($1/\sqrt{2}(|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle)$). The other isomer, termed "ortho (o-)," represents the spin-1 triplet state ($|\uparrow\downarrow\rangle$, $|\downarrow\uparrow\rangle$, $1/\sqrt{2}(|\uparrow\downarrow\rangle + |\downarrow\uparrow\rangle)$). A notable energy difference of **14.7 meV**, equivalent to approximately 170 K, distinguishes these two isomers within hydrogen

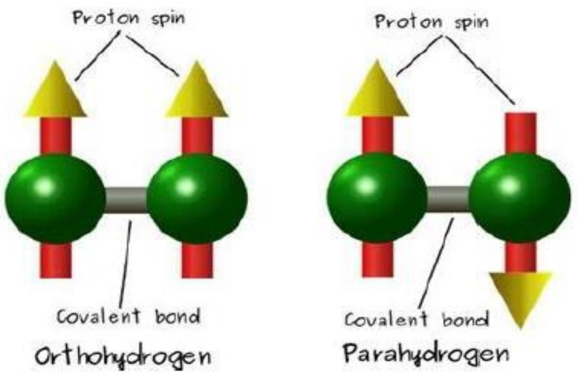


Fig.1 Spin isomer of molecular hydrogen

3.2.1 O-H and P-H cross sections.

At neutron energies above **0.1 eV,** the cross-sections for both isomers are nearly identical as shown at **Fig.2.** However, when neutron energy drops below 0.1 eV, the cross-section for parahydrogen experiences a sharp decline, while for ortho-hydrogen continues to increase. This distinctive **"filter-like"** behavior in the cross-section of parahydrogen, characterized by a substantial cross-section for fast-incoming neutrons and a smaller cross-section for already moderated neutrons, is highly advantageous.

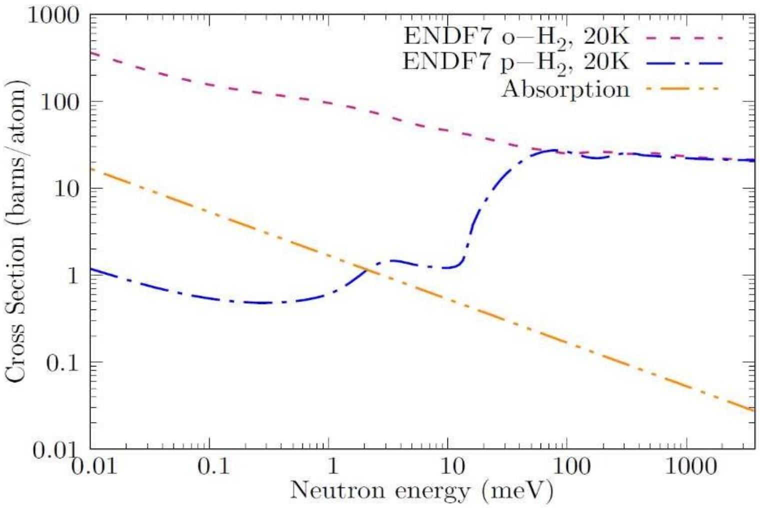


FIG. 2. Scattering and absorption cross sections for o- and p-H2 at 20K

Given the last points discussed, parahydrogen is the preferred choice for a moderator as it enables the construction of "low-dimensional" moderators, once an incoming neutron is moderated to the cold energy range it can easily traverse the moderator and exit it (emerge) with minimal risk of being "up-scattered" to higher energies, but with taking into consideration that this choice does introduce other effects, including non-isotropic emission and spectra that deviate from the Maxwellian distribution.

The effect of temperature:

- At room temperature, the distribution of hydrogen isomers tends to approach a ratio of 25% para (p-) and 75% ortho (o-).
- Temperatures decrease significantly below 170 K, as is common in liquid H moderators, the equilibrium distribution shifts towards 100% **parahydrogen**, which has notable implications for liquid hydrogen cold moderators.

Hydrogen (deuterium) molecules exhibit distinct spin isomers with contrasting properties, and at lower temperatures relevant to liquid hydrogen moderators, the para-isomer becomes the predominant form.

The initial Cold Neutron Sources (CNSs) that utilized liquid hydrogen at (RR) were disk-shaped configurations, with diameters 15 to 20 cm and thicknesses between 5 and 7 cm. These CNSs were positioned within the radial or tangential channels of the reactor's reflector.At modern CNSs, achieving a very **high proportion of p-hydrogen** has become crucial in addition to hydrogen, liquid deuterium serves as an effective moderator for Cold Neutron Sources (CNSs). at **Fig. 3,** the scattering cross-section for liquid para- and ortho-deuterium is displayed, revealing a behavior similar to that observed in hydrogen, for neutron energies below 3 meV, there is a sharp decline in the scattering cross-section when deuterium is the moderator material.

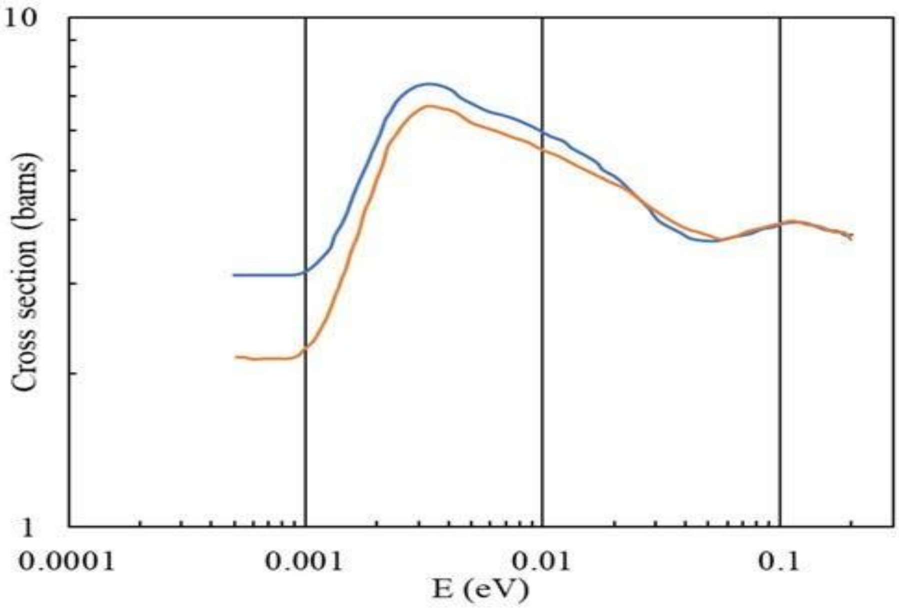


FIG. 3. Scattering cross section for liquid p-deuterium (orange) and liquid o-deuterium (blue) at 19K.

Liquid hydrogen and liquid/solid deuterium are the preferred moderator materials for over 90% of Cold Neutron Sources (CNS) in steady-state research reactors, but some few reactors deviate from this and use hydrocarbon moderators like liquid propane (C3H8) or mesitylene (C9H12). This limitation underscores the significance of solid **mesitylene** as a CNS moderator material, especially in pulsed reactors like IBR-2 in **Dubna**, Russian Federation. The relatively high melting point of mesitylene (228 K) allows for the adjustment of the temperature inside the moderating chamber, ranging from 20 K to 150 K. This temperature tuning capability enables the fine-tuning of the neutron spectrum, allowing it to shift from shorter to longer wavelengths and back. Mesitylene moderators also offer high neutron intensity, and their radiation resistance can be further improved when a mixture of **mesitylene and m-xylene** in a 3:1 proportion is utilized. A significant drawback of liquid hydrogen moderators is their relatively low proton density.

3.2.2 Deuterium

Deuterium possesses favorable characteristics, including a ξ value of 0.73, an atomic mass of 2, and a boiling point of 23.6 K at atmospheric pressure. Deuterium has a scattering cross-section smaller than hydrogen, but its absorption of neutrons remains low. However, a key consideration when using deuterium is the necessity for larger volumes ~ tens of liters, of liquid deuterium to achieve the desired moderation effect in CNSs.

3.2.2.1 Deuterium positioning:

The specific placement of a deuterium source, whether it is tangentially or radially positioned, influences the gain factor. **Radial placement is more sensitive to flux gradients**, and this difference in gain factor based on the CNS's location can vary by a factor of 2–2.5. For optimal performance, a deuterium source requires a moderator layer with **a thickness of at least 20 cm,** so the maximum cold neutron flux tends to concentrate near the center of the source. To extract these neutrons effectively and achieve a higher gain factor, deuterium sources can be equipped with cavities filled with helium or gaseous deuterium.

H and D mixture

Mixtures of hydrogen and deuterium may be employed where the volume of a deuterium source is insufficient to thermalize the neutron flux, to optimize the calculations, it is assumed that the percentage of each component can be used as a straightforward parameter.

3.3. Liquid and solid hydrocarbon moderators

The parameter ξ reaches its maximum value of 1 when neutrons scatter off hydrogen nuclei. In contrast, for nuclei of other chemical elements, ξ is considerably smaller. From an efficiency perspective in cold neutron production, a source employing a hydrocarbon moderator yields a slightly higher gain factor than hydrogen within the 4–10 Å region. Hydrocarbons like methane and mesitylene have been the primary choices and are commonly used in pulsed neutron sources and low-power research reactors, with liquid and solid methane being the most used. An exception to this is the steady-state reactor IR-8 in the Russian Federation, which utilized liquid propane as a moderator.

3.3.1 Methene

Methane is favored due to its high hydrogen density and a substantial density of states in both liquid and solid forms, making it an excellent moderator. But it is suspectable to radiolysis, especially in its solid phase.

3.3.1.1 Methene radiolysis

It happens due to the formation of radical species as defects under irradiation, which can become trapped and subsequently recombine, leading to a phenomenon referred to as **'burping.'** The pressure generated during 'burping' can be substantial enough to damage the moderator vessel, so there was a need to search for other hydrocarbons which have higher radiolysis resistance, mesitylene (1,3,5-trimethylbenzene, $C9H12$) is the most used alternative to methane in accelerators and pulsed reactors, due to the improved resistance to radiation-induced effects.

Practical constraints on moderator materials: the selection of a moderator material depend on various factors, some of them are the following:

1. Quality of Cross Section Data at Low Temperatures: Ensuring that accurate cross-section data are available for the desired temperature range.

2. Wavelength of Interest: Considering the specific neutron wavelengths required for the experiment or application.

3. Interface with Cold Neutron Beam and Guides: Ensuring compatibility with the neutron beamline and guide systems.

In most existing CNSs, natural convection of the moderator has been employed because of its straightforward. However, forced convection provides more efficient cooling and enhances neutronic performance but it presents greater technical complexities compared to natural circulation. If H or D is used and requires pumping for forced convection this leads to additional challenges to safety.

3.3.2 Mesitylene

In this section, we will look further into Mesitylene, our cold moderator material in our work, and at IBR-2 in JINR, Dubna. Mesitylene has a more complex molecular structure compared to simple materials like hydrogen, resulting in additional rotational and vibrational degrees of freedom within the molecule, contributing to incoherent neutron scattering, so the choice between mesitylene and other moderators depends on the specific requirements and constraints of a given neutron scattering experiment or facility

3.3.2.1 Mesitylene properties

Mesitylene, trimethylbenzene (C9H12), is a favorable coolant for producing cold neutrons in research reactors for several reasons:

1. **Moderation Efficiency:** it can effectively slow down fast neutrons to the energy levels required for cold neutron production. Due to its high hydrogen content.

2. **Low Boiling Point:** relatively low boiling point at atmospheric pressure, maintaining it in a liquid state at cryogenic temperatures, as needed for cold neutron sources.

3**. Low Neutron Absorption:** it does not significantly absorb neutrons, allowing more neutrons to be available for experimentation.

4. **Stability:** It remains stable and doesn't readily undergo chemical reactions or radiolysis under neutron bombardment, ensuring consistent performance over time.

5**. Moderate Density**: Mesitylene has a moderate density, which allows for the efficient moderation of neutrons without creating excessive bulk.

6. **Availability**: It is commercially available and can be procured relatively easily.

7. **Resistant to Radiolysis:** Mesitylene demonstrates resistance to radiolysis, minimizing the formation of undesirable by-products that can affect the performance of the cold neutron source.

3.3.2.1.1 properties of mesitylene in terms of rotational and translational effects:

Rotational Properties:

1. **Complex Molecular Structure:** aromatic hydrocarbon composed of three methyl groups attached to a central benzene ring as shown in **fig.4**. This structural complexity gives rise to several rotational and vibrational degrees of freedom within the molecule.

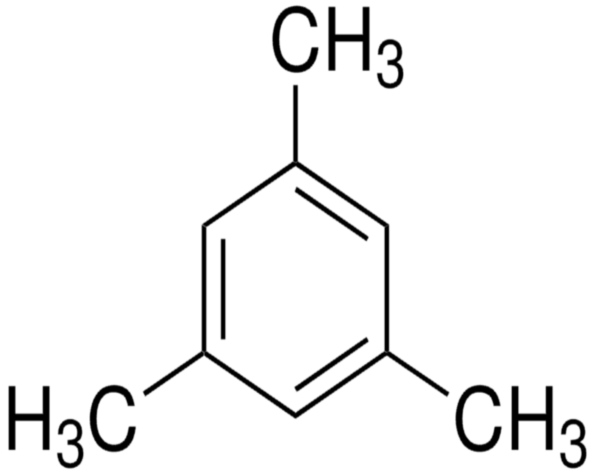


Fig.4.Showing the Structural formula of Mesitylene.

2. **Rotational Modes:** Mesitylene has multiple rotational modes due to the three methyl groups rotating around the carbon-carbon (C-C) bonds. which can contribute to the scattering of neutrons and affect the moderation process.

3**. Incoherent Scattering**: The rotational motions in mesitylene can lead to incoherent neutron scattering, where neutrons interact with individual atoms or groups within the molecule in a way that is not easily predictable. contributing to neutron moderation and is a property exploited in some cold neutron sources.

Transportation Properties:

1. Density: Mesitylene has a moderate density compared to other materials used as moderators. affecting the probability of neutron interactions and, therefore, its efficiency in slowing down neutrons.

2. Handling Temperature: One notable advantage of mesitylene is its ability to be used at higher temperatures compared to cryogenic moderators like liquid hydrogen. This characteristic simplifies transportation and handling because it doesn't require extreme cooling.

3. **Neutron Scattering Cross-Section:** Mesitylene contains hydrogen atoms, which can scatter neutrons efficiently, and this is crucial for neutron moderation.

4. Design of CNS and modeling

The CNS design is an iterative process that involves integrating and optimizing several factors related to neutronics. The design must seamlessly integrate with the physical infrastructure of the reactor or accelerator and harmonize with the control and safety systems.

4.1. NEUTRONICS

Neutronics calculations represent an initial and highly significant phase of the CNS design for the optimal parameters for the moderator and reflector that will yield the highest performance of the CNS, all while adhering to the constraints of the project.

Modeling the interactions of neutrons can be achieved using various Monte Carlo codes, each paired with corresponding cross-section libraries. These libraries, including resources like the Evaluated Nuclear Data File (ENDF), encompass both general-purpose and specialized data.

In simulations, accurately modeling the transport of high-energy neutrons becomes especially crucial. Currently, MCNP6/MCNPX8 are the most employed Monte Carlo code for comprehensive simulations.

4.1.1. Cold moderator neutronics

The primary function: decelerate neutrons generated from a target or fuel to the extremely low energies required for neutron beam experiments. To achieve high intensities in the cold neutron region, cryogenic moderators operating within the temperature range from a few Kelvins up to 150 K are employed.

4.1.2 Location and geometrical constraints on the moderator chamber

The configuration of the moderator chamber is influenced with some considerations encompass factors such as the desired neutron wavelength, compatibility with cold neutron guides, physical dimensions, placement limitations, etc.

4.1.3 Reflector neutronics

The role of a reflector is to increase neutron intensities by reflecting neutrons towards the moderator. The possible materials used will be shown in our model and how it will affect on the neutron flux. At some reactors, heavy (or light) water is used as a reflector and coolant at the same time. An interesting combination is present at Russian Federation**, where a combination of a hydrogen chamber with deuterium surrounding it is used. It was upgraded by filling the space surrounding the liquid hydrogen moderator with heavy water as a reflector.**

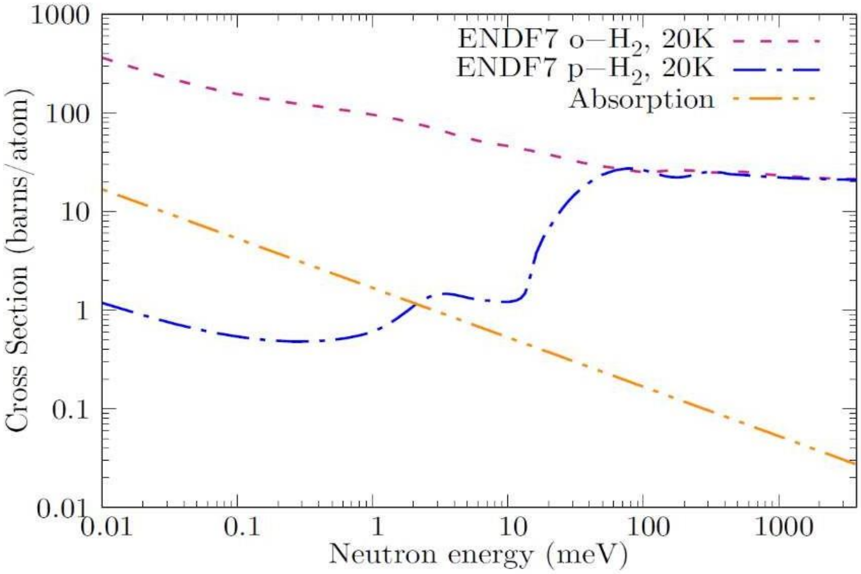


FIG. 5*.Scattering and absorption cross sections for o- and p-H2 at 20K*

At **Fig.5.** the scattering cross-section for liquid para- and ortho-deuterium is displayed, revealing a behavior similar to that observed in hydrogen, for neutron energies below 3 meV, there is a sharp decline in the scattering cross-section when deuterium is the moderator material.

This limitation underscores the significance of solid **mesitylene** as a CNS moderator material, especially in pulsed reactors like IBR-2 in **Dubna**, Russian Federation. The relatively high melting point of mesitylene (228 K) allows for the adjustment of the temperature inside the moderating chamber, ranging from 20 K to 150 K. This temperature tuning capability enables the fine-tuning of the neutron spectrum, allowing it to shift from shorter to longer wavelengths and back.

5. Model description

In this part we are concerned in choosing the most suitable reflector material from the following set of materials (Be- Ni- Pb-Pb-208) with a certain thickness to get an effective reflector to the system and make use of most of the neutron yield.

5.1 Methodology

Our CNS model is used to get the cold and thermal neutron fluxes, so mesitylene is being used as the cold moderator material with thickness of **2 cm,** thermal moderator is represented with a sphere of Water which has a radius of **5 cm,** a reflector represented as a sphere for each material that may be used; **further details in the next section,** also two detectors inserted at point 1 and 2 along the channel to get the neutron flux, calculations are obtained with the use of MCNP tallies and JEFF3.3 library.

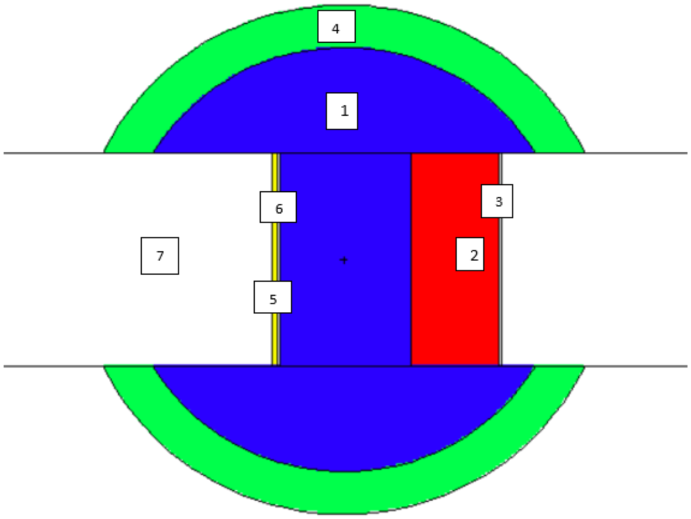


Fig.6. Geometrical representation of the simplified model using VISED; (1) The thermal moderator, (2) The cold moderator, (3) The detector to get the cold and thermal neutrons at point2 (what we are concerned in) , (4) The reflector , (5) The Be target, (6) Detector 1 at point 1 to check and compare our results while working .

5.2 Process of working:

1- For each material, we will take a different radius of the sphere till we have a spherical reflector with **55 cm radius.**

2- Detectors have been used at different points to sense the change in the neutron flux, as this will give us how the material used will enhance the neutron scattering leading to more neutrons which in turn increases the flux too, or it will cause the absorption to be more dominant at certain thicknesses, but this won't be covered within our thickness range.
3- The obtained fluxes for certain neutron energy ranges (Thermal- Cold) will be plotted and results will be discussed and analyzed.
4- Albedo ratio will also be compared for all the materials.

Notes:

1- The flux obtained is **n/sec** and to get the flux in unit **n/cm^2.sec** you need to multiply the result in the source intensity.
2- Fluxes are obtained by using F4 tally in MCNP and calculated at point 1,2.
3- Current in and out and total are being calculated by tally F1.
4- The range of energies used for fast, thermal, and cold neutrons are shown in the next table.

Neutron' classification	Cold	Thermal	Fast
Energy range (Mev)	From 12E-11 to 12E-9	From 12E-9 to 5E-7	From 5E-7 to 20

5.3 Results and discussion:

This section contains:

1- The total (Thermal and fast) flux resulting from each material observation will be discussed.
2- The Albedo ratio for each material.

5.3.1 Total thermal flux

Observations: From what is shown at **fig.7,** the effect of the Beryllium (Be) is found to give more thermal neutron flux compared with the other materials at this range of ~50 cm radius to have a difference of power 10 more than all the materials mentioned. After that the thickness increases of Be result in less flux, unlike lead that is known for its effectiveness for a higher range of thicknesses (around 4m), so for thickness no more than

~ 50 cm Beryllium will be the most suitable choice to get a higher thermal flux, with optimum thickness of 30:35 cm.

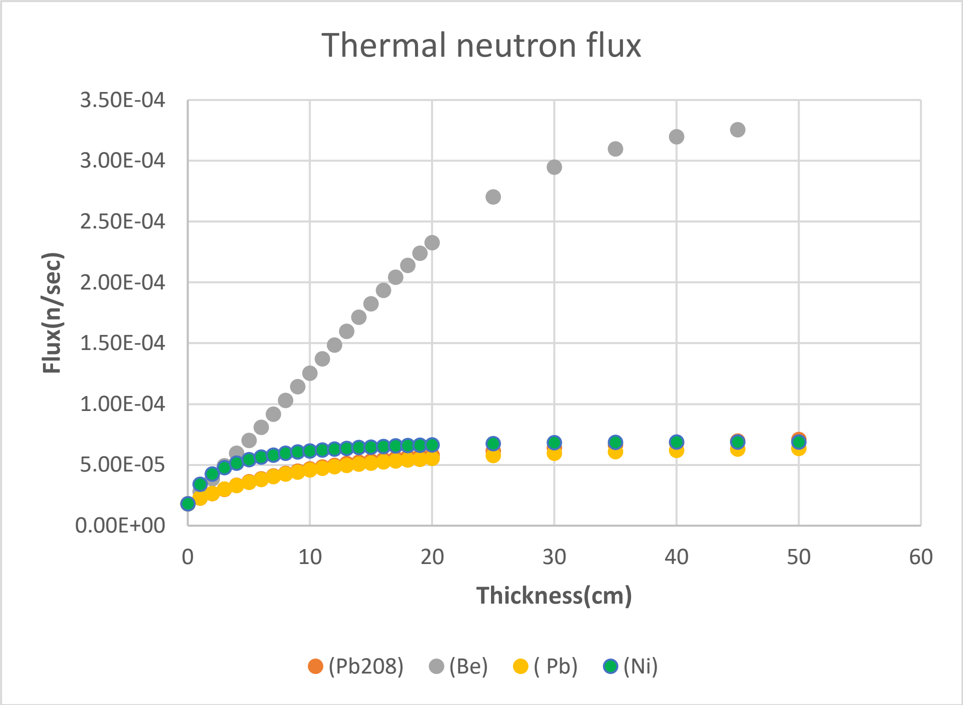


Fig.7. the thermal flux for all the materials tested for our model.

5.3.2 The total cold neutron flux:

Observations

As shown from the following **fig.8.** that for the range of 50 cm thickness all the materials behave as a reflector for the cold neutrons with almost the same efficiency as they are all within the same order of magnitude, so the final choice will depend on certain parameters that will be discussed in the conclusion.

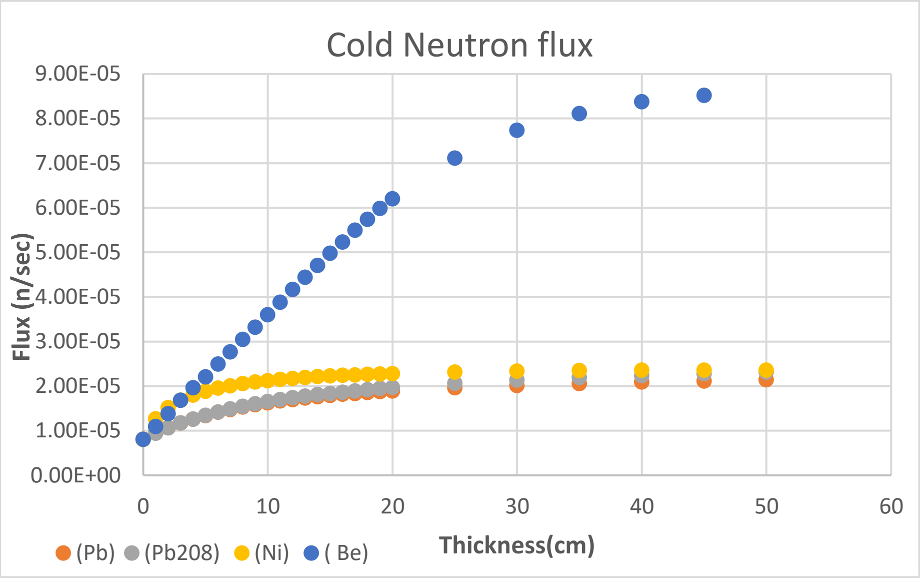


Fig.8. the cold flux for all the materials tested for our model.

5.3.3 The albedo ratio

The albedo ratio is defined as the ratio of reflected or scattered neutrons to incident neutrons on a surface or boundary. It is an important parameter in the context of nuclear criticality and radiation shielding, and here from the following data as shown in the next **fig.9** that Beryllium will have the highest albedo ratio between the following range of thickness and there is no doubt that with increasing the thickness one of the materials will be dominant effect rather than Be.

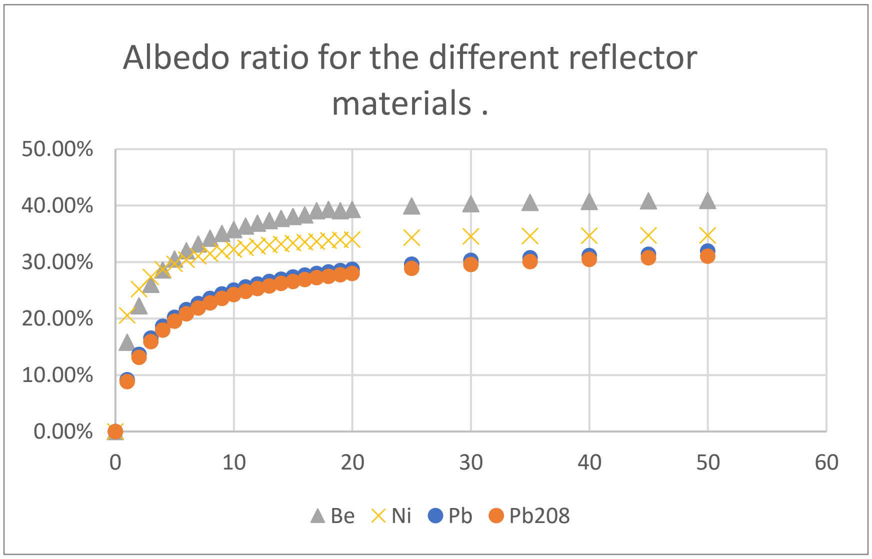


Fig.9. The relation between the albedo ratio and the thickness of the reflector material.

Conclusion

From the observations and analysis of our data that shows the importance of choosing the proper reflector material with certain thickness either for the importance of maintaining a rich neutron field for the goal of reducing neutron leakage which is also for economics, so for the range of 50 cm thickness of reflector, Beryllium is the most suitable material giving the highest thermal, and cold neutron flux, also the highest albedo ratio coming from the thickness of 30 cm till 50 cm, so the facility can use beryllium with 30 cm and build on it another material with favorable properties depending on the desired flux as the CNS plays a crucial role in the world due to its useful uses in different fields, with further research improvements to be conducted by research organization worldwide, including JINR for their efforts in reaching better materials either the previous proven efforts with mesitylene as a moderator material or any other upcoming improvements for the current operating reactor IBR-2 or the next generation's' reactors, because The coupling between reflector and moderator is very important when designing an efficient CNS.

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