

Министерство науки и высшего образования Российской Федерации  
 федеральное государственное автономное  
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 «Национальный исследовательский Томский политехнический университет» (ТПУ)

Инженерная школа ядерных технологий  
Направление подготовки 14.04.02 Ядерные физика и технологии  
Отделение ядерно-топливного цикла

### МАГИСТЕРСКАЯ ДИССЕРТАЦИЯ

Тема работы
Расчетно-экспериментальное определение поля нейтронного излучения в защите из полиэтилена

УДК: 539.125.5.074

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School of Nuclear Science & Engineering  
 Field of training (specialty): 14.04.02 Nuclear Science and Technology  
 Specialization: Nuclear Power Engineering  
Nuclear Fuel Cycle Division

### MASTER THESIS

Topic of research work			
<b>Measurement and calculation of neutron field in polyethylene shielding</b>			
UDC: <u>539.125.5.074</u>			
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Group	Full name	Signature	Date
0AM9И1	Abouellail Abdelmeguid Fathy Ahmed		

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## LEARNING OUTCOMES

Competence code	Competence name
<b>Universal competences</b>	
<b>UC(U)-1</b>	Ability to make critical analysis of problem-based situations using the systems analysis approach, and generate decisions and action plans.
<b>UC(U)-2</b>	Ability to run a project at all life-cycle stages.
<b>UC(U)-3</b>	Ability to organize and lead the teamwork and generate a team strategy to achieve the target goal.
<b>UC(U)-4</b>	Ability to use modern communication technologies to realize academic and professional interaction.
<b>UC(U)-5</b>	Ability to analyze and account for cultural diversity in the process of intercultural interaction.
<b>UC(U)-6</b>	Ability to set and pursue individual and professional activity priorities and ways to modify professional activity based on the self-esteem.
<b>General professional competences</b>	
<b>GPC(U)-1</b>	Ability to formulate goals and objectives of the research study, select assessment criteria, identify priorities for solving problems.
<b>GPC(U)-2</b>	Ability to apply modern research methods, evaluate and present the results of the performed research.
<b>GPC(U)-3</b>	Ability to present research outcomes in the form of articles, reports, scientific reports and presentations using computer layout systems and office software packages.
<b>Professional competences</b>	
<b>PC(U)-1</b>	Ability to manage personnel, taking into account the motives of behavior and ways of developing business behavior of personnel, apply methods for assessing the quality and performance of personnel, develop and implement measures aimed at preventing industrial injuries and environmental violations.
<b>PC(U)-2</b>	Ability to develop and ensure the implementation of measures aimed at improving, modernizing, unifying manufactured devices, facilities and their components, developing standards and certificates, improving reliability of equipment operation.
<b>PC(U)-3</b>	Ability to apply basic methods, techniques and means of obtaining, storing, processing information to plan and manage the life cycle of manufactured products and their quality.
<b>PC(U)-4</b>	Ability to create theoretical and mathematical models describing the condensed state of matter, the propagation and interaction of radiation with matter, the physics of kinetic phenomena, processes in reactors, accelerators, the effect of ionizing radiation on materials, humans and environmental objects.
<b>PC(U)-5</b>	Ability to use fundamental laws in the field of nuclear physics, nuclear reactors, condensed matter, ecology in a volume sufficient for independent combination and synthesis of real ideas, creative self-expression.
<b>PC(U)-6</b>	Ability to evaluate prospects for the development of the nuclear industry, use its modern achievements and advanced technologies in research activities related to the development of technologies for obtaining new types of fuel and materials, radioactive waste management methods and techniques.

<b>PC(U)-7</b>	Ability to assess risks and determine safety measures applied for new facilities and technologies, draw up and analyze scenarios of potential accidents, develop methods to reduce the risk of their occurrence.
<b>PC(U)-8</b>	Ability to analyze technical and computational-theoretical developments, take into account their compliance with the requirements of laws in the field of industry, ecology and safety, and other regulations.
<b>PC(U)-9</b>	Ability to carry out independent experimental or theoretical research to solve scientific and technical problems using modern equipment, calculation and research methods.
<b>PC(U)-10</b>	Ability to draw up technical assignments, use information technology, standard design automation tools and application software packages in the design and calculation of nuclear facilities, materials and devices, apply knowledge of methods of ecological efficiency and economic-value analysis in the design and implementation of projects.
<b>PC(U)-11</b>	Ability to develop design process documentation, execute engineering design and production projects.
<b>PC(U)-12</b>	Ability to conduct training sessions and develop instructional materials for the training courses within the cycle of professional training programs (bachelor degree programs).

Министерство науки и высшего образования Российской Федерации  
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School of Nuclear Science & Engineering  
Field of training (specialty): 14.04.02 Nuclear Science and Technology  
Specialization: Nuclear Power Engineering  
Nuclear Fuel Cycle Division

APPROVED BY:  
 Program Director  
 \_\_\_\_\_ Verkhoturova V.V.  
 « \_\_\_\_ » \_\_\_\_\_ 2021

**ASSIGNMENT  
for the Graduation Thesis completion**

In the form:

Master Thesis
---------------

For a student:

Group	Full name
0AM9И1	Abouellail Abdelmeguid Fathy Ahmed

Topic of research work:

Measurement and calculation of neutron field in polyethylene shielding	
Approved by the order of the Director of School of Nuclear Science & Engineering (date, number):	№ 29-49/c dated January 29, 2021  № 104-43/c dated April 14, 2021 (Todor Gusvitskiy, Nikita Alexeev, Ernazar Mukanov)

Deadline for completion of Master Thesis:	05.06.2021
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**TERMS OF REFERENCE:**

Initial date for research work: <i>(the name of the object of research or design; performance or load; mode of operation (continuous, periodic, cyclic, etc.); type of raw material or material of the product; requirements for the product, product or process; special requirements to the features of the operation of the object or product in terms of operational safety, environmental impact, energy costs; economic analysis, etc.)</i>	Measurement and calculation of neutron field in polyethylene shielding. The neutron flux was measured by the BDKN-03 neutron detector. The measurements were compared with the calculations done by PHITS code. The shield material was polyethylene. The neutron source was Pu-Be source.
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<p><b>List of the issues to be investigated, designed and developed</b>  <i>(analytical review of literary sources with the purpose to study global scientific and technological achievements in the target field, formulation of the research purpose, design, construction, determination of the procedure for research, design, and construction, discussion of the research work results, formulation of additional sections to be developed; conclusions).</i></p>	<ol style="list-style-type: none"> <li>1. preparation of the short overview of methods of solution of a radiation propagation in matter;</li> <li>2. preparation of the short overview of computer codes for solution of the radiation propagation in matter;</li> <li>3. the overview of the PHITS-code</li> <li>4. collection of initial data and development of a calculation model;</li> <li>5. calculation and measurement of neutron field parameters;</li> <li>6. results analysis performance;</li> <li>7. Development of conclusions and recommendations.</li> </ol>
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<p><b>List of graphic material</b>  <i>(with an exact indication of mandatory drawings)</i></p>	
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**Advisors to the sections of the Master Thesis**  
*(with indication of sections)*

Section	Advisor
One: Literature review	Associate professor Silaev Maxim
Two: Collecting initial data and development of a calculation model	Associate professor Silaev Maxim
Three: Results and discussion	Associate professor Silaev Maxim
Four: Financial management, resource efficiency and resource conservation	Associate professor E.V. Menshikova
Five: Social responsibility	Associate professor Verigin D.A.

Date of issuance of the assignment for Master Thesis completion according to the schedule	05 .06 .2021
---	--------------

**Assignment issued by a scientific supervisor / advisor (if any):**

Position	Full name	Academic degree, academic status	Signature	Date
Associate professor	Silaev Maxim	PhD		

**Assignment accepted for execution by a student:**

Group	Full name	Signature	Date
0AM9H1	Abouellail Abdelmeguid Fathy Ahmed		

Министерство науки и высшего образования Российской Федерации  
 федеральное государственное автономное  
 образовательное учреждение высшего образования  
 «Национальный исследовательский Томский политехнический университет» (ТПУ)

School of Nuclear Science & Engineering  
Field of training (specialty): 14.04.02 Nuclear Science and Technology  
Specialization: Nuclear Power Engineering

Level of education: Master degree program  
Nuclear Fuel Cycle Division  
 Period of completion: spring semester 2020/2021 academic year

Form of presenting the work:

Master Thesis
---------------

**SCHEDULED ASSESSMENT CALENDAR  
for the Master Thesis completion**

Deadline for completion of Master’s Graduation Thesis:	05.06.2021
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Assessment date	Title of section (module) / type of work (research)	Maximum score for the section (module)
15.02.2021	Literature Review and Methodology	
12.04.2021	Data collection	
21.04.2021	Analysis of the obtained experimental data	
26.04.2021	Preparation of the results and report submission	
20.05.2021	Defense preparation	

**COMPILED BY:**

**Scientific supervisor:**

Position	Full name	Academic degree, academic status	Signature	Date
Associate professor	Silaev Maxim	PhD		

**APPROVED BY:**

Program Director	Full name	Academic degree, academic status	Signature	Date
Nuclear Power Engineering	Vera V. Verkhoturova	PhD		

**TASK FOR SECTION  
«FINANCIAL MANAGEMENT, RESOURCE EFFICIENCY AND RESOURCE SAVING»**

To the student:

<b>Group</b>	<b>Full name</b>
0AM9I1	Abouellail Abdelmeguid Fathy Ahmed

<b>School</b>	Nuclear Science and Engineering	<b>Division</b>	Nuclear fuel cycle
<b>Degree</b>	Master	<b>Educational Program</b>	14.04.02 Nuclear physics and technologies

**Input data to the section «Financial management, resource efficiency and resource saving»:**

1. <i>Resource cost of scientific and technical research (STR): material and technical, energetic, financial and human</i>	– Salary costs – 189161 rubles – STR budget – 377842.16 rubles
2. <i>Expenditure rates and expenditure standards for resources</i>	– Electricity costs – 5.8 rubles per 1 kWh
3. <i>Current tax system, tax rates, charges rates, discounting rates and interest rates</i>	– Labor tax – 27.1 %; – Overhead costs – 30%;

**The list of subjects to study, design and develop:**

1. <i>Assessment of commercial and innovative potential of STR</i>	– comparative analysis with other researches in this field;
2. <i>Development of charter for scientific-research project</i>	– SWOT-analysis;
3. <i>Scheduling of STR management process: structure and timeline, budget, risk management</i>	– calculation of working hours for project; – creation of the time schedule of the project; – calculation of scientific and technical research budget;
4. <i>Resource efficiency</i>	– Integral indicator of resource efficiency for the developed project.

**A list of graphic material** (with list of mandatory blueprints):

1. <i>Competitiveness analysis</i>
2. <i>SWOT- analysis</i>
3. <i>Gantt chart and budget of scientific research</i>
4. <i>Assessment of resource, financial and economic efficiency of STR</i>
5. <i>Potential risks</i>

<b>Date of issue of the task for the section according to the schedule</b>	
--	--

**Task issued by adviser:**

<b>Position</b>	<b>Full name</b>	<b>Scientific degree, rank</b>	<b>Signature</b>	<b>Date</b>
Associate professor	E.V. Menshikova	PhD		

**The task was accepted by the student:**

<b>Group</b>	<b>Full name</b>	<b>Signature</b>	<b>Date</b>
0AM9I1	Abouellail Abdelmeguid Fathy Ahmed		



## Task for section «Social responsibility»

To student:

group	Full name
0AM9I1	Abouellail Abdelmeguid Fathy Ahmed

School	Nuclear Science and Engineering	Department	Nuclear fuel cycle
Degree	Master programme	Specialization	Nuclear Physics and Technology

Title of graduation thesis:

<b>Measurement and calculation of neutron field in polyethylene shielding</b>	
<b>Initial data for section «Social Responsibility»:</b>	
1. Information about object of investigation (matter, material, device, algorithm, procedure, workplace) and area of its application	Neutron field of a Pu-Be source in polyethylene. Application area: shielding against neutrons
List of items to be investigated and to be developed:	
<b>1. Legal and organizational issues to provide safety:</b> <ul style="list-style-type: none"> <li>– Special (specific for operation of objects of investigation, designed workplace) legal rules of labor legislation;</li> <li>– Organizational activities for layout of workplace.</li> </ul>	<ul style="list-style-type: none"> <li>– Labor code of Russian Federation #197 from 30/12/2001 GOST 12.2.032-78 SSBT</li> <li>– Sanitary Rules 2.2.2/2.4.1340-03. Hygienic requirements for PC and work with it</li> <li>– Sanitary Rules 2.6.1.2523-09 Radiation safety standards</li> </ul>
<b>2. Work Safety:</b> 2.1. Analysis of identified harmful and dangerous factors 2.2. Justification of measures to reduce probability of harmful and dangerous factors	<ul style="list-style-type: none"> <li>– Enhanced electromagnetic radiation level</li> <li>– Insufficient illumination of workplace</li> <li>– Excessive noise</li> <li>– Deviation of microclimate indicators</li> <li>– Electric shock</li> <li>– Ionizing radiation</li> </ul>
<b>3. Ecological safety:</b>	– Indicate impact of radionuclides production on hydrosphere, atmosphere and lithosphere
<b>4. Safety in emergency situations:</b>	– Fire safety;

<b>Assignment date for section according to schedule</b>	
--	--

**The task was issued by consultant:**

Position	Full name	Scientific degree, rank	Signature	date
Associate Professor Division for Nuclear-Fuel Cycle School of Nuclear Science & Engineering	Verigin D.A.	Cand.of Sc.		

**The task was accepted by the student:**

Group	Full name	Signature	date
0AM9I1	Abouellail Abdelmeguid Fathy Ahmed		

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## **Abstract**

The purpose of this work is verification of PHITS-code calculations for the simulation of neutron field parameters from the sealed  $^{239}\text{Pu}$ -Be source in polyethylene shielding. The verification was made by means of comparison of calculation results with the experimental data. The laboratory model consists of two main components. The first component is the  $^{239}\text{Pu}$ -Be source and the second component is the polyethylene prism. An identical PHITS model was generated to simulate the laboratory case. The neutron flux for both thermal and fast neutrons was calculated by PHITS code for every 1 cm in the range from 0 to 30 cm in front of the irradiation channel of the prism.

Experiments have been performed in TPU laboratory. The neutron flux was measured in the laboratory for thermal neutrons at discrete distance range 0, 5, 10, 20, 30 cm from the front side of the polyethylene shield prism (same geometry as it was in calculation model). The fast neutrons flux was measured at 20, and 30 cm distance from the front side of the prism.

The results of calculations and measurements were compared. The sources of uncertainties of measurement and PHITS calculation were discussed as well as possibilities of its reduction. Recommendations for the continuation of the work have been made.

### **Objective of the work**

The objective of the master degree work is verification of PHITS-code use for the simulation of neutron field parameters from the sealed  $^{239}\text{Pu}$ -Be source in polyethylene shielding.

### **Tasks of the work**

There are several tasks should be achieved to get the work objectives. They are following:

8. preparation of the short overview of methods of solution of a radiation propagation in matter;
9. preparation of the short overview of computer codes for solution of the radiation propagation in matter;
10. the overview of the PHITS-code
11. collection of initial data and development of a calculation model;
12. calculation and measurement of neutron field parameters;
13. results analysis performance;
14. Development of conclusions and recommendations.

## **Introduction**

This research work is devoted to many important applications in both educational and industrial purposes.

For educational purposes this research work can provide a simple study for bachelor and master students at TPU in the field of neutron physics and shielding calculations as well as the using of PHITS code.

For nuclear industry this research work can serve the development of the radiation shielding techniques and materials. Development of the existing shielding material such as concrete can be achieved by the same techniques followed in this research work. The future work can provide the nuclear industry with new materials for different shielding purposes. The new shielding materials are important for fabrication of casks and containers for storage and transport of not only the radioactive waste but also for storage and transport of the radioactive source which are used in the laboratories and nuclear medicine facilities. Shielding materials are also used for building a shield from radiation in the accelerator facilities and nuclear power facilities at many parts such as the reactor core, turbine part and also the control room.

Sealed sources of neutron radiation are extensively used in laboratories for education and experimental purposes, have broad application at different facilities such as nuclear reactors, industrial enterprises and hospitals. Effectiveness of the use of neutron sources depends on the capability to predict parameters of radiation at different conditions of a work performance. The calculation of radiation field parameters can be made by means of different engineering approaches or by solution of the integro-differential radiation transfer equation based on various assumptions. Using of calculation codes are very popular for the solution of the radiation transfer equation because of facilitation of the work and time saving.

The master degree work is devoted to the simulation of the neutron fields and corresponded dose rate parameters from the ( $\alpha$ , n) sealed neutron source in laboratory conditions by means of PHITS v 2.88 code.

( $\alpha$ , n) neutron sources have several types and produce neutrons of different energies spectrum. Neutron flux of sealed sources supported by other types of radiation such as roentgen, alpha, beta and gamma. Therefore, the neutrons sources must be placed in a suitable radiation shielding because of its high radiation hazard. The polyethylene shielding is one of the most effective from neutron radiation because of its good moderation and neutron absorption properties. In process of polyethylene interaction with neutron radiation, it produce secondary gamma rays with relatively small energy (in comparison with other famous shielding materials such as iron and tungsten). Moreover, the energy of gamma radiation produced by polyethylene (4620 and 1758 Kev) can be reduced by means of incorporation the boron with concentration of 5-30% to its matrix. Boron capture most of the neutrons moderated by polyethylene and it produce secondary gamma radiation with 0.48 MeV only. Several more advantages of polyethylene are relatively low cost and technological convenience in application. The polyethylene shielding is manufactured in the form of blocks. Blocks of polyethylene material are available in many shapes, dimensions and can be arranged into different configurations[1].

## **chapter 1. Literature review**

### **1.1 Methods of solution of a radiation propagation in matter**

#### **1.1.1 Transport equation.**

The transport equation is one of the important approaches to describe the radiation field for electrically neutral particles photons and neutrons. The transport equation gives the exact description of the particles radiation field[2][3]. The transport equation takes into account all possible interactions between the particles and the medium. The solution of the transport equation gives the expected value of particles fluence or flux density of the radiation throughout the considered shielding material. The transport equation is linear because all neutron-neutron and all photon –photon interactions are neglected[4].

For shielding analysis it's important to know the photon or neutron distribution through the shield material. For many shielding applications we consider a steady state. To achieve the steady state the particles of the radiation field of specific energy  $E$  and specific direction  $\omega$  must satisfy the following four factors balance equation.

$$A + B = C + D$$

Where:

A: is the net flow rate of particles out of a specific volume  $V$  across a surface  $S$ .

B: is the rate of the particle interaction with the medium in the specified volume  $V$ .

C: is the production rate of the secondary particles with the specific energy  $E$  and the specific direction  $\omega$ .

D: is the production rate of the primary particles by the source in the volume  $V$ .

The balance equation is important for understanding the particle propagation through the matter. The four terms of the balance equation express all important conditions in the particles behavior. The term A considers the particles leaving the medium. The term B considers the number of particles suffering collisions with the medium. The term C express the resulting secondary

particles from collisions or interactions between the primary particles and the medium under consideration. Using the balance equation all four terms could be expressed mathematically and the transport equation could be obtained.

### **1.1.2 Approximations to the transport equation.**

The transport equation describes the particle radiation field in more details. For radiation shielding applications some details are not important. We need to simplify the transport equation to reduce the effort of calculations and decrease the computational time. This technique depends on providing less information about the radiation field to calculate the flux density and the dose rate comparing to the information provided in the same case for the transport equation. Many approximations were followed to achieve such a task. The exponential attenuation, diffusion approximation, multi-group approximation,

### **1.1.3 Monte Carlo method**

#### **1.1.3.1 General Monte Carlo method**

Monte Carlo methods are numerical solutions for complex tasks that may have no exact solution by random number of iterations as numerical integration and the higher the number of iterations applied the closer the results to the exact solution. The Monte Carlo method provides approximate solutions to a variety of problems, which may have many variables[5].

For example it's easy to get an exact solution for the area of the square by this function:

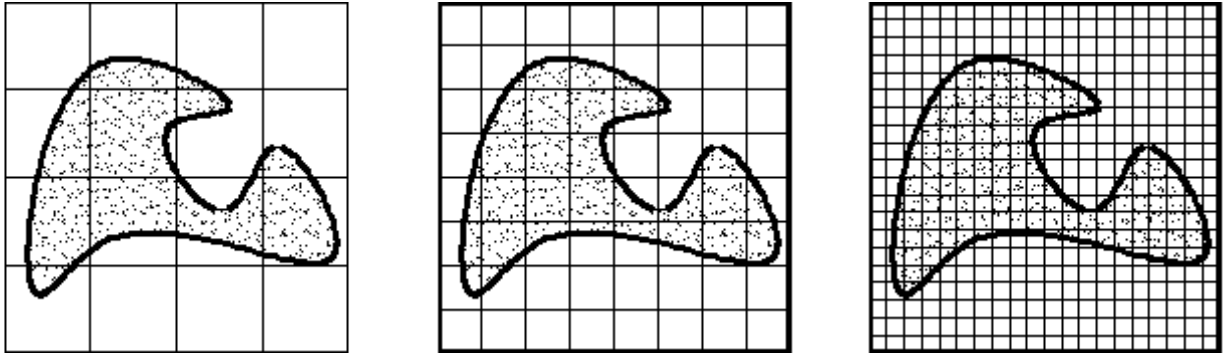
$$A = L^2$$

Where A: the area of the square

L: the length of one side



On the other side we can't calculate the exact value for the area of complex shapes by using equations but approximate area of this shape can be calculated with an accuracy depends on the number of squares dividing this shape into small areas and then the number of squares could be multiplied by the area of one square to get the total area of this shape as it shown in these drawings



Calculation of the area for complex shape by mesh method

Area of the shape= number of squares inside the shape\* area of one square

$$E_1=E_2=E_3=E$$

$$N_1 \neq N_2 \neq N_3$$

**Input data**

**Function**

**Output data**

E1→

→ N<sub>1</sub>

E2→

unknown f(x)=?

→ N<sub>2</sub>

E3→

→ N<sub>3</sub>

The accuracy of calculations increase from the left graph to the right as the number of mesh units increased to cover all the area of this shape with the minimum missing space or not complete unit inside the shape, we should note that increasing the number of mesh units give higher accuracy in calculations but needs many iteration and when using computers it need larger memory and more processing time or even super computers if we applied the same case of more complex tasks with larger input values.

There are many examples to describe the Monte Carlo theory such as Laplace's method (1886) of calculation  $[\pi]$  value or the Buffon's needle example.

Monte Carlo method was developed by John Neumann during the Second World War, but already known before. It was used to study radiation shielding and distance that neutrons would likely travel through any material. Monte Carlo name is taken from a casino name in Italy in Monaco city because it's related to the Rolette game and the probability of the ball to go for a specific number.

Monte Carlo can describe any system and model the system using the so-called probability density functions (PDF) through three stages first to input the system data



and second define the theory finally the theory should be fitted to the data, the Monte Carlo methods are widely used in many fields such as Particle physics, Quantum field theory, Astrophysics, Molecular modeling, Semiconductor devices, Light transport calculations, Traffic flow simulations, Environmental sciences, Financial market simulations, Optimization problems and it can be fitted to any other use.

### **1.1.3.2 Monte Carlo method in particle physics**

Monte Carlo method is an advanced method to give an approximate solution for particle transport tasks through the matter. Monte Carlo method can give a solution with no need of application of the transport equations. The Monte Carlo method needs only mathematical expressions for the probabilities of particle interactions with the matter[6][7]. Using the particle history the Monte carol method can generate one scenario for the result of particle propagation through the matter from its first birth in the source till the particle absorption or leaving the system under consideration. So the particle history could be called as the particle track. The particle history used to express all types of interactions which could happen to the particle during its path through the matter science the particle leaves the source till the end point that the particle reach by leaving the system or even been absorbed by the matter. To get more accurate results by using Monte Carlo method many particle histories are to be generated[7][8]. The average of all random particles tracks is consider as the solution of Monte Carlo method. Depending on the results of the particle track through the matter many other physical quantities could be obtained. The track length, the energy, the direction and also the generation of new particles could be obtained by the Monte Carlo method. Another quantities could be calculated such as the particle flux, the absorbed dose and many other quantities[9][10].

## **1.2 Overview of computer codes for solution of the radiation propagation in matter**

PHITS code is not the only Monte Carlo simulation code but there are many codes developed all over the world which are written in different languages and do the same purpose with different data libraries inside it, some of these codes are developed

for the same purpose as GEANT4 which was developed by CERN in order to serve their researches in LHC (the large hadron collider)[11][5] , many other codes for particle physics applications were produced by collaboration between many global organizations such as FLUKA, EGS, Super MC and the world standard MCNPX[12][13][14]. These codes have related purposes and each of them has advantages and disadvantages according to the performed task or from different point of view strength points, PHITS is considered the simplest code for individual users and it doesn't require any FORTRAN language skills, also it can be used on a computer with not too high hardware requirements unlike GEANT4 code which require a strong machine and other codes may require a previous knowledge with programming language such as c + + , PHITS code come with all necessary lectures in form of presentations to explain it for new users and also with a very good user manual for explaining almost all function with all possible examples, this give the flexibility to the new users to check a large number of examples to apply their tasks in the right manner and discover all possible errors and solve them with help of the frequently asked questions, Here in the table a short comparison between PHITS and some other MC codes that do similar tasks.

Table 1. 1 Common MC Codes.

<b>Name</b>	<b>Developer</b>	<b>Language</b>	<b>Field of application</b>
PHITS	JAEA with collaboration of some Japanese institutes	FORTRAN	<ul style="list-style-type: none"> <li>- Accelerator</li> <li>- Radiology</li> <li>- Astronomy</li> </ul>
MCNPX	LANL	FORTRAN	<ul style="list-style-type: none"> <li>- Radiology</li> </ul>
GEANT4	CERN	C + +	<ul style="list-style-type: none"> <li>- high energy experimental physics</li> <li>- Radiology</li> <li>- Accelerator</li> </ul>
FLUKA	CERN, INFN	FORTRAN	<ul style="list-style-type: none"> <li>- Radiation shielding</li> <li>- Detector response</li> <li>- Cosmic ray studies</li> <li>- Dosimetry</li> </ul>

			- Medical physics and radio-biology
Super MC	FDS	C++	- Fusion, radiology
EGS	KEK, SLAC	FORTRAN	- Radiology

### 1.3 The overview of the PHITS-code

#### 1.3.1 PHITS code v 2.88 description

PHITS v 2.88 (Particle and Heavy Ion Transport code System) is a general purpose Monte Carlo particle transport simulation code. PHITS is written in FORTRAN language and can be executed on almost all types of computer machines such as Windows, Mac, Linux[15]. PHITS was developed under collaboration between Japanese atomic energy agency JAEA and many research institutes in Japan, basically the PHITS code was designed to support the Japanese researches in the Japanese accelerator J-PARC (Japan proton accelerator complex). The first code which was designed for this purpose in the accelerator was called NMTC/JAM code and it was the first step to get PHITS code produced after many stages of development on NMTC/JAM code, that is because the previous versions of NMTC/JAM didn't include the heavy ion transport[16]. So PHITS code is a large all in one package containing a huge number of nuclear interaction models and some massive updated nuclear data libraries. This code applies Monte Carlo method for simulating particle physics tasks of many types and purposes according to many types of facilities[16].

#### 1.3.2 Nuclear data library JENDL-4.0

The Japanese Evaluated Nuclear Data Libraries JENDLs are a series of nuclear data libraries developed by The Japanese Nuclear Data Committee (JNDC) with the help of Nuclear Data Center NDC of the Japanese Atomic Energy Agency (JAEA). The libraries are categorized into general-purpose and special-purpose ones [17].

The JENDL-4.0 is a general purpose of the Evaluated Nuclear Data Libraries the first data library JENDL-1.0 was released in 1977 and it was developed periodically

Table 1. 2 Development of JENDLs

Library	Date of release	Main application	Number of isotopes	Number of natural elements	Number of nuclides with secondary $\gamma$ -production
JENDL-1.0	1977	FBR	66	6	0
JENDL-2.0	1982	FBR, LWR	173	8	0
JENDL-3.0	1989	General	152	19	59
JENDL-3.1	1990	General	205	19	59
JENDL-3.2	1994	General	318	22	66
JENDL-3.3	2002	General	335	2	114
JENDL-4.0	2010	General	405	1	354

These nuclear data are mainly used for nuclear energy applications such as the design of fission and fusion reactors, radiation shielding, and radiation damage to materials and so on.

Nuclear data libraries are generated according to the measurements. The updates are achieved by the help of the new theoretical knowledge in nuclear physics and the new experimental results. The JENDL-4.0 contains the nuclear data of 405 isotopes and 1 natural element and containing 354 radionuclide which contain secondary gamma ray production also this library contains other useful data. The nuclear data is not only the cross sections but also the nuclear structure of the element. For nuclear engineering and other fields the necessary nuclear data for whole energy regions (ranging, from  $10^{-5}$  eV to 20 MeV)[18].

The world interest for nuclear data libraries led to generating many data libraries in many countries according to the local researches and experimental data achieved in these countries. These data libraries are devoted to general purpose libraries and they are not limited to a special field. The most common general purpose nuclear data libraries are shown in the table.

Table 1. 3 The latest versions of major general-purpose libraries

Name of data library	Country	Date of release
----------------------	---------	-----------------

JENDL-4.0	Japan	2010
ENDF/B-VII.1	USA	2011
JEFF-3.1.2	EU	2012
BROND-2.2	Russia	1993
ROSFOND-2010	Russia	2010
CENDL-3.1	China	2009

The special purpose libraries are another type of nuclear data libraries were developed for applications in a particular field of nuclear science. The special-purpose nuclear data libraries are used for a specific application such as dosimetry and activation[19][17].

Table 1. 4 Typical special purpose libraries.

Name of data library	Country/ Organization	Date of release	Purpose
JENDL/AC-2008	Japan	2008	For transmutation study
EAF-2010	UK	2010	For activation and transmutation studies
FENDL-2.1	IAEA	2004	For fusion applications
IRDFF-1.0	IAEA	2012	For dosimetry applications

### 1.3.3 ANGEL graphics program v 4.35

ANGEL is written in FORTRAN language. ANGEL creates EPS (Enhanced PostScript) files from the input. PS (PostScript) is a programming language which was optimized for printing graphics and text introduced by Adobe in 1985. PS language can describe images and texts. PS language used to write the PS files. PS files can be played on the screen by some software on windows such as GS view and Ghost script software. The graphs could be viewed on the screen or printed by using the previous mentioned programs.

When we have the data as a result from the calculation and we need to show it in graphs now this is the role of ANGEL. By ANGEL we can add some commands to the output file of the calculations or experimental data and then it will be converted to EPS file. EPS file can be easily shown on the screen or printed. The data could be from different types it may be a couple of data like (x, y), or 3D data array, or multi-values with error bars. Only one simple step and you can see them on graphs by ANGEL commands.

#### **1.3.4 Reliability of PHITS code (benchmark & validation)**

The simulation processes which are done by Monte Carlo codes such as PHITS code has an excellent reliability and this can be ensured by developers of the PHITS code and also can be ensured by the users of PHITS code[20][21].

Developers of PHITS code in the JAEA and other associated Japanese institutes are ensuring regularly the reliability of their code versions by doing several benchmark tests on the new version while releasing it for users, benchmark testing done by experts under supervision of the main developers of the code by applying many field experiments from the Japanese accelerator J-PARC (Japan proton accelerator complex) and other research facilities in Japan and Europe to ensure the reliability of new functions and calculate the uncertainty to predict the percentage of future errors, the benchmark testing for the new version of the code is to compare the result of simulation with the experimental data and check them well according to the case of the study and the nuclear data libraries, all the benchmark tests for all PHITS code versions are available on the web in research papers and scientific magazines[22].

Users of PHITS code can also validate their simulation results calculated by the code by comparing their results with the experimental results to ensure that they are using the code in the right manner, because there are many cases that can result in not too accurate results and it could be considered as fatal mistakes, these mistakes could happen in case of wrong defined data library or cut off energy which mean that the energy range of the transported particles are not sufficient for the nuclear interaction model or the method of calculation inside the code, the validation of code results are highly important specially for the transport of low energy particles below 30 Mev[23].

### 1.3.5 PHITS code purpose

PHITS code can simulate the transport of nearly all particles over wide energy ranges (neutrons, photons, protons, heavy ions and electrons) as it can deal with neutron transport from thermal energies up to 200 GeV[24]. The backbone of PHITS code is two general components the first component is several nuclear reaction models and the second component is nuclear data libraries. PHITS is called a multi-purpose code because of its wide field of applications as it can support many researches in the fields of accelerator technology, radiotherapy, space radiation, and in many other fields which are related to particle and heavy ion transport phenomena. In this research we are interested in using PHITS-code for simulation of the low energy neutron propagation through the media. Among the wide energy range for transport neutrons using PHITS code we only focus in this task on low energy neutrons ( $E_{\text{neutron}} < 20$  MeV) because the Pu-Be source in our experiment produces neutron with energy spectrum and the maximum energy of a neutron beam is less than 12 MeV. This is important to be mentioned because PHITS divided the range of energy and use a specific data library for each energy range which affects the reliability of simulation results done by PHITS. The producers of PHITS code recommended the nuclear models and data libraries that should be used in each case according to the energy range of the transported particles to get accurate results, for neutrons with energy below 20 MeV PHITS use nuclear data library while it use parameterization for neutrons with energy above 20 MeV and they divided the energy range in PHITS for neutrons with the related interaction-model and data library as follow[25]

Table 1. 5 Neutron energy range and related option in PHITS

<b>Neutrons energy range</b>	<b>Applied model and data library in PHITS</b>
Neutrons below 20 MeV	Nuclear data library (JENDL-4.0)
Neutrons from 20 MeV to 3.0 GeV	Intra-nuclear cascade (INCL 4.6) + Evaporation (GEM)
Neutrons from 3.0 GeV to 200 GeV	Intra-nuclear cascade (JAM) + Evaporation (GEM)

### 1.3.6 Some tally functions used in PHITS code

PHITS code v 2.88 with nuclear data library (JENDL-4.0) is used for calculations in this work, PHITS includes many functions that can be used to simulate neutrons propagation through the media and draw the suitable output form of the results in graphs with the chosen scale and units. Here we mentioned some functions that have been used in our calculations done by PHITS code and their purposes:

Table 1. 6 Tally functions and it applications in PHITS

<b>Name of PHITS-Tally function</b>	<b>Purpose of application</b>
T-Track	<ul style="list-style-type: none"> <li>- Checking 2d Geometry.</li> <li>- Calculate neutron flux density through a specified region or volume.</li> <li>- T-Track can simulate a volume detector.</li> <li>- Calculate neutron flux distribution on specified axis X, Y or Z.</li> <li>- Tracking the particles transport through the media.</li> </ul>
T-3dshow	<ul style="list-style-type: none"> <li>- Checking 3d-Geometry</li> </ul>
T-Point	<ul style="list-style-type: none"> <li>- Calculate neutron flux density through a specified point.</li> <li>- T-Point can simulate a point detector and/or a ring detector with a specified ring radius at the specified point co-ordinates.</li> </ul>
T-Deposit	<ul style="list-style-type: none"> <li>- Calculate the deposit energy in the material after passing of the particles through it.</li> <li>- Calculate the absorbed dose and plot graphs for the dose distribution according to the distance in the shield material.</li> </ul>



## **chapter 2. Collecting initial data and development of a calculation model**

The experiment was carried out in TPU laboratory to determine the neutron field characteristics near a pure polyethylene shielding.

There are several data have to be collected for calculation model development. Data relates to main laboratory components such as:

- polyethylene prism:
- neutron source;
- Detection system.

### **2.1 Prism description**

There are two things need to be described in the calculation model about the polyethylene prism. They are geometry and material.

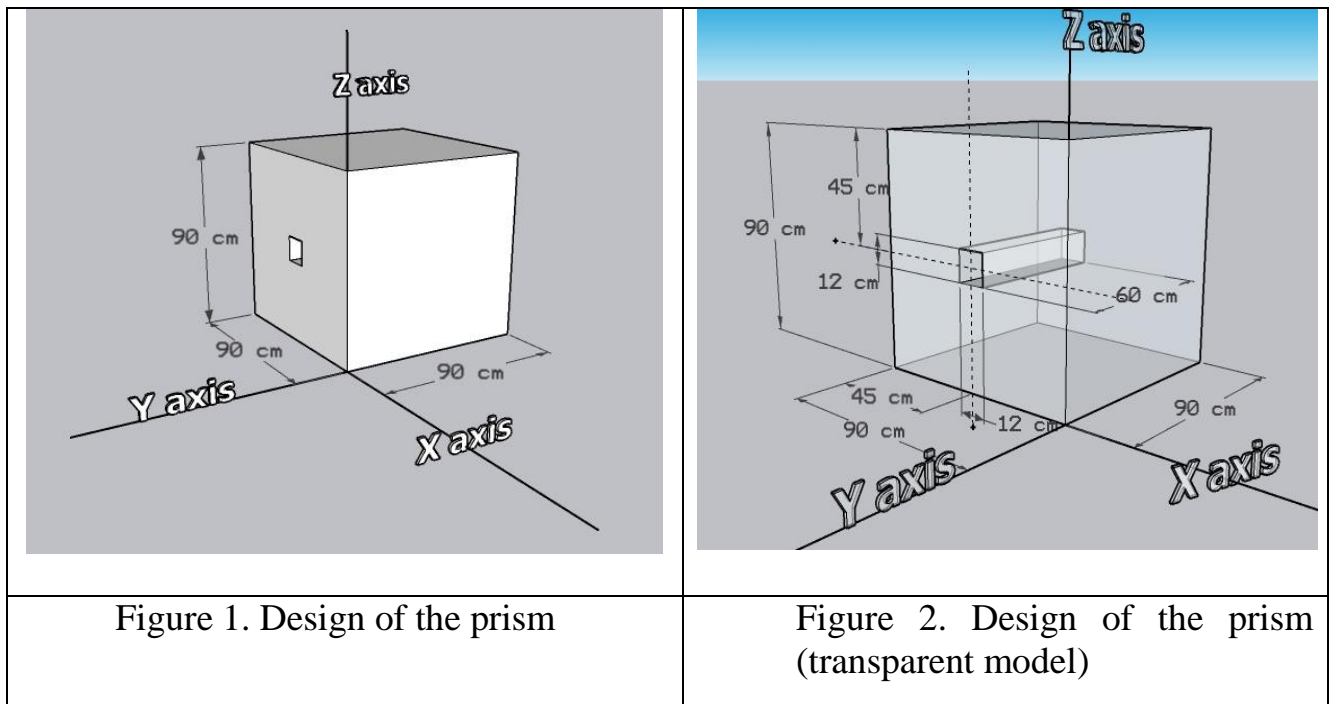
#### **2.1.1 Prism geometry**

The prism is a cubic of a pure polyethylene shielding with 90\*90\*90 cm. It has an irradiation channel located at the side axis of the prism. The channel is 60 cm deep and has the exit at the front side of the prism. The dimensions of the channel is 12\*12\*60 cm. The source of neutrons is placed to the end of the channel and in the geometry center of the prism.

The prism is rested on the laboratory floor and situated in the corner of the laboratory premises. The corner is limited by the right and the back wall sides from the room entrance. This data is important to be discussed in detail because it will effect to the neutron spectrum by means of neutron leakage, reflection, and moderation. Initial data about the polyethylene prism geometry are presented in the table 0.1. 3-dimensional models of prism are shown in figures 1, 2.

Table 2. 1 Dimensions of the polyethylene prism and the inner channel

Name of part	X direction	Y direction	Z direction
Polyethylene prism	90 cm	90 cm	90 cm
Channel at the center of the prism for storing the Pu-Be source	12 cm	60 cm This direction is the depth of the channel inside the prism	12 cm

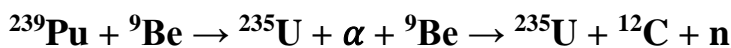


### 2.1.2 Prism material

The prism made from pure polyethylene which has a chemical composition of carbon and hydrogen (C<sub>2</sub>H<sub>4</sub>) with density equal to 0.9 g/cm<sup>3</sup>.

### 2.2 Neutron source

A <sup>239</sup>Pu-Be neutron source was used to produce fast neutrons by means of alpha-neutron (α, n) reaction [26]:



Main technical characteristics of TPU laboratory source (**IBN-10 type**) a presented in the table 2.2 Data taken from the technical passport on the source.

Table 2. 2 Technical characteristics on TPU IBN-10 neutron source

<b>Characteristic</b>	<b>IBN-10 value</b>
Neutron flux $\Phi$	$1.01 \cdot 10^7$ neutron.cm <sup>-2</sup> .s <sup>-1</sup>
Activity A	$2.5 \cdot 10^{11}$ Bq = 6.8 ci
Outer diameter D	35±0.2 mm
Outer height H	45 mm
Inner diameter d	27 mm
Inner height h	27 mm
Date of measurements	31.07.2009

The containment of the source made from the stainless steel. The steel is the 12X18H10T. The content of different elements in the steel are presented in the tab.2. 3.

Table 2. 3 Chemical composition of the 12X18H10T steel [27]

<b>Element contents, %</b>									
<b>C</b>	<b>Si</b>	<b>Mn</b>	<b>Ni</b>	<b>S</b>	<b>P</b>	<b>Cr</b>	<b>Mo</b>	<b>W</b>	<b>Ti</b>
max 0.12	max 0.8	max 2	9 - 11	max 0.02	max 0.035	17 - 19	max 0. 03	0.2	(5 - 0.8) remaining in Fe

Sealed neutron sources have a continuous spectrum. The initial neutron spectrum is another important feature should be taken into account for calculation model development[28][29].

The spectrum is not specified in the source passport. Therefore, spectrum data were obtained from the scientific publications[29][30].

The impurity of the nuclear materials also did not specify. Nevertheless, the content of <sup>241</sup>Pu and <sup>241</sup>Am can change the initial spectrum and become a one of the sources of measurements uncertainties. Moreover,  $\beta^-$  decay of <sup>241</sup>Pu increase problems with effect of Am-241 on the spectrum with time [31][32].

### 2.3 Detection system

Universal radiometer - dosimeter MKS-01R was used for neutron and dosimetry neutron measurements. The portable handheld multifunctional dosimeter-radiometer MKS-01R is designed for measurement of surface contamination with alpha- and beta-active substances; equivalent dose and equivalent dose rate of roentgen and gamma radiations; flux density and fluence of thermal, fast and epi-thermal neutrons.

Measurement of various types of radiation sources and various quantities (equivalent dose rate, flux density, etc.) is carried out using a set of replaceable detection units that convert the radiation energy into a sequence of pulses, the number of which is proportional to the amount of radiation.

In the front control panel (fig. 3) of the device there are three switches and they can be used to adjust the mode of measurements and the time measurement intervals.

This device is used for operational control of radiation safety in fields, industrial, and laboratory conditions.

The detection system is used at TPU laboratory as stationary one and has an external power supply block.

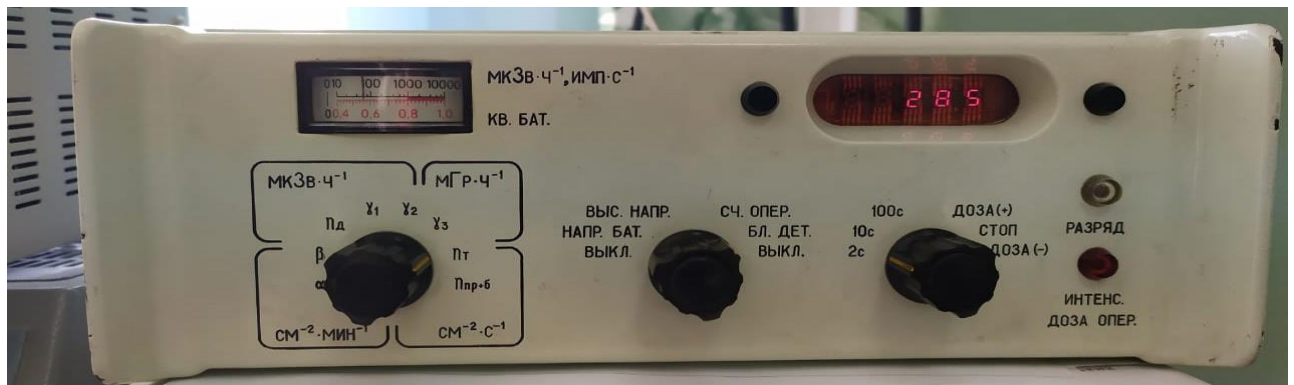


Figure 3. The front panel of MKS-01R.



Figure 4. Power supply block with low voltage adjustment

MKS-01R device save its functions in conditions presented at the tab. 2.4.

Table 2. 4 Requirements to external conditions for MKS-01R operation

External parameter	Working range
temperature	from -10 to + 40 ° C
relative humidity	up to 98% at + 25 ° C
atmospheric pressure	86-106 kPa

The dosimeter-radiometer MKS-01R is a multifunctional portable measuring instrument with digital indication of readings, including a unit for processing and displaying information (BOI with a built-in Geiger-Muller counter) and external intelligent detection units (detectors). The tab. 6 presents the information about MKS-01R detector types and its assignments.

Table 2. 5 MKS-01R detectors and its assignments

Detector	Measured characteristic	Unit of measurement
BDPA-01R	Flux density of $\alpha$ -particles	Particle.cm <sup>-2</sup> .min <sup>-1</sup>
BDPB-01R	Flux density of $\beta$ -particles	Particle.cm <sup>-2</sup> .min <sup>-1</sup>

BDKG-02R	Gamma equivalent dose rate	$\mu\text{Sv}\cdot\text{hr}^{-1}$
BDKN-01	Flux density of epithermal and fast neutrons	$\text{n}\cdot\text{cm}^{-2}\cdot\text{s}^{-1}$
BDKN-03	Flux density of thermal neutrons	$\text{n}\cdot\text{cm}^{-2}\cdot\text{s}^{-1}$
BDKN-03-01	Flux density of epithermal and fast neutrons	$\text{n}\cdot\text{cm}^{-2}\cdot\text{s}^{-1}$
BDKN-03R	Neutron dose rate	$\mu\text{Sv}\cdot\text{hr}^{-1}$

There are several other assignments not important for this work performance. Different modification of BDKN-03 detector was used for detection of flux of thermal and epithermal neutrons as well as neutron dose rate (see fig. 5-9 pictures).



Figure 5 . BDKN-03 detector for measurement of thermal neutron flux



Figure 6. Polyethylene sphere in cadmium shielding for measurement of epithermal neutron flux



Figure 7. BDKN-03 detector in the sphere for measurement of epithermal neutron flux



Figure 8. External polyethylene sphere for neutron dose rate measurements

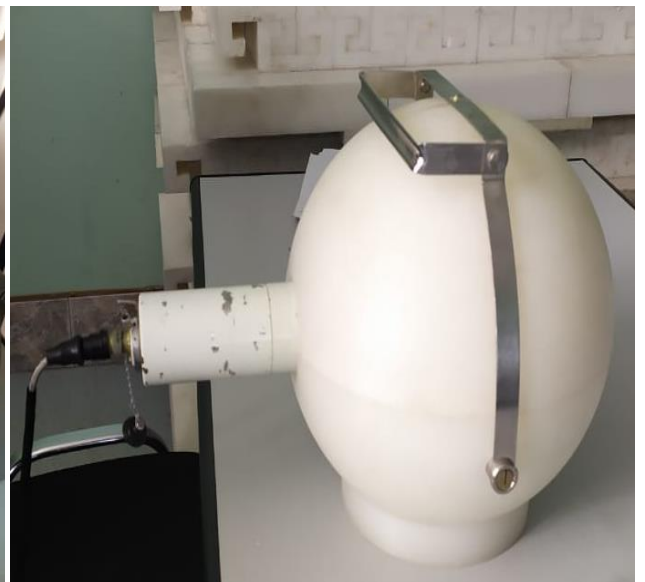


Figure 9. BDKN-03 detector for neutron dose rate measurements

The information from the detector unit is transmitted via a special cable to the information processing unit. Processed information is reflected at a digital display. Main technical characteristics of BDKN- 03 detector is shown at the table. 2.6.

Table 2. 6 BDKN-03R neutron detector technical characteristics

<b>Detector</b>	<b>BDKN-03R</b>
Detector	plastic with incorporated zinc sulfide
Energy range	0.025 eV – 14 MeV
Measurement range of ambient radiation dose rate equivalent	0.1 $\mu\text{Sv/h}$ – 10 mSv/h
Measurement range of ambient radiation dose equivalent	0.1 $\mu\text{Sv}$ – 10 Sv
Typical sensitivity to neutron radiation of Pu-Be source (In dose rate measurement mode)	0.355 cps/ $(\mu\text{Sv}\cdot\text{h}^{-1})$
Neutron flux density measurement range	0.1 – $10^4$ neutron $\cdot\text{s}^{-1}\cdot\text{cm}^{-2}$
Typical sensitivity to neutron radiation of Pu-Be source (In flux density measurement mode)	0.5 cps/(neutron $\cdot\text{s}^{-1}\cdot\text{cm}^{-2}$ )
Limit of intrinsic relative measurement error	$\pm 20\%$
Protection rating	IP64
Overall dimensions, weight	314x220x264 mm, 8 kg

The neutron energy range, which the detector (BDKN-03) can measure and consider, is a 0.025 eV for thermal neutrons, and 1 keV – 14 MeV for the epithermal and fast neutron. This information important for comparison of measurement results with calculation one.

## **2.4 PHIS – Code data input and graphs**

### **2.4.1 Geometry definition in PHITS**

The geometry definition in PHITS-code has many options to be used during building a new model inside the code.

The geometry in PHITS should be defined in three sections and they are not separated from each other, these sections are material, surface and cell, in the material section the chemical composition of the material and density could be described and every described material in the material section should have its specific number. For the surface section the dimensions of the prism and its co-ordinates x, y and z were defined for each part of the prism. Finally, the cell section combine both the material section with the surface section. It includes the cell number, material number, surface number and the density of the material to form the required prism and it is called region



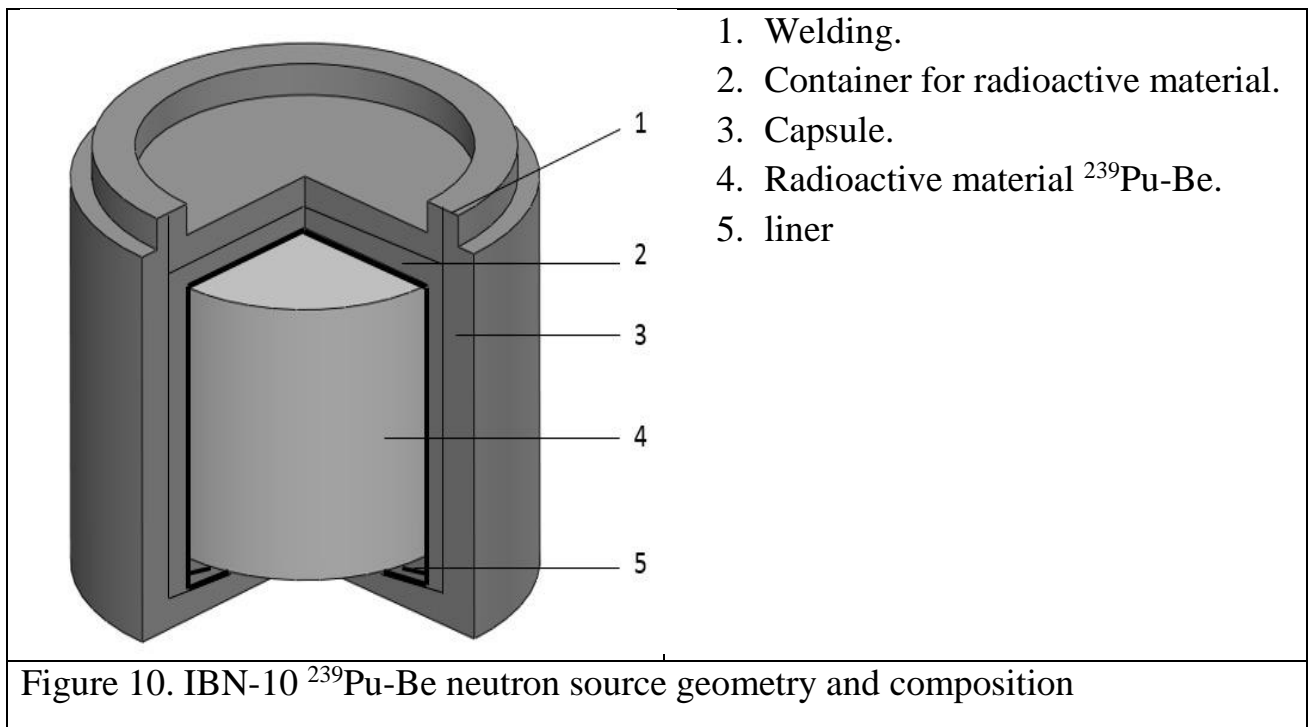
inside PHITS. The geometry for the polyethylene prism model is cubic as it was mentioned above.

It should be known that every region inside PHITS-code should be defined only one time as a specific material or to be described as a void. The double defined region in PHITS can give wrong calculation results. To avoid this error during building PHITS model T-track tally with g-show was used. It is revision of 2D view after making any change to the geometry as it would be discussed later in tally definition section.

#### 2.4.2 Source definition in PHITS

In the source section inside PHITS-code are information about the source such as source dimensions, the type of the generated particles, directions of particles and its energy.

The geometry of the source was defined as cylinder. Source details are shown in figure 10.



Energy distribution of the source is given by a spectrum[33]. The spectrum data were described in model as a bar chart with neutron energy ranges and its probabilities of generation. The generated neutrons in range were defined as an isotopic radiation source.

The problem that the neutron spectrum does not described as a passport characteristic. There are some information about spectrum can be found in scientific articles but it is not reflected a spectrum belongs to the particular sealed neuron source. The spectrum depends on the source isotope composition and size and can significantly differ.

Nevertheless, two spectrum pictures from articles were used for modeling of Pu-Be sealed source spectrum[34][35]. The initial (reference) pictures of spectrum are shown in the fig. 10, 11.

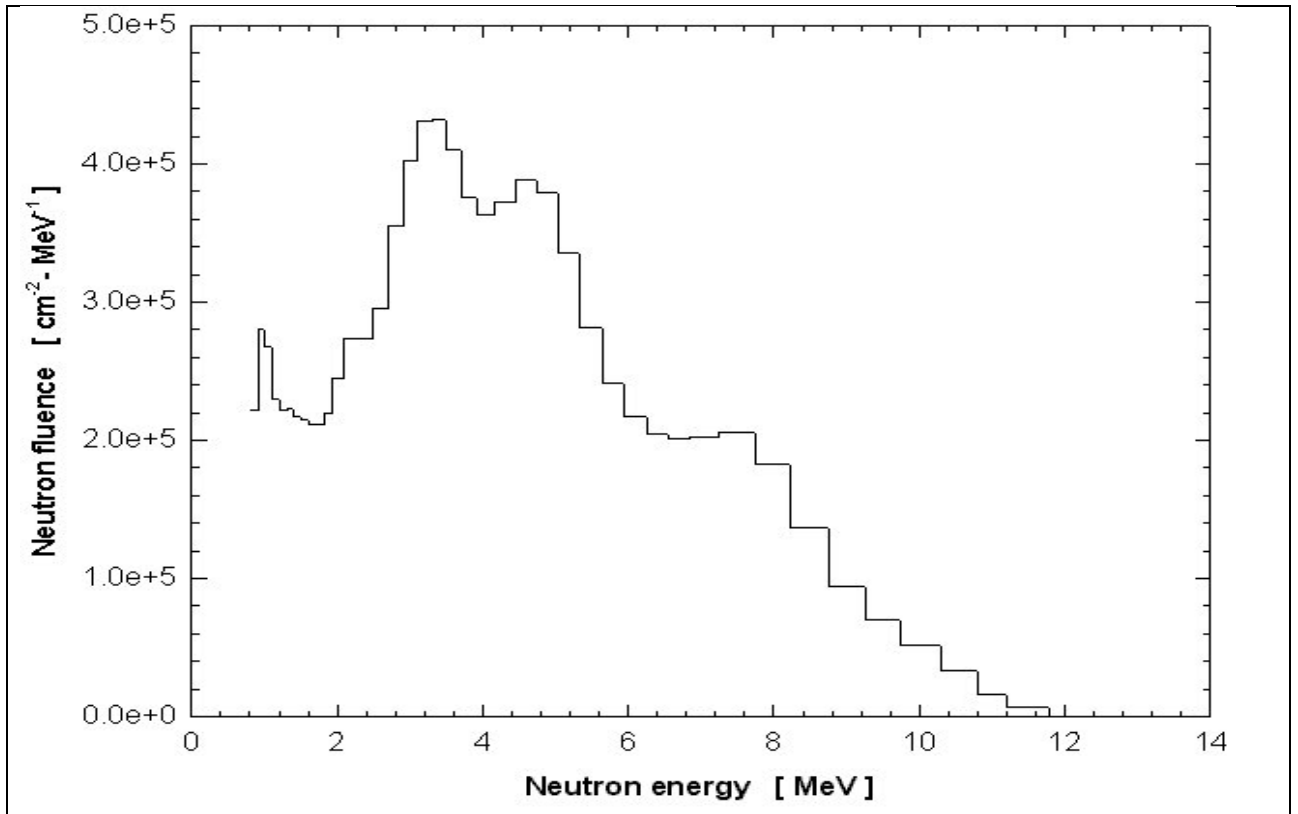


Figure 11 . The first reference spectrum used in model.[34].

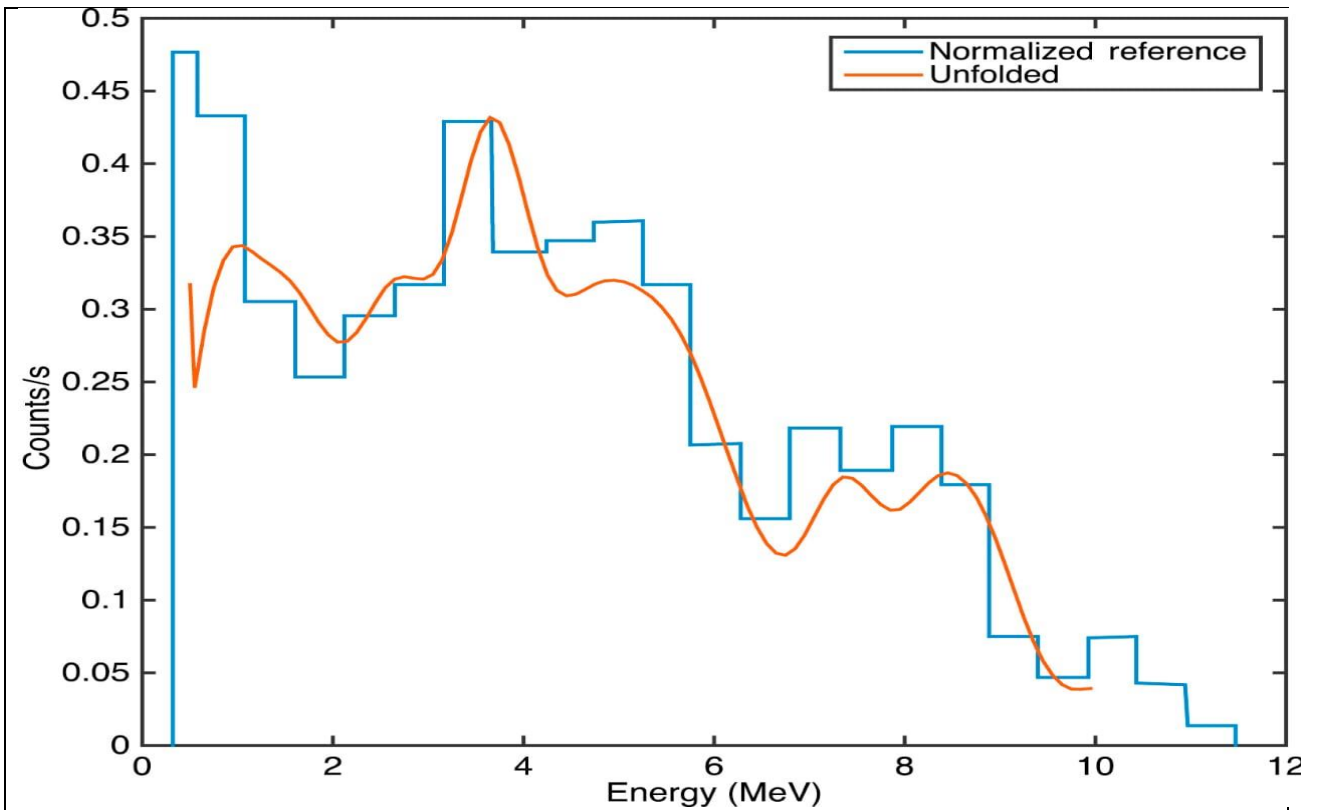


Figure 12. The second reference spectrum used in model.[35].

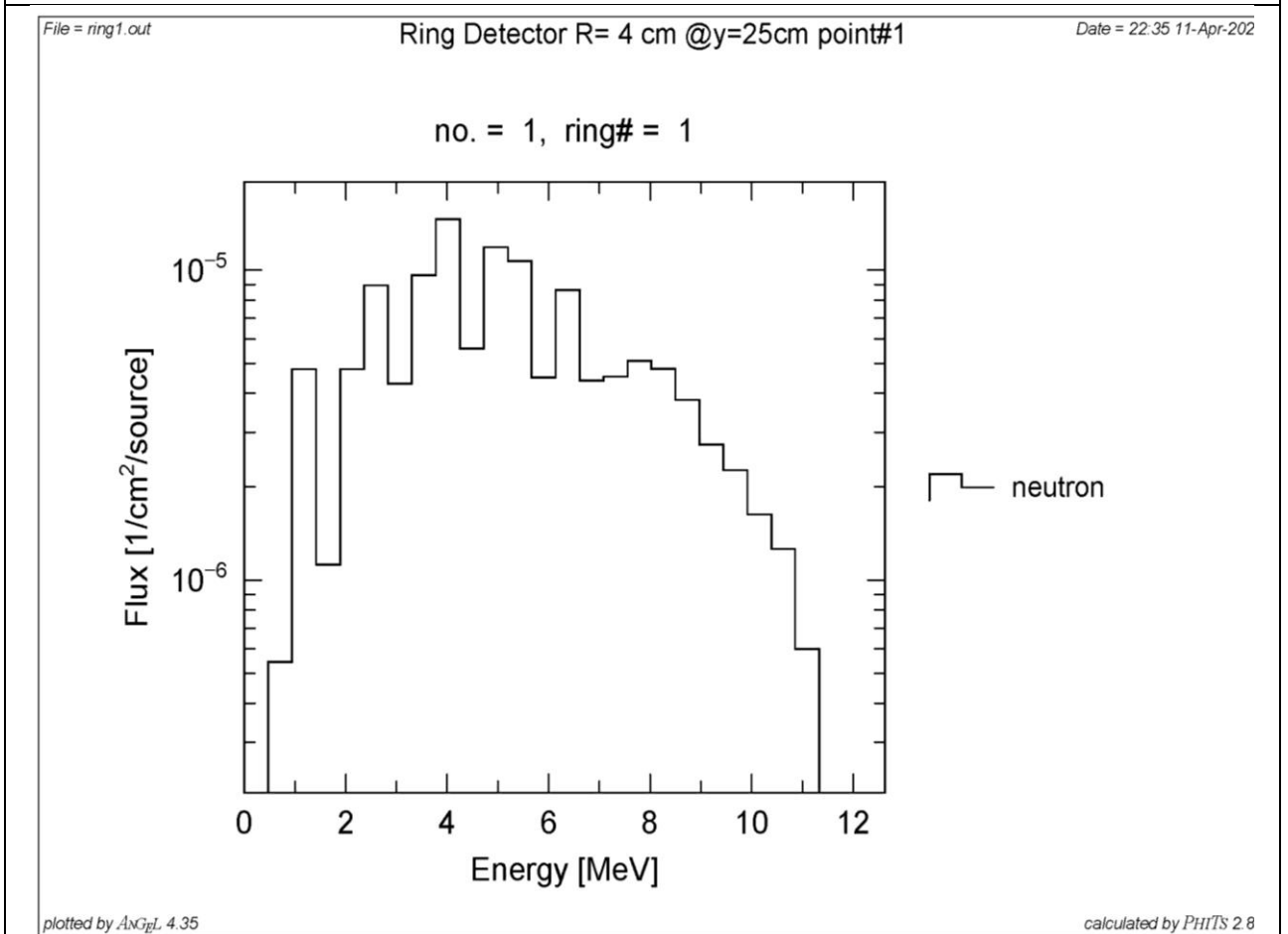
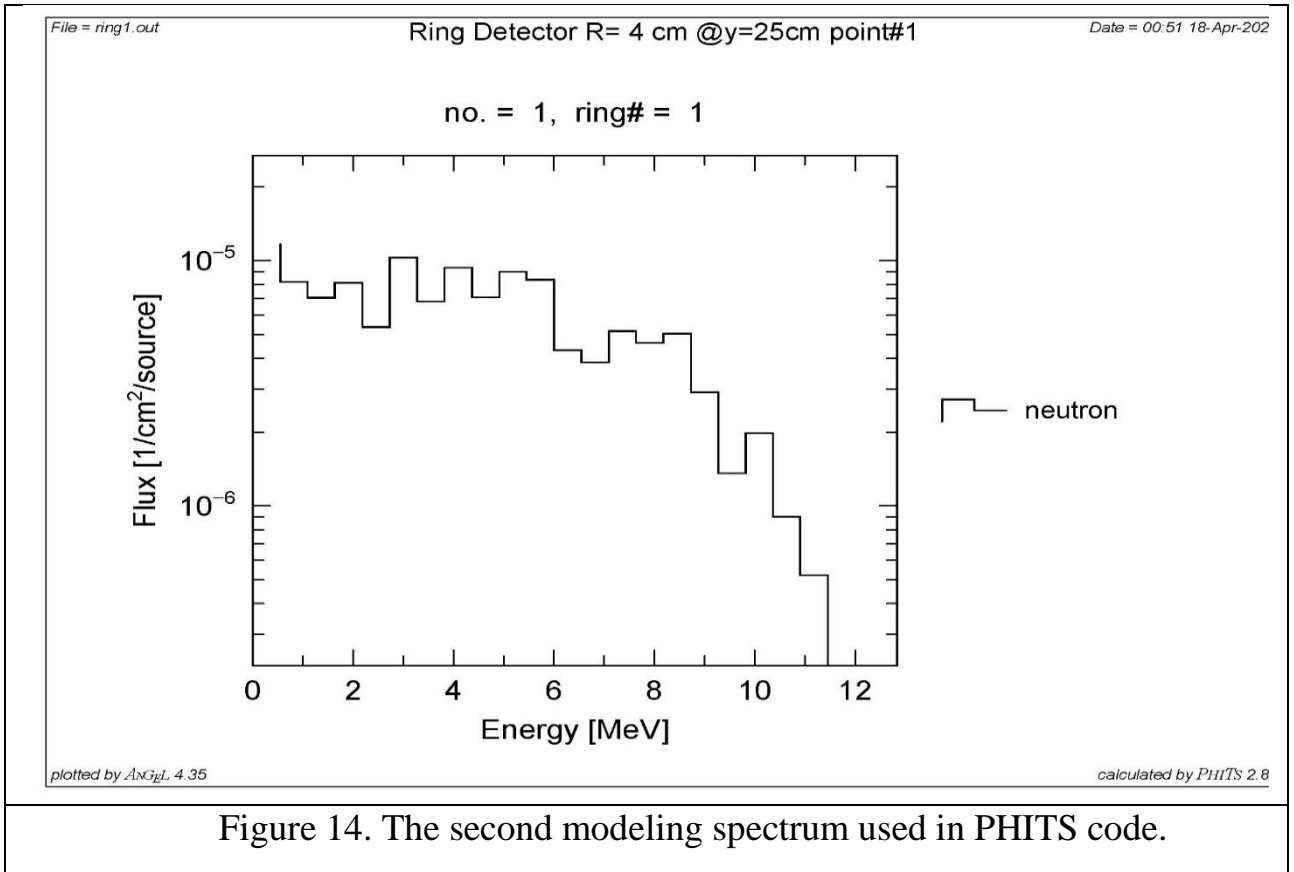


Figure 13. The first modeling spectrum used in PHITS code.



The number of energy groups were used is 22 groups. These groups were expressed as the neutrons energy range with the related weight probability of generating neutrons. The spectrum was tallied using the ring detector with diameter equal to 4 cm and it was tallied at a distance equal to 25 cm from the source.

### 2.4.3 Tally definition in PHITS

Tally functions were used in PHITS calculations to complete the task. Mainly three tallies (see section 2.4.3.1) were set to check the model in 2D and 3D track of particles through the calculation model geometry, simulation of a ring detector, simulation of a point detector and simulation of a volume detector

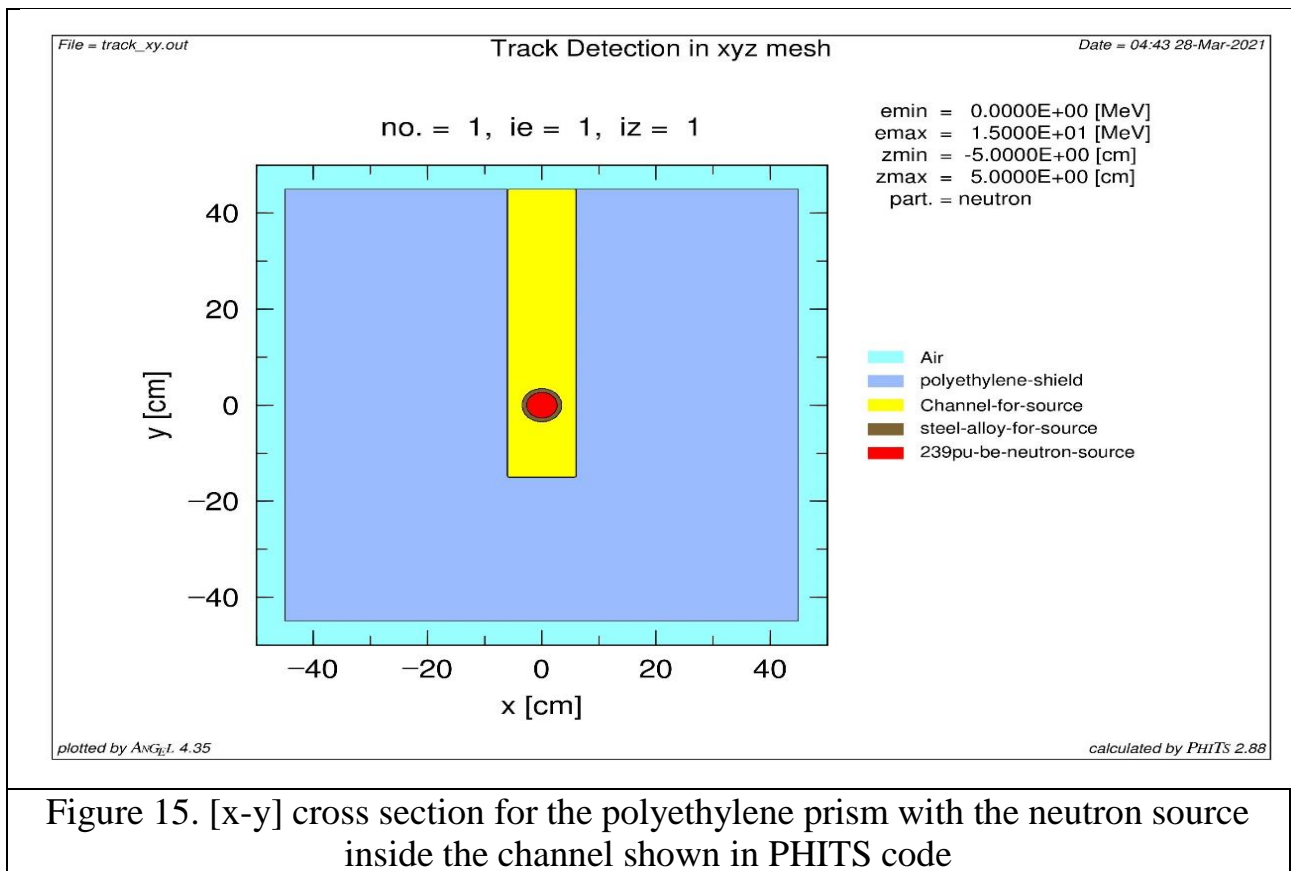
#### 2.4.3.1 [T-track] definition

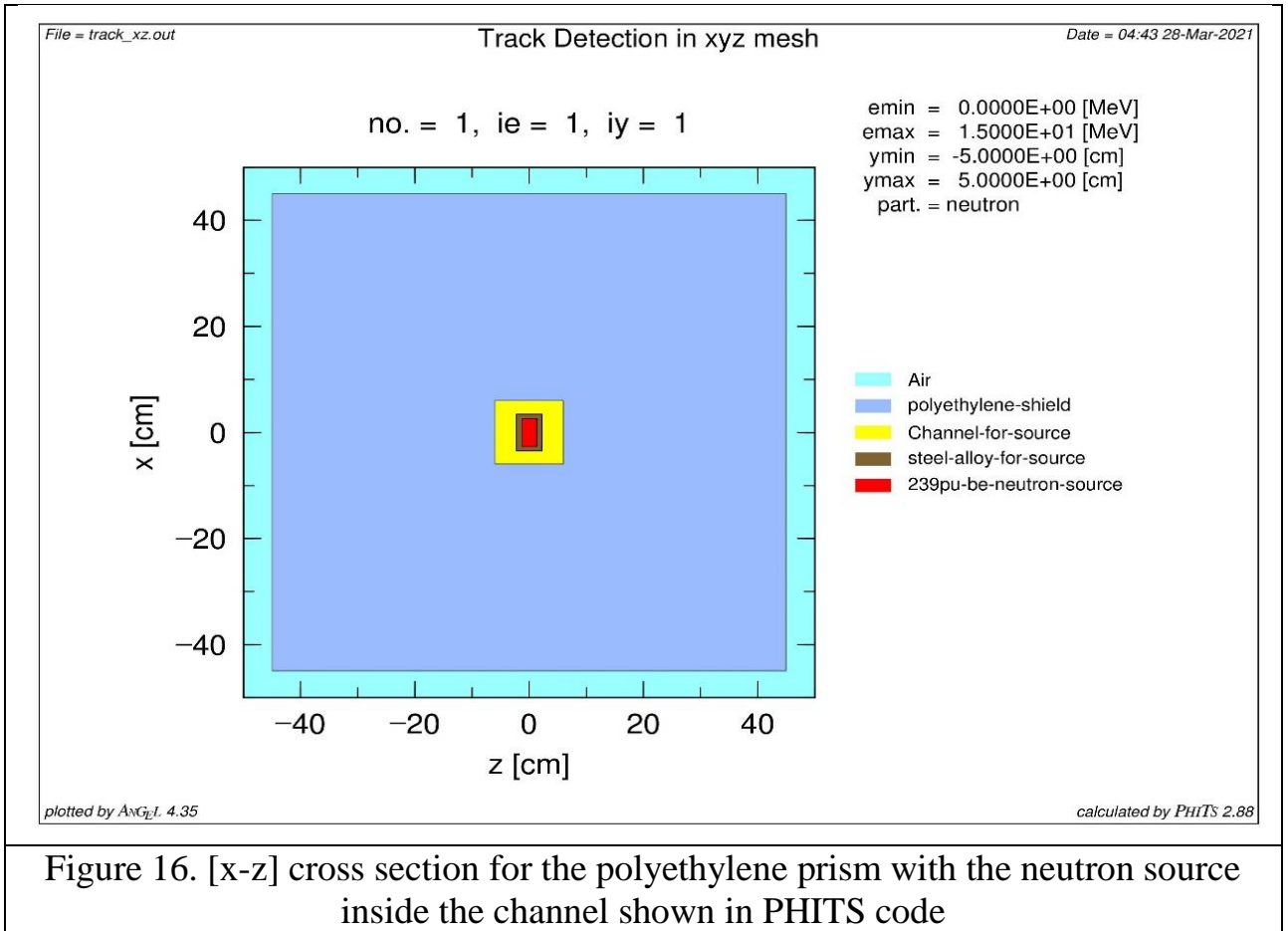
The main tally in PHITS-code is [T-track] and it has been used to do many functions such as:

- to check geometry errors by means of 2d checking tool;
- to drawing 2d layouts by g-show tool;
- to track neutrons propagation through the polyethylene prism and air;

- to draw graphs for neutron energy spectrum and flux distribution along axes x, y, z;
- To simulate of a volume detector.

Checking geometry using [T-track] by g-show option it is the first step after generating a model in PHITS code to avoid errors during calculations. First of all, the mode of PHITS code in the parameter section for geometry checking (incl=8) have to be adjusted (it is different from the normal operation mode (incl=0)). The axes of geometry checking should be also adjusted as xy or xz or yz. The borders of checking geometry need to be outline out of the prism borders to ensure that all calculations inside and outside the prism are considered by PHITS. Finally, PHITS generate an .eps file and an output file with errors descriptions and calculation results. This tally was repeated for xy plan and xz plan separately (any errors in geometry would marked in black for the geometry pictures). An example of the geometry checking is shown in fig.14 and fig.15.





The same case as the previous process was repeated for tracking neutrons inside the polyethylene shield using [T-track] and drawing the eps file showing neutron flux density in each region inside and outside the polyethylene shield, the only difference from checking geometry is that the mode of calculation was set to be the normal mode (inctl=0), the process was repeated for xy plan and xz plan separately. The results of [T-track] tally for particle transport are shown in the fig. 16, 17 below.

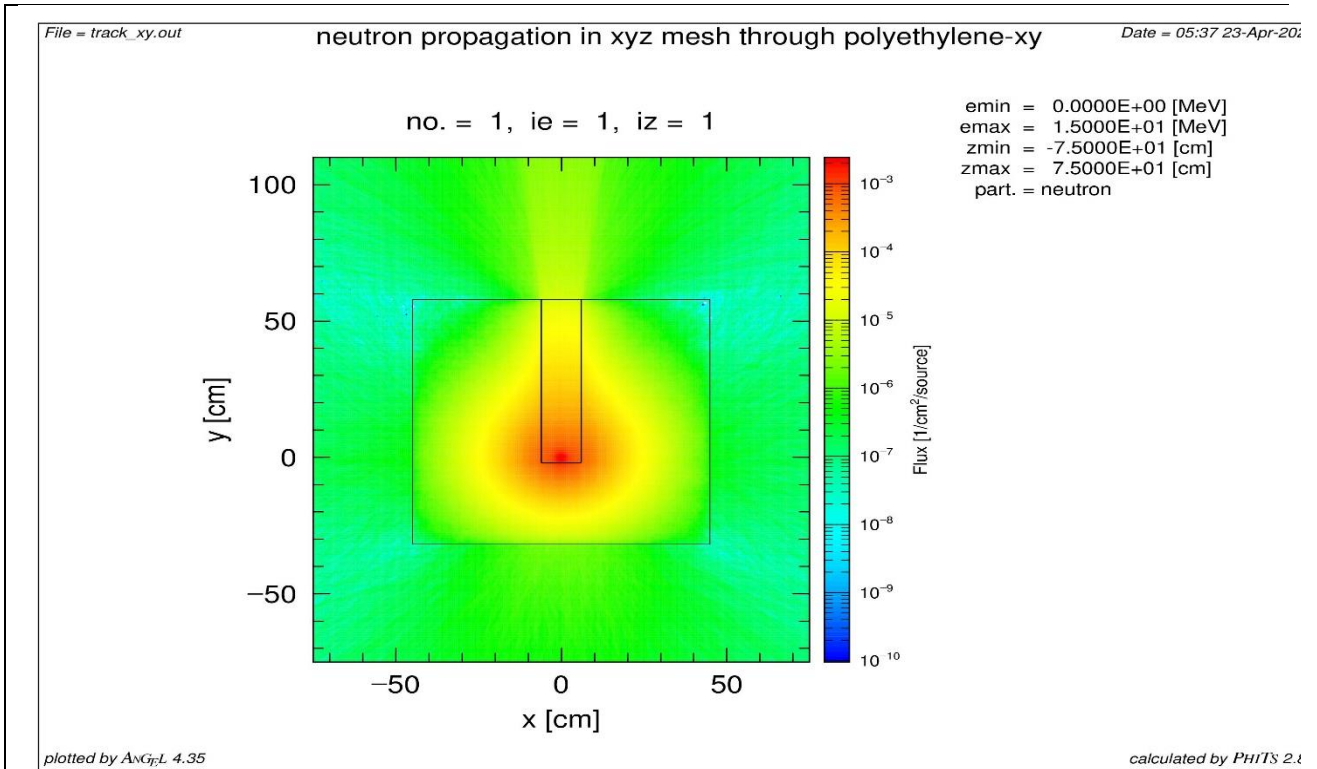


Figure 17. the neutron propagation through polyethylene shield in xy-plan

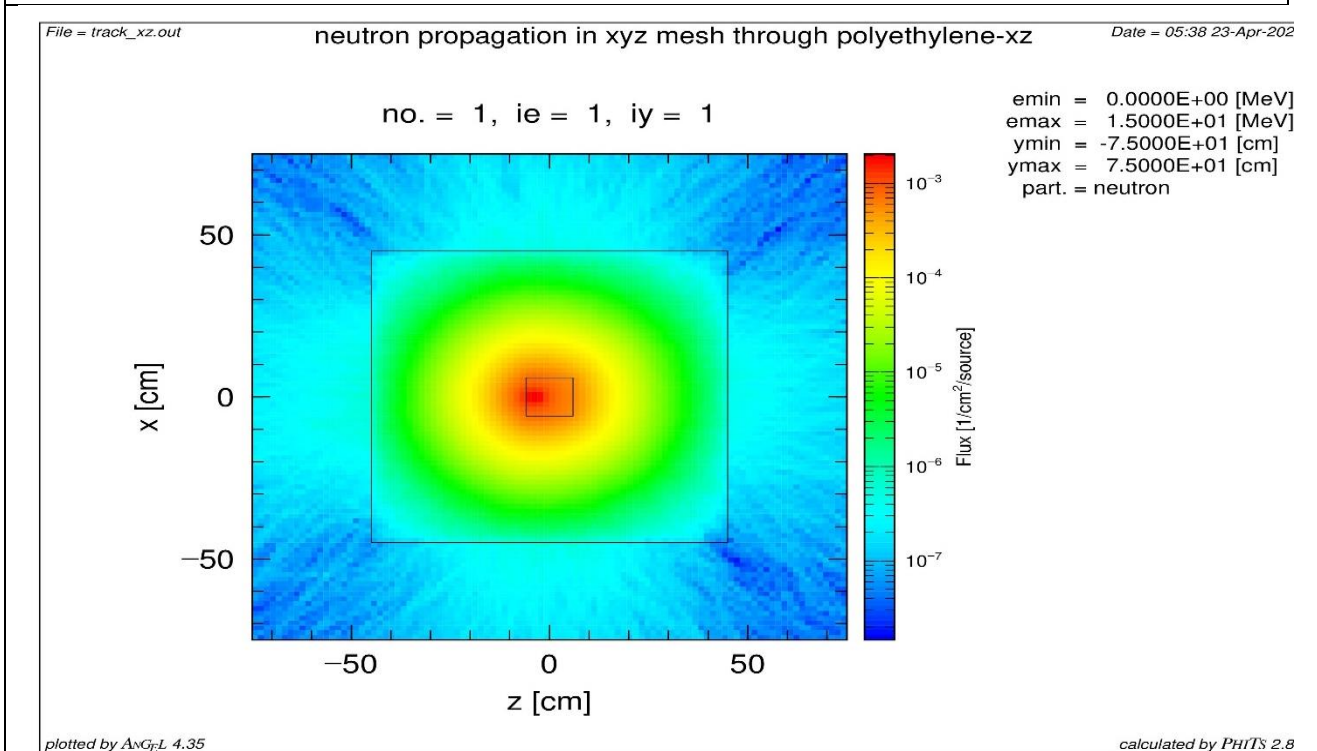


Figure 18. the neutron propagation through polyethylene shield in xz-plan

The [T-Track] tally was used to draw neutron flux distribution curves, The flux was distributed as a function of distance along x, y and z axes. The flux was tallied in both cases without the polyethylene shield and with the polyethylene shield

respectively. The results in the following graphs showed the effect of the polyethylene shielding for neutron attenuation in a short distance. There are some successive steps were followed to draw the flux distribution curves using [T-Track].

- Set the output axis to be x or y or z axis.
- Set the minimum and the maximum distance in cm.
- Set the energy range of neutrons.
- Set the calculation mode in PHITS.

In this task the flux was distributed on x, y and z axes separately, the minimum distance was set -45 cm and the maximum distance was set 45 cm, these distances are the outer dimensions of the polyethylene shielding prism, the energy range of neutrons was set from 0 to 15 Mev, the calculations was performed in the normal operation mode. The neutron flux distribution curves are shown in the figures from 18 to 23 below.

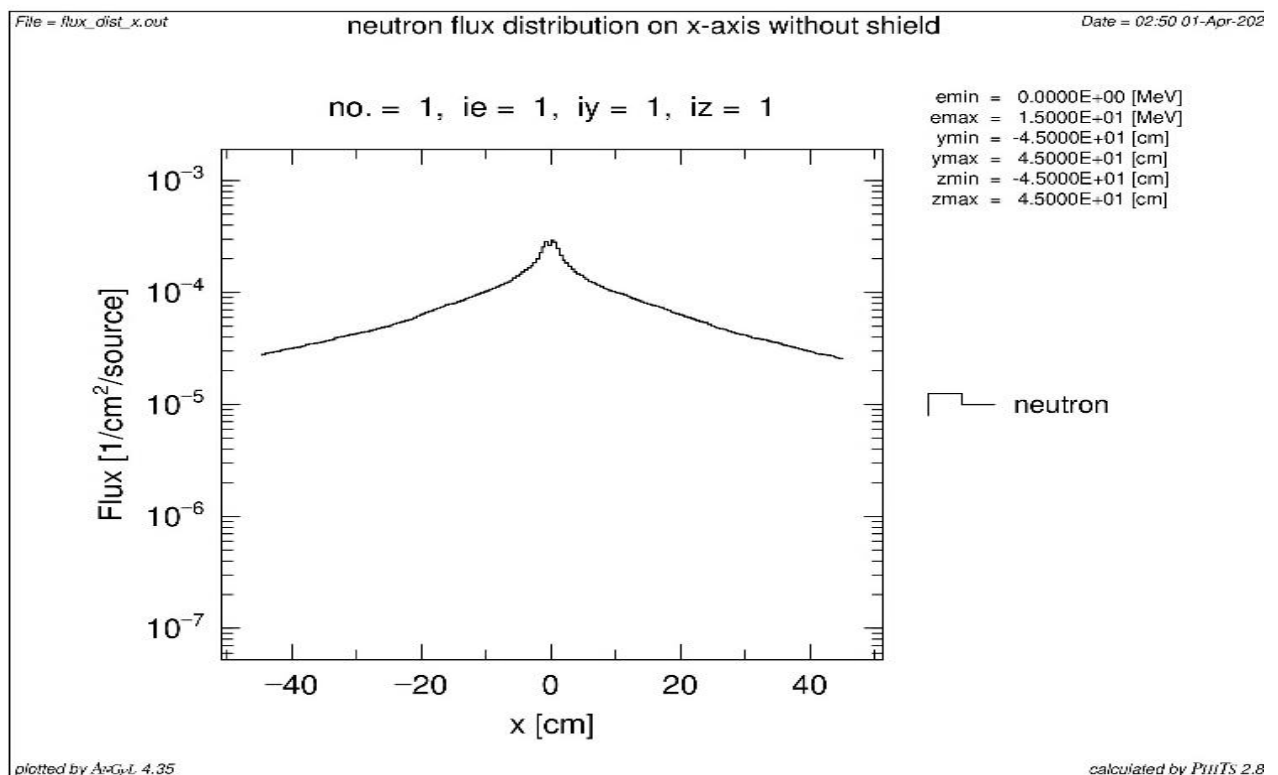


Figure 19. Neutron flux distribution on X axis without shielding



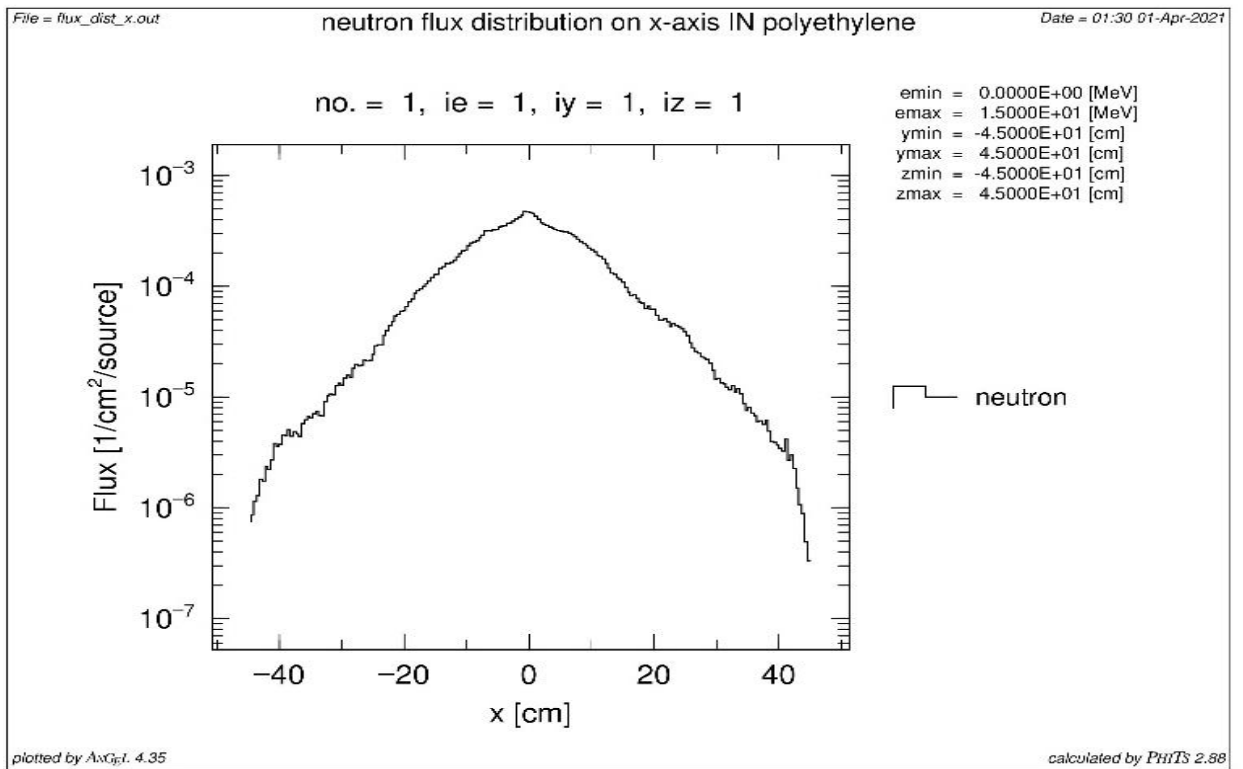


Figure 20. Neutron flux distribution on X axis with polyethylene shielding

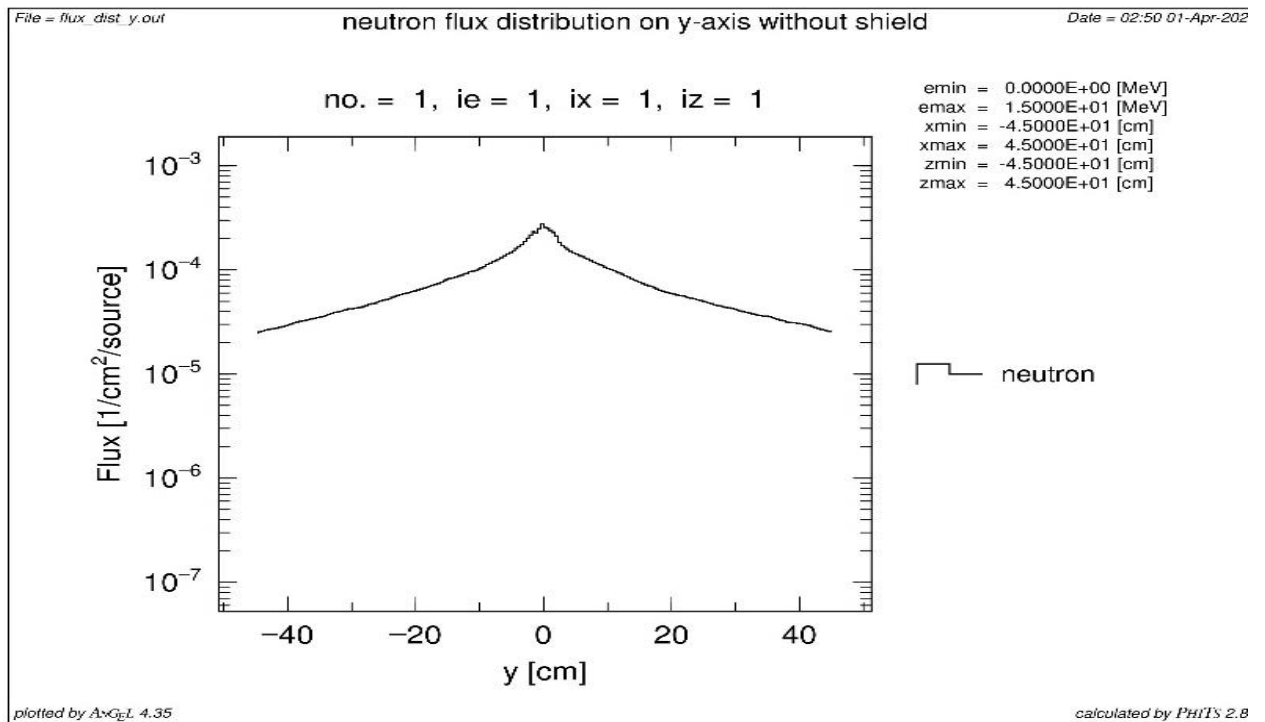


Figure 21. Neutron flux distribution on Y axis without shielding

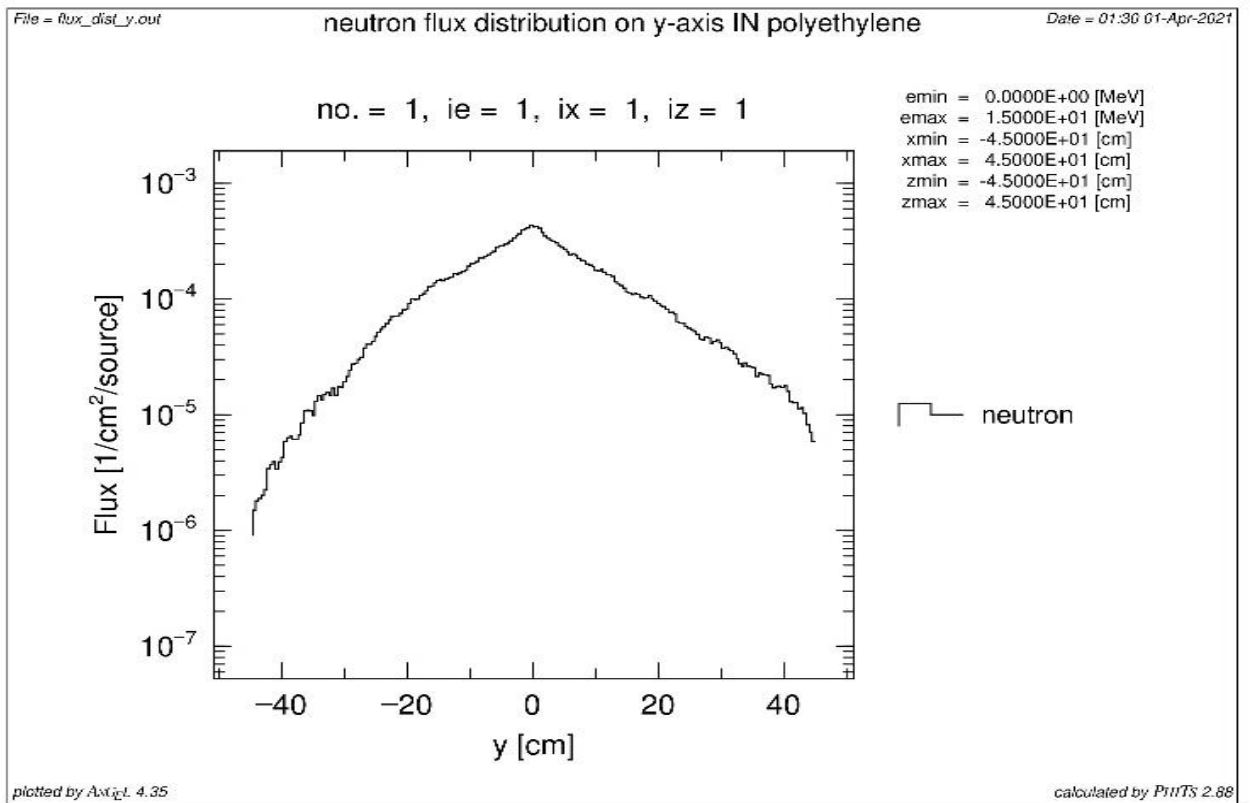


Figure 22. Neutron flux distribution on Y axis with polyethylene shielding

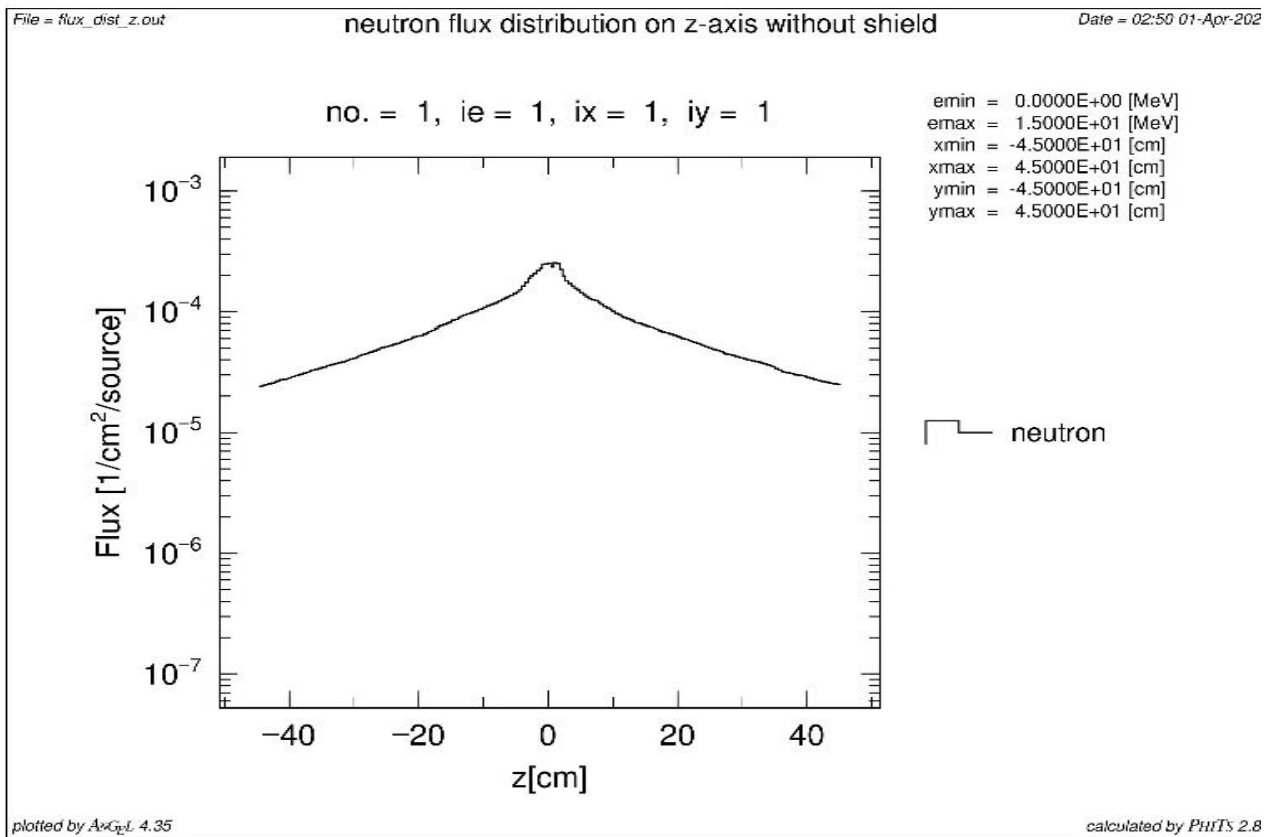


Figure 23. Neutron flux distribution on Z axis without shielding

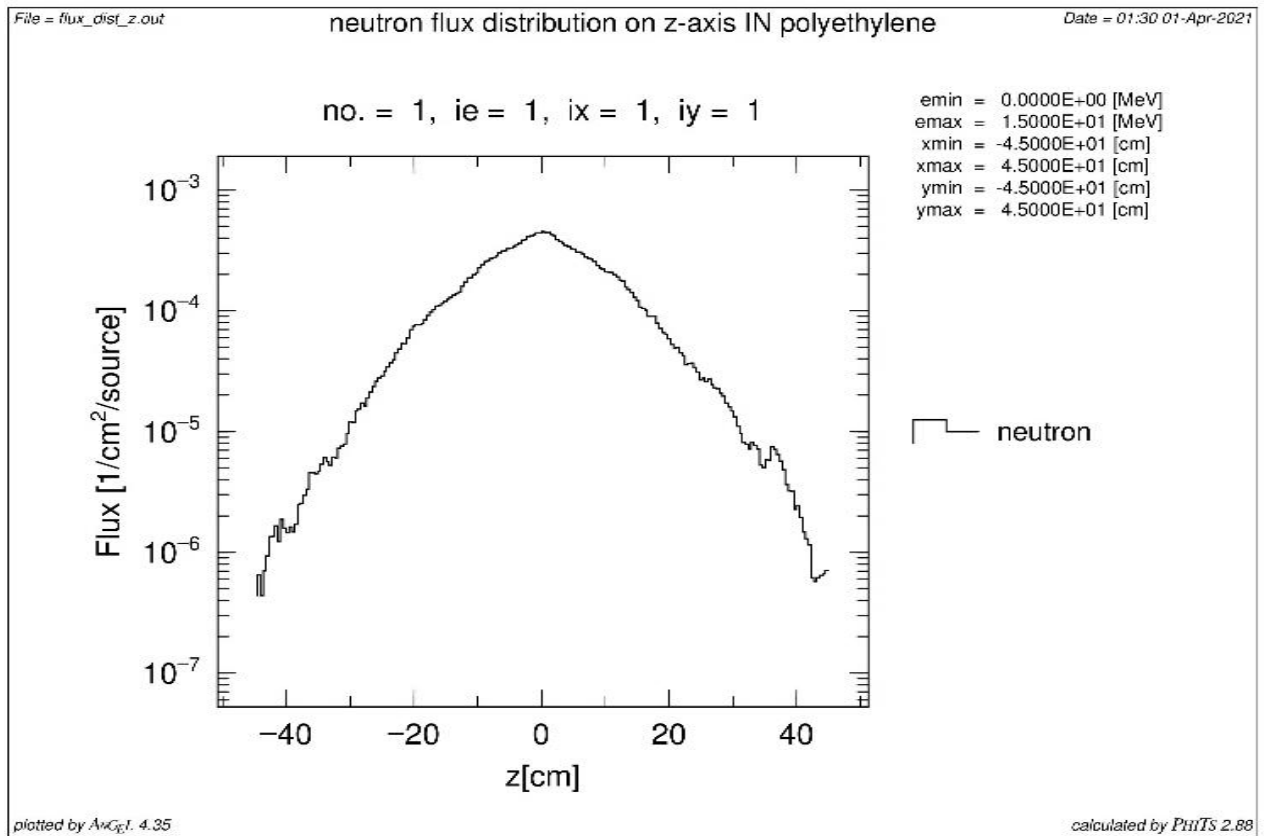


Figure 24. Neutron flux distribution on Z axis with polyethylene shielding

[T-Track] was used to simulate the volume detector. The accuracy of the volume detector is not high. The volume detector can give general expression in this work while the ring detector is more preferable because of its good accuracy. To simulate the volume detector the following steps were followed

- The output axis was set as energy.
- The energy range of neutrons was chosen.
- The number of groups was set.
- The volume of the detector in cm<sup>3</sup> was defined by coordinates in x, y and z.
- The type of the tracked particles was set.
- The unit of the flux on the vertical axis was set.
- The calculation mode was set.

In this task the energy range was set from  $10^{-11}$  Mev to 12 Mev. The number of groups is 2 groups. The volume of the detector was set as the same volume of the polyethylene shielding prism. The type of the tracked particles are neutrons. The unit

of flux is (1/cm<sup>2</sup>/source) as a probability. The calculations were performed in the normal mode. The volume detector result is shown in the fig 24 below.

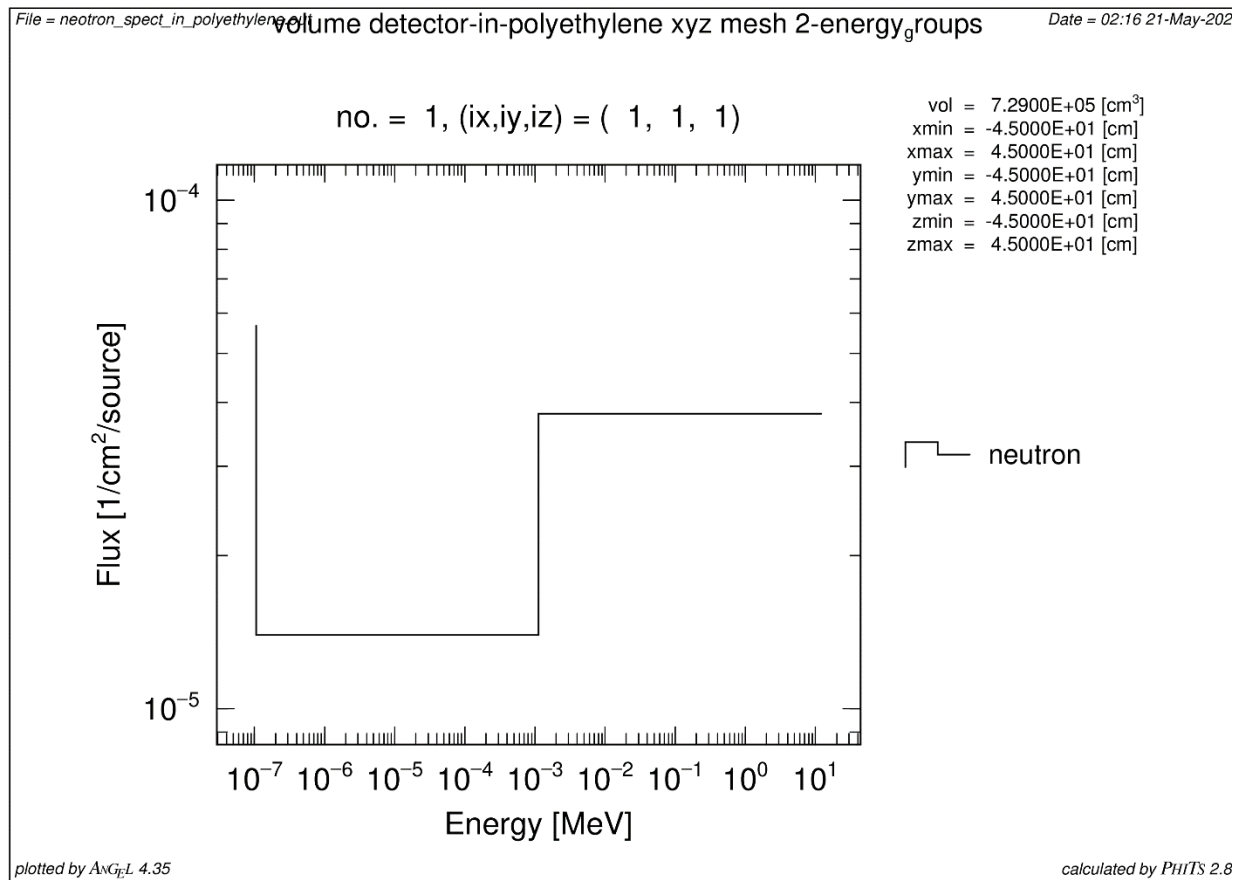


Figure 25. Neutron flux using the volume detector.

#### 2.4.3.2 [T-3dshow] definition

This tally is a one purpose tally, it was used to check the geometry in 3d by a special mode in PHITS, to use this tally in a right manner the borders of the graph were set, the direction to the heaven (the up direction) was set as z-direction, all angles are to be set for the suitable view, the result of [T-3dshow] tally is shown in the following picture.

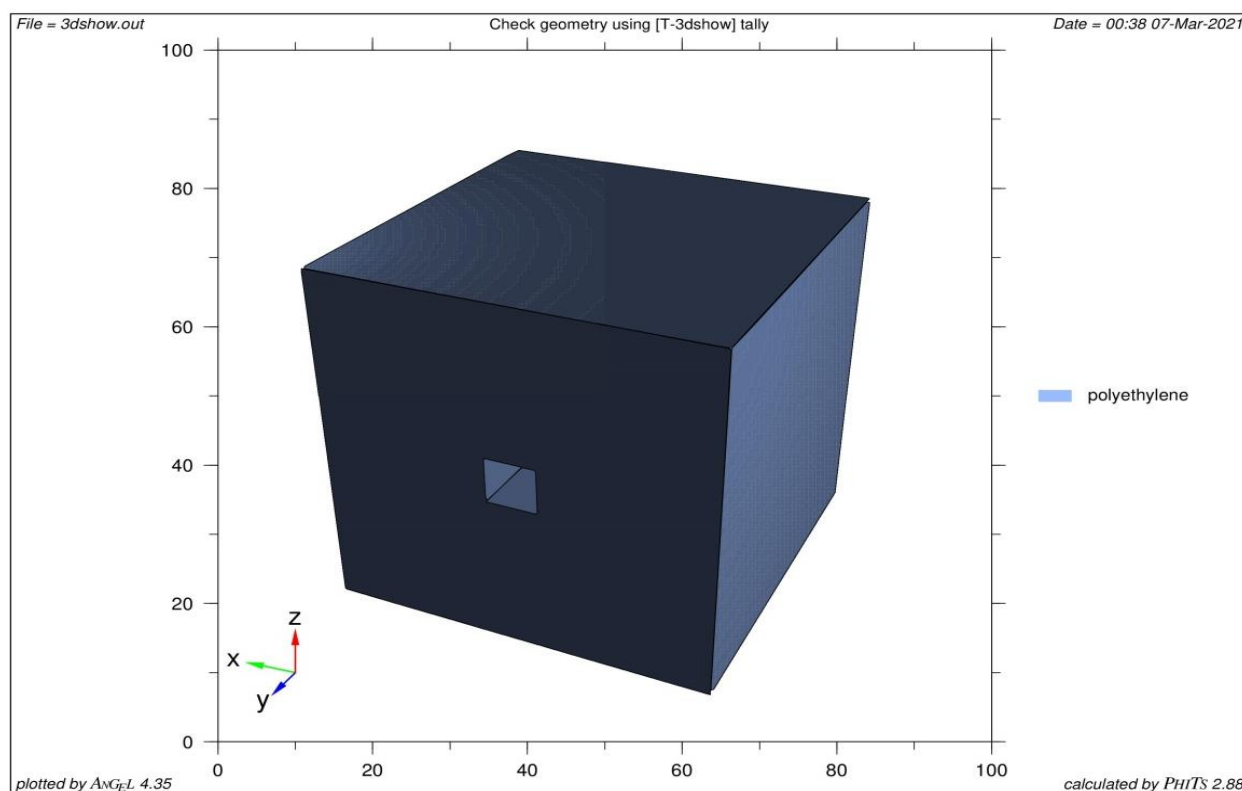


Figure 26. 3d view of prism of polyethylene shield with the channel shown in PHITS code by [T-3dshow] tally.

### 2.4.3.3 [T-point] definition

The most important tally in this task and it was used to calculate neutron flux density at many distances from the center of the cylindrical Pu-be neutron source, this tally was developed to tally only neutrons and photons but with higher reliability than [t-track] and other tallies that could be used to calculate neutron flux density.

To use [T-point] tally to simulate the point detector and the ring detector at any distance, the axis was set also the distance and was set every 1 cm from the front face of the polyethylene prism for ring detector also the ring radius was set to be 2 cm as a real detector finally the particle to be tallied was set as neutron.

The point detector is the same as ring detector but with more flexibility in choosing the location of detector by setting the point co-ordinates in x, y, z but the problem with this tally is that it need to be compared was too accurate experimental results specially in the location of the detector and this is logic because it is a point and it is not an easy task to set the detector by co-ordinates in the laboratory.

## **chapter 3. Results and discussion**

### **3.1 Calculation and measurement of neutron field parameters**

#### **3.1.1 PHITS calculations**

The neutron flux density was tallied by [T-point] tally in PHITS code every 1cm from the front face of the polyethylene shield, the point detector and the ring detector were included by this tally and they were tallied separately in two tally functions. The maximum number of points or rings to be defined in one [T-point] tally is 20 points so that, the total [T-point] tallies used for calculating the following results are 4 tallies functions.

The point detector was defined by co-ordinates x, y, z. All points were tallied on Y axis so X=0 and Z=0 for all points.

The ring detector was defined by axis and distance from the origin, all rings were tallied on Y axis so only the distance was changed as steps every 1cm and the ring radius was set to be 2 cm as the detector on the laboratory of TPU.

The tallied particle was defined as only neutron and the neutron energy range was divided into 3 groups. The intermediate group was neglected to take only the 2 groups because the laboratory detector can respond only for these two groups. These two groups are (0.025ev – 1ev) for the thermal group and ( $10^{-3}$ Mev – 14Mev) for the fast group. The epithermal neutron group with energy range (higher than 1ev – lower than  $10^{-3}$ Mev) was neglected. The following tables show all the results for this case of calculations for two different energy spectrums.

Table 3. 1 PHITS calculation results in case of the first neutron spectrum.

distance (cm)	Neutron flux (n.cm <sup>-2</sup> .s <sup>-1</sup> ) for the thermal neutron group (0.025 ev- 1 ev)		Neutron flux (n.cm <sup>-2</sup> .s <sup>-1</sup> ) for the fast neutron group (1 kev-12 Mev)	
	Point detector	Ring detector	Point detector	Ring detector
0	420.7 ±0.021	416.1 ±0.022	418.9 ±0.009	416.5 ±0.013
1	373.5 ±0.021	371.7 ±0.019	398.9 ±0.01	397.7 ±0.011
2	328.9 ±0.022	324.0 ±0.023	384.8 ±0.01	379.8 ±0.009
3	293.3 ±0.022	288.2 ±0.023	367.8 ±0.009	362.3 ±0.007
4	261.3 ±0.016	254.6 ±0.026	349.3 ±0.008	347.9 ±0.010
5	235.4 ±0.026	230.0 ±0.025	336.2 ±0.008	332.0 ±0.009
6	204.8 ±0.023	202.1 ±0.024	321.9 ±0.009	319.4 ±0.007
7	185.7 ±0.020	183.2 ±0.021	303.3 ±0.007	305.2 ±0.008
8	169.4 ±0.020	165.3 ±0.025	293.1 ±0.007	288.1 ±0.008
9	152.7 ±0.017	148.6 ±0.022	281.9 ±0.008	280.7 ±0.007
10	138.6 ±0.021	135.2 ±0.019	269.9 ±0.008	268.2 ±0.008
11	126.8 ±0.014	125.8 ±0.018	259.0 ±0.006	257.5 ±0.007
12	117.3 ±0.018	115.5 ±0.015	248.9 ±0.006	247.1 ±0.006
13	107.9 ±0.018	105.6 ±0.019	238.1 ±0.007	238.3 ±0.008
14	99.9 ±0.018	98.8 ±0.019	230.3 ±0.005	228.9 ±0.006
15	91.7 ±0.016	90.8 ±0.017	222.0 ±0.005	218.9 ±0.006
16	86.6 ±0.012	86.3 ±0.015	214.4 ±0.005	213.0 ±0.005
17	81.3 ±0.013	80.4 ±0.016	206.3 ±0.004	205.9 ±0.004
18	75.7 ±0.013	75.5 ±0.016	199.8 ±0.005	198.5 ±0.006
19	71.2 ±0.011	71.5 ±0.012	193.8 ±0.004	192.6 ±0.008
20	67.3 ±0.008	67.4 ±0.009	186.9 ±0.005	187.5 ±0.005
21	64.0 ±0.012	63.7 ±0.013	182.0 ±0.004	180.8 ±0.004
22	60.4 ±0.009	60.6 ±0.006	175.6 ±0.004	174.7 ±0.004
23	56.8 ±0.008	57.2 ±0.009	170.2 ±0.004	169.3 ±0.004
24	54.4 ±0.012	55.0 ±0.009	165.6 ±0.004	164.7 ±0.003
25	51.7 ±0.011	51.6 ±0.010	160.5 ±0.003	159.9 ±0.004
26	49.2 ±0.011	48.9 ±0.012	156.0 ±0.004	154.9 ±0.004
27	46.6 ±0.010	46.3 ±0.015	151.5 ±0.002	150.9 ±0.002
28	44.6 ±0.009	44.6 ±0.014	147.4 ±0.004	147.4 ±0.004
29	43.0 ±0.009	41.8 ±0.012	143.6 ±0.002	144.2 ±0.003
30	41.5 ±0.015	40.5 ±0.013	139.7 ±0.003	139.4 ±0.004

Table 3. 2 PHITS calculation results in case of the second neutron spectrum.

distance (cm)	Neutron flux (n.cm <sup>-2</sup> .s <sup>-1</sup> ) for the thermal neutron group (0.025 ev- 1 ev)		Neutron flux (n.cm <sup>-2</sup> .s <sup>-1</sup> ) for the fast neutron group (1 kev-12 Mev)	
	Point detector	Ring detector	Point detector	Ring detector
0	507.6 ±0.016	498.6 ±0.011	417.9 ±0.009	419.6 ±0.009
1	443.3 ±0.018	446.6 ±0.021	401.5 ±0.01	399.0 ±0.007
2	400.0 ±0.015	387.4 ±0.021	386.7 ±0.008	385.0 ±0.011
3	352.8 ±0.015	345.3 ±0.022	366.8 ±0.008	364.4 ±0.010
4	316.8 ±0.016	305.0 ±0.019	351.8 ±0.008	349.7 ±0.008
5	287.2 ±0.028	273.5 ±0.014	336.1 ±0.007	332.2 ±0.006
6	256.0 ±0.028	248.7 ±0.028	319.7 ±0.007	321.3 ±0.007
7	230.8 ±0.034	220.3 ±0.017	306.6 ±0.006	302.9 ±0.007
8	203.5 ±0.014	199.3 ±0.012	293.2 ±0.005	290.7 ±0.006
9	181.9 ±0.013	183.3 ±0.017	279.5 ±0.008	279.7 ±0.008
10	167.1 ±0.014	165.8 ±0.019	270.7 ±0.006	268.9 ±0.005
11	153.5 ±0.014	149.4 ±0.016	259.2 ±0.005	257.3 ±0.007
12	142.6 ±0.021	139.5 ±0.017	248.4 ±0.006	247.9 ±0.005
13	129.4 ±0.015	128.1 ±0.014	239.4 ±0.006	236.9 ±0.006
14	121.0 ±0.014	119.7 ±0.015	230.1 ±0.005	230.4 ±0.005
15	113.3 ±0.015	111.6 ±0.014	221.9 ±0.007	220.8 ±0.004
16	105.4 ±0.015	104.3 ±0.015	214.5 ±0.005	213.6 ±0.006
17	99.1 ±0.013	98.3 ±0.017	207.6 ±0.004	205.1 ±0.004
18	93.3 ±0.017	93.1 ±0.021	199.9 ±0.005	199.6 ±0.005
19	88.5 ±0.022	88.9 ±0.028	193.3 ±0.005	192.6 ±0.004
20	84.7 ±0.035	82.5 ±0.022	187.2 ±0.004	185.2 ±0.005
21	80.6 ±0.036	79.7 ±0.022	181.2 ±0.003	179.8 ±0.003
22	74.1 ±0.022	73.9 ±0.019	179.1 ±0.003	174.5 ±0.005
23	70.3 ±0.017	70.5 ±0.016	170.7 ±0.003	170.7 ±0.004
24	66.3 ±0.013	66.4 ±0.017	164.9 ±0.004	164.9 ±0.004
25	63.2 ±0.012	62.3 ±0.013	160 ±0.004	159.9 ±0.005
26	60.7 ±0.013	59.2 ±0.018	156.1 ±0.004	155.5 ±0.004
27	57.7 ±0.013	57.7 ±0.011	151.8 ±0.003	150.1 ±0.003
28	55.2 ±0.014	55.1 ±0.014	147.4 ±0.002	147.3 ±0.004
29	52.3 ±0.013	52.1 ±0.012	143.3±0.003	143.2 ±0.005
30	50.5 ±0.016	49.7 ±0.011	139.2±0.003	139.6 ±0.005



### 3.1.2 Measurements

Measurements of neutron flux produced by Pu-be neutron source was carried out in the TPU laboratory, the measurements were done using MKS-01R radiometer-dosimeter with the detection unit BDKN-03 which was described previously, the MKS-01R device was connected to a power supply with voltage 13.3 volts and a current 0.07 A, the BDKN-03 detector was installed on a metal stand and was located in the front of the channel to measure the thermal neutron flux, the BDKN-03 detector was modified with the cadmium sphere to measure fast neutron flux, the following photos show the detector during measurements.

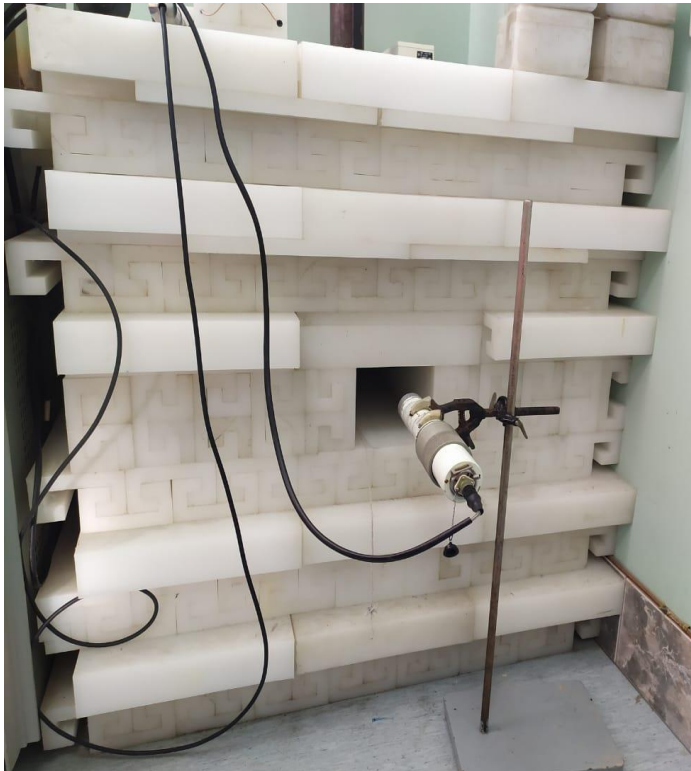


Figure 27. The detector position during measurements of thermal neutrons flux.



Figure 28. The detector position during measurements of fast neutrons flux.

The neutron flux density for thermal neutron group was measured in the front of the channel at distances 0, 10, 20, 30 cm from the front face of the polyethylene prism, for fast neutron group the neutron flux was measured at distances 20, 30cm from the front face of the prism as shown in the following scheme.

Ten measurements were taken for each point and the average value of neutron flux was calculated by the formula:

$$\text{Average value of flux}(x') = \frac{\sum \text{flux}}{\text{number of measurements}}$$

The standard deviation for each point was calculated by the formula:

$$SD = \sqrt{\frac{\sum |x - x'|^2}{n}}$$

Where:

SD: standard deviation value

X: the measured value of neutron flux

X': the average value of neutron flux

n: number of measurements

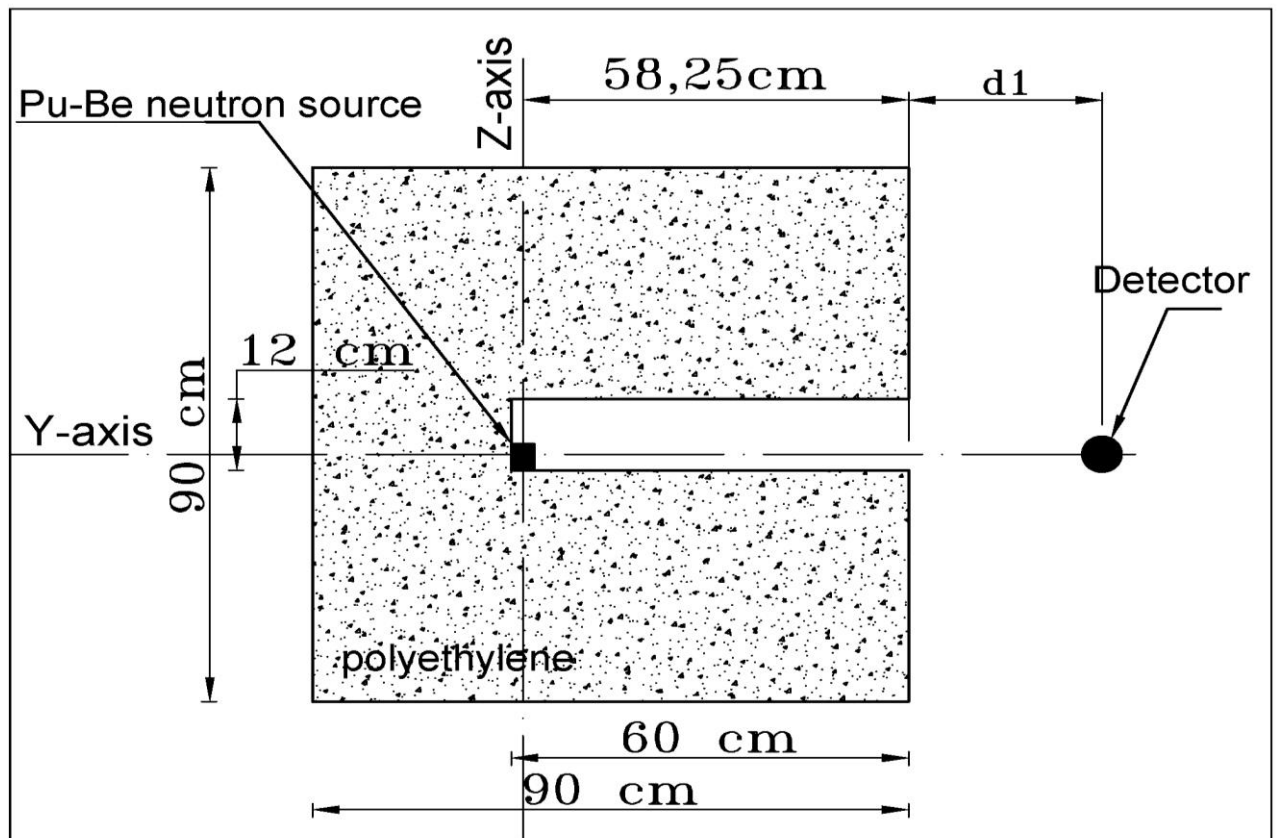


Figure 29. General scheme for laboratory model Y-Z cross-section (side view).

Table 3. 3 measurements results.

Point no	1	2	3	4	5
Distance d1 (cm)	0	5	10	20	30
Measured neutron flux for thermal group (n.cm <sup>-2</sup> .s <sup>-1</sup> )	503 ±14.68	292.9 ±15.81	190.7 ±9.59	104.6 ±7.03	64.5 ±3.64
Measured neutron flux for fast group (n.cm <sup>-2</sup> .s <sup>-1</sup> )	-	-	-	205.02 ±4.83	152.09 ±5.11

### 3.2 Results analysis performance

The calculation were done using PHITS 2.88 with the nuclear data library JENDL-4.0 on a computer machine which have a processor unit from the type core i5 2.4 GHz.

The calculations made by PHITS-code shows high reliability when we compare these results with the measured values in the laboratory

#### 3.2.1 Results comparison

The calculation results from the first and the second neutron spectrums were compared with the measurements. The calculation results from the second neutron spectrum showed more reliability comparing to the measurements.

#### Case1 (the first spectrum)

Table 3. 4 Comparison between calculated and measured thermal neutron flux in front of the channel (Case 1)

Distance d1(cm)	Measured	PHITS point detector	PHITS ring detector	Coincidence
0	503 ±14.68	420.7 ±0.021	416.1 ±0.022	17.29 %
5	292.9 ±15.81	235.4 ±0.026	230 ±0.025	21.23 %
10	190.7 ±9.59	138.6 ±0.016	135.2 ±0.019	29.10 %
20	104.6 ±7.03	67.3 ±0.008	67.4 ±0.009	35.56 %
30	64.5 ±3.64	41.5 ±0.015	40.5 ±0.013	37.2 %

Table 3. 5 Comparison between calculated and measured fast neutron flux in front of the channel (Case 1)

Distance d1(cm)	Measured	PHITS point detector	PHITS ring detector	Coincidence
20	205.03 ±4.83	186.9 ±0.005	187.5 ±0.005	9.26 %
30	152.09 ±5.11	139.7 ±0.003	139.4 ±0.004	8.34 %

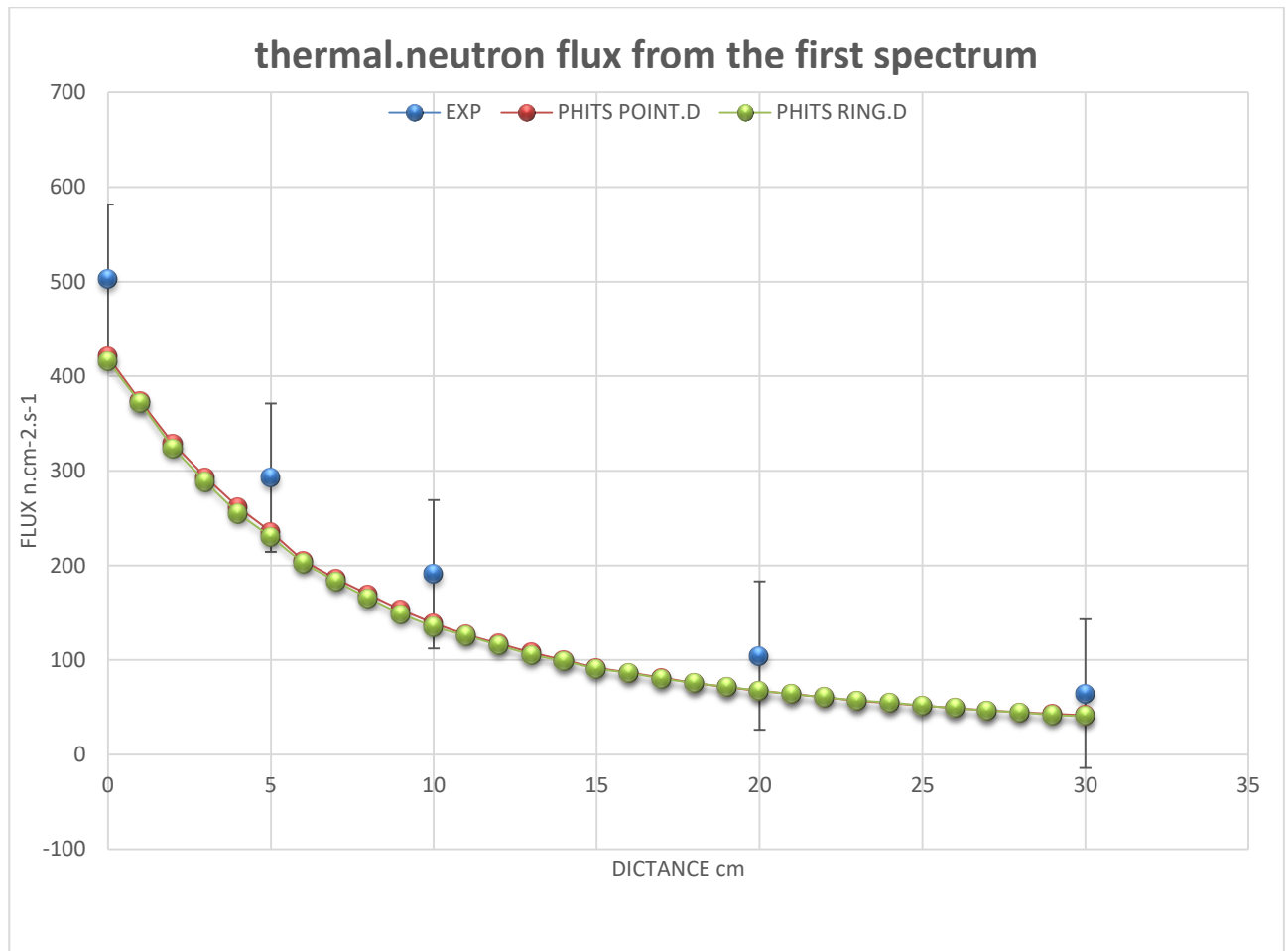


Figure 30. The flux distribution of thermal neutrons for both measured and calculated values (Case 1)

### Case 2 (the second spectrum)

The comparison between calculation and measurement according to the second spectrum would be discussed in this section because the calculation results according to the first spectrum were not accepted due to the big coincidence we will discuss the this factors of uncertainty later in this part but firstly it's important to see the following table for comparison between the calculated values and experimental values.

Table 3. 6 Comparison between calculated and measured thermal neutron flux in front of the channel (Case 2)

Distance d1(cm)	Measured	PHITS point detector	PHITS ring detector	Coincidence
0	503 ±14.68	507.6 ±0.016	498.6 ±0.011	0.99 %
5	292.9 ±15.81	287.2 ±0.028	273.5 ±0.014	6.62 %
10	190.7 ±9.59	167.1 ±0.014	165.8 ±0.019	13 %
20	104.6 ±7.03	84.7 ±0.035	82.5 ±0.022	20.6 %
30	64.5 ±3.64	50.5 ±0.016	49.7 ±0.011	22.9 %

Table 3. 7 Comparison between calculated and measured fast neutron flux in front of the channel (Case 2)

Distance d1(cm)	Measured	PHITS point detector	PHITS ring detector	Coincidence
20	205.03 ±4.83	187.2 ±0.004	185.2 ±0.005	9.75 %
30	152.09 ±5.11	139.2 ±0.003	139.6 ±0.005	8.55%

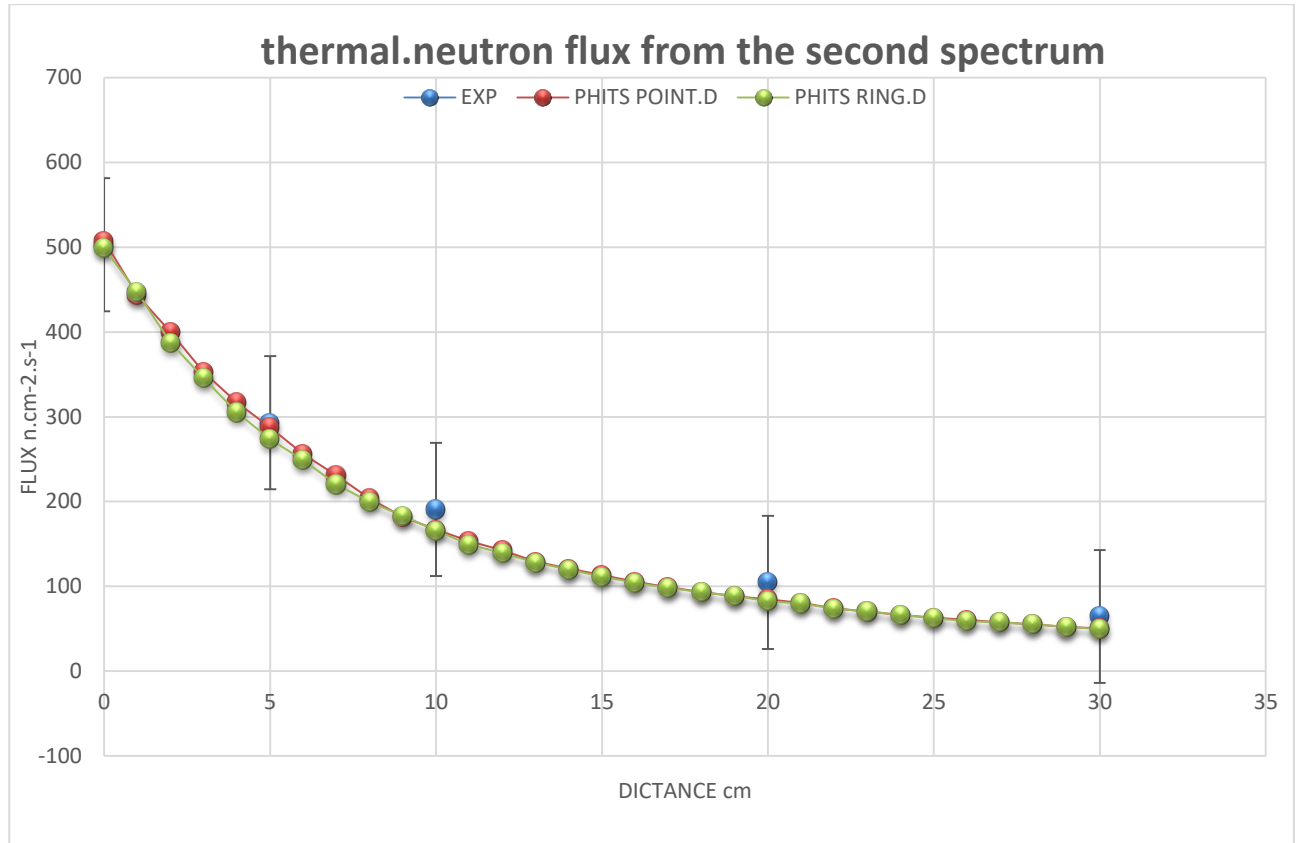


Figure 31. The flux distribution for thermal neutrons for both measured and calculated values (Case 2)

The neutron flux for fast neutrons was only measured at distances 20 cm and 30 cm because it is not possible to place the detector with the cadmium sphere more close because of the sphere dimensions.

### 3.2.2 Sources of uncertainty

The sources of uncertainty in this work affected the measurements as well as affecting the calculations and they are the reason for some deviation between the measurements and the calculations, the sources of uncertainty could be divided into two groups, the first group of uncertainty produces errors in PHITS calculations and the second group of uncertainty produces error in measurements, the first group of uncertainty caused by the missing initial data from the attached documents with the source and the detector, the second group of uncertainty produced by the devices error such as the distance measurements devices and the detector error  $\pm 20\%$ .

The main factor which can give totally different values of calculation and not acceptable results from PHITS is the initial data input to the code for example from

this work the neutron energy spectrum for the Pu-be source, as we mentioned in the source description that there are a missing initial data which should be attached with the source passport, to overcome this problem common energy spectrums from references were used and the first spectrum shows very close calculated results comparing to the measurements of the fast neutrons flux at the same time the thermal flux values from calculation were lower than the measurements, another neutron energy spectrum was used as an input data in the source definition in PHITS, the second spectrum showed very close calculation results to the measurements in both thermal and fast neutrons flux, the main difference between the second spectrum and the first spectrum is the probability of the neutrons flux for the neutrons with energy below 2 Mev as it was shown in the spectrum figures 10, 11 this probability is higher at the second spectrum.

The main factor of uncertainty is the initial data errors as mentioned in case of the spectrum, the results were not accepted for calculations which were done according to the first spectrum, the second factor which is considered a source of uncertainty is the accuracy in the measurement of the distance  $d_1$  during neutron flux measurements to avoid this factor and make the discussion about the results more clear the flux was calculated by two different types of detectors in PHITS every 1 cm from the distance  $d_1=0$  cm till  $d_1=30$ cm. The difference between the neutron flux at  $d_1=0$  cm and  $d_1=1$  cm is 64 for thermal neutrons and around 17 for the fast neutron this can show the big effect of the distance on the neutron flux especially for the thermal neutrons, it should be mentioned that the accuracy of 1 cm couldn't be achieved during measurements in TPU laboratory because the used tools were not accurate enough especially in determining the position of the detector this will appear more in the distances 20 cm and 30 cm which show an error nearly +2.5 to +3 cm, the error in distance will affect the measurements of both thermal and fast neutron flux separately, by another word the value of distance error during measurements are not the same for fast and thermal neutrons because the fast neutron flux and the thermal neutron flux are measured in two different position one position with the cadmium sphere in case of fast neutron

flux and the other position without the sphere for measuring the thermal flux, any change in distance could happen during installing or removing the cadmium sphere.

Another source of uncertainty during measurements is the reflected neutrons from the surrounding objects in the laboratory and from the laboratory walls, this source of uncertainty will affect only the value of thermal neutron flux because the reflected neutrons are thermal and they will increase the total measured value of thermal neutron flux, the reflected neutrons have lower effect than the error in the distance  $d_1$  but it should be mentioned.

The previous mentioned sources of uncertainty were not 100% fixed but other sources of uncertainty were prevented during calculation, these sources are as follow:

The energy range for every neutron group was considered during PHITS calculation because in the real life the detector BDKN-03 energy range for the thermal neutron group is 0.025 eV and for fast neutrons group is ( $10^{-3}$  Mev – 14 Mev)

The energy range was divided in PHITS to simulate the same case as the real detector and the middle part of neutron flux values ( $10^{-6}$  Mev- $10^{-3}$  Mev) was neglected for more reliability.

The radius of the detector is another source of uncertainty which was prevented, the radius for the real detector is 2 cm and this will consider only a specific surface during measurements so using different type of detector with different dimensions will be considered a factor of uncertainty, to avoid this source of uncertainty ring detector with the same radius of the real detector has been used during calculations using PHITS and also point detector has been used.

PHITS mode of calculation and parameters set during calculation has the main effect on the results of calculations and changing the parameters in PHITS such as history number and batch number affect directly on the accuracy of PHITS results, increasing the history number increases the number of iterations done by PHITS and this increases the accuracy of calculations but on the other side this need much processing time and a powerful machine, also another parameter in PHITS can give totally wrong calculations depending on the energy range of particles, in our task the low energy neutrons were considered as the incident particles in PHITS with energy



lower than 20 Mev so its recommended by PHITS developer to use nuclear data library JENDL-4.0 instead of nuclear interaction models intra-nuclear cascade (INCL4.6) which is the default option in PHITS 2.88.

## **chapter 4. Financial management, resource efficiency and resource conservation**

For any research work it is highly important to discuss some issues which are related to the issues of competitiveness, resource efficiency and resource saving, as well as financial costs regarding the object of study of Master's thesis. Competitiveness analysis is carried out for this purpose. SWOT analysis helps to identify strengths, weaknesses, opportunities and threats associated with the project, and give an idea of working with them in each particular case. For the development of the project requires funds that go to the salaries of project participants and the necessary equipment, a complete list is given in the relevant section. The calculation of the resource efficiency indicator helps to make a final assessment of the technical decision on individual criteria and in general.

This research work can help developing the nuclear industry in the field of storage of radioactive materials such as laboratory radioactive sources and/or nuclear radioactive waste, this study will give a simple approach for shielding a neutron source depending on both experimental results and calculations by PHITS code. Studying different shielding materials could help the companies which are responsible of transport and storage of radioactive materials to develop this industry and reduce the final product cost by choosing the most effective and the cheapest materials for the purposed shield.

### **4.1 Competitiveness analysis of technical solutions**

In order to find sources of financing for the project, it is necessary, first, to determine the commercial value of the work. Analysis of competitive technical solutions in terms of resource efficiency and resource saving allows to evaluate the comparative effectiveness of scientific development. This analysis is advisable to carry out using an evaluation card.

First of all, it is necessary to analyze possible technical solutions and choose the best one based on the considered technical and economic criteria. Evaluation map analysis presented in Table 4.1. The position of the research and competitors is

evaluated for each indicator on a five-point scale, where 1 is the weakest position and 5 is the strongest.

As competing developments were adopted:  $p_f$  – the neutron flux measurements in the laboratory,  $p_1$  – PHITS code calculations results,  $p_2$  – GEANT4 code. These three methods for doing the same task are of high competition, the main factor which affect the decision of choosing the method in this task was availability of experience in the chosen method in the staff of researchers, basically the three methods in competition are of a high reliability and widely used and they offer the flexibility for doing similar tasks.

The weights of indicators determined in the amount should be 1. Analysis of competitive technical solutions is determined by the formula:

$$C = \sum W_i \cdot P_i, \quad (4.1)$$

C - the competitiveness of research or a competitor;

$W_i$  – criterion weight;

$P_i$  – point of i-th criteria.

You can use the following criteria for the model of expert evaluation:

- noise immunity;
- set of terminals relay protection;
- reliability of relay protection;
- smart interface quality;
- energy efficiency;
- ease of operation;
- ability to connect to PC;
- estimated lifetime;
- safety;
- etc.

Table 4. 1 Evaluation card for comparison of competitive technical solutions

Evaluation criteria <i>example</i>	Criterion weight	Points			Competitiveness Taking into account weight coefficients		
		$P_f$	$P_{i1}$	$P_{i2}$	$C_f$	$C_{i1}$	$C_{i2}$
1	2	3	4	5	6	7	8
<b>Technical criteria for evaluating resource efficiency</b>							
1. Energy efficiency	0.1	3	4	4	0.3	0.4	0.4
2. Reliability	0.2	4	3	5	0.8	0.6	1
3. Safety	0.2	4	4	5	0.8	0.8	1
4. Functional capacity	0.1	5	5	5	0.5	0.5	0.5
<b>Economic criteria for performance evaluation</b>							
1. Development cost	0.1	4	4	5	0.4	0.4	0.1
2. Market penetration rate	0.1	5	4	3	0.5	0.4	0.3
3. Expected lifecycle	0.2	4	4	5	0.8	0.8	1
<b>Total</b>	<b>1</b>	<b>29</b>	<b>28</b>	<b>32</b>	<b>4.1</b>	<b>3.9</b>	<b>4.3</b>

The followed method in measurements and calculation of neutron flux is considered one of the most efficient and proved methods in this field and also it is very economic and competitive with any other method which can be followed to do the same task and get such good results, by comparing these three methods it was noted that they have close rating and the last decision for using the PHITS code was the availability of experience and support for the code, also the experimental measurements were used as verification method, GEANT4 code is also a great choice for completing similar tasks and it is planned to use this code in future researches .

#### 4.2 SWOT analysis

Complex analysis solution with the greatest competitiveness is carried out with the method of the SWOT analysis: Strengths, Weaknesses, Opportunities and Threats. The analysis has several stages. The first stage consists of describing the strengths and

weaknesses of the project, identifying opportunities and threats to the project that have emerged or may appear in its external environment. The second stage consists of identifying the compatibility of the strengths and weaknesses of the project with the external environmental conditions. This compatibility or incompatibility should help to identify what strategic changes are needed.

Table 4. 2 SWOT analysis

	<p><b>Strengths:</b>  S1. The MKS-01 radiometer-dosimeter is a trusted device and commonly used.  S2. The BDKN-03 detector is highly sensitive and intelligent;  S3. PHITS code is a trusted code and it was validated many times and its reliability was proved by many researches</p>	<p><b>Weaknesses:</b>  W1. Missing initial data can affect the final results.  W2. The tools used in the laboratory were not accurate in some stages of the experiment  W3. Some documents were not available or only available in Russian language especially for the detector description.</p>
<p><b>Opportunities:</b>  O1. The research is more effective in storage of radioactive sources in laboratories.  O2. Testing new shielding materials can help developing the containers for radioactive waste  O3. Results can provide other researchers to avoid some problems with PHITS calculations.</p>	<p><b>Strategy which based on strengths and opportunities:</b>  testing many materials by the same method to provide a good reference for some shielding materials against neutron radiation</p>	<p><b>Strategy which based on weaknesses and opportunities:</b>  validation of the code according to the task and compare the both experimental results and calculations to avoid the expected errors</p>
<p><b>Threats:</b>  T1. The hazard of the neutron source on the health during the experiment</p>	<p><b>Strategy which based on strengths and threats:</b>  1. Follow all safety recommendations during dealing with</p>	<p><b>Strategy which based on weaknesses and threats:</b>  Using some references to get the missing data and decrease the probability of</p>

<p>T2. Deviation between measurements and calculations</p> <p>T3. The time of initial data measurements of the neutron source</p> <p>T4. The missing neutron spectrum for the source</p>	<p>radioactive sources and spend the minimum time to finish the experiment with the required accuracy.</p> <p>2. Use the flexibility of PHITS code calculations to avoid the harmful effect of radiation exposure and expect the regions of maximum flux to avoid the exposure to radiation</p>	<p>deviations between results.</p>
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### 4.3 Project Initiation

The initiation process group consists of processes that are performed to define a new project or a new phase of an existing one. In the initiation processes, the initial purpose and content are determined and the initial financial resources are fixed. The internal and external stakeholders of the project who will interact and influence the overall result of the research project are determined.

Table 4. 3 Stakeholders of the project

<b>Project stakeholders</b>	<b>Stakeholder expectations</b>
<p>TPU (Tomsk Polytechnic University)</p>	<p>Developing the experimental measurements results in TPU laboratories and proving the measurements by available software codes such as PHITS to get up to date techniques.</p>
<p>JAEA ( Japanese Atomic Energy Agency)</p>	<p>Increasing the PHITS code applications and increasing the number of PHITS code users all over the world to help developing the code</p>

Table 4. 4 Purpose and results of the project

Purpose of project:	Validation of PHITS code according to the measurements of neutron flux from pu-be source in polyethylene
Expected results of the project:	<ol style="list-style-type: none"> <li>1. Measurements results for the thermal and fast neutrons flux</li> <li>2. PHITS calculation results for thermal and fast neutrons flux</li> <li>3. The right manner to use PHITS code and the experimental devices to get accurate results</li> </ol>
Criteria for acceptance of the project result:	The final uncertainty should not exceed 25% and the output graphs of PHITS code should fulfill the proved nuclear experimental results.
Requirements for the project result:	The research results have Some applications for work on the future shielding material testing, the new shielding materials can help developing the storage of radioactive materials and help to improve the casks/container for storage of radioactive waste.

#### 4.3.1 The organizational structure of the project

It is necessary to solve the some questions: who will be part of the working group of this project, determine the role of each participant in this project, and prescribe the functions of the participants and their number of labor hours in the project.

Table 4. 5 Structure of the project

№	Participant	Role in the project	Functions	Labor time, hours (working days (from table 7) × 6 hours)
1	Maxim E. Silaev (Associated professor)	Supervisor	Formulation of research topic and direction of research Verification work through weekly meetings Control of deadlines and	28days *6 hrs. =168 hrs.

			Objectives in the research.	
2	Abdelmeguid.F.A Engineer	Engineer	Selection of main evaluation and scientific literatures Studies. Collection of data and analyzing collected data	122 days * 6 hrs. = 732 hrs.

### 4.3.2 Project limitations

Project limitations are all factors that can be as a restriction on the degree of freedom of the project team members.

Table 4. 6 Project limitations

<b>Factors</b>	<b>Limitations / Assumptions</b>
3.1. Project's budget	<b>328666.11Rubles</b>
3.1.1. Source of financing	Internal TPU
3.2. Project timeline:	01/09/2020 to 12/05/2021
3.2.1. Date of approval of plan of project	01/09/2020
3.2.2. Completion date	20/05/2021

### 4.3.3 Project Schedule

This research demands that a working calendar graph is drawn to represent activities undertaken during the course of the project. This was used to monitor and guide the progress of work Chart.

Table 4. 7 Project Schedule

Job title	Duration, working days Without holidays	Start date	Date of completion	Participants



Development of technical specifications	4	1.02.2021	4.02.2021	Scientific supervisor
Drafting and approval of the Terms of Reference	3	4.02.2021	7.02.2021	Scientific supervisor
Research Direction	4	7.02.2021	11.02.2021	Scientific supervisor, Engineer
Collection and study scientific technical literature	25	11.02.2021	7.03.2021	Engineer
Data collection	35	7.03.2021	12.04.2021	Engineer
Analysis of the obtained experimental data	15	6.04.2021	21.04.2021	Engineer, Scientific supervisor
Summary and assessment of results	2	21.04.2021	23.04.2021	Scientific supervisor, Engineer
Compilation of results for report preparation	15	1.04.2021	15.04.2021	Engineer
Preparation of the results and report submission.	6	20.04.2021	26.04.2021	Engineer
Defense preparation	20	30.04.2021	20.05.2021	Engineer

A Gantt chart, or harmonogram, is a type of bar chart that illustrates a project schedule. This chart lists the tasks to be performed on the vertical axis, and time intervals on the horizontal axis. The width of the horizontal bars in the graph shows the duration of each activity. The Gantt chart was used to map the distribution of the work carried out. Gantt chart is a type of bar charts which is used to illustrate the planned schedule of project, in which the works can be shown the extensive length of

time, characterized by the dates of beginning and end of the implementation of these works. Calendar schedule of R&D on the topic:

Table 4. 8 A Gantt chart

№	Activities	Participants	T <sub>c</sub> , days	Duration of the project																	
				February			March			April			May			June					
				1	2	3	1	2	3	1	2	3	1	2	3	1	2	3			
1	Development of technical specifications	Scientific supervisor	4	█																	
2	Drafting and approval of the Terms of Reference	Scientific supervisor	3	█	█	█															
3	Research Direction Scientific	supervisor, Engineer	4		█	█	█	█													
4	Collection and study scientific technical literature	Engineer	25		█	█	█	█	█	█	█	█	█	█	█	█	█	█			
5	Data collection	Engineer	35		█	█	█	█	█	█	█	█	█	█	█	█	█	█			
6	Analysis of the obtained experimental data	Engineer	15								█	█	█	█	█	█	█	█			
7	Summary and assessment of results Scientific	supervisor, Engineer	2									█	█								
8	Compilation of results for report preparation	Engineer	15									█	█	█	█	█	█	█			
9	Preparation of the results and report for submission.	Scientific supervisor, Engineer	6									█	█	█	█	█	█	█			
10	Defense preparation	Engineer	20													█	█	█			



Engineer

scientific supervisor



#### 4.4 Scientific and technical research budget

The amount of costs associated with the implementation of this work is the basis for the formation of the project budget. This budget will be presented as the lower limit of project costs when forming a contract with the customer.

To form the final cost value, all calculated costs for individual items related to the manager and the student are summed.

In the process of budgeting, the following grouping of costs by items is used:

- Material costs of scientific and technical research;
- costs of special equipment for scientific work (Depreciation of equipment used for design);
- basic salary;
- additional salary;
- labor tax;
- Overhead.

##### 4.4.1 Calculation of material costs

The calculation of material costs is carried out according to the formula:

$$C_m = (1 + k_T) \cdot \sum_{i=1}^m P_i \cdot N_{consi} \quad (4.2)$$

Where  $m$  – the number of types of material resources consumed in the performance of scientific research;

$N_{consi}$  – the amount of material resources of the  $i$ -th species planned to be used when performing scientific research (units, kg, m, m<sup>2</sup>, etc.);

$P_i$  – the acquisition price of a unit of the  $i$ -th type of material resources consumed (rub./units, rub./kg, rub./m, rub./m<sup>2</sup>, etc.);

$k_T$  – coefficient taking into account transportation costs.

Prices for material resources can be set according to data posted on relevant websites on the Internet by manufacturers (or supplier organizations).

Table 4. 9 Material costs

Name	Unit	Amount	Price per unit, rub.	Material costs, rub.
A4 size printer paper	pcs	1	240	240
Printer Cartridge	pcs	1	2300	2300
Total				2540

#### 4.4.2 Costs of special equipment

This point includes the costs associated with the acquirement of special equipment (instruments, stands, devices and mechanisms) necessary to carry out work on a specific topic.

Table 4. 10 Costs of special equipment (+software)

№	equipment identification	Quantity of equipment	Price per unit, rub.	Total cost of equipment, rub.
1.	Laptop	1	40000	40000
2	Neutron detector (three parts with the spheres)	1	60000	60000

OR

Calculation of the depreciation. Depreciation is not charged if an equipment cost is less than 40 thousand rubles, its cost is taken into account in full.

If available equipment were used, then depreciation should be calculated:

$$A = \frac{C_{\text{перв}} \cdot H_a}{100} \quad (4.3)$$

$C_{dq}$  - daily amount of depreciation;

$C_{eq}$  - initial cost of the equipment;

$H_a = \frac{100}{T_{\text{сл}}} - \text{rate of depreciation};$

$T$  - Life expectancy.

Detector:

The neutron detector was used for 8 days, the cost of equipment

$$Cdq = \frac{Ceq}{T} = \frac{60000}{365 \cdot 10} = 16.4 \text{ rub/day}$$

Depreciation for the duration of the project, rub =  $16.4 \cdot 8 =$

Table 4. 11 Depreciation of special equipment (+software)

№	equipment identification	Quantity of equipment	Total cost of equipment, rub.	Life expectancy, year	Depreciation for the duration of the project, rub.
1	Laptop	1	40000	5	1994.5
2	Neutron detector (three parts)	1	60000	10	131.8
total					2126.3

#### 4.4.3 Basic salary

This point includes the basic salary of participants directly involved in the implementation of work on this research. The value of salary costs is determined based on the labor intensity of the work performed and the current salary system

The basic salary ( $S_b$ ) is calculated according to the formula:

$$S_b = S_d \cdot T_w, \quad (4.4)$$

Where  $S_b$  – basic salary per participant;

$T_w$  – the duration of the work performed by the scientific and technical worker, working days;

$S_d$  - the average daily salary of an participant, rub.

The average daily salary is calculated by the formula:

$$S_d = \frac{S_m \cdot M}{F_v}, \quad (4.5)$$

где  $S_m$  – monthly salary of an participant, rub .;

$M$  – the number of months of work without leave during the year:

at holiday in 48 days,  $M = 11.2$  months, 6 day per week;

$F_v$  – Valid annual fund of working time of scientific and technical personnel (251 days).

Table 4. 12 The valid annual fund of working time

<b>Working time indicators</b>	
Calendar number of days	365
The number of non-working days	
- weekend	52
- holidays	14
Loss of working time	
- vacation	48
- isolation period	
- sick absence	
The valid annual fund of working time	251

Monthly salary is calculated by formula:

$$S_{month} = S_{base} \cdot (k_{premium} + k_{bonus}) \cdot k_{reg}, \quad (4.6)$$

where  $S_{base}$  – base salary, rubles;

$k_{premium}$  – premium rate;

$k_{bonus}$  – bonus rate;

$k_{reg}$  – regional rate.

Table 4. 13 Calculation of the base salaries

Performers	$S_{base}$ , rubles	$k_{premium}$	$k_{bonus}$	$k_{reg}$	$S_{month}$ , rub.	$S_d$ , rub.	$T_p$ , work days (from table 7)	$W_{base}$ , rub.
Supervisor	36174	-	-	1,3	47026.2	2098.4	28	58755.2
Engineer	18426				23953.8	1068.9	122	130405.8
Total					189161			

#### 4.4.4 Labor tax

Tax to extra-budgetary funds are compulsory according to the norms established by the legislation of the Russian Federation to the state social insurance (SIF), pension fund (PF) and medical insurance (FCMIF) from the costs of workers.

Payment to extra-budgetary funds is determined of the formula:

$$P_{social} = k_b \cdot (W_{base} + W_{add}) \quad ((4.7))$$

Where  $k_b$  – coefficient of deductions for labor tax.

In accordance with the Federal law of July 24, 2009 No. 212-FL, the amount of insurance contributions is set at 30%. Institutions conducting educational and scientific activities have rate - 27.1%.

Table 4. 14 Labor tax

	Project leader	Engineer
Coefficient of deductions	0,271	
Salary (basic and additional), rubles	58755.2	130405.8

Labor tax, rubles	15922.65	35339.97
Total	51262.62	

#### 4.4.5 Overhead costs

Overhead costs include other management and maintenance costs that can be allocated directly to the project. In addition, this includes expenses for the maintenance, operation and repair of equipment, production tools and equipment, buildings, structures, etc.

Overhead costs account from 30% to 90% of the amount of base and additional salary of employees.

Overhead is calculated according to the formula:

$$C_{ov} = k_{ov} \cdot (W_{base} + W_{add}) \quad (4.8)$$

Where  $k_{ov}$  – overhead rate.

Table 4. 15 Overhead

	Project leader	Engineer
Overhead rate	0,7	
Salary, rubles	58755.2	130405.8
Overhead, rubles	41128.64	91284
Total	132412.64	

#### 4.4.6 Other direct costs

Energy costs for equipment are calculated by the formula:

$$C = P_{el} \cdot P \cdot F_{eq} = 5.8 \cdot 0.08 \cdot 732 \approx 339.6 \text{ rub.}, \quad (4.9)$$

Where  $P_{el}$  – power rates (5.8 rubles per 1 kWh);

$P$  – Power of equipment, kW;

$F_{eq}$  – Equipment usage time, hours.



#### 4.4.7 Formation of budget costs

The calculated cost of research is the basis for budgeting project costs.

Determining the budget for the scientific research is given in the table 15.

Table 4. 16 Items expenses grouping

Name	Cost, rubles
1. Material costs	2540
2. Equipment costs	2126.3
3. Basic salary	189161
4. Additional salary	0
5. Labor tax	51262.62
6. Overhead	132412.64
7. Other direct costs	339.6
<b>Total planned costs</b>	<b>377842.16</b>

#### 4.5 Evaluation of the comparative effectiveness of the project

Determination of efficiency is based on the calculation of the integral indicator of the effectiveness of scientific research. Its finding is associated with the definition of two weighted average values: financial efficiency and resource efficiency.

The integral indicator of the financial efficiency of a scientific study is obtained in the course of estimating the budget for the costs of three (or more) variants of the execution of a scientific study. For this, the largest integral indicator of the implementation of the technical problem is taken as the calculation base (as the denominator), with which the financial values for all the options are correlated.

The integral financial measure of development is defined as:

$$I_f^d = \frac{C_i}{C_{\max}}, \quad (4.10)$$

Where  $I_f^d$  – integral financial measure of development;

$C_i$  – the cost of the i-th version;

$C_{\max}$  – the maximum cost of execution of a research project (including analogues).

The obtained value of the integral financial measure of development reflects the corresponding numerical increase in the budget of development costs in times (the value is greater than one), or the corresponding numerical reduction in the cost of development in times (the value is less than one, but greater than zero).

Since the development has one performance, then  $I_f^d = 1$ .

The integral indicator of the resource efficiency of the variants of the research object can be determined as follows:

$$I_m^a = \sum_{i=1}^n a_i b_i^a \quad I_m^p = \sum_{i=1}^n a_i b_i^p \quad (4.11)$$

where  $I_m$  – integral indicator of resource efficiency for the i-th version of the development;

$a_i$  – the weighting factor of the i-th version of the development;

$b_i^a, b_i^p$  – score rating of the i-th version of the development, is established by an expert on the selected rating scale;

$n$  – number of comparison parameters.

The calculation of the integral indicator of resource efficiency is presented in the form of table 15.

Table 4. 17 Evaluation of the performance of the project

<b>Criteria</b>	<b>Weight criterion</b>	<b>Points</b>
1. Energy efficiency	0.1	3
2. Reliability	0.2	4
3. Safety	0.2	4
4. Functional capacity	0.1	5

<b>Economic criteria for performance evaluation</b>		
1. The cost of development	0.1	4
2. Market penetration rate	0.1	5
3. Expected life	0.2	4
<b>Total</b>	1	4.1

The integral indicator of the development efficiency ( $I_e^p$ ) is determined on the basis of the integral indicator of resource efficiency and the integral financial indicator using the formula:

$$I_e^p = \frac{I_m^p}{I_f^d}; I_e^a = \frac{I_m^a}{I_f^a}. \quad (4.12)$$

$$I_{\text{исп.2}} = \frac{I_{\text{р-исп2}}}{I_{\text{финр}}} \text{ и т.д.}$$

Comparison of the integral indicator of the current project efficiency and analogues will determine the comparative efficiency. Comparative effectiveness of the project:

$$E_c = \frac{I_e^p}{I_e^a} \quad (4.13)$$

Thus, the effectiveness of the development is presented in table 18.

Table 4. 18 Efficiency of development

<b>№</b>	<b>Indicators</b>	<b>p<sub>f</sub></b>	<b>p<sub>i</sub></b>
1	Integrated Financial Development Indicator	1	0.78
2	Integral indicator of resource efficiency of development	4.1	3.9

3	Integral indicator of the development efficiency	4.1	5
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Comparison of the values of integral performance indicators allows us to understand and choose a more effective solution to the technical problem from the standpoint of financial and resource efficiency.

#### **Conclusion on chapter 4**

Thus, in this section was developed stages for design and create competitive development that meet the requirements in the field of resource efficiency and resource saving.

These stages includes:

- development of a common economic project idea, formation of a project concept;
- organization of work on a research project;
- identification of possible research alternatives;
- research planning;
- assessing the commercial potential and prospects of scientific research from the standpoint of resource efficiency and resource saving;
- Determination of resource (resource saving), financial, budget, social and economic efficiency of the project.

From Financial management, resource efficiency and resource saving analysis

It can be concluded that the big part of financial resources goes into paying salaries which have a value of **189161** rubles in basic salaries. The total budget of the project was calculated at **377842.161** rubles. In every scientific undertaking financial management, resource efficiency and serving is a very import aspect to ensure successful completion of project.

## **chapter 5. Social responsibility**

### **5.1 Introduction**

In the subsection a brief summary of the research work or the essence of the graduation thesis on the topic should be given. The application area, real or potential users of the developed solution, the administrative or geographical location of the workplace should be indicated. An assessment of the social orientation (relevance) of the work should be given.

This research work mainly focus on validation for calculation of neutron filed in polyethylene shield by means of a Monte Carlo simulation code called PHITS code, the calculations performed by PHITS code were compared with the measurements done in the laboratory, this work can be applied for shielding materials testing and developing shields against nuclear radiation, the casks/ containers industry can be supported by such research works because developing shielding materials give more flexibility to this industry which affect the nuclear fuel cycle as a solution for the nuclear spent fuel, and also support the nuclear research laboratories for storage of radioactive sources, this work aim to protect people and environment against the radiation hazards as one of the three radiation safety principles (time, distance, shielding) and this work focus on the third principle (shielding).

### **5.2 Legal and organizational items in providing safety**

Nowadays one of the main ways to radical improvement of all prophylactic work referred to reduce Total Incidents Rate and occupational morbidity is the widespread implementation of an integrated Occupational Safety and Health management system. That means combining isolated activities into a single system of targeted actions at all levels and stages of the production process.

Occupational safety is a system of legislative, socio-economic, organizational, technological, hygienic and therapeutic and prophylactic measures and tools that ensure the safety, preservation of health and human performance in the work process [36].

According to the Labor Code of the Russian Federation, every employee has the right:

- To have a workplace that meets Occupational safety requirements;
- To have a compulsory social insurance against accidents at manufacturing and occupational diseases;
  - to receive reliable information from the employer, relevant government bodies and public organizations on conditions and Occupational safety at the workplace, about the existing risk of damage to health, as well as measures to protect against harmful and (or) hazardous factors;
  - To refuse carrying out work in case of danger to his life and health due to violation of Occupational safety requirements;
  - be provided with personal and collective protective equipment in compliance with Occupational safety requirements at the expense of the employer;
  - For training in safe work methods and techniques at the expense of the employer;
  - for personal participation or participation through their representatives in consideration of issues related to ensuring safe working conditions in his workplace, and in the investigation of the accident with him at work or occupational disease;
  - for extraordinary medical examination in accordance with medical recommendations with preservation of his place of work (position) and secondary earnings during the passage of the specified medical examination;
  - for warranties and compensation established in accordance with this Code, collective agreement, agreement, local regulatory an act, an employment contract, if he is engaged in work with harmful and (or) hazardous working conditions.

The labor code of the Russian Federation states that normal working hours may not exceed 40 hours per week, The employer must keep track of the time worked by each employee.

Rules for labor protection and safety measures are introduced in order to prevent accidents, ensure safe working conditions for workers and are mandatory for workers, managers, engineers and technicians.

### **5.3 Basic ergonomic requirements for the correct location and arrangement of researcher's workplace**

The workplace when working with a PC should be at least 6 square meters. The legroom should correspond to the following parameters: the legroom height is at least 600 mm, the seat distance to the lower edge of the working surface is at least 150 mm, and the seat height is 420 mm. It is worth noting that the height of the table should depend on the growth of the operator.

The following requirements are also provided for the organization of the workplace of the PC user: The design of the working chair should ensure the maintenance of a rational working posture while working on the PC and allow the posture to be changed in order to reduce the static tension of the neck and shoulder muscles and back to prevent the development of fatigue.

The type of working chair should be selected taking into account the growth of the user, the nature and duration of work with the PC. The working chair should be lifting and swivel, adjustable in height and angle of inclination of the seat and back, as well as the distance of the back from the front edge of the seat, while the adjustment of each parameter should be independent, easy to carry out and have a secure fit.

### **5.4 Occupational safety**

A dangerous factor or industrial hazard is a factor whose impact under certain conditions leads to trauma or other sudden, severe deterioration of health of the worker [36].

A harmful factor or industrial health hazard is a factor, the effect of which on a worker under certain conditions leads to a disease or a decrease in working capacity.

#### **5.4.1 Analysis of harmful and dangerous factors that can create object of investigation**

The object of investigation is "Investigation of the effect of the Pu-Be neutron source during the measurements in the laboratory and the harmful effect to health and objects if there is no shield for this source". The Pu-Be neutron source produce neutrons with energy range starting from less than 1 Mev to 14 Mev with secondary gamma rays. The fast neutron and gamma rays have high penetration abilities to the

different materials. The radiation damage to any material can be induced by displacement of the atoms of the irradiated matter and other nuclear interactions. The exposure to the radiations from the Pu-Be neutron source can affect the man health in different scenarios depending on the three basic radiation safety principles; time, distance and shielding. The exposure to radiation from this Pu-Be source can cause death in case of the close distance and long time without shielding. Many other scenarios can cause damage to human cells or lead to cancer. The other objects in the laboratory also could face different levels of damage according to the material of the object. Damage to objects results from the interactions of radiation with the matter. Using the polyethylene shield we decrease the neutron radiation dose and avoid the harmful effect of the radiation to people and environment.

#### **5.4.2 Analysis of harmful and dangerous factors that can arise at workplace during investigation**

The working conditions in the workplace are characterized by the presence of hazardous and harmful factors, which are classified by groups of elements: physical, chemical, biological, psychophysiological. The main elements of the production process that form dangerous and harmful factors are presented in Table 5.1.

Table 5. 1 Possible hazardous and harmful factors

Factors (GOST 12.0.003-2015)	Work stages			Legal documents
	Development	Manufacture	Exploitation	
1. Deviation of microclimate indicators	+	+	+	Sanitary rules 2.2.2 / 2.4.1340–03. Sanitary and epidemiological rules and regulations "Hygienic
2. Excessive noise		+	+	
3. Increased level of electromagnetic radiation	+	+	+	



<p>4.Insufficient illumination of the working area</p>		<p>+</p>	<p>+</p>	<p>requirements for personal electronic computers and work organization."</p> <p>Sanitary rules 2.2.1 / 2.1.1.1278–03. Hygienic requirements for natural, artificial and combined lighting of residential and public buildings.</p> <p>Sanitary rules 2.2.4 / 2.1.8.562–96. Noise at workplaces, in premises of residential, public buildings and in the construction area.</p> <p>Sanitary rules 2.2.4.548–96. Hygienic requirements for the microclimate of industrial premises.</p>
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5. Abnormally high voltage value in the circuit, the closure which may occur through the human body	+	+	+	Sanitary rules GOST 12.1.038-82 SSBT. Electrical safety. Maximum permissible levels of touch voltages and currents.
6. Increased levels of ionizing radiation	+	+	+	Sanitary Rules 2.6.1. 2523 -0 9. Radiation Safety Standards (NRB-99/2009).

The following factors effect on person working on a computer:

- physical:
  - temperature and humidity;
  - noise;
  - static electricity;
  - electromagnetic field of low purity;
  - illumination;
  - presence of radiation;
- psychophysiological:
  - psychophysiological dangerous and harmful factors are divided into:
    - physical overload (static, dynamic)
    - Mental stress (mental overstrain, monotony of work, emotional overload).

### 5.4.2.1 Deviation of microclimate indicators

The air of the working area (microclimate) is determined by the following parameters: temperature, relative humidity, air speed. The optimum and permissible values of the microclimate characteristics are established in accordance with [37] and are given in Table 5.2.

Table 5. 2 Optimal and permissible parameters of the microclimate

Period of the year	Temperature, °C	Relative humidity,%	Speed of air movement, m/s
Cold and changing of seasons	23-25	40-60	0.1
Warm	23-25	40	0.1

### 5.4.2.2 Excessive noise

Noise and vibration worsen working conditions, have a harmful effect on the human body, namely, the organs of hearing and the whole body through the central nervous system. It result in weakened attention, deteriorated memory, decreased response, and increased number of errors in work. Noise can be generated by operating equipment, air conditioning units, daylight illuminating devices, as well as spread from the outside. When working on a PC, the noise level in the workplace should not exceed 50 db.

### 5.4.2.3 Increased level of electromagnetic radiation

The screen and system blocks produce electromagnetic radiation. Its main part comes from the system unit and the video cable. According to [37], the intensity of the electromagnetic field at a distance of 50 cm around the screen along the electrical component should be no more than:

- in the frequency range 5 Hz - 2 kHz - 25 V / m;
- In the frequency range 2 kHz - 400 kHz - 2.5 V / m.

The magnetic flux density should be no more than:

- in the frequency range 5 Hz - 2 kHz - 250 nT;
- In the frequency range 2 kHz - 400 kHz - 25 nT

#### 5.4.2.4 Abnormally high voltage value in the circuit

Depending on the conditions in the room, the risk of electric shock to a person increases or decreases. Do not operate the electronic device in conditions of high humidity (relative air humidity exceeds 75% for a long time), high temperature (more than 35 ° C), the presence of conductive dust, conductive floors and the possibility of simultaneous contact with metal components connected to the ground and the metal casing of electrical equipment. The operator works with electrical devices: a computer (display, system unit, etc.) and peripheral devices. There is a risk of electric shock in the following cases:

- with direct contact with current-carrying parts during computer repair;
- when touched by non-live parts that are under voltage (in case of violation of insulation of current-carrying parts of the computer);
- when touched with the floor, walls that are under voltage;
- Short-circuited in high-voltage units: power supply and display unit.

Table 5. 3 Upper limits for values of contact current and voltage

	Voltage, V	Current, mA
Alternate, 50 Hz	2	0.3
Alternate, 400 Hz	3	0.4
Direct	8	1.0

#### 5.4.2.4 Insufficient illumination of the working area

Light sources can be both natural and artificial. The natural source of the light in the room is the sun, artificial light are lamps. With long work in low illumination conditions and in violation of other parameters of the illumination, visual perception decreases, myopia, eye disease develops, and headaches appear.

According to the standard, the illumination on the table surface in the area of the working document should be 300-500 lux. Lighting should not create glare on the surface of the monitor. Illumination of the monitor surface should not be more than 300 lux.

The brightness of the lamps of common light in the area with radiation angles from 50 to 90° should be no more than 200 cd/m, the protective angle of the lamps should be at least 40°. The safety factor for lamps of common light should be assumed to be 1.4. The ripple coefficient should not exceed 5%.

#### 5.4.2.5 Increased levels of ionizing radiation

Ionizing radiation is radiation that could ionize molecules and atoms. This effect is widely used in energetics and industry. However, there is health hazard. In living tissue, this radiation could damage cells that result in two types of effects. Deterministic effects (harmful tissue reactions) due to exposure with high doses and stochastic effects due to DNA destruction and mutations (for example, induction of cancer).

To provide radiation safety with using sources of ionizing radiation one must use next principles:

- a) keep individual radiation doses from all radiation sources not higher than permissible exposure;
- b) forbid all activity with using radiation sources if profit is low than risk of possible hazard;
- c) Keep individual radiation doses from all radiation sources as low as possible.

There are two groups of people related to work with radiation: personnel, who works with ionizing radiation, and population.

Quantity	Dose limits	
	personnel	population
Effective dose	20 mSv per year in average during 5 years, but not higher than 50 mSv per year	1 mSv per year in average during 5 years, but not higher than 5 mSv per year
Equivalent dose per year in eye's lens	150 mSv	15 mSv
skin	500 mSv	50 mSv
Hands and feet	500 mSv	50 mSv

Effective dose for personnel must not exceed 1000 mSv for 50 years of working activity, and for population must not exceed 70 mSv for 70 years of life.

In addition, for women from personnel of age below 45 years there is limit of 1 mSv per month of equivalent dose on lower abdomen. During gestation and breast feeding women must not work with radiation sources.

For students older than 16, who uses radiation sources in study process or who is in rooms with increased level of ionizing radiation, dose limits are quarter part of dose limits of personnel.

### **5.4.3 Justification of measures to reduce the levels of exposure to hazardous and harmful factors on the researcher**

#### **Deviation of microclimate indicators**

The measures for improving the air environment in the production room include: the correct organization of ventilation and air conditioning, heating of room. Ventilation can be realized naturally and mechanically. In the room, the following volumes of outside air must be delivered:

- at least 30 m<sup>3</sup> per hour per person for the volume of the room up to 20 m<sup>3</sup> per person;
- natural ventilation is allowed for the volume of the room more than 40 m<sup>3</sup> per person and if there is no emission of harmful substances.

The heating system must provide sufficient, constant and uniform heating of the air. Water heating should be used in rooms with increased requirements for clean air.

The parameters of the microclimate in the laboratory regulated by the central heating system, have the following values: humidity 40%, air speed 0.1 m / s, summer temperature 20-25 ° C, in winter 13-15 ° C. Natural ventilation is provided in the laboratory. Air enters and leaves through the cracks, windows, doors. The main disadvantage of such ventilation is that the fresh air enters the room without preliminary cleaning and heating.

#### **5.4.3.1 Excessive noise**

In research audiences, there are various kinds of noises that are generated by both internal and external noise sources. The internal sources of noise are working equipment, personal computer, printer, ventilation system, as well as computer equipment of other engineers in the audience. If the maximum permissible conditions are exceeded, it is sufficient to use sound-absorbing materials in the room (sound-absorbing wall and ceiling cladding, window curtains). To reduce the noise penetrating outside the premises, install seals around the perimeter of the doors and windows.

#### **5.4.3.2 Increased level of electromagnetic radiation**

There are the following ways to protect against EMF:

- Increase the distance from the source (the screen should be at least 50 cm from the user);
- The use of pre-screen filters, special screens and other personal protective equipment.

When working with a computer, the ionizing radiation source is a display. Under the influence of ionizing radiation in the body, there may be a violation of normal blood coagulability, an increase in the fragility of blood vessels, a decrease in immunity, etc. The dose of irradiation at a distance of 20 cm to the display is 50  $\mu\text{rem} / \text{hr}$ . According to the norms [37], the design of the computer should provide the power of the exposure dose of x-rays at any point at a distance of 0.05 m from the screen no more than 100  $\mu\text{R} / \text{h}$ .

Fatigue of the organs of vision can be associated with both insufficient illumination and excessive illumination, as well as with the wrong direction of light.

#### **5.4.3.3 Increased levels of ionizing radiation**

In case of radiation accident, responsible personnel must take all measures to restore control of radiation sources and reduce to minimum radiation doses, number of irradiated persons, radioactive pollution of the environment, economic and social losses caused with radioactive pollution.

Radiation control is a main part of radiation safety and radiation protection. It is aimed at not exceeding the established basic dose limits and permissible levels of radiation, obtaining the necessary information to optimize protection and making decisions about interference in the case of radiation accidents, contamination of the environment and buildings with radionuclides.

The radiation control is control of:

- Radiation characteristics of radiation sources, pollution in air, liquid and solid wastes.
- Radiation factors developed with technological processes in working places and environment.
- Radiation factors of contaminated environment.
- Irradiation dose levels of personnel and population.

The main controlled parameters are:

- Annual effective and equivalent doses
- intake and body content of radionuclides
- volume or specific activity of radionuclides in air, water, food products, building materials and etc.
- radioactive contamination of skin, clothes, footwear, working places and etc.
- dose and power of external irradiation.
- particles and photons flux density.

Radiation protection office establish control levels of all controlled parameters in according to not exceed dose limits and keep dose levels as low as possible. In case of exceeding control levels radiation protection officers start investigation of exceed causes and take actions to eliminate this exceeding.

uring planning and implementation of radiation safety precautions, taking any actions about radiation safety and analysis of effectiveness of mentioned action and precautions one must value radiation safety with next factors:

- characteristics of radioactive contamination of the environment;



- probability of radiation accidents and scale of accidents;
- degree of readiness to effective elimination of radiation accidents and its aftermaths;
- number of persons irradiated with doses higher than controlled limits of doses;
- analysis of actions for providing radiation safety, meeting requirements, rules, standards of radiation safety;
- analysis of irradiation doses obtained by groups of population from all ionizing radiation sources.

#### **5.4.3.4 Abnormally high voltage value in the circuit**

Measures to ensure the electrical safety of electrical installations:

- disconnection of voltage from live parts, on which or near to which work will be carried out, and taking measures to ensure the impossibility of applying voltage to the workplace;
- posting of posters indicating the place of work;
- electrical grounding of the housings of all installations through a neutral wire;
- coating of metal surfaces of tools with reliable insulation;
- Inaccessibility of current-carrying parts of equipment (the conclusion in the case of electroporation elements, the conclusion in the body of current-carrying parts) [38].

#### **5.4.3.5 Insufficient illumination of the working area**

Desktops should be placed in such a way that the monitors are oriented sideways to the light openings, so that natural light falls mainly on the left.

Also, as a means of protection to minimize the impact of the factor, local lighting should be installed due to insufficient lighting, window openings should be equipped with adjustable devices such as blinds, curtains, external visors, etc.

## **5.5 Ecological safety**

### **5.5.1 Analysis of the impact of the research object on the environment**

During life cycle atomic power plant use nuclear fuel and produce electricity and nuclear waste. Spent nuclear fuel and waste are highly radioactive substances. The special cask should be used to store these materials, due to their leak could poison environment.

Nuclear fuel consists from different isotopes with different half-life times. 97% of the waste produced in atomic power plant is classified as low- or intermediate-level waste (LLW or ILW). Low and intermediate level waste has been disposed of in near-surface storages for many years.

Other type of radioactive waste is classified as high-level waste (HLW). The amount of HLW produced (including used fuel when this is considered as waste) during nuclear production is small; a typical large reactor (1 GWe) produces about 25-30 tons of used fuel per year. High level waste has been disposed of in deep storages for many years

The radioactivity of nuclear waste naturally decays, and has a finite radiotoxic lifetime. Within a period of 1,000-10,000 years, the radioactivity of HLW decays to that of the originally mined ore.

The dangerous impact could be to hydrosphere and lithosphere due to leakage of waste in accidents. Therefore, international scientific collaboration is needed to develop safe storages for each types of radioactive waste.

Polyethylene material or polythene (abbreviated PE; IUPAC name polyethene or poly (methylene)) is the most common plastic in use today. It is a polymer, primarily used for packaging (plastic bags, plastic films, geomembranes, containers including bottles, etc.). As of 2017, over 100 million tons of polyethylene resins are being produced annually, accounting for 34% of the total plastics market.

Mass production of plastic began only 60 years ago. During this time, its output increased 180 times. Recycling takes only 9% of the plastic. Another 12% is burned, and 79% goes to landfills and the environment.

As a result, there is pollution by debris of the lithosphere and hydrosphere. Due to the circulation of currents in the oceans, "garbage islands" are formed. At the same time, plastic not only drifts on the surface, but sinks to the bottom.

In addition to large plastic wastes, there are also wastes due to micro plastics. According to international classification, any plastic particle less than 5 mm in length falls into this category. Micro plastic is divided into primary and secondary. Primary is most often fibers added to synthetic clothing. When rubbing on a surface or washing, thousands of fibers are separated from it, "hanging" in the air or washed off into the sewer. The second most important source is particles of artificial rubber from tires, which each car leaves 20 grams per 100 km of track. In addition, cars erase markings from roads, which also contain plastic. Secondary micro plastic is added to this - "large" debris, broken up into small pieces. As you know, plastic has decomposed for centuries. But it can quickly degrade to tiny parts, while maintaining its molecular structure.

The solutions to the plastic problem today are legislative restrictions on the use of plastic and disposable products, sorting and processing of waste. But they are still not effective solutions to the problem.

### **5.5.2 Analysis of the environmental impact of the research process**

Process of investigation itself in the thesis do not have essential effect on environment. One of hazardous waste is fluorescent lamps. Mercury in fluorescent lamps is a hazardous substance and its improper disposal greatly poisons the environment.

Outdated devices goes to an enterprise that has the right to process wastes. It is possible to isolate precious metals with a purity in the range of 99.95–99.99% from computer components. A closed production cycle consists of the following stages: primary sorting of equipment; the allocation of precious, ferrous and non-ferrous

metals and other materials; melting; refining and processing of metals. Thus, there is an effective disposal of computer devices.

### **5.5.3 Justification of environmental protection measures**

Pollution reduction is possible due to the improvement of devices that produces electricity, the use of more economical and efficient technologies, the use of new methods for generating electricity and the introduction of modern methods and methods for cleaning and neutralizing industrial waste. In addition, this problem should be solved by efficient and economical use of electricity by consumers themselves. This is the use of more economical devices, as well as efficient regimes of these devices. This also includes compliance with production discipline in the framework of the proper use of electricity.

Simple conclusion is that it is necessary to strive to reduce energy consumption, to develop and implement systems with low energy consumption. In modern computers, modes with reduced power consumption during long-term idle are widely used.

## **5.6 Safety in emergency**

### **5.6.1 Analysis of probable emergencies that may occur at the workplace during research**

The fire is the most probable emergency in our life. Possible causes of fire:

- malfunction of current-carrying parts of installations;
- work with open electrical equipment;
- short circuits in the power supply;
- non-compliance with fire safety regulations;
- presence of combustible components: documents, doors, tables, cable insulation, etc.

Activities on fire prevention are divided into: organizational, technical, operational and regime.

## **5.6.2 Substantiation of measures for the prevention of emergencies and the development of procedures in case of emergencies**

Organizational measures provide for correct operation of equipment, proper maintenance of buildings and territories, fire instruction for workers and employees, training of production personnel for fire safety rules, issuing instructions, posters, and the existence of an evacuation plan.

The technical measures include compliance with fire regulations, norms for the design of buildings, the installation of electrical wires and equipment, heating, ventilation, lighting, the correct placement of equipment.

The regime measures include the establishment of rules for the organization of work, and compliance with fire-fighting measures. To prevent fire from short circuits, overloads, etc., the following fire safety rules must be observed:

- elimination of the formation of a flammable environment (sealing equipment, control of the air, working and emergency ventilation);
- use in the construction and decoration of buildings of non-combustible or difficultly combustible materials;
- the correct operation of the equipment (proper inclusion of equipment in the electrical supply network, monitoring of heating equipment);
- correct maintenance of buildings and territories (exclusion of the source of ignition - prevention of spontaneous combustion of substances, restriction of fireworks);
- training of production personnel in fire safety rules;
- the publication of instructions, posters, the existence of an evacuation plan;
- compliance with fire regulations, norms in the design of buildings, in the organization of electrical wires and equipment, heating, ventilation, lighting;
- the correct placement of equipment;
- well-time preventive inspection, repair and testing of equipment.

In the case of an emergency, it is necessary to:

- inform the management (duty officer);
- call the Emergency Service or the Ministry of Emergency Situations  
- tel. 112;
- take measures to eliminate the accident in accordance with the instructions.

### **5.7 Conclusions**

In this section about social responsibility the hazardous and harmful factors were revealed. All necessary safety measures and precaution to minimize probability of accidents and traumas during investigation are given.

Possible negative effect on environment were given in compact form describing main ecological problem of using nuclear energy.

It could be stated that with respect to all regulations and standards, investigation itself and object of investigation do not pose special risks to personnel, other equipment and environment.

## Conclusions and recommendations

Neutron flux from the  $^{239}\text{Pu}$ -be neutron source was calculated using PHITS code and the calculations results were compared to the measurements which were done in TPU laboratory.

The calculations which were performed using PHITS code v2.88 and JENDL-4.0 have shown a good reliability comparing to the measurements, it's recommended to use the nuclear data library JENDL-4.0 for the calculations of low energy neutrons ( $E < 20 \text{ Mev}$ ) because of the high resonance of low energy neutrons.

The measurements were done at discrete distances from the front face of the polyethylene shielding prism (d1) 0, 5, 10, 20, 30 cm for thermal neutron flux and 20, 30 cm for fast neutron flux. The dosimeter-radiometer MKS-01R device was used with the neutron detection unit BDKN-03 for detecting thermal neutrons and this detection unit was installed with the cadmium sphere to detect the fast neutrons. A simple ruler was used to measure the distance d1 in cm.

PHITS calculations were performed using two different types of detectors inside the code. These detectors are the point detector and the ring detector. Results of calculations using ring detector and point detector were compared to the measurements. The ring detector by [T-point] tally showed good reliability for calculation while the point detector results were also close to measurements but slightly higher than the results from the ring detector because the point position was set on the Y-axis where the neutron flux should have the maximum values and the values of neutron flux will decrease by increasing the distance from the axis in any side. The recommended detector to be used in PHITS calculations in this work and similar tasks is the ring detector.

During calculations using PHITS code it's also recommended to set the history number and the batch number to get accepted accuracy and processing time according to the final value of error, increasing the history number will increase the accuracy of the calculations till a specific point and after this point increasing the history number should be considered as a waste of processing time and not necessary.

Considering the energy range for each neutron group will affect the value of the neutron flux for each group and it's recommended to set the values of energy for each group as the same value in the real detector manual which was used in the measurements.

The calculations show the effect of the distance  $d_1$  on the flux values for both thermal and fast neutron, The distance effect is significant in case of the thermal neutrons but this effect is lower in case of the fast neutrons.

During the measurements the neutron flux for thermal neutrons and fast neutrons was measured in two different situation (without the cadmium sphere and with the cadmium sphere respectively) and the position of the detector was determined by a simple tape measure and this caused an error in the measured distance and affected the neutrons flux values especially the thermal neutrons flux values, its recommended to determine the position of the detector using more advanced tools considering not only the distance but also the angle from the Y-axis in the horizontal and the vertical direction.

In this work the calculations performed using PHITS 2.88 with JENDL-4.0 had shown a reliability comparing to the measurements with error  $< 22.9\%$  in the worst cases and the error decrease by decreasing the distance and this insures the effect caused by the distance error. The difference between the calculations and the measurements at  $d_1 = 0$  cm is  $< 1\%$  and this also insure the good reliability of PHITS calculations.

This work is considered as a preliminary work and all results have acceptable accuracy. The improvement of this work could be achieved depending on three factors, the first factor is doing the measurements with more strict rules and more precise tools especially for determination of the detector position, the second factor to improve results is the initial data as it should be more available and enough, the third factor is the detector as it should have more flexibility in the detected neutron energy range. These factors are considered some of many factors affecting the results but they are the clearest ones according to our experience during this work.



## Future work

The same installation in TPU laboratory will be used for testing the new developed shielding materials. The new shielding material could be placed in the channel as shown in the figure 32. The thickness ( $x$ ) of the new shielding material could be changed and the results could be scored for many cases. Testing different types of new developed materials for shielding can be performed by measurements and calculations of different parameters. The neutron source could be replaced by another radioactive source such as gamma ray source and repeat the same calculations and measurements. The results then could be analyzed and the material which has the best shielding characteristics would be chosen. Many factor could be taken into consideration during the work such as material cost, availability, chemical properties and mechanical properties.

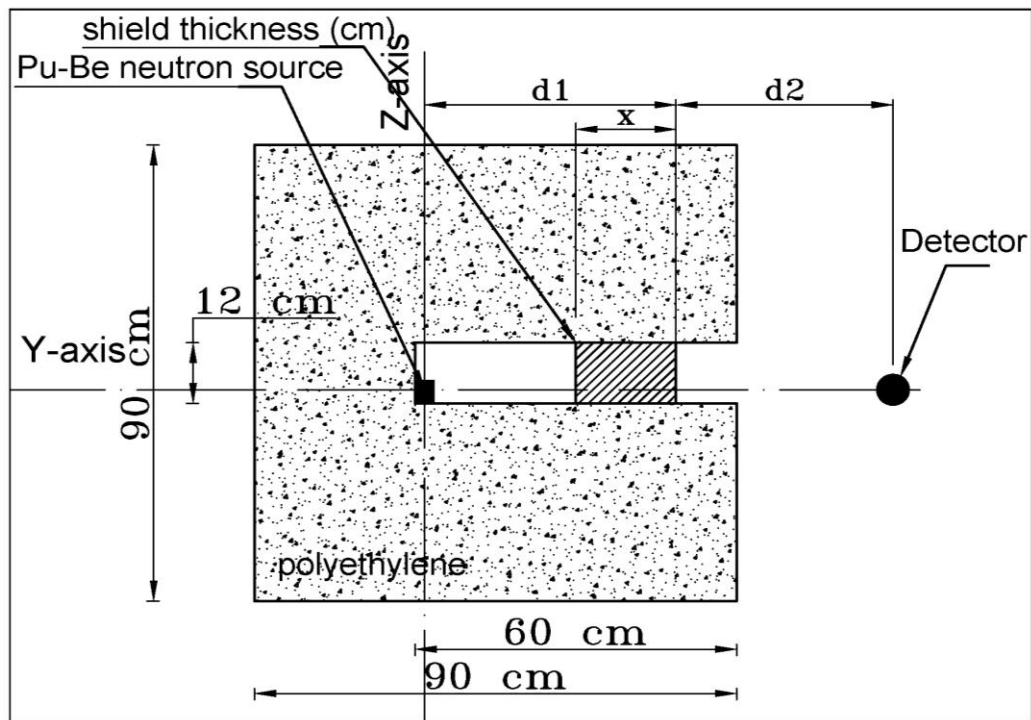


Figure 32. Scheme to describe the lab-model during measurements

Material	d 1 (cm)	d 2 (cm)	X (cm)
polyethylene			2, 4, 8, 12, 16, 20,24, 28, 32, 36, 40
Borated polyethylene			2, 4, 8, 12, 16, 20,24, 28, 32, 36, 40
Concrete 1			10, 15, 20, 25, 30
Concrete 2			10, 15, 20, 25, 30

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