JOINT INSTITUTE FOR NUCLEAR RESEARCH
Frank Laboratory of Neutron Physics

FINAL REPORT ON THE SUMMER STUDENT PROGRAM

Numerical modeling of the efficiency of the neutron multi-counter systems

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Theme "Numerical modeling of the efficiency of the neutron multi-counter systems".

Abstact: The aim of this work - numerical calculation of effectiveness of thermal neutron counter assemblies. A program, written on Python, has been developed to calculate the efficiency of these assemblies. Changes of multi-counter system effectiveness as a function of individual counter diameter and their relative positions was calculated. The analysis of these dependencies allows optimizing the number of counters in the assembly to obtain the required efficiency.

INTRODUCTION

Thermal neutron proportional counters are subtype of ionization detectors in which the principle gas electron amplification is realized. They are widely used in nuclear physics experiments. The principle of their operation is as follows. The counter consists of a cylindrical cathode tube with a thin anode wire, located co-axial with the cathode. The positive high-voltage potential is usually applied to the anode. Hermetic volume of counter filled with the gas mix, that contains thermal neutron converter, usually ^{3}He. After interaction of a neutron with the atom nucleus of converter two charged particles appears: the proton and nuclei of ^{3}H (triton), with total energy of 764 keV. These charged particles causing initial ionization of the gas in the counter. Electrons and ions from initial ionization begin to move in opposite direction along the electric field that exists inside the counter. If the energy acquired by electrons on length of free run is more than ionization potential of atoms of the gas, they can ionize the gas by themselves. The new electrons which arose at the same time in turn manage to gain energy sufficient for ionization. This so-called mechanism of avalanche amplification multiplies the initial ionization many times. The charge induced on the electrodes can be registered electronically. The charge induced on the electrodes can be registered electronically, informing us about the fact that the neutron passes through the counter.

The purpose of this work was to calculate average effectiveness of neutron counters with various diameter and multi-counter systems, made from this counters. Usually, during experiment the counters located perpendicular to the beam. In this case, for a cylindrical counter, the efficiency will be non-uniform; it has maximum at the center of the counter, and drops to zero near the edges. To increase efficiency, the counters are arranged in several layers. During this work we considered various geometries of systems of counters, and calculate their averaged effectiveness depending from such parameters as gas pressure and the diameter of counter. Our calculations will allow finding optimum configurations of the multi-counter systems corresponding to the effectiveness demanded for an experiment. We assume that the voltage on the counter is set correctly, and we register all the neutrons that interact with the converter. Also, we assume that all electronic noises and gamma-background are under the discriminator threshold. Our calculation was made for neutrons with wavelength 1 A and 1,8 A.

THE MAIN PART

During the work, two programs were written in the Python language, differing in the way of calculating the effectiveness. The first program splits the area covered by the detector into many small parts, and creates an array of efficiency values for each part. With this approach, the efficiency of multi-counter system made from several layers will be the product of arrays for each individual layer. The second program calculates the efficiency for the detector at a given point. For multi-counter systems, it iterates through all detectors, calculating the resulting efficiency. The calculations for the same systems with identical parameters made by both programs completely coincide. The second program is easier to use as it is better suited to specify the geometry of a multi-counter system. The program allows varying such parameters as neutron energy, diameter of the cylindrical counter, converter gas pressure, neutron beam absorption by detector walls, number of layers and number of counters in one layer for multi-layer systems.

RESULTS

The following tables and figures show the results of calculations for different diameters of standard counters and different geometries. (various arrangement of counters in the first and second layers). Also the program can count averaged effectiveness for each layer of detectors, and for set of several layers (these data were not included in the report as excessive).

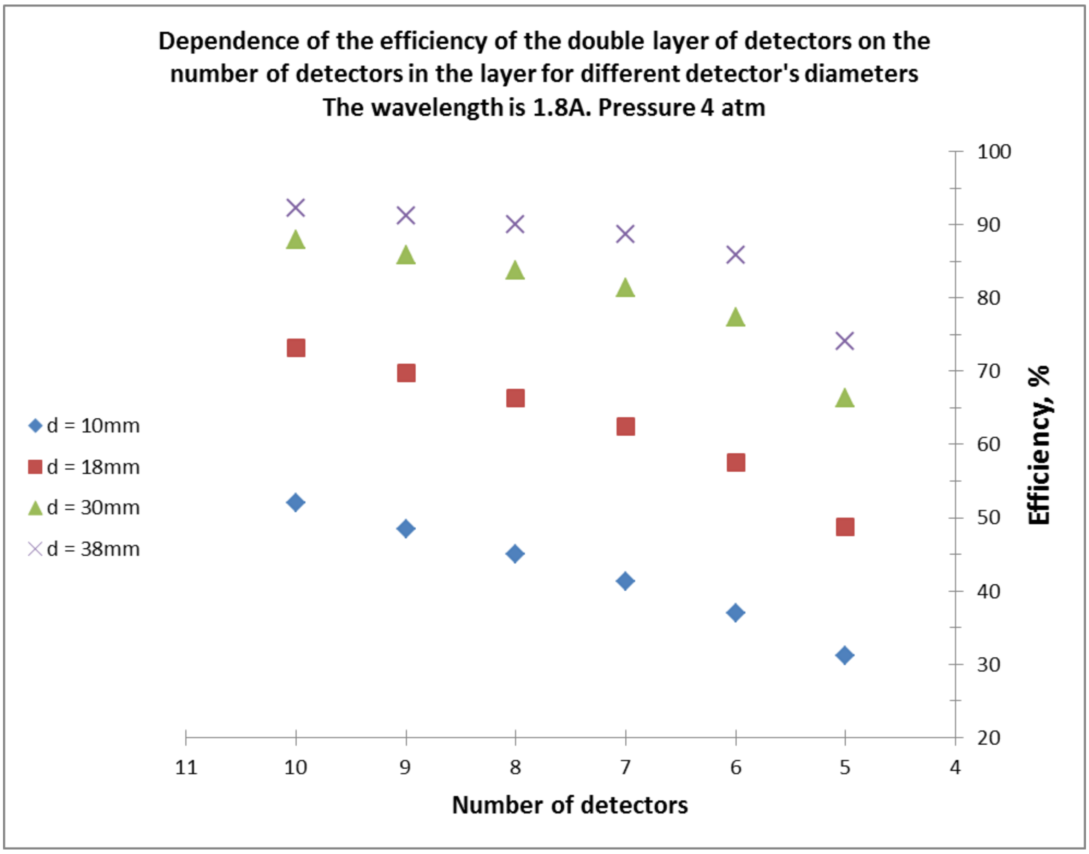
Number of detectors in a layer from 10 possible	Effectiveness, %				
	the first layer	the second layer	The third layer	double-layer detector	Three- layer detector
The wavelength 1.8 A The pressure P = 8 atm					
Diameter of detectors = 10 мм					
10	51,5	24,5	10	76	86
9	46,35	26,4	10,7	72,76	83,43
8	41,2	28,26	11,33	69,5	80,8
7	36,05	29,75	12	65,8	77,8
6	30,9	29,9	12,46	60,8	73,27
5	25,75	25,75	10,91	51,5	62,42
Diameter of detectors d = 18 мм					
10	71,81	19,42	3,92	91,23	95,15
9	64,63	25,21	4,82	89,84	94,66
8	57,45	31,02	5,82	88,47	94,3
7	50,27	36,56	7,03	86,83	93,86
6	43,09	40,45	8,59	83,54	92,13
5	35,9	35,9	8,15	71,8	79,96
Diameter of detectors d = 30 мм					
10	85,84	10,77	0,73	96,61	97,34
9	77,26	19,74	1,15	97	98,15
8	68,67	28,92	1,64	97,6	99,24
7	60,09	38,18	2,33	98,27	99,99
6	51,51	46,48	3,65	97,99	99,99
5	42,92	42,92	4,22	85,84	90,06
Diameter of detectors d = 38 мм					
10	90,21	7,21	0,23	97,41	97,64
9	81,18	17,13	0,44	98,31	98,75
8	72,16	27,32	0,68	99,48	99,99
7	63,14	37,77	1,06	99,99	99,99
6	54,12	47,81	1,95	99,99	99,99
5	45,1	45,1	2,72	90,21	92,93

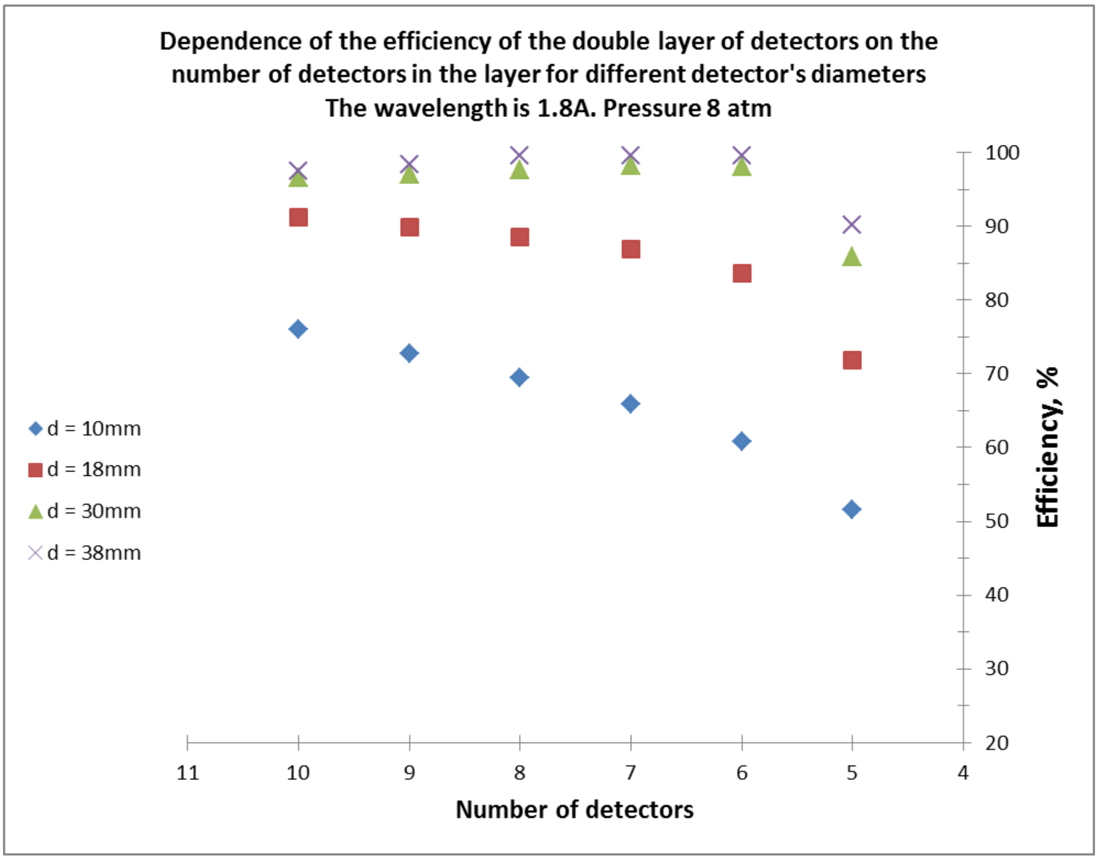
The wavelength 1.8 A The pressure P = 4 атм					
Diameter of detectors d = 10 мм					
10	31,09	20,89	13,19	51,97	65,16
9	27,98	20,51	12,9	48,5	61,4
8	24,87	20,08	12,6	44,95	57,56
7	21,76	19,47	12,23	41,23	53,47
6	18,65	18,29	11,58	36,94	48,52
5	15,54	15,54	9,88	31,09	40,97
Diameter of detectors d = 18 мм					
10	48,8	24,37	10,83	73,16	84
9	43,91	25,84	11,34	69,75	81,09
8	39,03	27,24	11,87	66,28	78,15
7	34,16	28,32	12,4	62,48	74,88
6	29,28	28,25	12,68	57,53	70,21
5	24,4	24,4	11,12	48,8	59,91
Diameter of detectors d = 30 мм					
10	66,36	21,52	5,64	87,88	93,52
9	59,72	26,09	6,6	85,82	92,4
8	53,09	30,65	7,61	83,74	91,34
7	46,45	34,88	8,79	81,33	90,12
6	39,81	37,56	10,13	77,37	87,5
5	33,18	33,18	9,38	66,36	75,74
Diameter of detectors d = 38 мм					
10	74,09	18,22	3,34	92,3	95,65
9	66,68	24,45	4,21	91,14	95,35
8	59,27	30,75	5,19	90,02	95,21
7	51,86	36,81	6,37	88,67	95,05
6	44,45	41,33	7,97	85,78	93,75
5	37,04	37,04	7,74	74,09	81,83

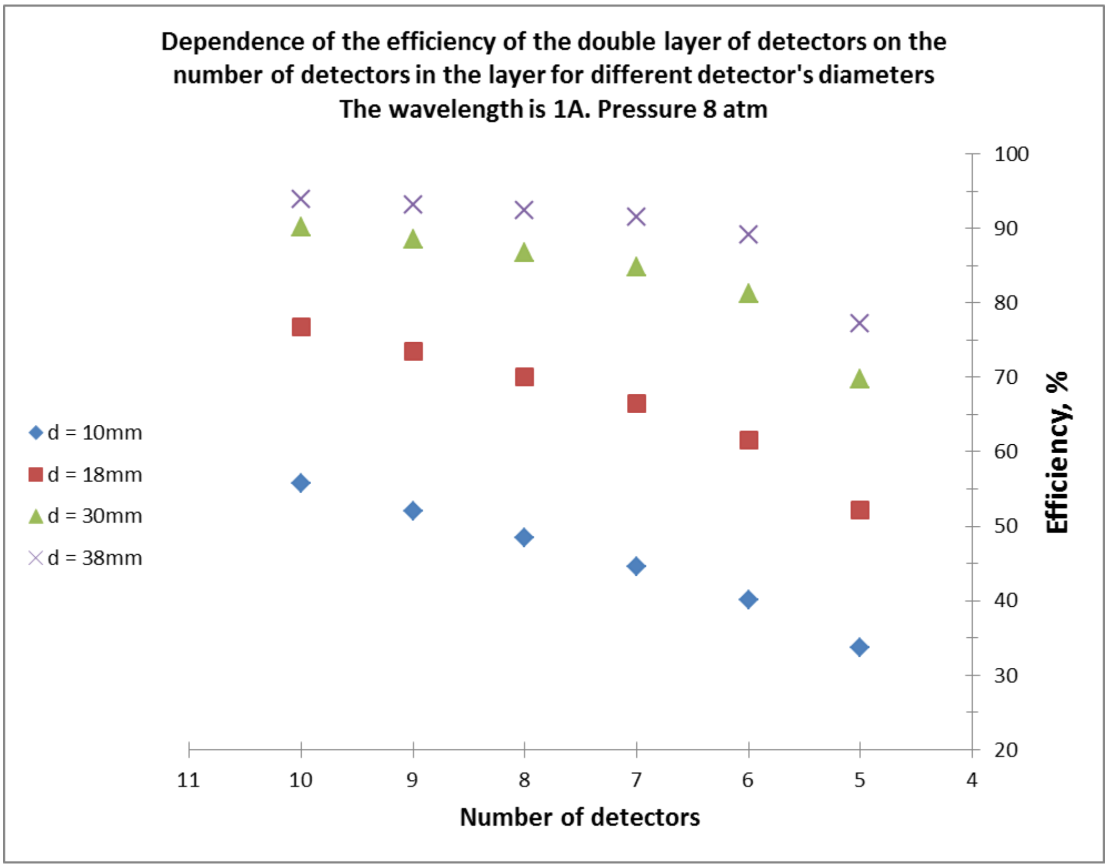
The wavelength 1 A The pressure P = 8 атм					
Diameter of detectors d = 10 мм					
10	33,75	21,91	13,25	55,67	68,91
9	30,38	21,71	13,07	52,09	65,15
8	27	21,45	12,87	48,45	61,33
7	23,63	20,98	12,61	44,6	57,21
6	20,25	19,84	12,04	40,09	52,12
5	16,88	16,88	10,29	33,75	44,04
Diameter of detectors d = 18 мм					
10	52,22	24,46	10,02	76,68	86,7
9	47	26,42	10,66	73,42	84,08
8	41,78	28,32	11,33	70,1	81,43
7	36,56	29,88	12,03	66,43	78,46
6	31,33	30,16	12,52	61,49	74,01
5	26,11	26,11	11,04	52,22	63,26
Diameter of detectors d = 30 мм					
10	69,8	20,37	4,64	90,17	94,82
9	62,82	25,65	5,57	88,47	94,04
8	55,84	30,93	6,6	86,77	93,38
7	48,86	35,92	7,82	84,78	92,6
6	41,88	39,32	9,31	81,2	90,51
5	34,9	34,9	8,76	69,8	78,56
Diameter of detectors d = 38 мм					

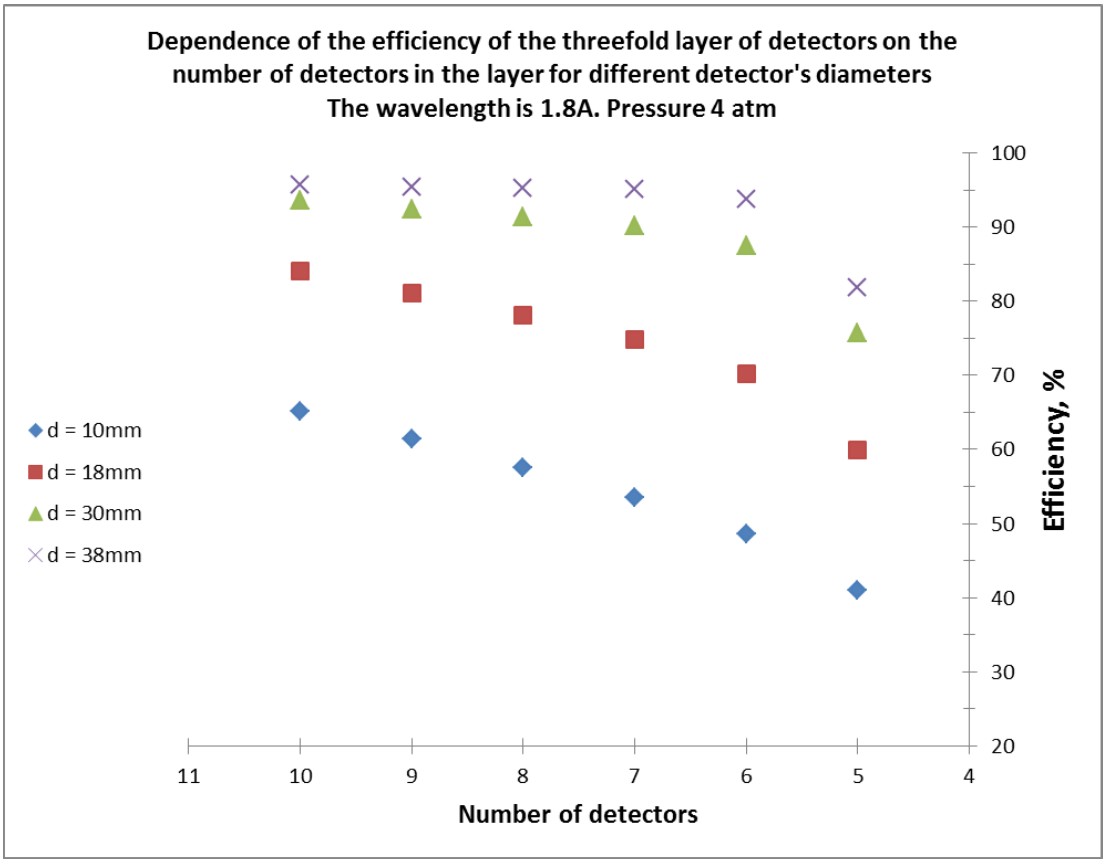
10	77,23	16,68	2,56	93,9	96,46
9	69,5	23,61	3,35	93,12	96,46
8	61,78	30,63	4,25	92,41	96,65
7	54,06	37,47	5,37	91,53	96,89
6	46,34	42,83	7	89,16	96,16
5	38,61	38,61	7	77,23	84,21

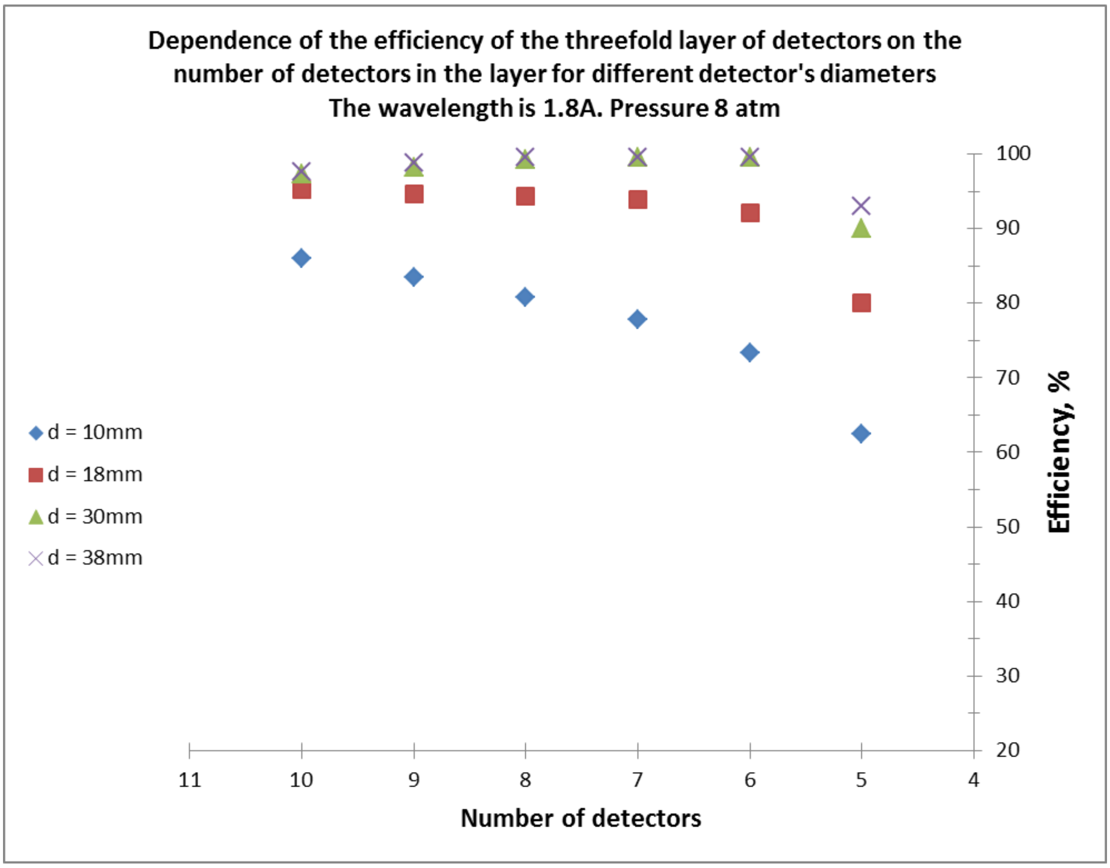
On figures below you can see dependences of average effectiveness from the number of detectors in layer for two and three layers of counters.

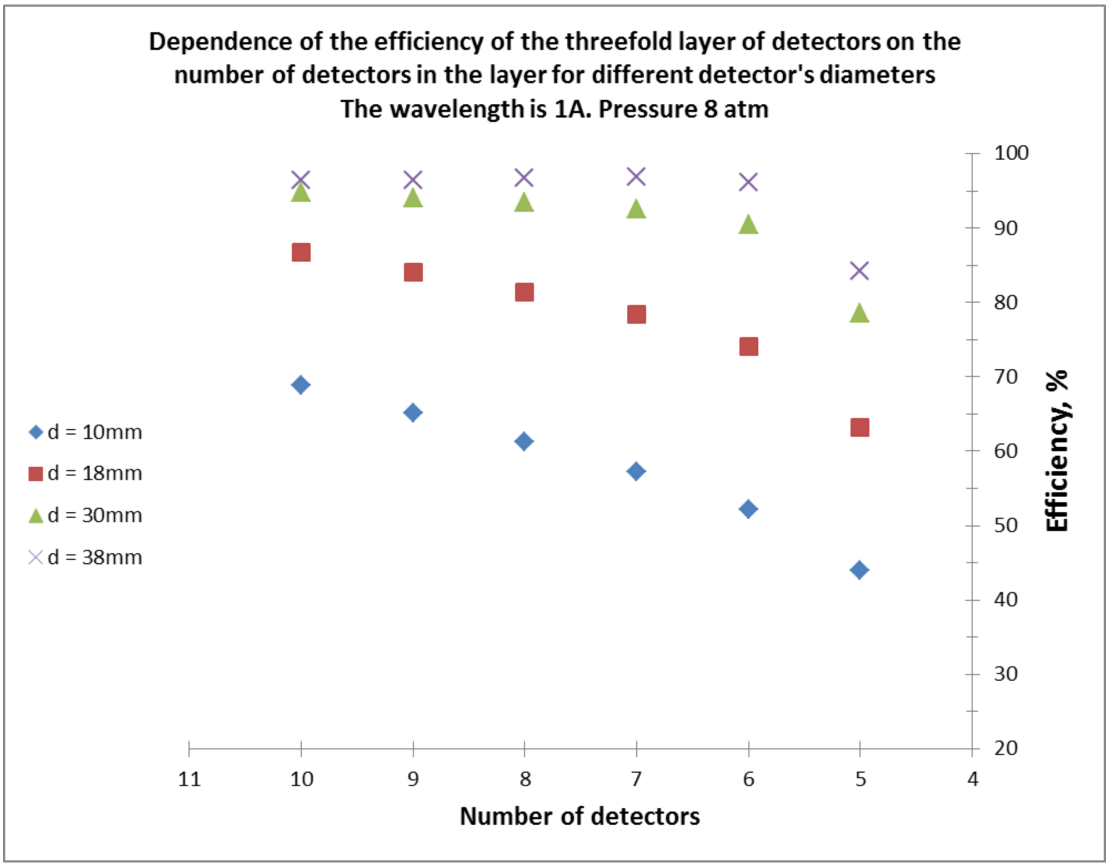



Dependence of the efficiency of the double layer of detectors on the number of detectors in the layer for different detector's diameters
The wavelength is 1.8A. Pressure 8 atm
◆ d = 10mm
■ d = 18mm
▲ d = 30mm
× d = 38mm
Efficiency, %
100
90
80
70
60
50
40
30
20
11
10
9
8
7
6
5
4
Number of detectors


Dependence of the efficiency of the double layer of detectors on the number of detectors in the layer for different detector's diameters
The wavelength is 1A. Pressure 8 atm
◆ d = 10mm
■ d = 18mm
▲ d = 30mm
× d = 38mm
Efficiency, %
100
90
80
70
60
50
40
30
20
11
10
9
8
7
6
5
4
Number of detectors


Dependence of the efficiency of the threefold layer of detectors on the number of detectors in the layer for different detector's diameters
The wavelength is 1.8A. Pressure 4 atm
◆ d = 10mm
■ d = 18mm
▲ d = 30mm
× d = 38mm
100
90
80
70
60
50
40
30
20
Efficiency, %
11
10
9
8
7
6
5
4
Number of detectors


Dependence of the efficiency of the threefold layer of detectors on the number of detectors in the layer for different detector's diameters
The wavelength is 1.8A. Pressure 8 atm
◆ d = 10mm
■ d = 18mm
▲ d = 30mm
× d = 38mm
100
90
80
70
60
50
40
30
20
Efficiency, %
11
10
9
8
7
6
5
4
Number of detectors



CONCLUSION

A program for calculating the effectiveness of multi-detector systems has been developed. We made calculations for some most common neutron counters and reference parameters. The calculations show that an increase in the number of counters above a certain number is not effective, and can lead to deterioration in the efficiency of the entire system. The optimal number of counters depends on the diameter of the counter, gas pressure, neutron energy and should be calculated depending on the purpose of the experiment.

ASKNOWLEDGMENTS

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