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THE BASIC STATISTICAL CHARACTERISTICS OF A NEUTRON SOURCE AND THEIR INFLUENCE ON THE NEUTRON CHARACTERISTICS OF ROCKS

ZÁKLADNÍ STATISTICKÉ CHARAKTERISTIKY NEUTRONOVÉHO ZÁŘIČE A JEJICH VLIV NA NEUTRONOVÉ CHARAKTERISTIKY HORNIN

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Abstract

The log analysts originally disregarded an influence of various types of neutron sources about neutron characteristics of substances. They have expected that differences among various neutron sources are tiny and just this was why they neglected their influence on results of neutron logs. From this premise there was it already close to the statement that the correction charts simulated for one type of neutron source were useable for all other ones. Unfortunately, this is not right. These, who think like that, make a large mistake, because the length of moderation of fast neutrons is dependent on the middle energy of neutron source. That means the various types of neutron sources have this neutron characteristic various too. The aim of this paper is an explanation of influence of energetic spectrum of the neutron source on well-logs.

Abstrakt

Karotážní analytici původně nevěnovali pozornost vlivu různých typů neutronových zářičů na neutronové charakteristiky látek. Očekávali, že rozdíly mezi různými neutronovými zářiči jsou nepatrné a to byl právě důvod, že zanedbali jejich vliv na výsledky záznamů neutronové karotáže. Od tohoto předpokladu bylo už blízko ke konstatování, že interpretační nomogramy konstruované pro jeden typ neutronového zářiče jsou použitelné pro všechny ostatní typy zářičů. Bohužel toto není pravda. Ti, kteří uvažovali tímto způsobem, udělali velkou chybu, protože délka zpomalení rychlých neutronů závisí na střední energii neutronového zářiče. To znamená, že různé typy neutronových zářičů mají tuto neutronovou charakteristiku také rozdílnou. Cílem práce je vysvětlení vlivu energetického spektra neutronového zářiče na karotážní záznamy.

Keywords

neutron characteristics of rocks, middle energy of radio-isotopic neutron source, the length of moderation of neutrons

Klíčová slova

neutronové charakteristiky hornin, střední energie radioisotopického zdroje neutronů, délka zpomalení neutronů

1 Introduction

The neutron source spectrum of energy can have one or more peaks. The one-peak-spectrum is for the neutron sources such as ^{252}Cf, $^{210}Po/B$ and ^{235}U are. The resting neutron sources have two or more peaks. They are, for instance, $^{210}Po/Be$, $^{226}Ra/Be$, $^{241}Am/Be$ and other ones. The neutron sources produce neutrons in a wide energetic band. To account it analytically – it is impossible. However, we can characterize the more-peak-spectrum of source by an average value of energy and hence we transform the spectrum having more peaks at the spectrum with only one peak. For all other calculations we consider then the mentioned average value of energy which characterizes the given type of neutron source.

The characteristics of neutron sources are following:

- F (E)…the distributive function having energy E in the interval $E > E_k$; E_k is the boundary energy [MeV],
- g_j (E)….the weighted function of spectrum for j-th interval,
- E_0 …….the middle energy of neutron source [MeV] and
- D (E) …the dispersion of energy of neutron source [MeV^2].

Characteristics of rocks being significant for moderation of neutrons are these:

- L_z… the length of moderation of fast neutrons [cm]; registered are epithermal neutrons. For various neutron sources is different.
- L_M… the common length of neutrons [cm]; registered are thermal neutrons. For various neutron sources is different too, because is dependent on characteristic L_z .
- $L_{n,\gamma}$… the common length both neutrons and gamma-photons [cm]; photons are emitted by nuclei of atoms. Registered are gamma-photons. For various neutron sources is different too, because is dependent on characteristic L_M.

More in detail about characteristics is in next chapters.

It is evident that the neutron characteristics of rocks depend, through the cross-section of single elements, on average energy of the neutron source used. That energy is, however, for each of neutron sources different. Therefore when using various neutron sources we obtain for an identical rock also different value of the same neutron characteristic. This characteristic is the length of moderation of fast neutrons in rock denoted as L_z. As is contained too in next characteristics as L_M and $L_{n,\gamma}$ are, these are different too for various neutron sources.

2 Definition and derivation of the statistical characteristics

The influence of energetic spectrum on the length of moderation of fast neutrons can be described with the help of statistical characteristics. If we know course of curve bounded the neutron source spectrum, we can divide all interval of spectrum into n partial intervals having constant width. Those intervals for energy hold the following condition:

$$E \leq 0.5\,\text{MeV}\,. \qquad (1)$$

We need to account all surface of spectrum bounded by axis and the curve of spectrum. The every j-th interval is classified by weighted function of spectrum denoted as g_j (E). The weighted function for j-th interval is defined as the ratio:

$$g_j(E) = \frac{S_j}{S}\,, \qquad (2)$$

where S_j = the plain of the j-th interval of energy spectrum with constant width holding condition (1) expressed in [cm^2] and

S = the complete plain of all spectrum [cm^2].

$$S = \sum_{j=1}^{n} S_j\,. \qquad (3)$$

The plain S_j was accounted with the help of numeric methods, for example, by trapezoidal method. The next statistical characteristic of neutron spectrum is the distributive function of spectrum. For a continuous spectrum it is determined like that:

Tab.1 The statistical characteristics of Am/Be source

j	E_j [MeV]	s_j [cm^2]	$g_j(E)\times 10^2$	$F(E)\times 10^2$	$(E_j - E_0)^2$ [MeV^2]	Remarks
1	0	0.000	0.00	100.00	24.9001	E_0 = 4.99 MeV
2	0.25	0.550	0.78	99.97	22.4676	D(E) = 6.14 MeV^2
3	0.75	1.650	2.35	99.19	17.9776	
4	1.25	2.550	3.64	96.84	13.9876	
5	1.75	3.300	4.71	93.20	10.4976	
6	2.25	4.000	5.70	88.49	7.5076	
7	2.75	4.650	6.63	82.79	5.0176	
8	3.25	5.255	7.49	76.18	3.0276	
9	3.75	5.150	7.34	68.67	1.5376	
10	4.25	4.925	7.02	61.33	0.5476	
11	4.75	5.075	7.24	54.31	0.0576	
12	5.25	5.300	7.56	47.07	0.0676	
13	5.75	4.750	6.77	39.51	0.5776	
14	6.25	3.800	5.42	32.74	1.5876	
15	6.75	3.100	4.42	27.32	3.0976	
16	7.25	3.025	4.31	22.90	5.1076	
17	7.75	2.940	4.19	18.59	7.6176	
18	8.25	3.000	4.28	14.40	10.6276	
19	8.75	2.350	3.35	10.12	14.1376	
20	9.25	1.550	2.21	6.77	18.1476	
21	9.75	1.150	1.64	4.56	22.6576	
22	10.25	1.200	1.71	2.92	27.6676	
23	10.75	0.700	1.00	1.21	33.1776	
24	11.25	0.150	0.21	0.21	39.1876	
25	11.75	0.000	0.00	0.00	45.6976	
26	12.25	0.000	0.00	0.00	52.7076	
S[cm^2]		70.120				

$$F(E) = P\{E \rangle E_k\} = \int_E^\infty g(E_k)\, dE_k \,, \qquad (4)$$

where $F(E) = \mathrm{P}\{\mathrm{E} \rangle \mathrm{E_k}\}$ = the distributive function having energy E in the interval E > E_k, e.g., if E_k is the boundary energy [MeV].

If I replace the continuous integration by sum, I receive an expression for distributive function being convenient for calculation.

$$F(E) = \sum_{j=n}^{1} g_j(E). \qquad (5)$$

The most important statistical characteristics of neutron source are those being denoted as the middle energy of neutron source and the dispersion of energy of the same source. Both characteristics are defined as follows:

$$E_0 = \int_0^\infty E \times g(E)dE \,, \qquad (6)$$

$$D(E) = \int_0^\infty (E - E_0)^2 \times g(E)dE \,, \qquad (7)$$

where E_0 = the middle energy of neutron source [MeV] and

D (E) = the dispersion of energy of neutron source [MeV^2].

When we replace again the continuous integration by sum, we will get formulas being effective for account of an arbitrary neutron source.

$$E_0 = \sum_{j=1}^{n} E_j \times g_j(E), \qquad (8)$$

$$D(E) = \sum_{j=1}^{n} (E_j - E_0)^2 \times g_j(E). \qquad (9)$$

Thanks to E_0 and D (E) we are able to describe an arbitrary spectrum of neutron source. The formulas for continuous integration and the method have been published again by KOZHEWNIKOW, (1982). Only those formulas for non-continuous sum are derived by author.

3 Discussion over tables and figures

How to get the characteristics of neutron source, I can demonstrate it for the neutron source ^{241}Am/Be. Its spectrum I overdrove from the volume of Amersham's Centre published in 1969-1970. The spectrum is after authors Whitmore and Baker in Physics Review, 78, 1950. There in tab.1 are the characteristics of ^{241}Am/Be accounted after the published data. They are these: E_0, D (E), g_j (E) and F (E).

In the same table there are also values of S_j and S needed for g_j (E). Data g_j (E) and F (E) are expressed in percentage. For the neutron source ^{241}Am/Be there are these accounts: E_0 = 4.99 MeV and D (E) = 6.14 MeV^2.The next table, tab.2, publishes the characteristics of three neutron sources: ^{241}Am/Be, ^{210}Po/Be and ^{252}Cf. There in that table are the characteristics g_j (E) and F (E). It is clear that the more the middle energy of neutron source is, the deeper penetration of neutrons into rocks is.

Tab.2 The distributive functions of neutron sources Am/Be, Po/Be and Cf

	^{241}Am/Be		^{210}Po/Be		^{252}Cf	
E_j [MeV]	$g_j(E)\times10^2$	$F(E)\times10^2$	$g_j(E)\times10^2$	$F(E)\times10^2$	$g_j(E)\times10^2$	$F(E)\times10^2$
0	0.00	100.00	0	100.00	0.00	100.00
0.25	0.78	99.97	3.49	95.61	12.95	87.05
0.75	2.35	99.19	4.35	92.16	17.04	70.01
1.25	3.64	96.84	4.48	87.68	15.52	54.49
1.75	4.71	93.20	5.06	82.62	12.90	41.59
2.25	5.70	88.49	6.56	76.06	10.27	31.32
2.75	6.63	82.79	7.98	68.08	7.96	23.36
3.25	7.49	76.18	8.82	59.26	6.07	17.29
3.75	7.34	68.67	6.98	52.28	4.57	12.72
4.25	7.02	61.39	7.06	45.22	3.41	9.31
4.75	7.24	54.31	7.87	37.35	2.53	6.78
5.25	7.56	47.07	6.93	30.42	1.86	4.92
5.75	6.77	39.51	5.73	24.69	1.37	3.55
6.25	5.42	32.74	4.97	19.72	1.00	2.55
6.75	4.42	27.32	4.13	15.59	0.73	1.82
7.25	4.31	22.90	3.52	12.07	0.53	1.29
7.75	4.19	18.59	4.52	7.55	0.38	0.91
8.25	4.28	14.40	2.64	4.91	0.28	0.63
8.75	3.35	10.12	1.64	3.27	0.20	0.43
9.25	2.21	6.77	0.73	2.54	0.14	0.29
9.75	1.64	4.56	1.1	1.44	0.10	0.19
10.25	1.71	2.92	0.97	0.47	0.07	0.12
10.75	1.00	1.21	0.47	0.00	0.05	0.07
11.25	0.21	0.21	0	0.00	0.04	0.03
11.75	0.00	0.00	0	0.00	0.03	0.00

Tab.3 Basic data for fig.1 touching of Am/Be, Po/Be and Cf

	$F(E)\times10^2$		
E_j [MeV]	^{241}Am/Be	^{210}Po/Be	^{252}Cf
0	100.00	100.00	100.00
0.25	99.97	95.61	87.05
0.75	99.19	92.16	70.01
1.25	96.84	87.68	54.49
1.75	93.20	82.62	41.59
2.25	88.49	76.06	31.32
2.75	82.79	68.08	23.36
3.25	76.18	59.26	17.29
3.75	68.67	52.28	12.72
4.25	61.39	45.22	9.31
4.75	54.31	37.35	6.78
5.25	47.07	30.42	4.92
5.75	39.51	24.69	3.55
6.25	32.74	19.72	2.55
6.75	27.32	15.59	1.82
7.25	22.90	12.07	1.29
7.75	18.59	7.55	0.91
8.25	14.40	4.91	0.63
8.75	10.12	3.27	0.43
9.25	6.77	2.54	0.29
9.75	4.56	1.44	0.19
10.25	2.92	0.47	0.12
10.75	1.21	0.00	0.07
11.25	0.21	0.00	0.03

Tab.4 The middle energy, the dispersion of energy and the half-time of decay for various neutron sources

Source	T [years]	E_0 [MeV]	D(E) [MeV^2]
^{241}Am/Be	461	4.99	6.14
^{210}Po/Be	138 days	4.35	5.70
^{252}Cf	2.65	2.21	2.74
^{210}Po/B	138 days	3.07	1.00
^{239}Pu/Be	24400	4.07	6.92
^{226}Ra/Be	1620	3.63	8.17
^{227}Ac/Be	21.7	4.1	6.50
^{235}U	6.84×10^8	2.03	2.50

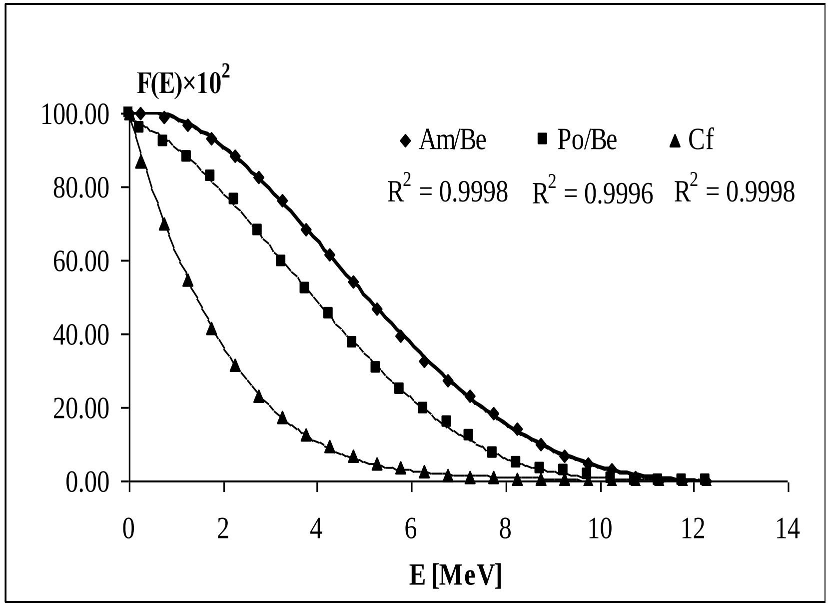

Fig.1 The distribution functions of Am/Be, Po/Be and Cf neutron sources

Data for ^{210}Po/Be and ^{252}Cf have been copied from KOZHEWNIKOW, (1982). Data of this table were copied again in tab.3 presenting for all three sources the basic data needed for fig.1. See it in tab.4, there are the characteristics E_0 and D (E) together with the half-time period remarked as T for various neutron sources. These data are again overtaken from KOZHEWNIKOW, (1982), only data for ^{241}Am/Be are added after author's calculations. Although characteristics of tab.4 are important, their information price is not fully complete, because it is not about the depth of neutron penetration into the wall of borehole. Just those characteristics of penetration are very important; each of the neutron sources has the mentioned characteristics different. Therefore it is too about a large study concerning to calculation of various neutron characteristics, mainly such characteristics as L_Z , L_M and $L_{n,\gamma}$ are, because just these have for evaluation of neutron penetration topic significance; more in detail in RYŠAVÝ, (1985). Next explanation is also in tab.5.

Tab.5 carries out data about the length of moderation of fast neutrons for various sources. The mentioned petrophysical characteristics have been enumerated by method published in RYŠAVÝ, (1985). I should emphasize that only this characteristic is influenced by energy of neutron source, because the diffusion characteristics are not affected by type of neutron source.

Deflections of neutron well-logs are equivalent to the following characteristics; L_z, L_M and $L_{n,\gamma}$. The characteristic L_z which presents the length of moderation of fast neutrons is registered at the moment of detection of epithermal neutrons. The characteristic L_M presenting the common length of neutrons is registered for thermal neutrons and its formula is following:

$$L_M = \sqrt{L_z^2 + L_d^2}\ , \qquad (10)$$

where L_d = the length of diffusion of thermal neutrons [cm].

The last characteristic denoted as $L_{n,\gamma}$ is the common length both neutrons and gamma-photons emitted by nuclei of atoms and are used for registration of gamma-photons:

$$L_{n,\gamma} = \sqrt{L_M^2 + L_\gamma^2}\ , \qquad (11)$$

where L_γ = the length of diffusion of gamma-photons emitted [cm].

It is clear that L_z is affected by the middle energy of neutron source directly, whereas, the resting characteristics L_M and $L_{n,\gamma}$ are influenced by the middle energy vicariously through L_z . The values being in tab.5 are distinctly different for various neutron sources if it is an identical rock.

Tab.5 The length of moderation of fast neutrons for Am/Be, Po/Be and Cf sources and different substances

Substance	**ρ [g/cm³]**	**^{241}Am/Be**	**^{210}Po/Be**	**^{252}Cf**
		L_z [cm]		
Water	1.00	9.5	8.2	6.3
Oil	0.875	9.6	8.4	5.7
Methane	0.00072	25930	21560	10920
Anthracite	1.50	8.4	7.0	4.7
Black coal	1.35	8.2	7.0	4.8
Brown coal	1.30	8.2	7.0	5.0
Quartz	2.65	53.2	38.8	47.9
Limestone	2.72	39.0	26.1	24.2
Dolomite	2.85	33.7	23.5	21.7
Anhydrite	2.94	47.6	31.7	42.0
Corundum	3.96	36.6	25.8	32.8
Hematite	5.24	33.0	21.7	35.1
Salt	2.16	65.3	61.9	51.1
Gypsum	2.32	6.7	5.6	4.9

Tab.5 clearly says too that you can reliably differentiate water from gas what is methane. To differentiate water from oil is impossible, because values of characteristic L_z are tiny. Despite of that certain differences between sources are there. The least sensitive is source ^{241}Am/Be whereas the source ^{252}Cf is the most sensitive. Such changes are in decimal places of tabulated values, however, they exist.

Absolutely other situation is when you have characteristic L_M and register thermal neutrons. Water contains chlorine Cl absorbing thermal neutrons. In beds with highly salt waters holds that $L_d \approx 0$ and so $L_M \approx L_z$, whereas the beds saturated with oil have $L_M = (L_z^2 + L_d^2)^{1/2}$. In case you measure both characteristics L_z and L_M simultaneously in common scale, deflections in the salt water-saturated beds will be equally high and any difference is not between them, so $L_M \approx L_z$ .The oil-saturated beds, however, such difference have, because $L_M > L_z$. The same holds too for beds saturated with fresh water. It needs to say so highly salt waters denoted as brines in Czech Republic are not. Here in Vienna Basin are only fresh and brackish waters. The same is in west area of Pannonien Basin in Slovakia. However, in the east area of Pannonien Basin of Slovakia is situation all other, because there brines are. So in such conditions the method of common registering epithermal and thermal neutrons can carry expected results.

You should pay attention to rocks without hydrogen. Generally speaking, the highest values are for ^{241}Am/Be, the middle ones for ^{210}Po/Be and the lowest ones for ^{252}Cf . However, for quartz, anhydrite, hematite and corundum it is a bit other. Whereas, the nuclear cross-section of hydrogen with growing of energy is decreasing, the other elements than hydrogen have their nuclear cross-section fast oscillating in wide band. Therefore just these elements forming a substance without any hydrogen are affected more than **by density** of substance **by**

oscillating the nuclear cross-section of those elements making composition of substance. That directs to that the length of moderation of fast neutrons accounted after the middle energy of neutron source varies for different sources. It does not hold generally for all such rock, for example, salt, limestone and dolomite confirm that, nevertheless, we must accept the fact that it exists.

Very interesting group is formed with anthracite and both types of coal. Their characteristic L_z is significantly lower than for water and oil. It holds for all three neutron sources. It can be explained with an extent quantity of carbon and higher density exceeding density of fresh water together.

4 Next possible applications of neutron methods

Neutron methods are not used only for oil and gas prospection. They are widely used too for investigation of mineral raw materials. Well are known methods of neutron activation analysis. By irradiation of rock environment the rocks being originally non-radioactive become radioactive. Owing to their gamma-spectrum that is measurable you can say which of elements in rock are. The process of irradiation is dependent on the length time of irradiation and too how power the source of neutrons is. At the beginning activation methods were connected with long time of irradiation. Continuous measurement, well known from boreholes was not be made; measurements were pointed in regular distances.

The all has gone when generators of neutrons have appeared. These work either in pulsed mode or in stationary mode. They emit neutrons with very power energy much higher than the classical neutron sources have. Just this makes possible to register continuous well-logging measurements. So you can directly analyse different elements in the rock environment. You can register boron, fluorine, manganese, cadmium, mercury, aluminium, silicon, sulphur and other elements. In Czech Republic and in Mongolia were successfully made hundreds of boreholes for fluorine, aluminium, silicon and sulphur. All theme of neutron activation analysis can be large than one monography; however, this paper is oriented on hydrocarbon prospection and investigation oil and gas deposits with classical sources.

5 Substances as moderators of fast neutrons

As moderators of fast neutrons we classify the substances containing elements like hydrogen, carbon, lithium and some next ones are. It is not only about elements and structure of molecules, but too about the substance state. The gaseous state of substances is not convenient for moderation; methane as a gas is not moderator. In contrary the substances being in liquid and solid state can be excellent moderators of fast neutrons.

Molecules in gaseous state present absolute chaos. Distances between them are ten times higher than their dimensions are. Molecules being in the volume of gas are distributed very sparsely; however, each of them is in the continuous thermal motion. It is evident that low density of substance is not good for moderation, because fast neutron has a low probability to meet some of molecules and to collide some of its atoms. However, if state of substance changes and when its density is getting higher, probability of collision will be higher too.

Substances being in the liquid state have more advantageous position. Molecules are much closer to one another; as are mutually so close they cannot so freely move as molecules in gas. However, they are too in the continuous thermal motion; as they are near each other their motion looks as a certain oscillation in static position. In reality it is very slow motion showing as flowing of fluid. Their density is substantially higher than it was for gas. That is why that probability of collision fast neutron with some of atoms of molecules is much higher than in case of gas.

In the solid substances there prevail forces of mutual action over the continuous thermal motion. Molecules remain on the only position; in this position oscillate too but do not move. The substantial density is generally higher than it is for liquid substances. So when fast neutron penetrates inside, there will be high probability of collision with some of atoms.

The state of substances is the first condition. The second one is structure of molecule and element composition. The highest moderator is hydrogen; has biggest dimension. However, the second one is carbon. Do not remember that the first atom reactor started on stadium in Chicago had carbon blocks as moderator. Dimension of carbon atom are lower than it is for hydrogen. However, both these elements are important in the practice.

It depends too how atoms are distributed in molecule. Fresh water is an excellent moderator of fast neutrons. Molecule of H_2O has planar structure as an isosceles triangle. In contrary carbonic-acid gas CO_2 has a linear symmetric structure. Methane CH_4 has three-dimensional structure as a tetrahedron. In its centre is atom of carbon; on all four vertexes are atoms of hydrogen. If you compare molecules H_2O and CH_4 **on molecular level** you will find the methane is significantly better moderator than water. Only when you take the fact that it is gas, is methane unfit for moderating. Methane can be also fluidized with density 400 kg/m^3 what is 0.40 g/cm^3 and in such case its moderating ability will get significant. Methane can be too in solid state as a methane-hydrate; formula is approximately as n $CH_4 \times 46$ H_2O for $n < 8$, density presents 900kg/m^3 what is 0.90 g/cm^3. Under this density holds methane is certainly better moderator than water.

Next significant substance is polyethylene $(CH_2)_n$. Its structure makes an infinite string. It is very power moderator; density is 0.92 g/cm^3. It holds for the high-pressure polyethylene. Besides the high-pressure polyethylene there exist, too, the low-pressure polyethylene having its density varying in the interval 1.9 – 9.3 g/cm^3. BROŽ, J. et al. (1980). Such polyethylene is much more powered than water; can serve not only as moderator but too as power absorber of gamma-ray. From polyethylene you can too manufacture standards for calibrating Neutron Logs.

In context with that I want to point out a thing. If you decide to calibrate Neutron Logs with the help of series of limestone standards being different in porosity, it needs to respect two basic conditions. The first is the porous space of standard ought to be fully saturated with fresh water; this is filled sometimes more, in other case less and never completely. In porous space always there remains small quantity of air. Some tens of years ago there existed some of log analysts, domestic and external ones, having declared that saturation of big blocks of limestone is not any problem. They claimed the limestone block takes water just as easy as a sugar lump in the tea, so all porous space is completely and mainly in the natural way, without any technical costs, saturated. It was not true at that time and is not up to contemporary days. The fault is caused with an existence of air in pores, what can be even higher than 10%, however, when it is less than 5%, the error can be neglected. Amount of air can be decreased thanks to technological processes to values around 5%; however, the air in pore space is permanently ever-present. Therefore is more correct to speak about wetness, not about porosity of rock. Such allegation with ignoring of air influence made big devastation in the right attitude to calibration of neutron methods.

The second condition is strictly-identical composition of matrix and matrix density for all series of limestone standards. The standards should be different only thanks to different porosity. Just this can be big problem. To find limestones having for each of standards approximately same matrix composition and matrix density and simultaneously to be different in porosity is very difficult. That is why you must count for limestone standards with real error, when you calibrate, and hope too that the error is not too big, that is less than 5%. In contrary standards manufactured from polyethylene such errors do not have. Different wetness/porosity you simulate with the help of different air gap between tool and polyethylene wall and too you can change the thickness of polyethylene standard. All such standards have the same matrix composition and the same matrix density.

In one time I speculated too about porous concrete standards. Technologists can manufacture all set concrete standards differing of porosity but their chemical composition of matrix is absolutely identical for each of them. It was very attractive, but later I left this idea, because such porous concrete standards would have problems with complete water saturation. Now I think that such problem can be eliminate when you will work not with porosity but with wetness what is multiple of porosity and the degree of water saturation.

Tab.6 The length of moderation of fast neutrons for Am/Be, Po/Be and Cf sources and different substances from perspective of moderating neutrons

			L_z [cm/m]		
Substance	**Formula**	**ρ [g/cm^3]**	**^{241}Am/Be**	**^{210}Po/Be**	**^{252}Cf**
Water	H_2O	1.00	9.5	8.2	6.3
Methane	CH_4	0.00072	259 m	216 m	109 m
Gypsum	$CaSO_4 \times 2H_2O$	2.32	6.7	5.6	4.9
Polyethylene	$(CH_2)_n$	0.92	9.1	8.0	5.4

Have a look in tab.6. For all three neutron sources holds that polyethylene is better moderator than fresh water. It is on condition that fresh water has higher density than polyethylene; despite of that here you see an influence of molecular structure prevails over substantial state. The next interesting moderator is gypsum; moderates distinctly more than fresh water. In this case it is not only about two molecules of water moreover, but too about higher density what affects moderating. Note please the before differences are also for various neutron sources a bit different.

I should like to say next something yet. When emerged neutron source ^{232}Cf , log analysts were enthused by it. They began to prefer this source over source ^{241}Am/Be. They did not compare what is depth of penetration for both sources. So it happened the logs made with source ^{232}Cf denoted at times a gas bed as water bed, whereas the logs made with source ^{241}Am/Be denoted the gas bed as really the gas one. Thanks to analysis it showed that lower penetration of ^{232}Cf was finished in invasion zone, however deeper penetration of ^{241}Am/Be got at a gas zone. Therefore log analysts working in oil and gas prospection returned to neutron source ^{241}Am/Be.

6 Conclusions

After analysing both tables and figure we can summarize all knowledge into these conclusions:

- The method of transformation after KOZHEWNIKOW, (1982) is convenient for the neutron sources having more peaks of energy, because it makes possible specify the neutron source with the help of its statistical characteristics and to transform the mentioned one on the one with only one peak of energy.
- The neutron source remarked as ^{241}Am/Be, in comparison to ^{252}Cf and ^{210}Po/Be, has the deepest penetration. This is confirmed by characteristic F (E) in fig.1 and data of tab.3.
- The higher penetration of neutrons for ^{241}Am/Be is distinct too in tab.5 where the rocks with lower or middle matrix density are characterized by the higher length of moderation of fast neutrons than it is for the both resting sources. However, for very high matrix density it is not valid.
- We cannot replace correction charts one another without considering an influence of neutron source, because each of the neutron sources has its own correction charts. It is very important conclusion for interpreters to respect that reality and not to make redundant errors.
- It is possible to manufacture standards for calibration of Neutron Logs from polyethylene. Standards have different thickness of cylinder wall; their inner diameter can be too various.

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