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Correction Algorithm of Epithermal Neutron Decay Time Spectrum for Uranium Pulsed Neutron Logging

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Abstract:

In the field of uranium exploration, the technology of direct pulsed-neutron-logging uranium measuremer studied abroad. However, it is still in the early stage of development in China. In view of the proble quantitative accuracy of uranium measurement is not good, this paper aims to correct the epithermal neu time spectrum from the uranium pulsed neutron logging based on the physical model of the interaction betwe and formation nuclides and the formation of uranium fission. The numerical model of uranium-bearing sand was constructed. The neutron variation law under different neutron flux and formation water content were means of the standard model and the numerical model. The epithermal neutron correction algorithm which c the accuracy of uranium content has been designed, and the effectiveness of the algorithm has been experiments.

***Keywords**: Uranium Fission, Pulsed Neutron Logging, Epithermal Neutron, Correction Algorithm.*

I. INTRODUCTION

Uranium pulsed neutron logging (UPNL) is the technology of "direct measurement of uranium". The rock formation 235U fission neutrons can be detected when pulsed thermal neutrons induce 235U fission.UPNL is mainly used in the field of uranium exploration, and it is a high-end nuclear logging technology. In 1961, there was a discussion of the “neutron-fission neutrons” in uranium in the field of uranium pulsed neutron logging [1]. In recent years, the theory of uranium logging has been continuously improved and applied to practical applications[2-6]. The developed countries such as USA and Russia have developed prompt neutron logging, and delayed neutron logging and other new technologies based on uranium (235U) fission. UPNL technology was close to or reached the practical level, and achieved a "direct measurement of uranium" and uranium quantitative[7].

In 2012, PenneyR. etc. compared the neutron logging with γ logging, fully affirmed the advantages of neutron logging [8]. In China, pulsed neutron logging ismaturer in the field of oil exploration and application, but incipient in the field of uranium exploration. In theoretical research work, Tang Bin, Zhang

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Feng, Zhang Ji-yun and others have discussed about the basic theory, done research and summary work [9-12]. Wang Xin-guang and others used Monte Carlo to simulate the response of pulsed neutron with different uranium content and porosity in different stratum porosity, and analyzed the relationship between prompt neutron logging, uranium content and porosity, and the relationship between delayed neutron logging, uranium content and porosity [13,14]. In practice, the team led by Professor Tang Bin from East China University of Technology has achieved initial success[15-17], developed China's first neutron logging uranium detection system, which uses multi-detector technology, and then directly Uranium ore for the measurement, to achieve a rapid measurement of uranium.

In summary, UPNL has been relatively mature abroad. The United States and Russia have produced logging tools and put into the production practice. More and more experts have paid attention to the study of the use of pulsed neutron logging technology for uranium measurement in China.In this paper, the study of epithermal neutron decay time spectrum correction algorithm based on double neutron detector is an important research content in this field. Under the condition of China's existing technology, it can effectively improve the accuracy of uranium content interpretation.

II. BASIC THEORY

Based on the double neutron detector, the uranium logging method is a hot topic at home and abroad. The basic principle is that fast neutrons are transmitted to the formation in the borehole, i.e., the original neutron. The neutrons slow into thermal neutrons, thermal neutron induces U-235 fission, and emits uranium fission prompt neutrons, i.e., secondary neutrons. Both neutrons and secondary neutrons are moderated to epithermal neutrons and thermal neutrons over time. Uranium fission neutrons extend the elapsed time of epithermal neutrons and are the physical basis for detecting uranium fission and uranium quantification. By studying the epithermal neutrons and the thermal neutrons decay time spectrum, the neutron moderating ability of the neutrons and the uranium fission persistence were extracted, and the uranium quantification algorithm was established.

Ⅲ. PURPOSE OF CORRECTION

According to the decay theory of neutrons in the stratum, it follows a negative exponential decay law, and the total number of uranium fission neutrons to epithermal neutrons in a certain interval is proportional to the uranium content.However, in the actual logging experiment, it is found that the decay time spectrum of the thermal neutrons is directly affected by the stratigraphic composition and the environment, which is reflected in the change of the thermal neutrons count rate and the elapsed time in the decay curve, will directly affect the total number of epithermal neutrons, thus affecting the use of epithermal neutrons count for uranium content interpretation accuracy.

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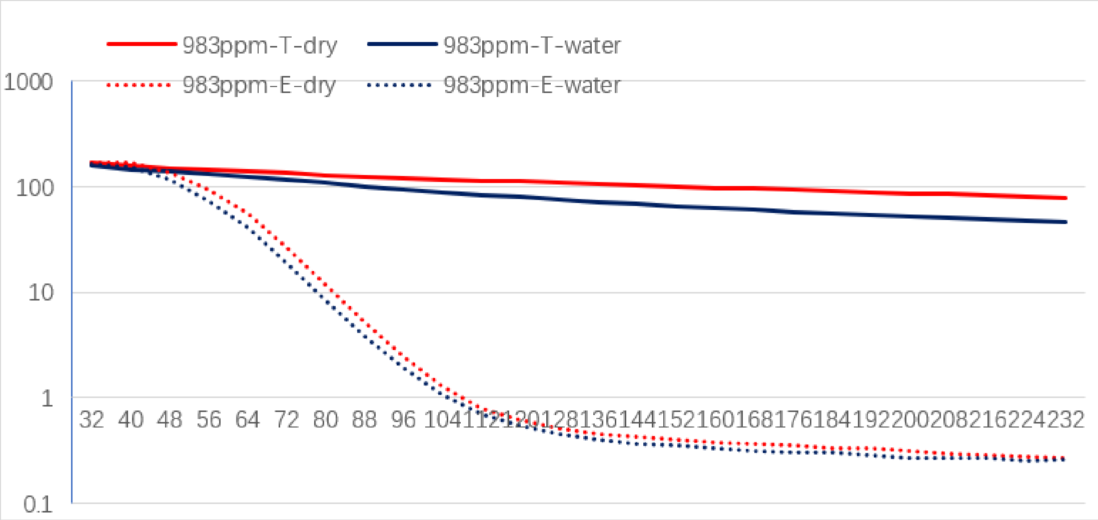

Fig.1 Variation curves of epithermal neutrons and thermal neutrons with different drill environment (logarithmic coordinates)

As shown in Fig. 1, the experimental data were subjected to water and non-water experimental data on a standard model with a 983ppmcontent uranium. As can be seen from the figure, in the water-bearing borehole, some of the thermal neutrons (T) were absorbed by water. The thermal neutron counting rate will be significantly reduced, and the elapsed time is shortened, thus affecting the total number of epithermal neutrons (E), and ultimately affecting the uranium quantification.

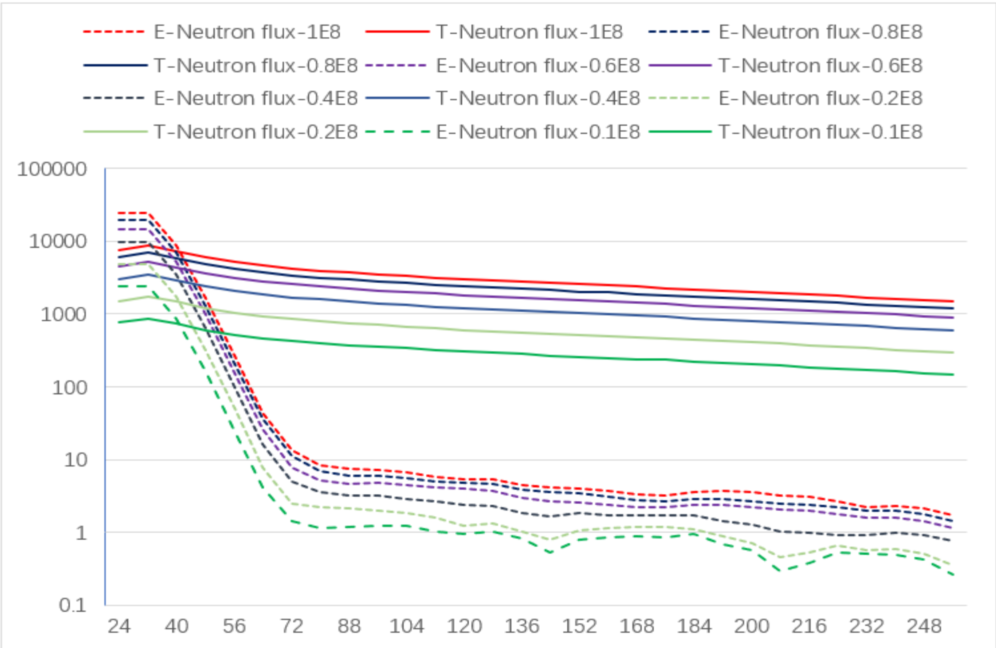

Fig.2 Monte Carlo simulation results with different neutron fluxes
(logarithmic coordinates) (E: Epithermal neutron, T: Thermal neutron)

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Fig.2 shows the neutron decay curves of the different flux neutron generators in the same uranium content model simulated by Monte Carlo. The numerical values shown in the graph on the right side of the graph are the neutrons of the Monte Carlo simulation. It can be seen that when the neutron generator flux is reduced, the thermal neutron counting rate will be decreased and the epithermal neutron counting rate will be reduced too. In order to be able to analyze the uranium content by using epithermal neutrons, it is necessary to correct the data. The correction algorithm studied in this paper can accomplish the correction of the data well.

In order to eliminate the pulled down thermal neutron decay curve caused by the environmental and hardware factors, and the impact of uranium content interpretation, the epithermal neutron decay time spectrum curve correction algorithm was studied and verified in this paper.

Ⅳ.CORRECTION ALGORITHM

The decay curves of the epithermal neutron and the thermal neutron satisfy the equation: $N(t) = ae^{-bt}$,in which a is called the decay constant, b equals $\frac{1}{\tau}$, τ is the thermal neutron lifetime, and t is the decay time.

In order to correct the change of the epithermal neutron decay time spectrum caused by the influencing factors, we first select a standard thermal neutron scale curve as the correction criterion, which referred to $N_0(t) = a_0 e^{-b_0 t}$. The curve can be obtained by using a logging tool on a desired standard model for a long-time measurement.

According to the UPNL theory, the total number of epithermal neutrons (in a certain interval of the decay curve) is an important parameter for the interpretation of uranium content, which is only the correction of the total number of epithermal neutrons in the specified interval, and the total number of epithermal neutrons and the total number of thermal neutrons satisfy the following formula:

$$\mathrm{a}_i = \frac{N_E}{N_T}$$

There into, a_i is the constant for specific uranium content, N_E is the total number of epithermal neutrons, and N_T is the total number of thermal neutrons.

$$N_i' = N_i \times \frac{\int_{t_0}^{\infty} N_0(t)}{\int_{t_0}^{\infty} N_i(t)} = N_i \times \frac{\frac{a_0}{-b_0} \cdot e^{-b_0 \cdot t_0}}{\frac{a_i}{-b_i} \cdot e^{-b_i \cdot t_0}}$$

Assume that the total number of epithermal neutrons to be corrected is N_i, corresponding to the thermal neutron decay curve $N_i(t) = a_i e^{-b_i t}$, the total number of epithermal neutrons after correction is as follows.

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$$N_i' = N_i \times \frac{\int_{t_0}^{\infty} N_0(t)}{\int_{t_0}^{\infty} N_i(t)} = N_i \times \frac{\frac{a_0}{-b_0} \cdot e^{-b_0 \cdot t_0}}{\frac{a_i}{-b_i} \cdot e^{-b_i \cdot t_0}}$$

In the above formula,

N_i is the count of epithermal neutrons measured for actual logging, s^{-1}.
N_i' is the count epithermal neutrons that are corrected, s^{-1}.

a_0 *and* b_0 are the coefficients in the scaled decay equation of the thermal neutron curve.

a_i *and* b_i are the coefficients in the measured decay equation of the thermal neutron curve.

τ_i is the thermal neutron lifetime measured for actual logging and τ_i *equals* $\frac{1}{b_i}$.

τ_0 isthe scaled thermal neutron lifetime of the standard model and τ_0 *equals* $\frac{1}{b_0}$.

According to the data of the existing instrumentsmeasured, the parameters a, b, c and d are different in differentperiods and different models, which cannot be similar and need to be calculated separately.

V. EXPERIMENTAL VERIFICATION

The experiments were tested in the standard model wells. The experimental modelconsists of several different standard models. The measurement curve is shown in Fig. 3. It can be seen from the data in the curve that the neutron decay time spectrum curves of different contents are different. There is a small deviation in the corresponding thermal neutron decay time spectrum curve. The deviation inevitably leads to changes in the epithermal neutron decay time spectrum curve, which ultimately affects the interpretation of uranium content.

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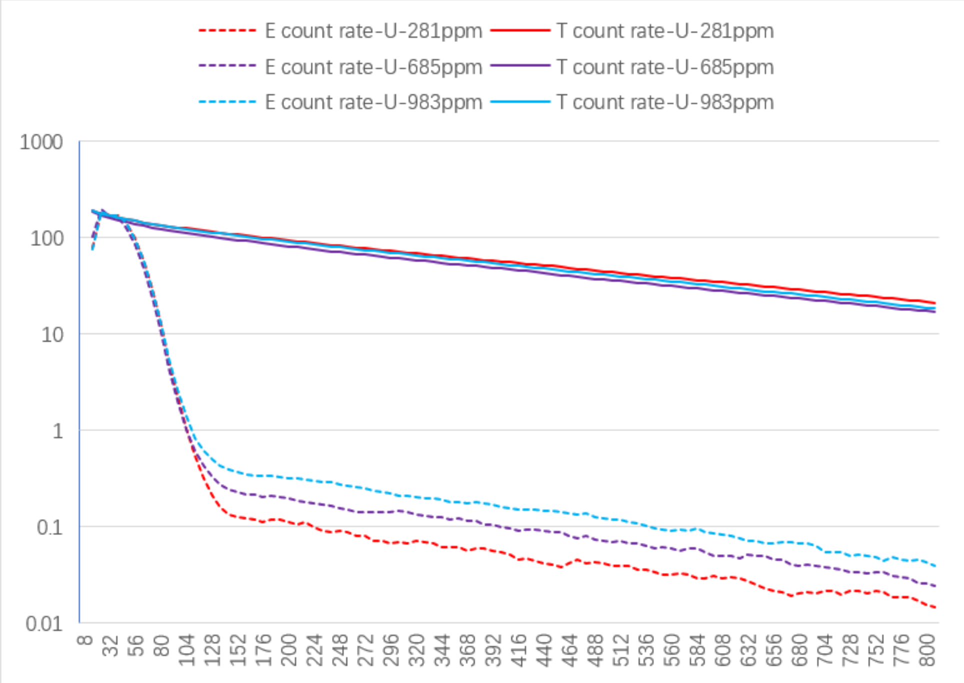

Fig.3 Epithermal neutron and thermal neutron curves from standard model
(E: Epithermal neutron, T: Thermal neutron)

TABLE I.Error comparison between uncorrected count and corrected count of the epithermal neutron

Num	**1**	**2**	**3**
Content (ppm)	281	3.507	2.838
Uncorrected Count of epithermal neutron (cps)	685	6.349	6.349
Corrected Count of epithermal neutron (cps)	983	10.409	9.230
Decay coefficient a	156.550	140.310	157.450
Thermal neutron lifetime	398.406	369.004	370.370
Count of thermal neutron (cps)	3280.340	2785.184	3129.236
Uncorrected explanatory content (ppm)	289.018	667.257	994.385
Corrected explanatory content(ppm)	286.266	672.961	990.301
Uncorrected interpretation error (%)	2.853	-2.590	1.158
Corrected interpretation error (%)	1.874	-1.758	0.743

The epithermal neutron decay time spectrum curve was modified by the correction algorithm designed in

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this paper, and the error was compared with the real content of the standard model before and after the correction. The error was calculated by using the total number of epithermal neutrons. The explanatory error of the model of which content is 281ppm is reduced from 2.853% to 1.874%. The explanatory error of the model of which content is 685ppm is reduced from -2.590% to -1.758%. The explanatory error of the model of which content is 983ppm is reduced from 1.158% to 0.743%, as shown in Table I. Using the correction algorithm designed in this paper, the experiment on the above model has improved the interpretation accuracy of uranium content to varying degrees.

In addition, the data processing algorithm is applied to Chinese UraniumPulsed Neutron Logging Tooland compared with Russian. The Russian tool uses a single epithermal neutron detector with a neutron flux monitoring module to correct the data and then calculates the uranium content. The logging tool's epithermal neutron correction algorithm is as follows:

$$N_E^{'} = N_E \cdot \frac{\Delta M_0}{\Delta M_1} \cdot \frac{\tau_{E0}}{\tau_{E1}} \cdot \frac{e^{-192/\tau_{E0}}}{e^{-192/\tau_{E1}}}$$

In the above formula,

$N_E^{'}$ is the corrected epithermal neutron count rate, directly used for content interpretation, s^{-1}.

N_E is the epithermalneutron count rate to be corrected, s^{-1}.

ΔM_0 is the calibration flux monitoring constant, s^{-1}.

ΔM_1 is the monitor value when actually logging, s^{-1}.

τ_{E0} is the epithermalneutron lifetime measured by the standard model well at the time of calibration, μs .

τ_{E1} is the measured lifetime of the epithermal neutron during logging, μs .

The following set of data contrast (Table II), is from the Russian pulsed neutron tool and Chinese logging tool, due to the differences in the structure of the two instruments, the final data processing algorithms are also some differences, The error in interpretation of the uranium content in the table is different because different epithermal neutron decay time spectrum correction algorithms are used in different instruments.

TABLEIIThe error contrast from two tools in the same model

Instrument	Nominaluranium content(10-6)	Measurementcontent(10-6)	Relative error(%)
Russian	98.3	99.7	1.4
Chinese	98.3	99.0	0.7

Judging from the final error, the interpretation accuracy of uranium content of the two tools meets the industry standard. However, the accuracy of Chinese uranium interpretation is slightly higher than Russian tool.

Ⅵ. CONCLUSION

In this paper, one of the key points to be solved in the current uranium fission prompt neutron logging technology isimproving the interpretation accuracy of uranium content in logging. Monte Carlo simulation and experimental verification are used to design and verify the correction of epithermal neutron decay time spectrum. The algorithm is used to prove that it can eliminate the influence of water and neutron tube flux on the epithermal neutron curve, and thus to improve the interpretation accuracy of uranium content.

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