CNIC-01504
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THE INFLUENCE OF PIPE ON MOISTURE RESPONSE FOR INSERTING TYPE NEUTRON GAUGE

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摘　要

采用双组双区理论模型对插入型中子水分计测量装置中导管对水分响应的影响进行了数值计算，选取 Fe 和 Cu 两种材料不同厚度的导管对热中子通量的影响和水分响应的影响加以比较，同时，给出了部分公式的理论推导。

The Influence of Pipe on Moisture Response for Inserting Type Neutron Gauge

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ABSTRACT

The theoretical calculations of the influence caused by the pipe in measurement installation on moisture response are carried out by means of two-group theoretical model. The comparisons between Fe and Cu pipes whose thickness is different for the influence on thermal neutron flux and on moisture response are made. The derivation of a part of theoretical formulas is given.

INTRODUCTION

In order to control the moisture of the raw materials used in industrial production, or to study the pollutant transfer in the media such as soil, sand, and other substances, we usually need to continuously measure the moisture in these media. There are many methods for this purpose, now neutron method is widely used in the field. Nanjing University has developed neutron moisture gauge [1～4], Lanzhou University has studied the moisture response for the neutron moisture gauge, and we have done the theoretical and experimental influence of medium density on the moisture response. But there are still some problems. One of them is how to solve the influence of the pipe in measurement installation on the moisture response. The purpose of this paper is to introduce a theoretical method.

1 THEORETICAL MODEL

As shown in Fig. 1, it is a sample tub in measurement installation. A pipe is inserted vertically in to the tub center to protect its inside neutron counting tube. A neutron source is put in the center of cylinder, its intensity is *S*. The wall thickness of the pipe is *a*, its inside radius is *c*. The tub radius is *b* and highness is 2*h*. We try to solve flux density distribution for thermal neutrons. For simplifying calculation, we don't consider the influence of the neutron counting tube and ignore the tube volume (order $c = 0$). Therefore, the outside radius of the pipe is regarded approximately as *a*.

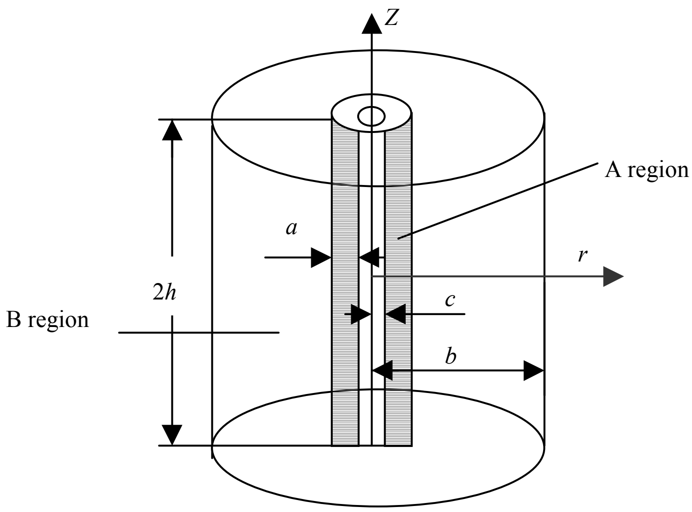

Fig.1 The sample tub in measurement installation

We take two group theoretical model, hold neutron slowing-down and diffusion process to be fast and thermal groups. In each group we take single group diffusion theory. From fast group to thermal group the group transfer section is

$$\Sigma_1 = \frac{D_1}{L_1^2} \tag{1}$$

where D_1 and L_1 refer to diffusion coefficient and slowing-down length of the fast group.

$$L_1^2 = \int_{E_{\text{th}}}^{E_0} \frac{1}{3\xi\Sigma_{\text{s}}\Sigma_{\text{tr}}} \frac{\text{d}E}{E} \tag{2}$$

$$D_1 = \frac{1}{3\Sigma_{\text{tr}}} \tag{3}$$

where E_0 is initial neutron energy, E_{th} is the neutron energy of slowing-down to thermal energy range.

According to single group diffusion theoretical model, in A region (the pipe) and B region (the media) the fast and thermal group diffusion equations are written as:

$$D_{1\text{A}}\nabla^2\Phi_{1\text{A}}(r,z) - \Phi_{1\text{A}}(r,z)\Sigma_{1\text{A}} + S(r,z) = 0 \qquad 0 \leqslant r \leqslant a \tag{4}$$

$$D_{2\text{A}}\nabla^2\Phi_{2\text{A}}(r,z) - \Phi_{2\text{A}}(r,z)\Sigma_{2\text{A}} + \Phi_{1\text{A}}(r,z)\Sigma_{1\text{A}} = 0 \qquad 0 \leqslant r \leqslant a \tag{5}$$

$$D_{1\text{B}}\nabla^2\Phi_{1\text{B}}(r,z) - \Phi_{1\text{B}}(r,z)\Sigma_{1\text{B}} = 0 \qquad a \leqslant r \leqslant b \tag{6}$$

$$D_{2\text{B}}\nabla^2\Phi_{2\text{B}}(r,z) - \Phi_{2\text{B}}(r,z)\Sigma_{2\text{B}} + \Phi_{1\text{B}}\Sigma_{1\text{B}} = 0 \qquad a \leqslant r \leqslant b \tag{7}$$

where subscript 1 and 2 refer to fast group and thermal group, respectively. Σ_2 is the macro absorb section of thermal neutrons. The neutron source intensity is

$$S(r,z) = S'\delta(r)\delta(z) \tag{8}$$

where S' is the emission rate of neutron density (n/s • cm^3), $\delta(r)$ and $\delta(z)$ are Dirac functions.

2 ANALYTIC EXPRESSION

In cylindrical coordinate system, $\nabla^2\Phi = 0$, the expression is

$$\frac{1}{r}\frac{\partial^2}{\partial r}\left(r\frac{\partial\Phi}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2\Phi}{\partial\psi^2} + \frac{\partial^2\Phi}{\partial z^2} = 0 \tag{9}$$

We solve Eq. (9) by the method of separation of variables. Let the solution be written as

$$\Phi(r,\psi,z) = R(r)\phi(\psi)Z(z) \tag{10}$$

When this solution is substituted into Eq. (9), the derivatives become ordinary. We obtain

$$\frac{r^2}{R}\frac{\mathrm{d}^2 R}{\mathrm{d}r^2}+\frac{r}{R}\frac{\mathrm{d}R}{\mathrm{d}r}+r^2\frac{Z''}{Z}=-\frac{\phi''}{\phi}=m^2 \qquad (m=0,1,2,\cdots) \tag{11}$$

The three separate ordinary differential equations are as follows

$$\frac{\mathrm{d}^2 R}{\mathrm{d}r^2}+\frac{1}{r}\frac{\mathrm{d}R}{\mathrm{d}r}+(\mu-\frac{m^2}{r^2})R=0 \tag{12}$$

$$Z''-\mu Z=0 \tag{13}$$

$$\phi''+m^2\phi=0 \tag{14}$$

The Eq. (12) and (13) are come from Eq. (15)

$$\frac{1}{R}\frac{\mathrm{d}^2 R}{\mathrm{d}r^2}+\frac{1}{rR}\frac{\mathrm{d}R}{\mathrm{d}r}-\frac{m^2}{r^2}=-\frac{Z''}{Z}=-\mu \tag{15}$$

where μ is a real constant. Now we discuss three situations about μ,

(1) if $\mu=0$, that is

$$Z(z)=C+Dz \tag{16}$$

$$R(r)=Er^m+F\frac{1}{r^m} \tag{17}$$

(2) if $\mu>0$, let $x\equiv\sqrt{\mu}r$, that is

$$x^2\frac{\mathrm{d}^2 R}{\mathrm{d}x^2}+x\frac{\mathrm{d}R}{\mathrm{d}x}+(x^2-m^2)R=0 \qquad \text{(Bessel equation)} \tag{18}$$

$$Z(z)=C\mathrm{e}^{\sqrt{\mu}z}+D\mathrm{e}^{-\sqrt{\mu}z} \tag{19}$$

(3) if $\mu<0$, let $x\equiv\sqrt{-\mu}r=\lambda r$, that is

$$Z(z)=C\cos(\lambda z)+D\sin(\lambda z) \tag{20}$$

$$x^2\frac{\mathrm{d}^2 R}{\mathrm{d}x^2}+x\frac{\mathrm{d}R}{\mathrm{d}x}-(x^2+m^2)R=0 \qquad \text{(imaginary quantity Bessel equation)} \tag{21}$$

Any solution of imaginary quantity Bessel equation is not real zero, if we require $R(r)$ to satisfy the homogeneous boundary condition at $r=a$, then $\mu<0$ is impossible. If we require $Z(z)$ to satisfy the homogeneous boundary condition at $z=h$, then $\mu\geqslant 0$ is impossible. For the model chosen in this paper, we require $\Phi(r,\psi,z)$ to satisfy the homogeneous boundary conditions at both the ends of cylinder, and require $\phi(\psi)$ to be isotropic for ψ. Therefore $\Phi(r,z)\sim R(r)\,Z(z)$. $R(x)$ is the linear superposition of imaginary quantity Bessel function $\mathrm{I}_m(x)$ and imaginary quantity Hankel function [7] $\mathrm{K}_m(x)$, where

$$\mathrm{K}_m(x)=\frac{\pi}{2}\frac{\mathrm{I}_{-m}(x)-\mathrm{I}_m(x)}{\sin(m\pi)} \tag{22}$$

$$\mathrm{I}_{\pm m}(x)=\sum_{k=0}^{\infty}\frac{1}{k!\,\Gamma(\pm m+k+1)}(\frac{x}{2})^{\pm m+2k} \tag{23}$$

According to above statement, we obtain

$$R(r) = A\mathrm{I}_0(\alpha r) + B\mathrm{K}_0(\alpha r) \tag{24}$$

$$Z(z) = \cos(\lambda z) + H\sin(\lambda z) \tag{25}$$

where A, B and H are arbitrary constants. $\mathrm{I}_0(x)$ and $\mathrm{K}_0(x)$ are the imaginary quantity Bessel function of order zero and the imaginary quantity Hankel function of order zero, respectively.

$$\alpha = (\lambda^2 + \frac{1}{L_i^2})^{\frac{1}{2}} \tag{26}$$

The source is at the center of the cylinder, the odd function of z should be eliminated, then H=0, and the solutions for the two regions become

$$\Phi_{1\mathrm{A}} = \sum_n [A_n \mathrm{I}_0(\alpha_n r) + B_n \mathrm{K}_0(\alpha_n r)]\cos(\lambda_n z) \tag{27}$$

$$\Phi_{1\mathrm{B}} = \sum_n [F_n \mathrm{I}_0(\gamma_n r) + G_n \mathrm{K}_0(\gamma_n r)]\cos(\lambda_n z) \tag{28}$$

where λ_n are the eigenvalues of zero-flux boundary condition at $z = h$. A_n, B_n, G_n and F_n are arbitrary constants, and

$$\alpha_n = (\lambda_n^2 + 1/L_{1\mathrm{A}})^{1/2} \tag{29}$$

$$\gamma_n = (\lambda_n^2 + 1/L_{1\mathrm{B}})^{1/2} \tag{30}$$

From $\cos(\lambda_n h) = 0$ we obtain $\lambda_n = n\pi/(2h) \quad (n = 1, 3, 5, \cdots)$

Because $\mathrm{I}_0(x)$ goes to infinity as x increases, then F_n=0. The constant B_n are determined from the source normalization, and are obtained from Fourier expansion.

$$S\delta(z) = \sum_{m=1}^{\infty} \mathrm{P}_m \cos(\lambda_m z) \qquad (m \text{ odd}) \tag{31}$$

$$\int_{-h}^{h} S\delta(z)\cos(\lambda_n z)\mathrm{d}z = \int_{-h}^{h} \sum_{m=1}^{\infty} \mathrm{P}_m \cos(\lambda_m z)\cos(\lambda_n z)\mathrm{d}z = \int_{-h}^{h} \mathrm{P}_n \cos^2(\lambda_n z)\mathrm{d}z$$

$$\text{(orthogonality)} \tag{32}$$

Both sides of Eq. (32) are integrated, then $\mathrm{P}_n = S/h$.

We take a small flat cylinder that surrounds the source and whose radius is r_1, then the neutron current passed it should equal to the source intensity S. The expression of current density is $-D_{1\mathrm{A}}(\frac{\partial \Phi_{1\mathrm{A}}}{\partial r})$.

$$\begin{aligned} &\frac{S}{h}\cos(\lambda_n z) = \lim_{r_1 \to 0}\{-D_{1\mathrm{A}}\frac{\partial \Phi_{1\mathrm{A}}}{\partial r}\} \cdot 2\pi r = \\ &\lim_{r_1 \to 0}\{-D_{1\mathrm{A}} A_n \frac{\partial}{\partial r}\mathrm{I}_0(\alpha_n r) \cdot 2\pi r - D_{1\mathrm{A}} B_n \frac{\partial}{\partial r}\mathrm{K}_0(\alpha_n r) \cdot 2\pi r\}_{r=r_1} \cos(\lambda_n z) = \\ &\lim_{r_1 \to 0}\{-D_{1\mathrm{A}} A_n \alpha_n \mathrm{I}_1(\alpha_n r_1) \cdot 2\pi r_1 + D_{1\mathrm{A}} B_n \alpha_n \mathrm{K}_1(\alpha_n r_1) \cdot 2\pi r_1\}\cos(\lambda_n z) = \\ &2\pi D_{1\mathrm{A}} B_n \cos(\lambda_n z) \end{aligned} \tag{33}$$

Thus,

$$B_n = \frac{S}{2\pi D_{1A} h} \tag{34}$$

A_n and G_n are determined by the continuous boundary conditions of flux and current density at $r = a$:

$$\Phi_{1A}(\alpha_n a) = \Phi_{1B}(\gamma_n a) \tag{35}$$

$$-D_{1A}\frac{\partial}{\partial r}\Phi_{1A}(\alpha_n r)\Big|_{r=a} = -D_{1B}\frac{\partial}{\partial r}\Phi_{1B}(\gamma_n r)\Big|_{r=a} \tag{36}$$

Thus,

$$A_n \mathrm{I}_0(\alpha_n a) + B_n \mathrm{K}_0(\alpha_n a) = G_n \mathrm{K}_0(\gamma_n a) \tag{37}$$

$$D_{1A}\alpha_n A_n \mathrm{I}_1(\alpha_n a) - D_{1A}\alpha_n B_n \mathrm{K}_1(\alpha_n a) = -D_{1B} G_n \gamma_n \mathrm{K}_1(\gamma_n a) \tag{38}$$

We obtain

$$A_n = [\frac{D_{1A}\alpha_n \mathrm{K}_0(\gamma_n a)\mathrm{K}_1(\alpha_n a) - D_{1B}\gamma_n \mathrm{K}_1(\gamma_n a)\mathrm{K}_0(\alpha_n a)}{D_{1A}\alpha_n \mathrm{K}_0(\gamma_n a)\mathrm{I}_1(\alpha_n a) + D_{1B}\gamma_n \mathrm{K}_1(\gamma_n a)\mathrm{I}_0(\alpha_n a)}]B_n \tag{39}$$

$$G_n = [\frac{(A_n / B_n)\mathrm{I}_0(\alpha_n a) + \mathrm{K}_0(\alpha_n a)}{\mathrm{K}_0(\gamma_n a)}]B_n \tag{40}$$

Therefore, the neutron flux densities of the fast group in A region and B region are

$$\Phi_{1A} = \frac{S}{2\pi D_{1A} h}\sum_n [\mathrm{K}_0(\alpha_n r) + \frac{A_n}{B_n}\mathrm{I}_0(\alpha_n r)]\cos(\lambda_n z) \tag{41}$$

$$\Phi_{1B} = \sum_n G_n \mathrm{K}_0(\gamma_n r)\cos(\lambda_n z) \tag{42}$$

In addition, taking $\Phi_{1A}\Sigma_{1A}$ and $\Phi_{1B}\Sigma_{1B}$ respectively as the source intensity of thermal group in A region and B region to solve diffusion equations, and connecting with literature [8] and [9], we obtain the analytical solutions as follows

$$\Phi_{2A} = \frac{Mh}{2}[\frac{\exp(-\frac{\sqrt{r^2+z^2}}{L_{1A}})}{\sqrt{r^2+z^2}} - \frac{\exp(-\frac{\sqrt{r^2+(z-2h)^2}}{L_{1A}})}{\sqrt{r^2+(z-2h)^2}} - \frac{\exp(-\frac{\sqrt{r^2+z^2}}{L_{2A}})}{\sqrt{r^2+z^2}} + \frac{\exp(-\frac{\sqrt{r^2+(z-2h)^2}}{L_{2A}})}{\sqrt{r^2+(z-2h)^2}}] + M\sum_n[(\frac{A_n}{B_n})\mathrm{I}_0(\alpha_n r) + \frac{C_n}{B_n S_4}\mathrm{I}_0(\beta_n r)]\cos(\lambda_n z) \tag{43}$$

$$\Phi_{2B} = \sum_n L_n \mathrm{K}_0(\delta_n r)\cos(\lambda_n z) + S_3 \Phi_{1B} \tag{44}$$

The parameters in Eq. (43) and (44) are as following:

$$
\left.
\begin{aligned}
&M = \frac{S}{2\pi D_{2\mathrm{A}} h}\left(\frac{L_{2\mathrm{A}}^2}{L_{1\mathrm{A}}^2 - L_{2\mathrm{A}}^2}\right) \\
&S_3 = \frac{D_{1\mathrm{B}} L_{2\mathrm{B}}^2}{D_{2\mathrm{B}}(L_{1\mathrm{B}}^2 - L_{2\mathrm{B}}^2)} \\
&S_4 = \frac{D_{1\mathrm{A}} L_{2\mathrm{A}}^2}{D_{2\mathrm{A}}(L_{1\mathrm{A}}^2 - L_{2\mathrm{A}}^2)} \\
&\beta_n = \sqrt{\lambda_n^2 + L_{2\mathrm{A}}^{-2}} \\
&\delta_n = \sqrt{\lambda_n^2 + L_{2\mathrm{B}}^{-2}} \\
&L_n = \frac{S_4 B_n}{\mathrm{K}_0(\delta_n a)}\left[\left(\frac{C_n}{B_n}\right)\frac{1}{S_4}\mathrm{I}_0(\beta_n a) - \mathrm{K}_0(\beta_n a) + (1-P)\mathrm{K}_0(\gamma_n a)\left(\frac{G_n}{B_n}\right)\right] \\
&C_n = \frac{T B_n S_4}{D_{2\mathrm{A}}\beta_n a \mathrm{I}_1(\beta_n a)\mathrm{K}_0(\delta_n a) + D_{2\mathrm{B}}\delta_n a \mathrm{K}_1(\delta_n a)\mathrm{I}_0(\beta_n a)}
\end{aligned}
\right\}
\tag{45}
$$

In Eq. (45),

$$
\left.
\begin{aligned}
T = {} & D_{2\mathrm{B}}\delta_n a \mathrm{K}_1(\delta_n a)\left[P\left(\frac{G_n}{B_n}\right)\mathrm{K}_0(\gamma_n a) + \mathrm{K}_0(\beta_n a) - \mathrm{K}_0(\alpha_n a) - \right. \\
& \left.\left(\frac{A_n}{B_n}\right)\mathrm{I}_0(\alpha_n a)\right] - \mathrm{K}_0(\delta_n a)\left\{D_{2\mathrm{A}}\gamma_n a P\left(\frac{G_n}{B_n}\right)\mathrm{K}_1(\gamma_n a) + \right. \\
& \left. D_{2\mathrm{A}}\left[\beta_n a \mathrm{K}_1(\beta_n a) - \alpha_n a \mathrm{K}_1(\alpha_n a) + \alpha_n a\left(\frac{A_n}{B_n}\right)\mathrm{I}_1(\alpha_n a)\right]\right\} \\
P = {} & \frac{D_{1\mathrm{A}} D_{2\mathrm{A}} L_{2\mathrm{B}}^2 (L_{1\mathrm{A}}^2 - L_{2\mathrm{A}}^2)}{D_{1\mathrm{B}} D_{2\mathrm{B}} L_{2\mathrm{A}}^2 (L_{1\mathrm{B}}^2 - L_{2\mathrm{B}}^2)}
\end{aligned}
\right\}
\tag{46}
$$

3 PARAMETER CALCULATION

Applying neutron moisture gauges to the process of steel production, we select ball-material as studying object. The components of the ball-material are in Table 1.

Table 1 The percent content of the ball-material

Element	Fe	Cu	Pb	Ca	Mg	Si	S	O
Content/ %	61.28	0.330	0.032	1.75	1.42	6.38	0.44	9.50

The physical parameters of fast and thermal groups, and formula expressions refer to literature [6].

$$\left.\begin{aligned}
L_1^2 &= \sum_{n=1}^{7} \frac{\ln(E_{u,n} / E_{l,n})}{3(\xi\Sigma_s)_n [\Sigma_s(1-\mu)]_n} \\
L_2^2 &= \frac{D_2}{\overline{\Sigma}_a} \\
D_1 &= \frac{1}{3\Sigma_{tr}} \\
D_2 &= \frac{1}{3[\Sigma_s(1-\mu) + \overline{\Sigma}_a]} \\
\Sigma_{tr} &= \sum_{n=1}^{7} n_w \{2[\sigma_s(1-\overline{\mu})]_{H,n} + [\sigma_s(1-\overline{\mu})]_{O,n}\} + \sum_{n=1}^{7}\sum_{x} n_x [\sigma_s(1-\overline{\mu})]_{x,n}
\end{aligned}\right\} \qquad (47)$$

3. 1 The slowing-down and diffusion parameters in different moisture

We select the moisture range required in production process. The parameters of ball-material in different moisture are listed in Table 2 .

Table 2 The results calculated for the parameters of ball-material

Moisture(m) /%	L_{1B}	L_{2B}	D_{1B}	D_{2B}
0	128.50	15.35	0.60	2.12
1.50	67.06	9.46	0.54	1.67
2.96	50.51	8.02	0.49	1.38
4.38	41.62	7.15	0.45	1.17
5.75	35.83	6.52	0.41	1.02
7.09	31.66	6.03	0.38	0.90
8.39	28.49	5.63	0.36	0.80
9.65	25.97	5.29	0.34	0.73
10.88	23.90	5.00	0.32	0.66
12.08	22.18	4.75	0.30	0.61
13.24	20.71	4.53	0.28	0.56
14.37	19.44	4.34	0.27	0.53
15.48	18.33	4.16	0.25	0.49
16.56	17.35	4.00	0.24	0.46
17.61	16.47	3.85	0.23	0.43
18.63	15.69	3.72	0.22	0.41
19.63	14.98	3.60	0.21	0.39
20.60	14.34	3.49	0.20	0.37
21.55	13.75	3.38	0.20	0.35
22.48	13.21	3.28	0.19	0.34
23.39	12.72	3.19	0.18	0.32
24.27	12.26	3.10	0.18	0.31
25.14	11.84	3.02	0.17	0.30

3. 2　The parameters of different pipe materials

We select Fe and Cu as pipe materials. The results are listed in Table 3.

Table 3　The parameters of pipe materials

Material	L_{1A}	D_{1A}	L_{2A}	D_{2A}
Fe	35.01	0.12	0.88	0.26
Cu	26.77	0.11	0.78	0.30

4　RESULTS

According to Simpson formula, we solve average flux density of thermal neutron. The neutron counting tube selected is 49 cm long. For having representative characters，we consider three cases：

We calculate average flux density of thermal neutron in z direction (order $r = 0$).

(1) The source of neutron is on the top of the tube

$$\overline{\Phi}_{2A} = \frac{1}{l}\int_0^l \Phi_{2A}(r,z)\mathrm{d}z \tag{48}$$

(2) The source of neutron is in the middle of the tube

$$\overline{\Phi}_{2A} = \frac{1}{l}\int_{-l/2}^{+l/2} \Phi_{2A}(r,z)\mathrm{d}z \tag{49}$$

(3) By the way, we select the tube laid in a parallel direction with r and $z = 1$ cm,

$$\begin{aligned}\overline{\Phi}_{2B} &= \frac{1}{l}\int_a^{l+a} \Phi_{2B}(r,z)\mathrm{d}r = \\ &\frac{1}{l}\int_a^{l+a} \Phi_{2B}(r)\mathrm{d}r \approx \\ &\frac{1}{l}\frac{l}{3n}\{0.5[\Phi_{2B}(a) - \Phi_{2B}(l+a)] + \sum_{i=1}^{n}[2\Phi_{2B}(a+(2i-1)h) + \Phi_{2B}(a+2ih)]\}\end{aligned} \tag{50}$$

where l is the length of tube, and a is the thickness of pipe, $h = l/(2n)$, $(i = 1, 2, \cdots, 2n-1)$, and n is positive integer.

According to above methods, the counting of moisture response is written as $C_R = 60V_{eff}\Sigma_a\overline{\Phi}_{2A}(or\ \overline{\Phi}_{2B})$. V_{eff} is the tube effective volume, Σ_a is the macro absorb section of thermal neutrons for ^{10}B gas. The results of C_R calculated are showed in Fig. 2 and Fig. 3. The influence of Fe and Cu pipes on thermal neutron flux is showed in Fig. 4 and Fig. 5.

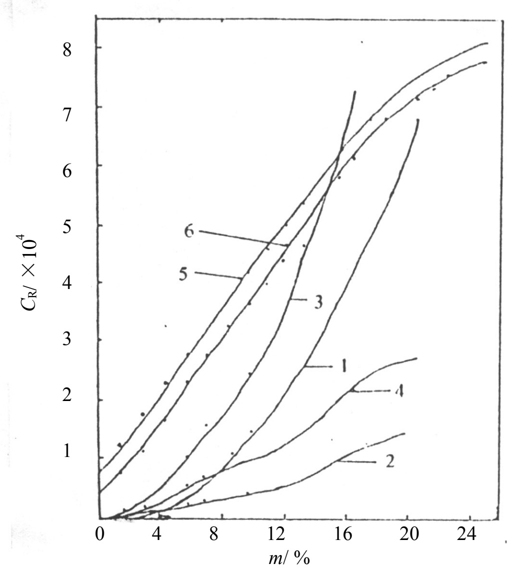

Fig.2 The curves of influence of Cu pipe having different thickness on moisture response

1. The tube is laid in the case of (1) for a=0.1 cm;
2. The tube is laid in the case of (1) for a=0.5 cm;
3. The tube is laid in the case of (2) for a=0.1 cm;
4. The tube is laid in the case of (2) for a=0.5 cm;
5. The tube is laid in the case of (3) for a=0.1 cm;
6. The tube is laid in the case of (3) for a=0.5 cm.

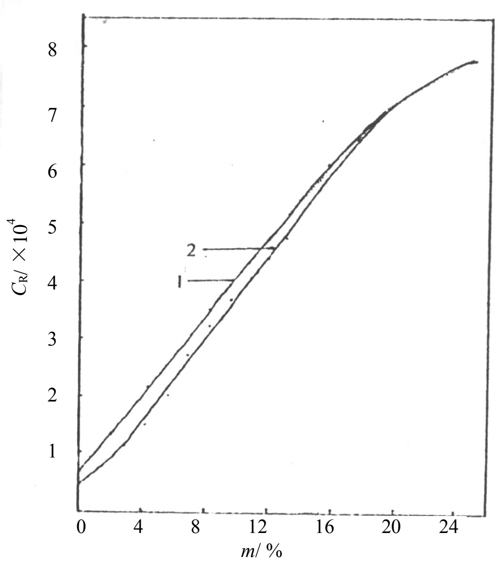

Fig.3 The curves of influence of Fe pipe having different thickness on moisture response

1. The tube is laid in the case of (3) for a=0.1 cm;
2. The tube is laid in the case of (3) for a=0.5 cm.

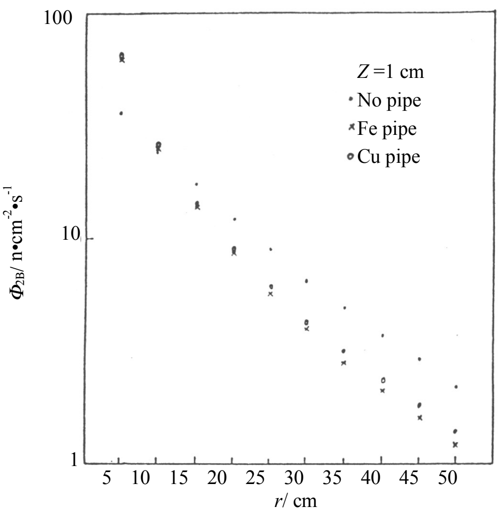

Fig.4 The influence of Fe and Cu pipes on thermal neutron flux for m = 4.38% and a =0.5 cm

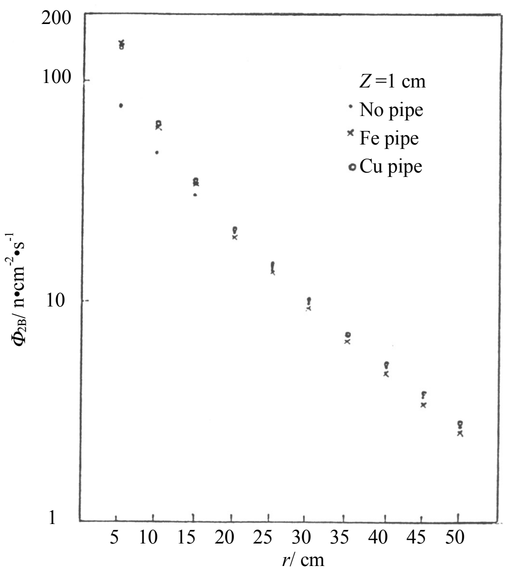

Fig.5 The influence of Fe and Cu pipes on thermal neutron flux for m =8.39% and a =0.5 cm

5 DISCUSSION

We select the sample tub whose radius is $b = 50$ cm and half highness is $h = 50$ cm. The neutron source is the ring state of ^{241}Am-Be, its activity is 3.7 GBq and neutron emission rate is 5.9×10^{-5} $n \cdot s^{-1} \cdot Bq^{-1}$. The neutron source emits 2.2×10^{5} neutrons per second. In the results showed in Fig. 2 to Fig. 5, we can get the conclusions as follows.

(1) The difference of the influence on the spatial distribution of thermal neutrons between Fe and Cu pipes that have same thickness is no significant, and the difference of influence on moisture response is also ignorant. Therefore, taking Fe or Cu to make the pipe is available. Considering the price of Fe and Cu, taking Fe to make the pipe is suitable.

(2) The influence of the pipes that are made of same materials and have different thickness on moisture response is evident. The more the thickness is increased, the more the counting is decreased. Therefore, selecting thin pipe is preferable when the applied conditions are permissive. Because of the pipe abrasion, selecting the pipe whose thickness is able to be used one year is necessary.

(3) The counting and the liner range of moisture response curve are greatly dependent on the relative position between the neutron source and the tube.

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