Study of safety performance of the ^{241}Am fire alarm source

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Abstract The safety performance of ^{241}Am fire alarm sources made by using powder metallurgical technology has been preliminarily studied, so as to determine an allowable maximum energy limit value of the alpha particles outgoing from this kind of sources in light of radiation safety and the present technology. The yielded results show that ^{241}Am leak has not been found when the peak energy of the alpha energy spectrum of this kind of sources is less than 4.96 MeV.

Keywords ^{241}Am fire alarm source, Alpha energy spectrum, ^{241}Am leak

CLC numbers TL929

1 Introduction

The ^{241}Am fire alarm source is used in the detector mounted in an ion smoke-sensitive fire alarm. The detectors fall into two kinds, i.e., twin-source detector and single-source detector. The ionizing electric current produced by the alpha particles from the ^{241}Am source in the ionization chamber of the detector keeps a certain intensity when there is not fire nearby. When fire happens, the alarm signal is given off once the smoke that gets into the ionization chamber is increased to a certain degree and the ionizing current in the ionization chamber obviously changes. The source performance demanded by individual alarm factory is slightly different, but the ionizing currents produced by the alpha particles of the source in the detector are definitely different when the fire happens and not. The alpha particle energies (branching ratio) of ^{241}Am are 5.442 (12.5%) and 5.484 MeV (85.2%), but the energies of the alpha particles from the ^{241}Am fire alarm source are lowered because there is a metallic coat on the surface of ^{241}Am source[1]. The energy of the alpha particle outgoing from the coated source alters when the thickness of metallic coat changes. The ^{241}Am will leak out from the source and radioactive contamination will happen when the metallic coat is too thin. There are two primary factors that influence the ionizing electric current in the detector, they are the alpha output rate and the alpha particle energy of the coated source. In order to keep the current unchanged, the alpha particle output rate must be decreased when the alpha particle energy is increased, whereas the source giving out a higher alpha particle output rate must be used when the alpha particle energy is lowered. The sources whose alpha particle energies are 2.80~3.80 MeV were used by factories before. The FWHM of the alpha energy peak in the energy range of the spectrum of the source was about 1 MeV. In recent years, the users pay more attention to reduce the mistaken alarming rate. The production of this kind of alarms is further normalized and the

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marketing competition is more intense day by day. It becomes urgent to use low activity ^{241}Am sources with a better alpha energy spectrum. The alpha energy spectrums become deteriorated with lowering the alpha peak energy of the fire alarm sources[2]. The present results show that the FWHM of the alpha energy spectrum can be decreased to less than or equal to 0.7 MeV when the thickness of the surface coat of the source is reduced to make alpha peak energy higher than or equal to 4.60 MeV[2]. Moreover, the thinner the surface coat of the source, the higher the alpha energy of the source, the better the alpha energy spectrum. However, the ^{241}Am will leak out when the surface coat of the source is too thin. Therefore, it is necessary to study the safety performance of the ^{241}Am fire alarm sources emitting higher energy alpha particles, which are made by using powder metallurgical technology. An allowable maximum energy limit value of the alpha particles outgoing from this kind of source can be determined in line with the radiation safety standard[3] and the technological condition. Systematic experiments on the safety performance of this kind of sources have be done.

2 Equipments

2.1 Alpha spectrum measuring and analyzing equipment

The alpha energy spectrum measuring and analyzing equipment used for the ^{241}Am fire alarm source is a special one equipped with a special software. The equipment holds a mixed standard source containing ^{241}Am, ^{238}Pu and ^{244}Cm nuclides and a precision pulser (type 8210, CANBERRA, U S A). The linearity of the precision pulser is better than 0.4% in 2~6 MeV. The FWHM of 5.484 MeV alpha energy spectrum measured with the equipment was 17.4 keV when the bias is 150 V and the shaping time is 1 μs.[2]

2.2 Equipment for measuring low alpha background

The equipment for measuring low alpha background consists of an alpha low background detector, a NIM machine frame, a type 570 amplifier, a type 1031 low-voltage power, a FH1008 single-channel analyzer, and a FH1011 scaler. The average background of the equipment is 0.70 counts/min.

2.3 Measuring equipment for alpha particle output rate of the ^{241}Am fire alarm source

The equipment for measuring relative alpha particle output rate of the ^{241}Am fire alarm source is a special one and it is fitted with a silicon barrier semiconductor, a fast preamplifier, and a fast amplifier. The dead time of the equipment is less than 1 μs.[4]

3 Results and discussion

The experiments on several major items of the safety performance of the ^{241}Am fire alarm sources emitting higher alpha energies have been done in accordance with the practical uses and the related demands. All the alpha energy spectrum data in the following tables are average values obtained from five measurements.

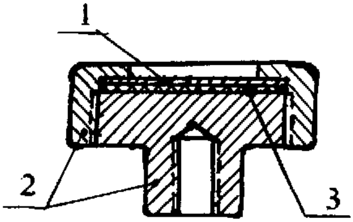

Fig.1 Schematic structure of an ^{241}Am fire alarm source
1 ^{241}Am source piece, 2 Stainless steel source shell, 3 A spacer

3.1 ^{241}Am leak experiments at the condition of difference peak energy of alpha energy spectrum

The present fire alarm source was made up of a stainless steel shell and an ^{241}Am source piece (see Fig.1). The piece was cut from an ^{241}Am source belt. The source belt was rolled by resorting to the powder metallurgical technology. The radioactive ^{241}Am piece was sandwiched between a surface coat (gold or gold-palladium alloy) and a silver bottom layer[1].

Six common source pieces with a diameter of ϕ7 mm were used in the present experiment. After radioactive ^{241}Am contamination and leak of the source pieces were tested according to Chinese national standards GB4076 (Sealed radioactive sources general) and GB15849 (leak test methods for sealed radioactive sources), each standard source piece was put into a source shell with a window diameter of ϕ5.0 mm. The alpha energy spectrum of each source piece was measured. Taking out the source piece from the source

Table 1 Energies and their FWHMs of the alpha particles outgoing from the fire alarm sources and ^{241}Am leak testing data

	Before rolling			After first rolling			After second rolling		
Source number	Energy /MeV	FWHM /MeV	Leakage /Bq	Energy /MeV	FWHM /MeV	Leakage /Bq	Energy /MeV	FWHM /MeV	Leakage /Bq
1	3.63	1.08	×	4.11	0.67	×	4.45	0.66	×
2	3.81	0.91	×	4.07	0.75	×	4.41	0.67	×
3	3.22	1.00	×	4.08	0.74	×	4.39	0.66	×
4	3.58	0.93	×	4.11	0.69	×	4.35	0.63	×
5	3.75	0.91	×	4.09	0.69	×	4.40	0.63	×
6	3.58	1.00	×	4.05	0.73	×	4.41	0.68	×
	After third rolling			After fourth rolling			After fifth rolling		
Source number	Energy /MeV	FWHM /MeV	Leakage /Bq	Energy /MeV	FWHM /MeV	Leakage /Bq	Energy /MeV	FWHM /MeV	Leakage /Bq
1	4.71	0.59	×	4.97	0.46	×	4.96	0.37	×
2	4.75	0.59	×	4.95	0.39	×	4.98	0.32	×
3	4.88	0.61	×	4.97	0.36	×	5.12	0.31	1367
4	4.73	0.57	×	5.01	0.37	213			
5	4.83	0.55	×	4.96	0.35	×	5.08	0.33	1203
6	4.71	0.52	×	4.92	0.45	×	4.97	0.37	×

Note: In the above table, the leakage is the large one of the two values recorded from two leak tests for one source piece, and × *indicates that no* ^{241}*Am leak is found* shell and rolling it again with a rolling mill, to make the surface coat thinner and the alpha particle energy higher. The radioactive leak test of the source pieces was done and then once again after 7 days. After the source piece was fixed at a certain position in the source shell, the alpha energy spectrum of every source was measured. The experiments on every source piece were done several times in the following sequence: rolling, leak testing, and than measuring its alpha energy spectrum until the ^{241}Am leak from the source piece was well affirmed. The data of experiments are listed in Table 1.

The Table 1 shows that the FWHMs of alpha energy spectrums narrow and the peak energies of the alpha spectrums rise after rolling and rolling. ^{241}Am leaks out when the peak energy of alpha energy spectrum is more than 5.00 MeV.

3.2 Leak experiments in the natural circumstance in Beijing

Six ^{241}Am fire alarm sources (having the shells) whose alpha peak energies lie between 4.95 MeV and 5.00 MeV were chosen. The sources were put on a platform in a normal laboratory, where people go in and out often, and the active surfaces of the sources were faced up. The leak testing was done once every month, and the alpha energy spectrums of these sources were measured at the beginning and end of each test. The data for 12 tests are arranged in Table 2.

Table 2 Leak experimental data in the natural circumstance

	1			2	3	4	5	6	7	8	9	10	11	12		
Source numbe	A	B	C	C	C	C	C	C	C	C	C	C	C	A	B	C
1	4.95	0.42	×	×	×	×	×	×	×	×	×	×	×	4.93	0.31	×
2	4.96	0.37	×	×	×	×	×	×	×	×	×	×	×	4.96	0.40	×
3	4.97	0.36	×	×	×	×	×	×	×	×	×	×	×	4.95	0.33	×
4	4.98	0.38	×	×	×	×	×	×	×	×	×	×	×	4.98	0.37	×
5	4.98	0.36	×	×	×	×	×	×	×	×	×	×	×	5.10	0.33	218
6	4.99	0.33	×	×	×	×	×	×	×	×	×	×	×	4.99	0.39	×

Note: In the table, A is the peak energy of alpha energy spectrum in units of MeV; B is the FWHM of alpha energy spectrum in units of MeV; C is the ^{241}Am leak testing data of sources in units of Bq, and × indicats that no ^{241}Am leak is found

3.3 Humidity experiments

Six ^{241}Am fire alarm sources (having the shells) whose alpha peak energies lie between 4.95 and 4.97 MeV were chosen. The sources were moved into a lasting temperature and humidity box immediately in which the temperature was kept at 40±2°C and the relative humidity was kept at 90%~95% for 96 h after the sources were put in a dry box to dry for 30 min at a temperature of 40±5°C. ^{241}Am leakage and alpha energy spectrums of the sources were tested before and after the experiment. The experimental data were listed in Table 3. In the Table, D is alpha particle output rate (alpha particles /second) of the ^{241}Am fire alarm source. ΔA is the peak energy change rate of alpha energy spectrum, $\Delta A = [(A_2 - A_1)/A_1]\times 100\%$. ΔD is the change rate of alpha particle output rate, $\Delta D = [(D_2 - D_1)/D_1]\times 100\%$[5].

Table 3 Experimental data for humidity

Source number	Before experiment				After experiment				ΔA	ΔD
	A_1	B_1	C_1	D_1	A_2	B_2	C_2	D_2		
1	4.95	0.38	×	27478	4.95	0.40	×	27693		+0.8%
2	4.95	0.43	×	25677	4.97	0.39	×	25613	+0.4%	-0.3%
3	4.96	0.41	×	23789	4.97	0.32	×	23699	+0.2%	-0.4%
4	4.96	0.43	×	23191	4.95	0.35	×	23233	-0.2%	+0.2%
5	4.97	0.38	×	27115	4.96	0.31	×	27250	-0.2%	+0.5%
6	4.97	0.33	×	29816	4.99	0.37	×	29733	+0.4%	-0.3%

Note: In the table, the meanings of A, B, C and × are the same as in the Table 2

3.4 Distilled water immersion experiments

Six ^{241}Am fire alarm sources (having the shells) whose alpha peak energies are between 4.95 and 4.97 MeV were chosen. The sources were put in to a container with distilled water. The active surfaces of the sources were faced up and the liquid surface was 3 cm higher than the upper surface of the source. The container which the sources were in was put in to a lasting temperature box after the container was covered. The sources were taken out after the temperature in the box was kept at 30±5°C for 144 h. The ^{241}Am leak of the sources were tested and the alpha energy spectrums of them were measured after the sources have been dried naturally. The experimental data were plotted in Table 4.

Table 4 Distilled water immersion experimental data of the ^{241}Am fire alarm source

Source number	Before experiment				After experiment				ΔA	ΔD
	A_1	B_1	C_1	D_1	A_2	B_2	C_2	D_2		
1	4.95	0.45	×	23927	4.96	0.43	×	23871	+0.2%	-0.2%
2	4.95	0.41	×	26738	4.95	0.39	×	26873		+0.5%
3	4.96	0.38	×	26631	4.95	0.40	×	26699	-0.2%	+0.3%
4	4.96	0.41	×	25436	4.97	0.39	×	25472	+0.02%	+0.2%
5	4.97	0.35	×	26217	4.98	0.36	×	26169	+0.2%	-0.2%
6	4.97	0.37	×	26112	4.97	0.38	×	26255		+0.6%

Note: In the table, the meanings of A, B, C and × are the same as in Table 2 and the meanings of D, ΔA and ΔD are the same as in Table 3

3.5 Seawater, acetone and trichloroethane immersion experiments

The experimental procedures using seawater, acetone, and trichloroethane instead of distilled water, respectively, are the same as described in Section 3.4. The experimental data were separately given in table 5, Table 6 and Table 7.

Table 5 Experimental data for seawater immersion

Source number	Before experiment A_1	B_1	C_1	D_1	After experiment A_2	B_2	C_2	D_2	ΔA	ΔD
1	4.95	0.53	×	22190	4.95	0.45	×	22093		-0.4%
2	4.95	0.49	×	21986	4.96	0.50	×	22054	+0.2%	+0.3%
3	4.96	0.41	×	25326	4.97	0.44	×	25492	+0.2%	+0.7%
4	4.96	0.43	×	25770	4.95	0.43	×	25837	-0.2%	+0.3%
5	4.97	0.45	×	25311	4.98	0.41	212	25403	+0.2%	+0.4%
6	4.97	0.43	×	27228	4.97	0.39	×	27184		-0.2%

Note: In the table, the meanings of A, B, C and × are the same as in Table 2 and the meanings of D, ΔA and ΔD are the same as in Table 3

Table 6 Experimental data for acetone immersion

Source number	Before experiment A_1	B_1	C_1	D_1	After experiment A_2	B_2	C_2	D_2	ΔA	ΔD
1	4.95	0.47	×	26535	4.94	0.45	×	26632	-0.2%	+0.4%
2	4.95	0.51	×	23798	4.95	0.43	×	23609		-0.8%
3	4.96	0.37	×	25442	4.96	0.34	×	25511		+0.3%
4	4.96	0.45	×	25826	4.95	0.43	×	25873	-0.2%	+0.2%
5	4.97	0.42	×	25389	4.99	0.38	×	25423	+0.4%	+0.1%
6	4.97	0.33	×	27437	4.98	0.33	×	27338	+0.2%	-0.4%

Note: In the table, the meanings of A, B, C and × are the same as in Table 2 and the meanings of D, ΔA and ΔD are the same as in Table 3.

Table 7 Experimental data for trichloroethane immersion

Source number	Before experiment A_1	B_1	C_1	D_1	After experiment A_2	B_2	C_2	D_2	ΔA	ΔD
1	4.95	0.42	×	21873	4.94	0.47	×	21792	-0.2%	-0.4%
2	4.95	0.55	×	21339	4.95	0.51	×	21403		+0.3%
3	4.96	0.48	×	22071	4.97	0.50	×	22152	+0.2%	+0.4%
4	4.96	0.55	×	20985	4.96	0.52	×	21133		+0.7%
5	4.97	0.39	×	24170	4.95	0.43	×	24263	-0.4%	+0.4%
6	4.97	0.45	×	25863	4.98	0.41	×	25812	+0.2%	-0.2%

Note: In the Table, the meanings of A, B, C and × are the same as in Table 2 and the meanings of D, ΔA and ΔD are the same as in Table 3

4 Conclusions

The experimental data listed in Table 1 show that the ^{241}Am might leak out when the surface coat of the source piece was too thin, that is to say, when the peak energy of alpha energy spectrum of the ^{241}Am fire alarm source was higher than 5.00 MeV. The experimental data in the Table 2 display that the ^{241}Am leak from the source placed in the natural circumstance in Beijing for as long as a year was found when the alpha peak energy was 4.98 MeV. The experiments for humidity, distilled water immersion, acetone immersion, and trichloroethane immersion testing indicate that no ^{241}Am leak was found under the present experiments condition. However, ^{241}Am leak from the source immersed in seawater was found as the peak energy of alpha spectrum was 4.97 MeV. Therefore, ^{241}Am sources whose peak energies of alpha energy spectrums are less than 4.96 MeV may be considered as having met the safety classfication test.

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