The research of activity range of α pollution source based on LRAD inside pipes

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Abstract

Backgroud: In order to solve the detection problem of internal surfaces of retired pipes of nuclear facilities, the technology of LRAD (Long Rang α Detection) is proposed by the researcher. Purpose: A safe, direct, rapid, real-time and nondestructive method of measuring the activity of α ray can be achieved, by the application of LRAD technology. But, there are many factors which can affect the measuring results of LRAD devices. Such as, detector-source distance, temperature and humidity and so on, all of these factors have a complicated non-linear relation with the measuring results. Thus it is necessary to study the non-linear relation in order to optimize the LRAD device and accurately achieve the range of the activity of α pollution sources in internal surfaces of pipes. Method: In this paper, we study the influence of detector-source distance, temperature and humidity. Then we build an analytic expression between the temperature (T), humidity (H) and measured value of unit activity (I_{avg}) and it is $I_{avg} = 136.14 - 1.62 * T - 0.821 * H$. Then the measured values in the different positions of pipe can be obtain by moving the ^{239}Pu standard source in the pipe. And he analytic expression between detector-source distance and the LRAD measured value (I) can be concluded by exponential curve fitting method, that is $I = 1643 + 623.65e^{-L/52.68}$ R^2 =0.99331. Result: Finally based on the above 2 formulas, the relation can be deduced between the activity range in pipe and the LRAD measured value. If the LRAD electric measured result is I fA, we can conclude the activity maximum value $A_{max} = I_{L_{max}}/I_{avg} = I * (0.725 + 0.275e^{-L_{max}/52.68})/(136.14 - 1.62 * T - 0.821 * H)$. And we also conclude the activity minimum value $A_{min} = I_0/I_{avg} = \frac{I}{0.725+0.275e^{-L_{max}/52.68}} / (136.14 - 1.62 * T - 0.821 * H)$. Where T represents temperature, H represents humidity, and L_{max} represents the maximum detector-source distance. Conclusions: Thus we can utilize the size of α pollution source's range and judge whether the radioactivity level of retired pipes is high or low.

Keywords

The technology of LRAD (Long Rang alpha Detection); Temperature and humidity; Detector-source distance; The Range of activity

1. Introduction

Looking at the development of nuclear energy in the world, there are a large number of equipment, tools, protective clothing and nuclear facilities et al, which is contaminated during the process of research or manufacture in nuclear fuel plants, nuclear power plants et al., and it is necessary to detect the level of radioactive contamination for these equipment, tools, protective clothing and retired nuclear facilities. While detecting the activity of α pollution sources is one of the ways to detect radioactive contamination level [1, 2].

However, in the retired nuclear facilities, the radioactive contamination levels in a few meters of retired pipes by means of detecting the activity of α sources has begun to be concerned by researchers [3-6]. It's necessary to be close to the source of contamination in order to sample it, which may have an impact on the health of the researcher for conventional surfaceαcontamination detection techniques, such as wipe α measurements and probe-type measurements [7-9]. α particles have some characteristics, such as the strong ionization ability, the weak penetration ability and so on, so the above detection technology of α pollution sources are difficult to realize direct, real-time and effective measurement of retired pipes outside the pipe.

In order to solve the problem of α pollution sources detection technology in the internal surface of pipes, the United States D. W. MacArthur et al. firstly proposed LRAD (Long Range alpha Detector) technology [10,11] in the American Nuclear Science Winter Conference. The LRAD technology uses α particles to ionize the air in the pipe for producing a large number of charged ion pairs, then the charged ion pairs is collected to the ionization chamber with the fan. Subsequently it can generate current accord to the application of electric field into the ionization chamber. And the current intensity is proportional to the activity of α particles. Thus we can calculate the approximate activity of the α pollution source basing on the current measurement. This technique overcomes some shortcomings of α particle, such as the short range and the weak penetration ability, and can detect any place where the air can penetrate. Thus it can realize the non-destructive monitoring of the α pollution source on internal surface of the retired pipe [14].

With the in-depth study for the LRAD technology measuring the α radioactive contamination on the internal surface of the pipe, people found that many factors impact LRAD technology to detect the activity of α particles, such as: detector-source distance (cm), temperature, humidity and so on [13]. Therefore, in the paper we study the relationship between temperature, humidity and the measured value of LRAD, and then use SPSS multiple regression method to establish the relationship between temperature, humidity and current measurement. Then we discuss the relationship between the measured value of LRAD and the detector-source distance, and use the index to fit their relationship. Because it is difficult to know the specific location of the α pollution source into the retired pipe, finally we use the relationship between the temperature, humidity and the measured value to infer the activity range of α pollution sources into the pipe.

2. LRAD measurement system and experiment conditions

2.1 LRAD measurement system

In this paper, we use the LRAD measurement system which is independently developed by research group, LRAD measurement system shown in Figure 1. This measurement system consists of five parts: 1) detection unit; 2) air drive unit; 3) power supply unit; 4) signal acquisition and processing unit;5) Storage and Display Unit [13, 14]. Please refer to [13, 14] for the function of each part.

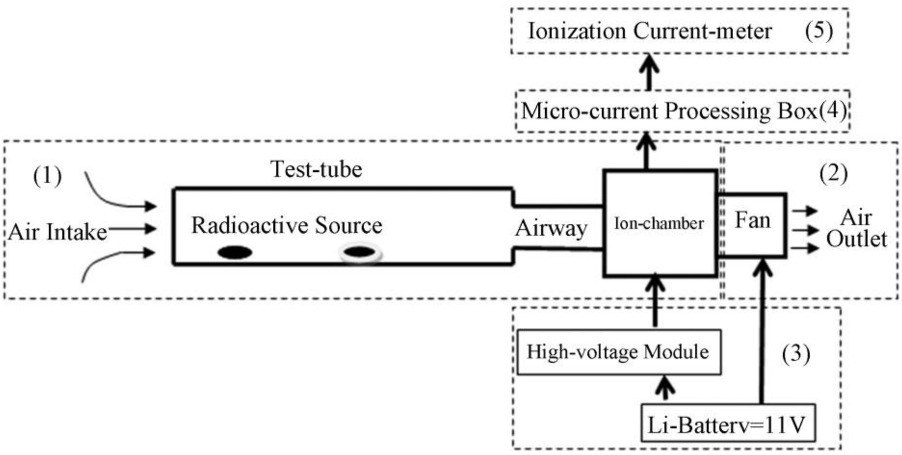

Fig.1 Measuring system diagram of LRAD [13, 14]

2.2 Experiment conditions

The experiment needs to simulate temperature and humidity under the conditions of natural environment, so we do the experiment in the artificial greenhouse room. Artificial greenhouse room has hygrometer, dehumidifier and heating and humidification equipment, in addition these devices can be automatically controlled to maintain temperature and humidity stability. And in the experiment, the optimum temperature range is within 8 ℃ ~ 35 ℃; the optimum range is within RH 19% -80%; the pipe is straight and its length and diameter is 180cm and 78mm respectively; the voltage of fan is 12 V; the measurement time is 60 s each time; the detector-source distance is 20 cm; the radioactive source is ^{239}Pu standard point source and its activity is 224.4 Bq.

3. The changes of temperature, humidity and detector-source distance for the influence of LRAD system measurement result

3.1 The changes of temperature and humidity for the influence of LRAD system measurement result

In this paper, 30 sets of data were measured in the artificial greenhouse room, and 20 sets of data were selected which was arranged according to the temperature from small to large, as shown in Table 1.

Table 1. The changes of temperature and humidity for the influence of Current Measurement Value

Temperature (℃)	Relative Humidity (%)	Current Measurement Value(fA)
8	70	16920
9	65	14974
9.1	80	10548
9.3	55	17013
9.4	75	10925
10.5	50	18999
11	67	16505
11.5	60	15812
13	62	14097
14	70	14835
15	61	14592
17	58	15312
20	30	11171
23	90	3691
25	45	13052
27	24	16759
29	23	13210
30.4	24.5	16805
30.8	22.4	16603
35	19	16151

Note: The above-mentioned current measurement has subtracted the influence of the background measured value, and is the average of the ionization current

Then, the data of table 1 are analyzed by SPSS multiple regression method to obtain the relationship between temperature, humidity and measured value, as shown in equation (1).

$$I = 30549.76 - 362.66 * T - 184.18 * H \qquad (1)$$

Where T is the temperature, H is the humidity, I is the current measurement value, the measurement time is 60 s (in the rest of this article, the measurement time are all 60 s).

In equation (1) the complex correlation coefficient is 0.756 and the coefficient of determination is 0.572. According to analysis of variance, we can obtain F = 11.353 and P = 0.001 (significance level).

Since the activity of the radioactive source is 224.4 Bq, the relationship between the different temperature, humidity and the measured value of the unit activity (1Bq) is as follows:

$$I_{avg} = 30549.76 - 362.66 * \mathrm{T} - 184.18 * \mathrm{H}/224.4 = 136.14 - 1.62 * \mathrm{T} - 0.821 * \mathrm{H} \quad (2)$$

Where T is the temperature and H is the humidity.

As can be seen from equation (2), the change of temperature and humidity in the environment has certain influence on the measurement result of LRAD system, and it is necessary to pay attention to the change for evaluating the level of radioactive pollution into retired pipe.

3.2 The changes of detector-source distance for the influence of LRAD system measurement result

In this paper, we select eight test points in the test pipe and the detector-source distance in the test points is shown in Table 2.The schematic of the experimental device shown in Figure 2.

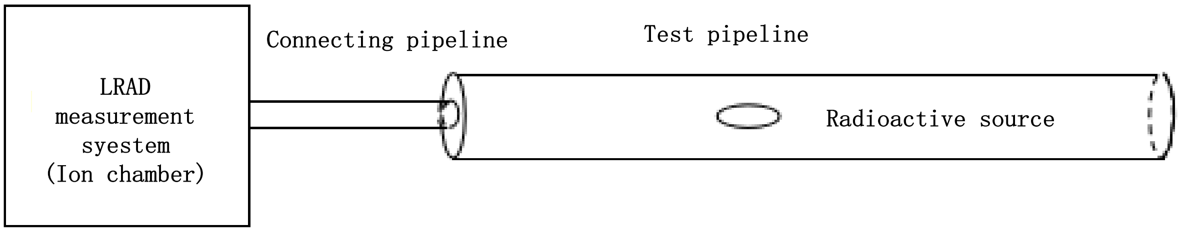

Fig.2 The diagram about experimental facility

Table 2. The current measurement value when the radioactive source is in the different measuring pipe's place and the diameter of pipe is 78mm

L/cm	10	30	50	70	90	110	130	140
Measurement Value(fA)	21680	19740	18900	18100	17720	17200	16940	16780

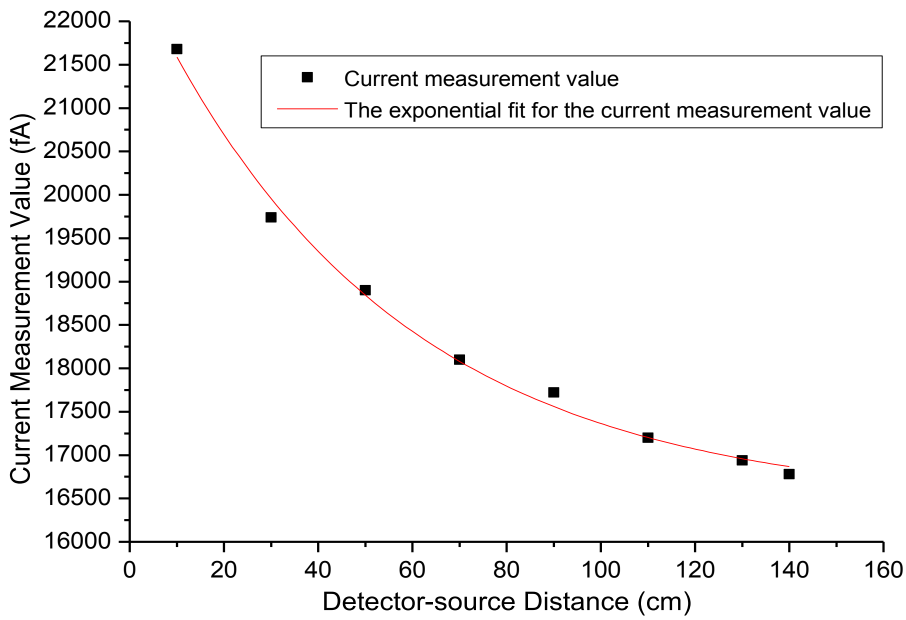

Fig.3 The current measurement value in different detector-source distance

Figure 3 reflects changes of the current measurement value in the different detector-source distance, then we using the index fitting for the trend. It can be seen from Figure 3 that the ionization current value of the radioactive source decreases with the increase of the detection distance. The fitting equation is given in equation 3.

$$\mathrm{I} = 16430 + 6236.5e^{-L/52.68} \qquad R^2 = 0.99331 \tag{3}$$

Where L is the distance between the detector and the radiation source; R^2 is close to 1 which indicates that the fitting effect is better.

It can be deduced by the formula (3) that the ratio of the measured values when the detector-source distance is L cm and 0 cm is:

$$I_L/I_0 = 16430 + \frac{6236.5e^{-L/52.68}}{22666.5} = 0.725 + 0.275e^{-L/52.68} \tag{4}$$

4. Result

This paper discusses the effect of temperature and humidity on measurement value of the LRAD measurement system, and obtains the relationship between the measurement current value and the temperature, humidity. The value is measured in the α source of the unit activity (1 Bq) and in the unit time (1 s):

$$I_{avg} = 136.14 - 1.62 * T - 0.821 * H \tag{5}$$

Then, we discussed the relationship between the current measurement value of the LRAD measurement system and the detector-source distance, the ratio of the measured value when the distance is L cm to 0 cm is:

$$I_L/I_0 = 0.725 + 0.275e^{-L/52.68} \tag{6}$$

However, in the actual measurement the detector-source distance can't be determined, so we can only give a approximate range to the activity of the α source measured by the LRAD measurement system. The calculation method of the α source activity range is as follows:

If the current measurement value of the LRAD measurement system is I fA, the calculation method of the α source activity range is divided into two steps.

Step 1: Calculating the maximum value A_{max} ofα activity.

Assuming that the current measurement value I fA is measured when the detector-source distance is 0 cm , and the maximum source distance is L_{max} cm, according to the formula (4) we can get that $I_{L_{max}} = I * (0.725 + 0.275e^{-L/52.68})$.Then it can be obtained by equation (2) that

$A_{max} = I_{L_{max}}/I_{avg} = I * (0.725 + 0.275e^{-L/52.68})/(136.14 - 1.62 * T - 0.821 * H)$.

Step 2: Calculating the minimum value of α activity.

Assuming that the current measurement value I fA is measured when the detector-source distance is L_{max} cm, we can obtain the current value I_0 when the source distance is 0 cm according to the formula (4), we can get that $I_0 = I/(0.725 + 0.275e^{-L/52.68})$, Then it can be obtained by equation (2) that $A_{min} = I_0/I_{avg} = I/(0.725 + 0.275e^{-L/52.68})/(136.14 - 1.62 * T - 0.821 * H)$.

5. Conclusion

As can be seen from the above calculation, when the current measurement value of the LRAD measurement system is I fA, we can know that the maximum value of the α source activity is $A_{max} = I_{L_{max}}/I_{avg} = I * (0.725 + 0.275e^{-L/52.68})/(136.14 - 1.62 * T - 0.821 * H)$, the minimum value is $A_{min} = I_0/I_{avg} = I/(0.725 + 0.275e^{-L/52.68})/(136.14 - 1.62 * T - 0.821 * H)$. The activity range of the α pollution source can provide the basis for evaluating the level of radioactive pollution in retired pipes.

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