A Detection Method of Atmospheric Neutron at the Civil Aviation Height

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Abstract. In order to solve the problem of atmospheric radiation data in SEE analysis and verification of civil aircraft, a new detection method of atmospheric neutron at the height of civil aviation is developed. Using the balloon of radiosonde to carry the nuclear radiometer, the radiation dose could be observed by the nuclear radiometer. On the basis of the conversion equation between radiation dose and neutron flux, the profile of atmospheric neutron flux is derived. The local detection experiments indicate that the detection results are reliable and effective. Effective results could be obtained by the method with low experiment cost.

1. Introduction
High energy radiation in the atmospheric environment is a serious threat to aircraft on board electronic equipment. The impact on aircraft system electronic components caused by these high energy particles is called Single Event Effect (SEE) [1]. The resulting Single Event Effects could cause various fault conditions, including hazardous misleading information and system effects in avionics equipment. [2] The effects of single events might mislead signals instantaneously or alter the physical layer permanently, resulting in the loss of a component or function.

With the development of aircraft avionics, the scale of electronic circuits in aircraft presents geometric growth, and the electronic computing components in aircraft system equipment are highly integrated and the operation logic is getting more and more complex. All these leads to the occurrence of single events more and more frequently [3-7]. The SEE phenomenon is particularly evident in the high-latitude and high-altitude civil aviation routes. Today, for the efficiency and economic propose, civil aviation aircraft flying higher and higher. The influence of high-energy particles in the atmosphere on the safety of civil aircraft has been paid more and more attention [3].

In the development of civil aircraft, the SEE hasn’t been taken into consideration in system safety design as aircraft level requirements. However, in the preliminary preparations for first flight, safety risks caused by SEE has emerged, which affected the aircraft's flight altitude. [8] For the consideration of system safety, the particular risk analysis research on SEE should be performed. But in the design phase of aircraft, it is difficult to calculate the failure rate of equipment caused by atmospheric radiation in safety analysis due to the lack of detection data of atmospheric neutron flux in the flight environment of aircraft.

The purpose of this paper is to describe a detection method of atmospheric neutron radiation at the height of civil aviation, for there is no neutron radiation detection for civil aviation altitude. In order to solve the problem of atmospheric radiation data in SEE analysis and verification of civil aircraft, a field detection method of atmospheric radiation for civil aviation altitude is proposed.
2. Detection Method
In the atmospheric radiation environment, there is a high flux of various energetic particles, contains neutrons, protons and pion, all of which could cause SEE in electronics. At the height of civil aviation, neutrons are the main concern and have been proved to be most responsible for causing Single Event Upsets [2]. In order to perform SEE analysis, the profile of atmospheric neutron flux need to be detected. For there is no effective remotely sense means to detect the neutron flux and the limitation of the experiment cost, the method using the radiosonde balloon to carry the radiation detector is proposed. The equipment involved in the method are radiosonde and nuclear radiometer. In this method, the radiation dose could be observed by the nuclear radiation detector. The flux of the atmospheric neutron flux could be derived on the basis of the conversion equation between radiation dose and neutron flux.

2.1. Equipment
The atmospheric high-energy particles are generally detected in the form of field detection using high-energy particle detection equipment carried by rockets, airplanes, airships and other carriers in the atmosphere [4]. Then the profile of high-energy particle parameters with atmospheric height is derived through detection data analysis.

In the detection, constrain by the cost, the lowest cost choice for the carrier can be selected as radiosonde system. The radiosonde system is an important tool for measuring and studying the high-altitude stratospheric atmosphere, mainly composed of radiosonde and ground receiving station [5], as shown in Figure 1.

![Figure.1 The balloon of radiosonde](image)

In high-energy particle detection, high-energy particle mass spectrometer is generally used to complete particle detection, but this kind of mass spectrometer is difficult to be used for high-altitude detection in practical space detection because of its huge equipment system and high price. Limited by cost, instead of mass spectrometer, the high-energy particle detector used in the method is a nuclear radiometer, as shown in Figure 2. The nuclear radiometer could provide detection of the radiation dose situation all day. Not only environmental pollution, but also the cumulative value and change rate of radiation dose could be monitored by the nuclear radiometer, which has a wide detection range and high detection accuracy. For the nuclear radiometer is smaller than high-energy particle mass spectrometer in size, it is convenient to be carried by the radiosonde balloon.
2.2. Detection procedure

The neutron flux detection procedure is shown below:

**Step 1:** The radiation detector shown in Figure 2 is placed into a well-grooved foam box with a GPS device. Then connect the communication equipment inside, and detect the good reception of signals. Finally, the foam box containing the instrument should be sealed and brought to the specified position. After the balloon filled with helium, it's ready to lunch.

**Step 2:** Releases the balloon to the height of civil aviation. The detection devices carried in the box would detect the dose equivalent and dose equivalent rate along the flight path;

**Step 3:** According to the conversion function of radiation dose equivalent rate and neutron flux, the neutron flux could be calculated according to radiation dose equivalent rate of the data in the high-energy particle detector by conversion relation shown in equation (1);

**Step 4:** Get the relationship between atmospheric radiation dose equivalent, dose equivalent rate and altitude, and get the relationship between neutron flux and altitude;

2.3. Data process

According to the standard Dose conversion coefficients for use in protection against neutron radiation [9], the radiation dose at the energy level 1-10 MeV can be converted into neutron flux. For $0.025 \leq E \leq 20 \text{MeV}$, the conversion function of radiation dose equivalent rate and neutron flux is shown in equation (1),

$$
\log_{10} \frac{H'(10)}{\phi} = \frac{a}{1+(b+cx)^2} + \frac{d}{1+e^{-gax}} + \frac{h}{1+e^{-kx}}
$$

where: $x = \log_{10} E$, $a = 1.02$, $b = 0.0102$, $c = 0.208$, $d = 2.33$, $f = 9.56$, $g = 1.98$, $h = 0.187$, $j = 93.3$, $k = 13.1$, $E$ is in electron volts(eV).

3. Detection Experiment

On the day of releasing the radiosonde balloon, the device was taken to the designated location. The detection equipment was then packed in a foam box as equipment cabin and tied to the balloon by a rope. Nine bottles of 35 kg helium were pumped into the 1,000-cubic metre balloon. When all the preparations were completed, the experiment was launched.

1) the first lunch in Day 1

At 10:10:19 on the morning of Day 1, the radiosonde balloon was lunched. The coordinates of the releasing place were (41.58608°N,108.4906°E), the altitude was 1295m, temperature 4.2°C, air pressure 869.88hPa and rising speed gradually increased. At 11:35:12, the sounding balloon rises to its highest point, coordinate (41.6428°N,109.4726°E), altitude 24417m, temperature -24.6°C, pressure 25.25 hPa. Then the balloon had flew horizontally at an average speed 1 m/s for 5 minutes. At 10:25, the rope between the box and balloon was cut by remotely controlled and the sounding balloon began to descend. At 12:29:12, the sounding balloon landed at (41.65476°N,110.042°E), altitude 2206.9 m, temperature 0.6°C, pressure 777.06hPa.

2) the first lunch in Day 2

At 8:58 on the morning of Day 2, the balloon was released. The coordinates of the flying place were (41.586°N,108.4906°E). The altitude was 1300m, temperature 1.7°C, air pressure 863.83hPa and rising speed was gradually increased. At 10:20, the sounding balloon reached its highest point, coordinate (41.804°N,109.4905°E), altitude 24686.3m, temperature -14.8°C, pressure 25.94 hPa. After been flying horizontally at an average speed 0.2 m/s for 5 minutes, at 10:25, the rope of the balloon was cut by
remotely controlled and the balloon began to descend. At 10:53:33, the sounding balloon landed at (41.886°N, 109.8826°E), altitude 2655.9 m, temperature 1.3℃, pressure 731.38hPa.

The position of the balloon was monitored in real time by GPS receiver. After the balloon reached the predetermined height, the equipment cabin and the sounding balloon were separated. The longitude and latitude of the equipment cabin were determined according to the landing position of the equipment cabin GPS feedback.

4. Results and discussion
The data information of the recovered radiation detector accumulated through the infrared (IR) communication channel and stored in the non-volatile memory was sent to the computer. The radiation dose equivalent and dose equivalent rate distribution over time of Day 1 and Day 2 were shown in Figure 3 and 4 respectively.

![Figure 3](image1.png)
**Figure 3 Measurement curve of radiation dose equivalent rate and dose equivalent in Day 1**

![Figure 4](image2.png)
**Figure 4 Measurement curve of radiation dose equivalent rate and dose equivalent in Day2**

By comparing the results of two sounding experiments, it is obvious that the curves are basically the same trend. As can be seen from the comparison in Figure 3-4, the data show that the detection method is stable in the same detection environment.

Figure 5 and 6 show the curves of neutron flux changing with altitude in the two radiosonde experiments. It could be clearly seen from Figure 5 and 6 that below 25km altitude, neutron flux tends to increase significantly with the increase of altitude, and the maximum value is 1.54 neutron/(cm²·s).
Comparing the profile of neutron flux shown in Figure 5 and 6 with the results published by Normand and Baker [1], the curve distribution obtained in this experiment could be considered basically consistent with the known profile. It indicates that there is no systematic error between the atmospheric neutron flux profile detected by the detection method described in this paper and the historical results.

5. Conclusion

The atmospheric radiation field detection method for the altitude of civil aviation is proposed in this paper. Based on the method, the variation profile of atmospheric neutron flux with altitude could be well detected. This method has the valuable characteristics of simple, convenient and low cost. The idea to use nuclear radiometer could also be applied to the other flying platform such as aircraft.

In the test flight of civil aircraft, the nuclear radiometer could be carried on the radiosonde balloon for wind field detection. In the wind field detection before the test flight [10], the flux profile detection of atmospheric neutrons could be completed by applying this method by carrying the nuclear radiometer as additional equipment. With the detection result, the background data for the verification of single event effect could be provide for the design of aircraft system safety.

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