Study on the Performance of Nuclear Security Basic System against Nuclear Electromagnetic Pulse

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Abstract. With the extensive application of nuclear technology and the improvement of emergency forewarning level for nuclear terrorism, it is urgent to study the performance of nuclear security basic system against nuclear electromagnetic pulse. In this paper, a basic nuclear security system is designed, and the weak link of the nuclear electromagnetic pulse is analyzed and simulated. In addition, the weak link is tested through experiments. The theoretical analysis is in good agreement with the experimental results. The results of this paper can provide technical support for the reinforcement of nuclear security system against nuclear electromagnetic pulse.

Keywords: Nuclear security basic system; Nuclear electromagnetic pulse; Weak link analysis; Nuclear electromagnetic pulse effects.

1. Introduction
With the wide and deep applications of nuclear technology in various fields, the construction and application of nuclear security system becomes more and more important. The objective of the nuclear security system is to prevent, detect and respond to nuclear security events, and to protect persons, property, society and the environment from harmful consequences associated with nuclear and other radioactive materials [1,2]. The basic nuclear security system is a collection of basic technical measures taken to achieve this purpose. In recent years, the application of nuclear materials and nuclear facilities is expanding continually in China, and thus, nuclear security risks are becoming more and more serious which makes the enforcement of nuclear security system critical and urgent [3]. High-altitude electromagnetic pulse (HEMP) is a transient electromagnetic wave that can be coupled to various electronic and electrical equipment through field lines or holes. This electromagnetic energy can cause interference or even permanent damage to normal working electronic and electrical equipment and the electromagnetism effects on various electronic system were studied in some researches [4-6]. In this study, to deal with the ability of nuclear security basic system to deal with nuclear electromagnetic pulse under extreme special circumstances, the basic nuclear security system is designed, and the weak link against nuclear electromagnetic pulse of the system is analyzed and simulated. In addition, the weak links are tested through experiments, and the theoretical analysis is in good agreement with the experimental results. The results of this paper can provide technical support for the reinforcement of nuclear security system against nuclear electromagnetic pulse.

2. Construction of Basic Nuclear Security System
A typical nuclear security system should consist of detection, delay, and response modules. In view of the first study of the performance of nuclear security systems against nuclear electromagnetic pulses, we have adopted a basic system, as shown in figure 1. Among them, infrared detector, microwave...
detector is a typical detection device, access guard is a typical delay device, alarm center end is a typical response device. The above devices are connected to the switch by fiber or twisted-pair wire to complete a basic nuclear security system. Based on this basic system, the weakness analysis and experiment of anti-nuclear electromagnetic pulse are carried out, and the reinforcement principles and techniques with certain regularity are studied and summarized.

Figure 1. A basic nuclear security system

3. Weak Link Analysis and Simulation
To analyze the weak link of the system, we must first confirm the input intensity of the nuclear electromagnetic pulse and the relevant parameters, and design the program according to the topology diagram of the basic nuclear security system. After that the weak links are simulated.

1) Basic parameters of nuclear electromagnetic pulse
As a powerful interference source, high-altitude nuclear electromagnetic pulse (HEMP) can be coupled to almost all macro-scale electronics and electrical equipment. Figure 2 shows the spectrum range of the electromagnetic environment, including HEMP [7].

Figure 2. Spectrum range of electromagnetic environment including HEMP [7]

2) Simulation analysis
In this paper, the coupling value of key equipment ports of nuclear security system is estimated based on the basic nuclear security system by using electromagnetic simulation analysis software, by setting relevant parameters under typical spectrum of the above mentioned nuclear electromagnetic pulse. It is divided into four parts, overhead cable voltage / current, buried cable voltage / current, cabinet cable voltage / current and cabinet internal field strength simulation calculation.

a) 10 m × 3 m frame high parallel double wire HEMP coupling voltage / current
First, we build a simulation circuit diagram of 10 m parallel frame high parallel two-line HEMP coupling field circuit as shown in figure 3, and then analyze the coupling voltage and current.

**Figure 3.** 10 m × 3 m parallel double wire HEMP coupling circuit diagram

From the coupling voltage of parallel double lines in Fig. 4, the current waveform diagram shows that the peak currents on each parallel double line can reach hundreds of amperes, and the voltage waveforms of the two lines cannot counteract with each other, so the coupling of HEMP in parallel double lines, the influence of common mode voltage and differential mode voltage should be considered as well.

According to the above simulation analysis, the parallel double-line common-mode injection and differential mode injection tests should be carried out for the entrance guard and alarm extension, respectively, and the injection grade is 100A, 200A and 500A.

b) 10 m-long and 3m-tall twisted pair wire HEMP coupling voltage / current

Second, we build a simulation circuit diagram of 10 m-long 3m-tall parallel frame high twisted pair wire HEMP coupling field circuit as shown in figure 5, and analyze the voltage and current based on it.

**Figure 5.** Simulation circuit diagram of HEMP coupling field circuit for 10 m parallel frame twisted pair wire
Figure 6. (1) Coupling voltage   (2) Coupling current
From the coupling voltage and current waveform of twisted-pair wire in fig. 6, we can see that the peak value of the current on the twisted-pair cable is up to 50A~150A, and the differential mode voltage of the twisted-pair cable port is approximately zero, so for the coupling of HEMP in a twisted-pair cable, there is need to consider the effect of common mode voltage, but not the effect of differential mode voltage. According to the above simulation analysis, twisted-pair common-mode injection test should be carried out for the entrance guard and alarm extension respectively, and the injection grade is 50A, 100A and 200A.

c) 1 m×0.5 m×2 m cabinet HEMP coupling electric field
A coupled electric field, shown in figure 8, has been established and will be tested on this basis.

Figure 7. Simulation diagram of HEMP coupling electric field in cabinet

Figure 8. Results of HEMP coupling electric field in cabin
For the cabinet, due to the existence of ventilation cooling holes, windows, wiring holes, and so on, as well as the reflection and superposition of the earth to the HEMP incident wave, the peak value of the
coupling electric field in the cabinet is slightly higher than the incident wave, which deserves to be considered emphatically. The coupling of HEMP in parallel twisted-wire twisted-pair and cabinet is predicted by CST simulation analysis, which provides data support for judging the weak link of nuclear security system. The differential mode voltage of the twisted-pair terminal is approximately zero, so the influence of the common-mode voltage on the twisted-pair cable should be considered. For parallel double lines, not only the effect of common mode voltage, but also the influence of differential mode voltage should be considered. High altitude nuclear electromagnetic pulse is a kind of very destructive electromagnetic signal. It is mainly through direct or indirect way to the nuclear security system communication, the power supply cable coupling, to the nuclear security system key equipment threat. Disturbs and even burns the device, causes the system to not work properly or malfunctions. Therefore, it is suggested that the weakness of the report should be tested and the necessary protection and reinforcement of the weakness should be carried out.

4. High Altitude Nuclear Electromagnetic Pulse Effects Tests
After weak link analysis and simulation, the nuclear electromagnetic pulse irradiation experiment and pulse injection experiment are carried out to further test the effectiveness of the system. In this experiment, the nuclear electromagnetic pulse environment generated by the vertical polarization bounded wave electromagnetic pulse simulator was used to directly irradiate the key equipment of the nuclear security system (access guard and alarm extension) in the working state at the same time. The ports associated with nuclear security system key connections (network and twisted-pair wires) are used for pulse current injection. Figure 9 shows the electromagnetic pulse simulator model of the vertical polarized bounded Wave.

![Vertical polarization bounded wave electromagnetic pulse simulator model](image)

The experiment is divided into two parts, irradiation test and pulse injection test. The irradiation test is mainly carried out for the outdoor entrance guard and alarm extension. The pulse injection test is mainly aimed at the switch, alarm center end and outdoor detector in the duty room. The test equipment should be in normal working condition.

a) Nuclear electromagnetic pulse irradiation experiment
In this experiment, the nuclear electromagnetic pulse environment simulated by the vertical polarization bounded wave simulator with a peak field strength of 10, 30 and 50 kV/m was used to irradiate the entrance guard and the alarm extension terminal. Adjusting the pulse source pressure value, the peak value of the field strength of the entrance guard and the alarm extension is about 10kV/m, 30kV /m and 50kV / m, and 3 experiments are conducted in each grade. After on-line observation of the function of access control and infrared detection and alarm, the entrance guard mainframe maintained its normal operation under the strong grade of 3 midfield, the alarm extension could not transmit the alarm signal normally, and the adapter burned down. Fig. 10 - 12 show the time domain waveforms of 10 kV/m, 30 kV/m and 50 kV/m electric field measurements respectively.
After each experiment, the access control and infrared detection and alarm function were observed online. The access control host maintained normal operation under the 3 strong midfield grades, and even the 10 kV/m alarm extension was working normally. Above the level of 10 kV/m, adapter was burning.
b) Pulse injection test
The common-mode current injection of twisted-pair wire is carried out on the access guard and alarm extension by capacitive coupling injection method. The injection current grade is divided into 50A, 100A and 200 A. Fig. 13 is a layout diagram of capacitive coupled injection mode.

![Capacitive coupling injection mode](image)

**Figure 13.** Capacitive coupling injection mode
The common-mode current and differential mode current need to be considered among the devices connected by the network wire. The injection grade is divided into 100A, 200A and 500 A. Inductively coupled injection mode is adopted. Figure 14 shows the layout of inductively coupled injection mode.

![Inductive coupling device](image)

**Figure 14.** Inductively coupled injection mode
Placing equipment according to Inductive injection mode, by adjusting the pressurization value of the pulse injection source, the pulse current with the peak value of 100A, 200A and 400A is coupled on the network line connected between the access guard and the switch by inductive injection, respectively. Three tests were conducted for each current level. After each experiment, the working conditions of the access guard and switch are observed. The switch works normally, the access guard appears the failure of the unlock relay, the main board heartbeat lights are extinguished, and the main board burns out. Fig. 15-17 is a current waveform coupled on a grid line with three different pulse levels.
Figure 15. Coupling current waveform on a grid line with a pulse injection rating of 100A

Figure 16. Coupling current waveform on a network line with a pulse injection rating of 200A

Figure 17. Coupling current waveform on a network line with a pulse injection rating of 400A

The equipment is arranged according to the capacitive direct injection mode, the pressure value of the pulse injection source is adjusted, the peak value of the twisted-pair wire connected between the alarm extension and the infrared detector is coupled by the capacitive direct injection method, and the peak
value is 50 A and 100A, respectively. Three levels of pulse current of 200A, each of which is tested three times. Under the condition of 50 A injection grade, the equipment works normally, the alarm input port is damaged at 100A and the port is still damaged after replacing the port. Interrupt the state of the experiment. Figure 20 is a typical time domain waveform of the pulse injection source output. Fig. 18 and Fig. 19 indicates coupled current waveforms on experimental twisted-pair wires with 50 A/100 A injection.

![Typical time domain waveform of the pulse injection source output](image)

**Figure 18.** Coupling current waveform on twisted-pair wire with a pulse injection rating of 50A

![Coupling current waveform on twisted-pair wires with a pulse injection rating of 100A](image)

**Figure 19.** Coupling current waveform on twisted-pair wires with a pulse injection rating of 100A

5. **Conclusion**

Based on the analysis and simulation of the weak link of electromagnetic pulse resistance in the nuclear security basic system, the experiments of electromagnetic pulse irradiation and pulse injection are carried out. Through simulation and experiment, it is found that the basic nuclear security system is in common mode, differential mode, and tolerance. Inductively, nuclear electromagnetic pulse resistance defects at different classification levels, such as for the devices and cables, provide theoretical and data support for system reinforcement in the future.

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