Effects of gamma-ray irradiation on electronic and non-electronic equipment of Large Helical Device

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Abstract: In deuterium operation on the Large Helical Device, measurement and control equipment placed in the torus hall must survive under the radiation environment. To study the effects of gamma-ray irradiation on equipment, an irradiation experiment is performed in the Cobalt-60 irradiation facility of Nagoya University. Transient and permanent effects on a personal computer, media converters, programmable logic controllers, isolation amplifiers, a web camera, optical flow meters, and water sealing gaskets are experimentally surveyed. Transient noise appears on a web camera. Offset of the signal increases with an increase of the integrated dose on a programmable logic controller. Devicenet module on the programmable logic controller is broken at the integrated dose of 72 Gy, which is the expected range of the integrated dose of the torus hall. The other equipment can survive under gamma-ray field in the torus hall.

Keywords: Large Helical Device, gamma-ray irradiation, radiation effect.

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1. Introduction

Highly integrated electronic components such as a programmable logic controller (PLC) are essential for the control and diagnostics of a plasma in order to achieve high-temperature and high-density plasmas. However, in a deuterium or a deuterium/tritium operation, radiation damages onto those electronic components might lead to a loss of the plasma control. Hence, understanding of irradiation effects on electric components is very important. The irradiation effects on equipment have been studied for ITER diagnostics[1,2]. The ITER group is designing the location of equipment and the radiation shielding according to the neutron and gamma-ray transport calculation and the irradiation resistivity of equipment.

Deuterium operation will be started from 2017 on the Large Helical Device (LHD)[3]. LHD is controlled by means of many semiconductor integrated circuits placed around LHD in the torus hall with remote control. These circuits are regularly replaced with the newest highly-integrated circuit. The integration of the electronic circuit becomes higher, which means that the number of atoms inside one chip is reduced and the operational voltage inside the circuit becomes lower. Therefore, the damage due to a gamma-ray on an atom can easily cause a problem compared with the electronic circuit with lower integration. Thus, the circuits become weaker against the radiation because of the higher integration. Water sealing gaskets made of polytetrafluoroethylene are widely used near LHD to serve the cooling water. We might need to rearrange the location of the components and make shields to prevent a serious event due to irradiation according to the radiation environment and the radiation resistance of devices.

However, unlike ITER, the radiation effect on equipment currently used in LHD is not known. Though some knowledge regarding irradiation test for ITER might be useful, we would like to know the resistance against irradiation of components currently used in LHD. Neutrons are mainly generated by deuterium reactions. On the other hand, gamma-rays are generated by materials activated by neutrons. By neutron and gamma-ray transport calculation, it is expected that the absorbed dose by Si within nine years is around 100 Gy and the gamma-ray is dominant in dose[4]. Both transient effect and permanent effect can be caused by irradiation on equipment. Therefore, for safe operation of LHD we need to investigate effects of radiation on electronic and non-electronic equipment in order to rearrange equipment near LHD. In this paper, detailed results of gamma-ray irradiation on electronic equipment and water sealing gaskets are reported.

2. Experimental Setups

Gamma-ray irradiation on equipment is done at the Cobalt 60 irradiation facility of Nagoya

University, which is one of the largest gamma radiation facilities in the Tokai area of Japan[5]. The facility was built in 1963 and has been operated for more than fifty years. The facility has ^{60}Co gamma-ray source whose intensity of 163 TBq was renewed in 2004. The gamma-ray dose rate to the silicon, which is a major ingredient of electronics components, evaluated by calculation on the day of the experiment (2015/7/14) is 190 Gy/h at 20 cm from the source, 86 Gy/h at 30 cm from the source, and 30 Gy/h at 50 cm from the source. The total radiation period is 4 hours. Figure 1 shows the experimental setup for irradiation. One personal computer (PC: HP Mini 5101, Hewlett-Packard), two media converters (DMC-700SC, D-Link), two programmable logic controllers (PLC1: FA-M3, YOKOGAWA and PLC2: CS1G, OMRON), two isolation amplifiers (P62-A, NF Corporation), one web camera (TS-WLCAM, I-O DATA), one optical flow meter (R-760-E, TOKYO KEISO Co., LTD), and four sets of water sealing gaskets (N7030 and 7010-EX, Nippon Valqua Industries) are used in this experiment. Note that PLC1 and PLC2 are used for controlling neutral beam injectors and an injector of hydrogen pellets, respectively. Note that we neglect the damage of the transmission line because the effect will appear over 10^6 Gy[6].

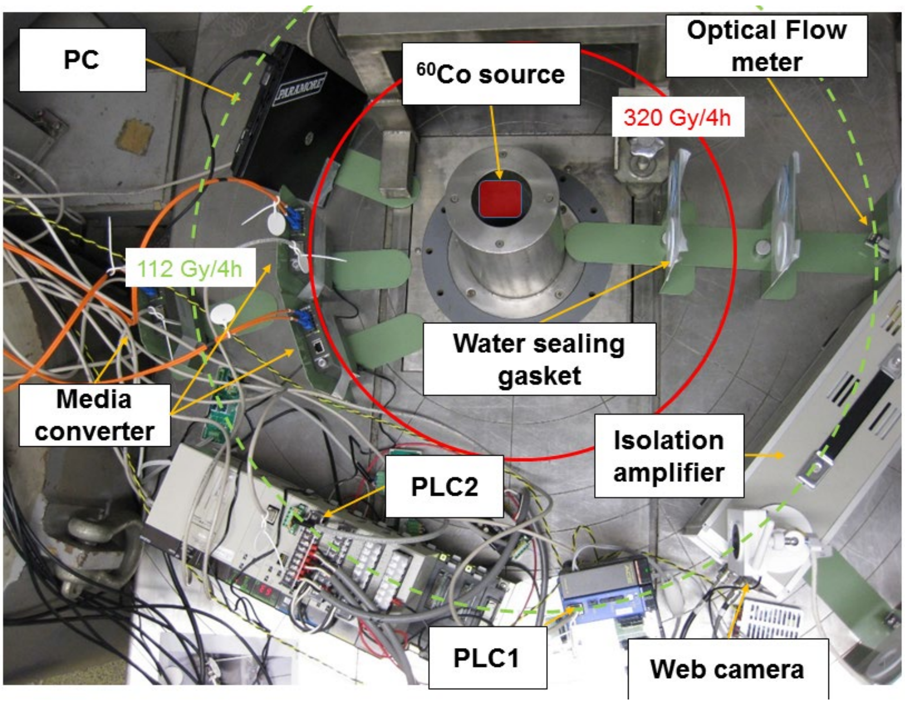

Fig.1 Experimental setups for gamma-ray irradiation

3. Effects of gamma-ray irradiation on electronic equipment

The status of electronic equipment is monitored from the diagnostic room next to the irradiation room. To see the effect of the irradiation on two media converters, we transfer the image taken by a web camera in the diagnostic room to the PC in the diagnostic room through the media converter placed in the irradiation room. We found that there is no transient noise and no decrease of the speed of the network up to the integrated dose of 320 Gy. We input the sinusoidal function created by the function generator in the diagnostic room to the isolation amplifier in the irradiation room. The output signal is monitored by the oscilloscope in the diagnostic room. The output signal does not change up to the integrated dose of 112 Gy. The optical flow meter is composed of a light emitting diode and a photodiode. The signal of a photodiode becomes a high level when the light emitting diode is off and becomes a low level when the light emitting diode is on. We use a simple logic circuit to obtain a light emitting diode with 1 Hz flashing. The output signal of the photodiode in the irradiation room is monitored by the oscilloscope to check the light emitting diode and the photodiode. The signal is stable up to the integrated dose of 240 Gy. A PC in the irradiation room is monitored through the network by means of the remote desktop application of Windows OS. Although the connection looks stable just before the integrated dose of 224 Gy, it is suddenly disconnected at 224 Gy. Note that, after irradiation, we could not start even the basic input/outputs system (BIOS) of the PC. The movie taken by a web camera placed in the irradiation room is monitored through the network from a PC (Fig 2 (a)). Noise due to the gamma-ray appears and disappears repeatedly from the beginning of the irradiation as shown in Fig. 2 (b). Here, the gamma-ray dose rate is around 8 mGy/s. The noise completely disappears when we stop the gamma-ray irradiation (Fig. 2 (c)). This means that the noise is the transient effect due to the gamma-ray. No permanent effect is observed up to 112 Gy. The status of the PLC1 (AD04-0V, YOKOGAWA) is monitored as shown below. 1) The status of the PLC modules is checked every two seconds. 2) A signal from the analog output channel one is applied to channel one of the analog input module. We compare the two signals. 3) The output signal from the analog output module channel two is monitored with the oscilloscope. 4) DC voltage (2 V) is applied to channel two of the analog input modules of the PLC1. The input/output signal is monitored through the network by the PC. Offset of the signal measured by the analog input module channel two is gradually increasing with an increase of the integrated dose (Fig. 3). The analog output module is

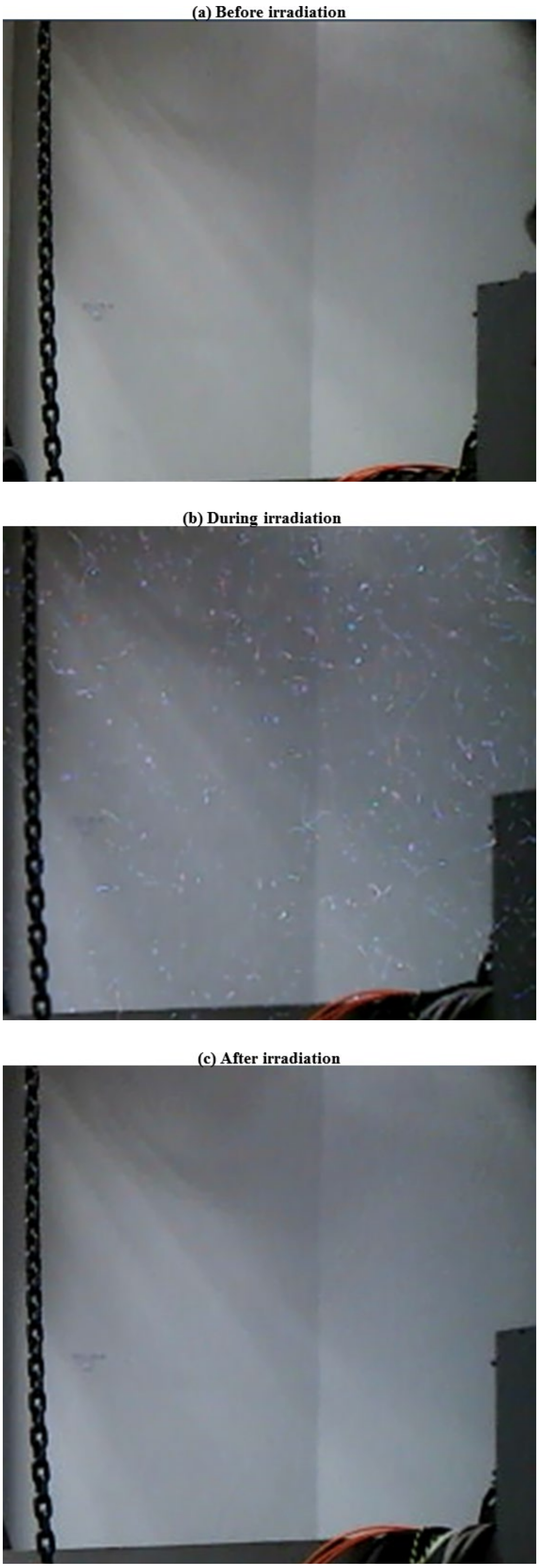

Fig.2 Photographs taken by web camera (a) before irradiation, (b) during irradiation, and (c) after irradiation. Noise due to gamma-ray only appears during irradiation.

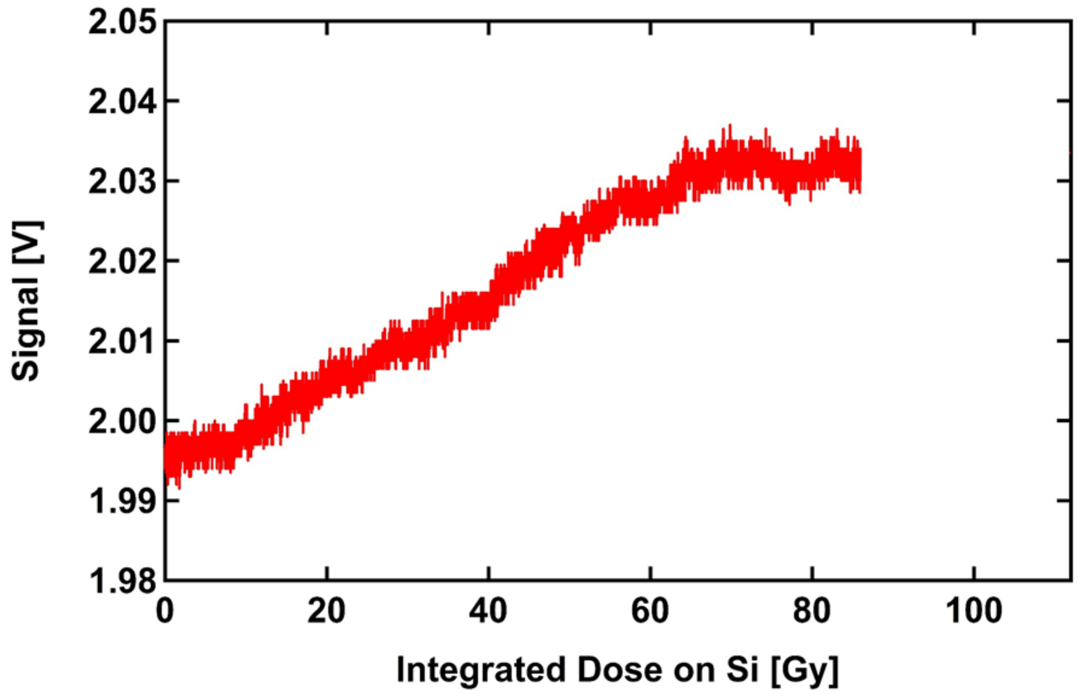

Fig.3 The analog input module signal of the PLC1 as a function of the integrated dose. Offset of signal increases with an increase of integrated dose.

broken at 88 Gy. The CPU module and the analog input module of the PLC1 are broken at 96 Gy. Time-varying voltage is applied from the analog output module (CS1W-DA08V, OMRON) to the Devicenet input module (CS1W-DRM21-V1, OMRON) on the PLC2. The input and output voltage is monitored from the PC through the network. Figure 4 shows the time evolution of input and output signals. The Devicenet input signal matches the analog output signal until the integrated dose of less than 72 Gy. However, the Devicenet input module is broken at 72 Gy. Note that the signal of both Devicenet input and analog output becomes zero after the integrated dose of 88 Gy. This is due to malfunction of the Ethernet module and the power module of the PLC2. Table 1 shows the summary of the gamma-ray irradiation experiment on the electronic equipment used in LHD.

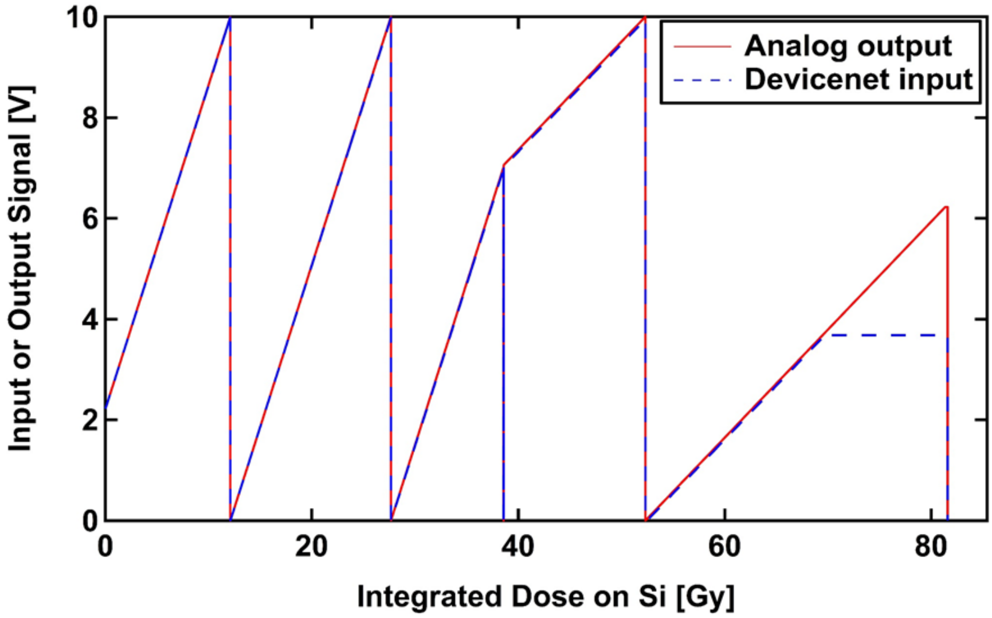

Fig.4 Signal of analog output module and Devicenet input module of the PLC2 as a function of integrated dose. Signal of analog output sweeps in time. Devicenet input module is broken at around 72 Gy.

Table1 Summary of gamma-ray irradiation experiment on electronic equipment of LHD

Component		Manufacture	Model Number	Maximum Dose (Gy)	Transient Effect	Permanent Effect
PC		Hewlett-Packard	HP Mini 5101	320	Not observed	Broken (224 Gy)
Media converter		D-Link	DMC-700SC	320	Not observed	Not observed
Optical Flow meter		TOKYO KEISO	R-760-E	240	Not observed	Not observed
Isolation amplifier		NF Corporation	P62-A	112	Not observed	Not observed
Web camera		I-O DATA	TS-WLCAM	112	Noise	Not observed
PLC1	CPU	YOKOGAWA	PU10-0S	112	Not observed	Broken (96 Gy)
	Power		SP71-4S	112	Not observed	Not observed
	Analog input		AD04-0V	112	Not observed	Offset increase Broken (96 Gy)
	Analog output		DA04-1N	112	Not observed	Broken (96 Gy)
PLC2	CPU	OMRON	CS1G-CPU42H	112	Not observed	Not observed
	Power		C200HW-PA204S	112	Not observed	Broken (112 Gy)
	Base		CS1W-BC083	112	Not observed	Not observed
	Ethernet		CS1W-ETN21	112	Not observed	Broken (112 Gy)
	Devicenet input		CS1W-DRM21-V1	112	Not observed	Broken (112 Gy)
	Analog output		CS1W-DA08V	112	Not observed	Not observed
	Analog input		CS1W-AD08-V1	112	Not observed	Broken (72 Gy)
	Relay output		CS1W-OC201	112	Not observed	Not observed
	24 V DC input		CS1W-ID211	112	Not observed	Not observed
	Analog terminal		DRT2-AD04H	112	Stopped	Not observed
	MIL connector		DRT2-MD32ML	112	Not observed	Not observed
	I/O relay terminal input		G7TC-ID16	112	Not observed	Not observed
	I/O relay terminal output		G7TC-OC16	112	Not observed	Not observed

4. Effects of gamma-ray irradiation on non-electronic equipment

Two types of water sealing gasket used for LHD are irradiated in this experiment. Gasket 1 (N7030, Nippon Valqua Industries) is made from VALFLON and the elastic core material. Its thickness is

2.8 mm. Gasket 2 (7010-EX (Nippon Valqua Industries) is made from NEW VALFLON. Its thickness is 3 mm. We use four pairs of gaskets; the total gamma dose is 880 Gy, 290 Gy, 140 Gy, and 72 Gy, respectively. Here, the dose to the water evaluated by calculation is used. Air leak of the gasket is surveyed by means of compressed air (1.0 MPa). We fasten 20 A flanges according to the specified torque. We put soap water around the gasket to see the leakage of air. Table 2 shows the result of the air leak test. There is no leak on Gasket 1. A small leak is observed on Gasket 2 #1 (880 Gy). We cannot stop the leak with the specified torque. Therefore, additional torque is needed to stop the small leak.

Table 2 Result of air leak test

Gasket	Torque (N m)	Air Pressure (MPa)	#1 (704 Gy)	#2 (232 Gy)	#3 (112 Gy)	#4 (57 Gy)
Gasket 1 N7030 (Nippon Valqua Industries) VALFLON and Elastic core material Torque: 22.5 N・m (water), 30 N・m (air) Pressure resistance: 1.5 MPa	22.5	1.0	No leak	No leak	No leak	No leak
	30.0	1.0	No leak	No leak	No leak	No leak
Gasket 2 7010-EX (Nippon Valqua Industries) NEW VALFLON Torque: 15.0 N・m (water), 22.5 N・m (air) Pressure resistance: 1.0 MPa	15.0	1.0	Small leak	No leak	No leak	No leak
	22.5	1.0	Small leak	No leak	No leak	No leak
	30.0 (over torque)	1.0	No leak	No leak	No leak	No leak

5. Summary

Investigation on effects of the gamma-ray irradiation on electronic component and the water sealing gasket used in the LHD is done at the Nagoya University Cobalt 60 irradiation facility. Transient effect appears on the web camera in this experiment. It is found that PLCs are broken at around 100 Gy, which is comparable to the dose in the torus hall of LHD. Other devices can survive over nine years under the gamma-ray irradiation environment of the LHD deuterium experiment.

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REFERENCES

[1] T. Nishitani, E. Ishitsuka, T. Kakuta *et al*., 1998, Fus. Eng. Des. **42** 443.

[2] S. Yamamoto, T. Shikama, V. Belyakov *et al*., J. 2000, Nucl. Mater. **283-287** 60-69.

[3] M. Osakabe, M. Yokoyama, K. Nagasaki *et al*., 2015, "Current status of the LHD project and its prospect for deuterium experiment," presented at the 25th Int. Toki Conf., 3-6 November, Toki-city, Japan.

[4] T. Nishitani, K. Ogawa, K. Nishimura and M. Isobe, 2016, Plasma Fus. Res, **11** 2405057.

[5] Nagoya University Cobalt 60 irradiation facility. http://co60.nucl.nagoya-u.ac.jp

[6] C. L. Hanks and D. J. Hamman, 1971, "Radiation Effects Design Handbook. Section 3, Electrical insulating Materials and Capacitors", NASA CR-1787-1971.