*35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-5.079 (2008)*

RADIATION DAMAGE IN VIDEO DIAGNOSTIC DEVICE FOR WENDELSTEIN 7-X

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At the Wendelstein 7-X stellarator (W7-X), CMOS cameras will be used for the video survey diagnostics. According to the present design, the sensor module of the cameras will be located at the plasma facing end of the selected tangential ports. A dedicated camera system (EDICAM: Event Detection Intelligent CAMera) has been developed for the diagnostics, which should operate in a harsh environment under neutron and gamma radiation. EDICAM (see fig.1.) is built up of three different modules: (a) a Sensor Module (SM) with reduced hardware and functional elements to reach a small and compact size and robust action in a harsh environment as well; (b) an Image Processing and Control Unit module handles all of the user predefined events and run image processing algorithms to generate trigger signals; (c) finally, a 10 Gigabit Ethernet compatible Image Readout Card serves as the network interface for the PC. In the present irradiation tests, a prototype of SM is used which contains only the CMOS sensor (LUPA-1300, CMOS sensor chip with 1280x1024 pixels) and 16-channel ADCs (12bits, 444 full frames/s). In order to estimate the radiation tolerance of CMOS video cameras constructed for the W7-X stellarator, the influence of gamma and neutron radiation on different CMOS cameras and electronics has been studied and the results are presented.

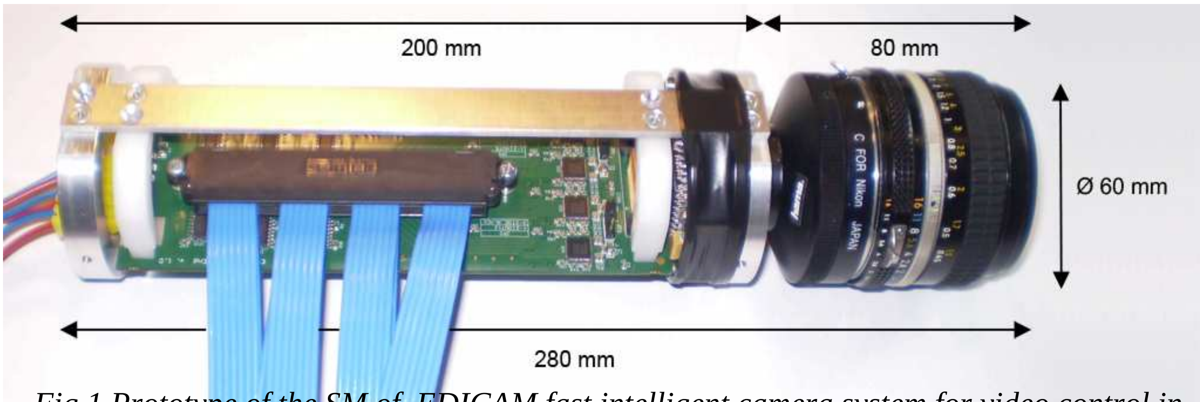

Fig.1 Prototype of the SM of EDICAM fast intelligent camera system for video control in fusion devices prepared for test

The expected gamma and neutron fields were estimated using yearly yields anticipated in the W7-X by carrying out detailed Monte Carlo simulations using the MCNP code [1]. The materials of the torus wall as well as the construction of the planned video port were taken into account in detail, where superconducting materials around the video port were also approximated (see Fig. 2). Immediately behind the front window located at the plasma facing entrance of the camera port the expected neutron fluence is calculated as $3.5{\cdot}10^{13}$ n/cm^{2}year (without applying additional shielding in the tube). The neutron spectrum is rather hard: half of it consists of fast neutrons (2.45MeV), the other half epithermal energy neutrons (0.2 eV-1 MeV). Gamma photons are produced due to neutron capture in different materials. Their energy is mainly below 1 MeV, but it has a prominent peak just below 1 MeV. Behind the window in a Silicon target we estimated a dose from gamma radiation as 16.7 Gy/year. In order to separate the effect of gamma and neutron irradiation, tests were executed separately.

The gamma irradiation experiments were carried out at the Training Reactor of the Budapest University of Technology and Economics. By shutting down the reactor after a period of 100 kW operation, we could achieve the gamma dose estimated above without exposing the device to significant neutron radiation. Under gamma radiation, we experienced flashing of the sensor pixels for the EDICAM fast CMOS camera (see fig 4). In this way we were able to prove that the camera developed is gamma radiation resistant and can withstand the estimated yearly gamma dose.

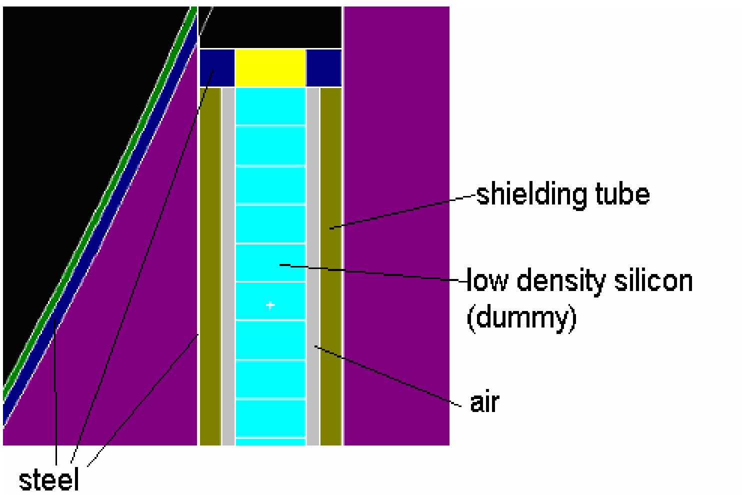

Figure 2. The MCNP model of the video port.

Neutron irradiation tests were carried out at the BIO testing site of the Budapest Neutron Centre where a good gamma shielding allows to reach the desired yearly neutron fluence and spectrum estimated by MCNP at low gamma background. First, an irradiation with lower neutron flux ($5.1 \pm 0.7 \times 10^6$ cm^{-2} s^{-1} for E_n>1 MeV) was carried out for 44.4 hours. After approximately one and a half hours, it was followed by an irradiation of larger neutron flux ($1.1 \pm 0.12 \times 10^7$ cm^{-2} s^{-1} for neutrons with E_n>1 MeV), for 22.1 hours, resulting in total neutron fluence of 1.7×10^{12} cm^{-2} for E_n>1 MeV neutrons, which is equivalent with a dose of 63.7 Gy (for water). The total gamma dose during the irradiation was kept as low as 3.5 Gy.

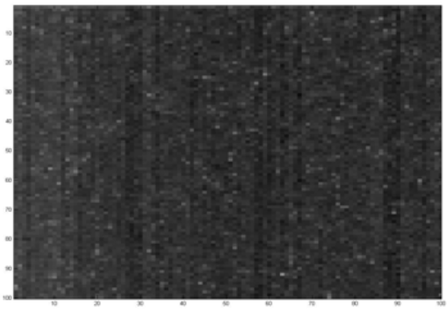

Fig.4. 100 by 100 pixels fragment of the total picture after3.8 Gy/h gamma irradiation

Fig.5 100 by 100 pixels fragment after the total neutron irradiation

During the irradiation, a series of pictures were taken at different times, i.e. at different doses with exposition time of 2, 20 and 200 ms. We found that the dark current grows linearly with the neutron fluence (see Fig.6., where two different flux ranges were applied, and Fig 7. for the shift of distribution function for 2 ms exposure time.

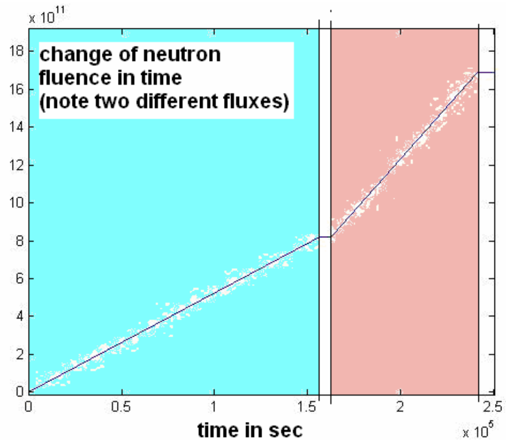

Fig.6 Change of fluence during neutron irradiation

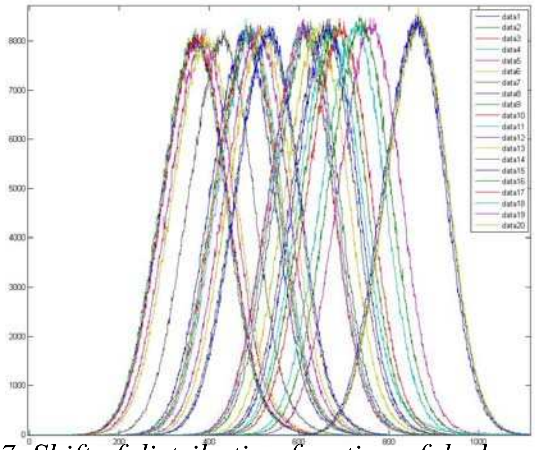

Fig 7. Shift of distribution function of dark current on picture taken with 2 ms exposure time

This means that the dark current grows with neutron fluence linearly (see fig. 8) for a small exposure time (2 ms). Between two irradiations and after them, a relaxation was observed.

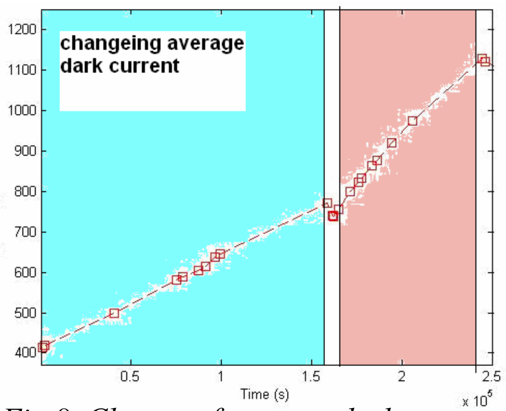

Fig.8. Change of average dark current at 20ms exp .time

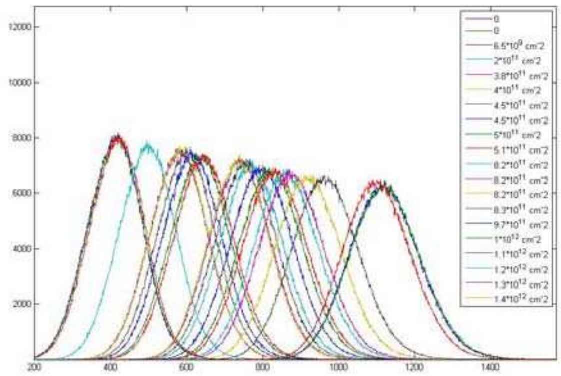

Fig.9 Shift of distribution at 20 ms exp. time

However, in spite of the fact that relaxation starts immediately (see Fig. 8 for a break), the dark current distribution did not return for 6 months only until the half of its shifts (growth in intensity). Similar behaviour has been observed for the 20 ms exposure time (see Fig 9.), however the shape of the distribution starts to distort (change of variance can be observed).

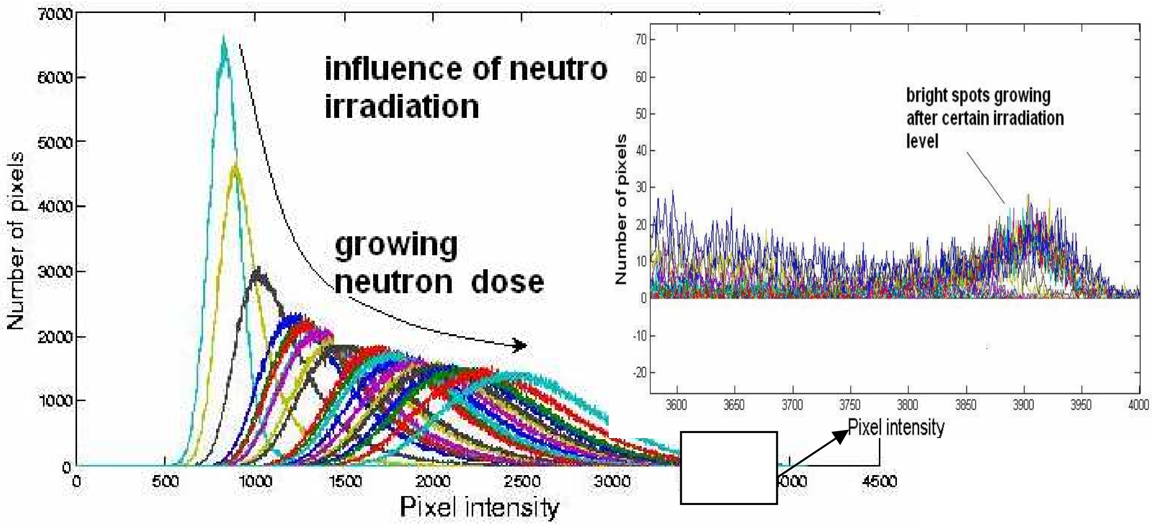

Fig.10. Shift of distribution (200msec exp.time), the originally high kurtosis falls to normal

Very interesting is the shit of APD taken with 200 ms (see fig 10). It starts with a very sharp form (high kurtosis) and tends to flatten.

SUMMARY

We calculated the expected neutron fluence for a year of operation and the total gamma dose for the W7-X stellarator video port using the MCNP code. The irradiation tests proved that our newly developed Sensor Module of a fast and intelligent camera can withstand the expected radiation of gamma rays and neutrons in the sense that it will not loose its ability to work. However, we have to face growing intensity of the dark current of the pixels of the camera, and also flattening the distribution curve till to maximum intensity values. Since this is the background of the picture that means we shall loose gradually the dynamics of the camera during the neutron irradiation. Every break in irradiation tends to return the camera towards the original state. However, while this return seems to be fast at the beginning of annealing, it becomes unstable, looses pace and 6 month after the irradiation we found that the distribution function returned back only approximately to the middle distribution exhibited in Fig.10, i.e. it is still far from the original stage.

Acknowledgements

The investigations were supported by Hungarian Grant NAP project by NKTH.