BEAM DUMP AND LOCAL SHIELDING LAYOUT AROUND THE ITEP RADIATION TEST FACILITY

RADIATION PROTECTION

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The Radiation Test Facility (RTF) is under construction at the Institute for Theoretical and Experimental Physics to control the electronics under irradiation of particles that imitate cosmic rays (protons, carbon, aluminum, iron, tin, bismuth, and uranium). For the norms of radiation safety of personnel and users of the RTF to be observed, a local shielding and beam dump must be designed. Simulations of the dose rates around the designed shielding and beam dump are carried out in the present work.

I. INTRODUCTION

Cosmic ray–induced single event upsets (SEU) in microelectronics recently became the dominant problem in terms of providing reliability of spacecraft equipment. The characteristics of the cosmic ionizing radiation sources (the Earth's inner and outer radiation belts, the galactic and solar cosmic rays) have been studied in sufficient detail. Low-energy protons produce the radiation dose effects that induce parametric and functional upsets. Ions and high-energy protons induce single radiation effects, resulting in reversible (malfunction) and irreversible (catastrophic) upsets. Analysis of the flight-time onboard equipment upsets has shown that SEU constitute 25 to 35% of all upsets, so the design of the test facility for direct controlling of SEU is extremely important.

II. DESCRIPTION OF THE TEST FACILITY

Direct tests of microelectronics to resist SEU will be realized in the Radiation Test Facility (RTF) using the external proton and heavy-ion beams extracted from the unique heavy-ion accelerator-accumulator complex, i.e., terawatt accumulator (the TWAC-ITEP project).[1] The RTF beams are planned to have the following basic parameters:

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1. 10-, 15-, 20-, 25-, 35-, 45-, 55-, 65-, 75-, 85-, 100-, 150-, 200-, and 400-MeV proton energies
2. 1×10^4, 3×10^4, 1×10^5, 3×10^5, 1×10^6, and 3×10^6 p/s·cm^{-2} (all energies) and 1×10^7 p/s·cm^{-2} (for 10 to 100 MeV) proton fluxes
3. ion energies (operation mode No. 1): ^{12}C, 45 MeV/A; ^{27}Al, 70 MeV/A; ^{56}Fe, 90 MeV/A; ^{120}Sn, 120 MeV/A; ^{209}Bi, 150 MeV/A; and ^{238}U, 150 MeV/A
4. ion energies (operation mode No. 2): ^{12}C, 18 MeV/A; ^{27}Al, 32 MeV/A; ^{56}Fe, 23 MeV/A; ^{120}Sn, 33 MeV/A; ^{209}Bi, 41 MeV/A; and ^{238}U, 32 MeV/A
5. ion fluxes: 1×10^2, 3×10^2, 1×10^3, 3×10^3, and 1×10^4 ion/s·cm^{-2}
6. nonuniformity: 15% within 15-mm diameter.

The beams with the above parameters will be formed by directing the accelerated particles from the accelerator ring to the transport channel via the slow extraction system with an $\sim 10^{11}$ particle/pulse intensity for protons and an $\sim 10^4$ to $\sim 10^6$ particle/flux intensity for ions. The proton energies below 25 MeV are attained using a wedge degrader.

III. THE INPUT DATA ON PARTICLE BEAM PARAMETERS

The above energy, flux density, and nonuniformity requirements of proton beams were taken to be the input particle beam data for dose rate simulations. Table I presents the proton and ion beam parameters, which were determined assuming that the beam lateral distribution is normal.

IV. GEOMETRY AND ARRANGEMENT OF RADIATION SHIELDING AND BEAM DUMP

Figure 1 shows the simulation version of the geometry and arrangement of the shielding blocks (around the aperture and final collimators) and the beam dump. The shielding block consists of two high-density concrete walls of 2.4 t/m^3 density, 0.5- to 0.6-m thickness, and 2.4-m height. The walls are placed along the beam line at 1.5 m from the beam line. The wall length at the corridor side is 9.1 m, and the opposite wall length is 6.5 m.

The beam dump placed at 8.8 m from the beam extraction point is a heavy concrete cube of 3.6-m depth. A hole of 10-cm diameter and 0.5-m depth is bored in the blind flange at the beam level height. The hole is used to pass the beam to the dump inside.

V. SIMULATION TECHNIQUES

The space distributions of dose fields were calculated using the MCNPX code[2] with the "Mesh Tally" technology that plots the calculated values in rectangular and cylindrical geometries. The SHIELD code[3] was used to simulate the neutron source space-energy distribution of neutrons produced by heavy-ion beams. The data in Secs. III and IV were used to prescribe the model geometry and the source parameters. Among the elements that surround the RTF, only the shield wall geometry was included in the calculations. The contributions from the instantaneous gamma-quanta and from the activation radiation to the dose rate were disregarded.

The dose rates in the controlled regions (see Fig. 1) were repeatedly calculated at different proton beam energies from 50 to 1600 MeV.

TABLE I

The Input Beam Parameters to Simulate Dose Levels

Parameter	Formula	Value
Irradiation time-averaged flux on beam axis, Φ_0	Input value	3.0×10^6 p/s·cm^{-2}
Collimated beam diameter, D	—/—	3.0 cm
Flux nonuniformity within diameter d: $W = (\Phi_0 - \Phi_d)/\Phi_0$, W	—/—	0.15
Nonuniformity determination diameter, d	—/—	1.5 cm
Pulse repetition rate, T	—/—	4 s
Pulse duration, t	—/—	0.3 s
Mean square deviation, σ	$d \cdot [8 \ln(1-W)^{-1}]^{-1/2}$	1.316 cm
The irradiation time-averaged beam current before aperture collimator, l	$\Phi_0 \cdot 2\pi\sigma^2$	3.26×10^7 p/s
The irradiation time-averaged beam current after aperture collimator, I_c	$I \cdot [1 - \exp(-D^2/8\sigma^2)]$	1.56×10^7 p/s
Flux during a single pulse at the beam axis, F	$\Phi_0 \cdot T/t$	4.0×10^7 p/s·cm^{-2}
Proton number per pulse (before the aperture collimator), N	$I \cdot T$	1.30×10^8 protons
Proton number per pulse (after the aperture collimator), N_c	$I_c \cdot T$	6.24×10^7 protons

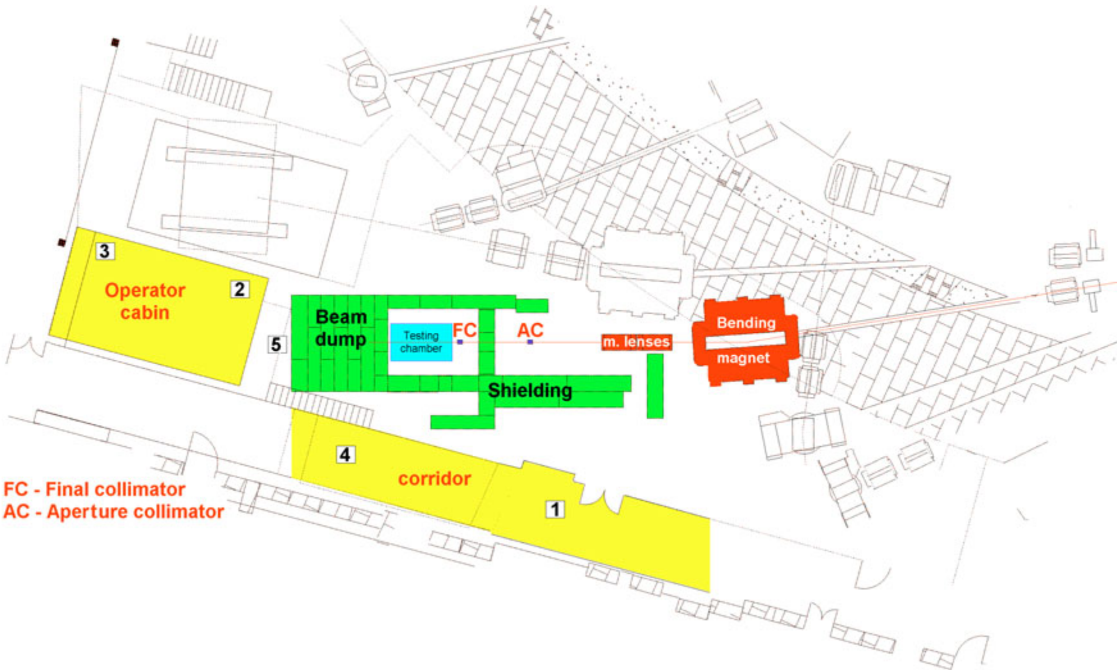

Fig. 1. A schematic of the shielding of the facility and the areas under control. The control points are marked by digits.

VI. THE RESULTS OF SIMULATING THE DOSE RATES

The calculations have resulted in the space distributions of dose rates. Figure 2 shows some examples of the calculated dose rate distributions around the facility at proton beam energies of 50, 100, 200, and 400 MeV. Table II presents the numerical values of the dose loads on personnel at 400 MeV. Figure 3 shows the maximum dose levels in the corridor zone $D_K(E)$ and in the operator cabin $D_M(E)$ versus proton beam energy.

TABLE II

Simulated Dose Loads on Personnel at 400-MeV Proton Energy

Point in Fig. 1	Location	Dose Rate (μSv/h)
1	Corridor in front of shielding blocks	2
2	Operator cabin front of the internal wall	<0.3
3	Operator cabin behind the internal wall	<0.1
4	Corridor in front of the beam dump	2
5	The rear butt of the beam dump	0.3

Based on a 2000 h/yr maximum possible workload of personnel and on Radiation Safety Norm 99 (RSN-99) (Ref. 4), we have obtained the following admissible dose rates for personnel of different categories:

1. category A (maintenance staff in the corridor zone): $D_A = 10\ \mu$Sv/h
2. category B (test staff in the operator cabin): $D_B = 0.5\ \mu$Sv/h.

The maximum dose levels versus energy in the corridor and in the operator cabin, shown in Fig. 3, can be readily used together with the admissible dose levels to obtain the highest admissible number of protons in a beam pulse:

$$N(E) = N_{Table\_1} \times \text{minimum}[D_A/D_K(E); D_B/D_M(E)] \ . \tag{1}$$

Figure 4 shows the resulting dependence $N(E)$.

VII. CONCLUSIONS

The proposed versions of the shielding and the beam dump provide the dose loads on the personnel of category A in the corridor and in the operator cabin at a level admissible in terms of radiation safety (5 μSv/h as in RSN-99), which allows for a twofold margin to validate the RTF project everywhere. The dose level for persons

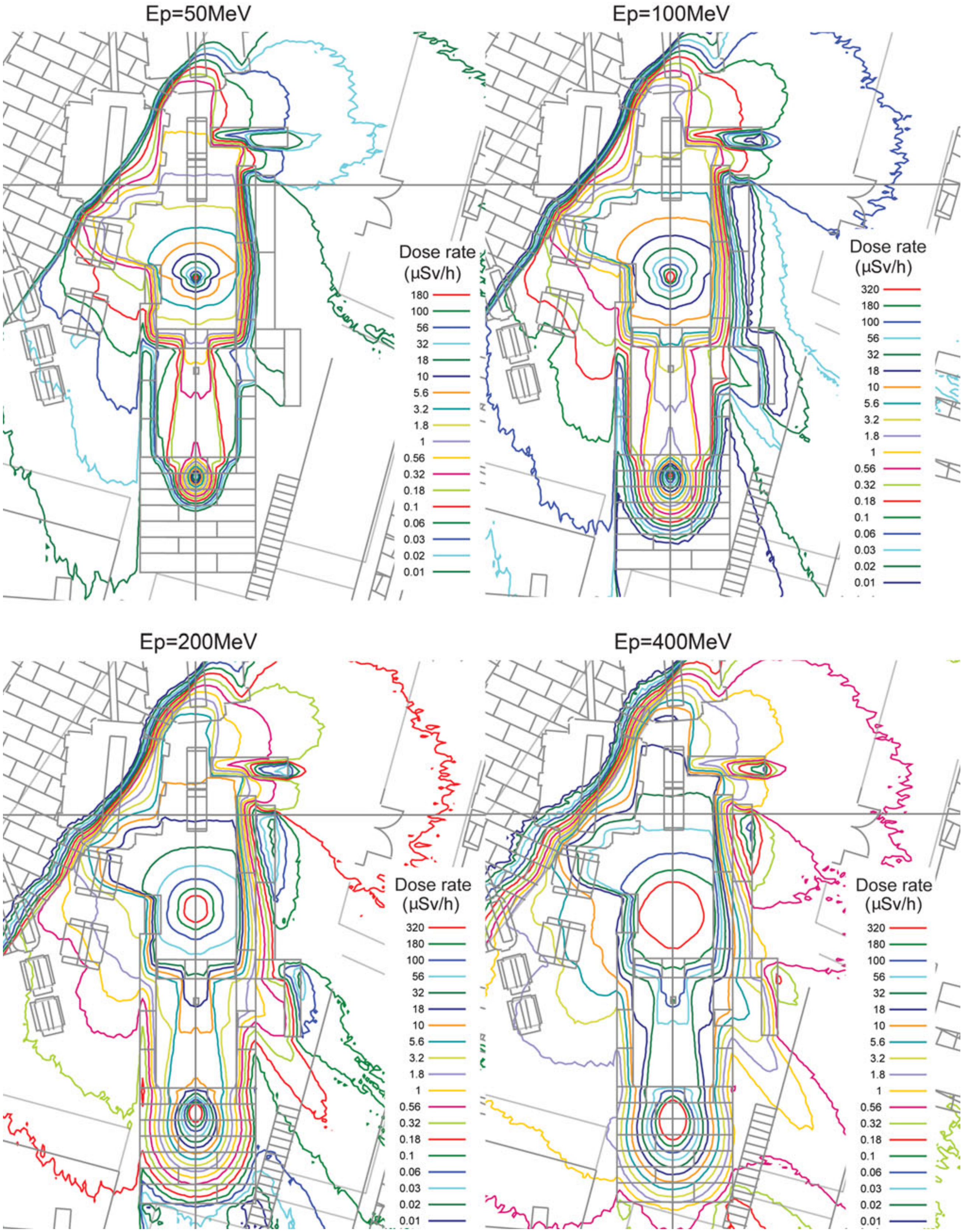

Fig. 2. The simulated dose distributions around the shielding at proton beam energies of 50, 100, 200, and 400 MeV. Note that the simulation used a simplified geometry description of the elements located outside the RTF shielding and beam dump.

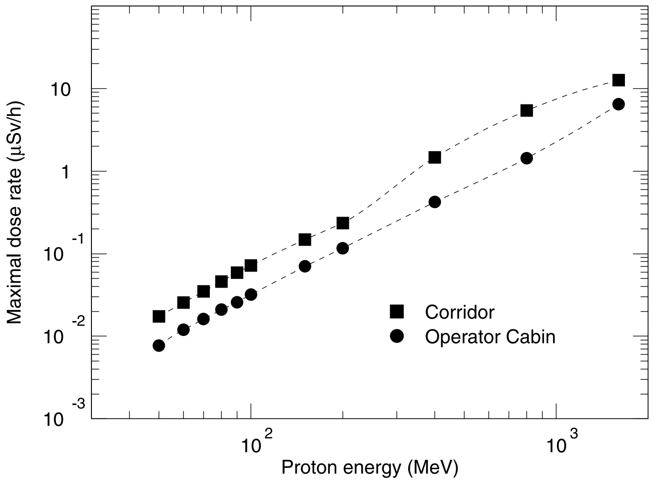

Fig. 3. The maximum dose in the zones under control versus beam energy.

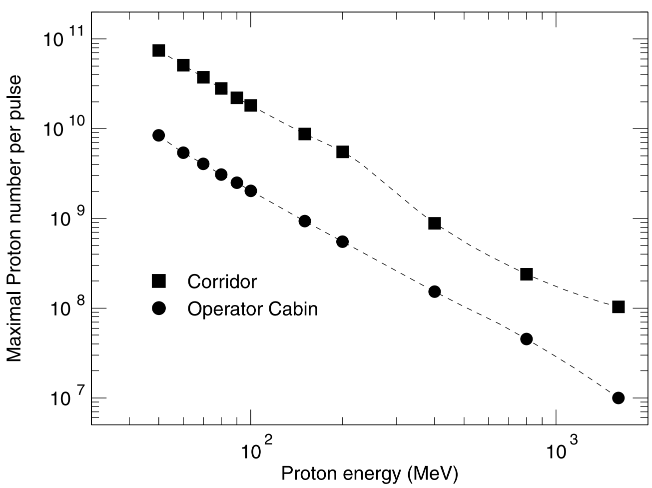

Fig. 4. Admissible numbers of protons in a beam pulse related to radiation load on personnel in the operator cabin and in corridor.

of "test staff" category B is provided in the operator cabin (below 1 μSv/h).

The energy dependence of the found dose rates shows that the admissible beam pulse rate exceeds $\sim 1 \times 10^{10}$ protons at proton beam energies below 50 MeV.

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REFERENCES

1. B. YU. SHARKOV et al., *Nucl. Instrum. Methods A*, **464**, 1 (2001).

2. J. S. HENDRICKS et al., "MCNPX EXTENSIONS Version 2.5.0," LA-UR-05-2675, Los Alamos National Laboratory (Apr. 2005); available on the Internet at http://mcnpx.lanl.gov/.

3. A. V. DEMENTYEV and N. M. SOBOLEVSKY, "SHIELD—Universal Monte Carlo Hadron Transport Code: Scope and Applications," *Radiat. Measurements*, **30**, 553 (1999).

4. "Radiation Safety Norms (RSN-99)," Public Health Ministry of Russia (1999) (in Russian).