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Strategy for Radiation Tolerance Assurance of the A&T Electronic Equipment

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The radiation environment encountered at high-energy accelerators differs from the environment relevant for space applications. The mixed field expected at modern accelerators is composed of charged and neutral hadrons (protons, pions, kaons and neutrons), photons, electrons and muons, ranging from very low (thermal) energies up to the TeV range.

This complex field is due to particles generated by the primary particle collisions in the experimental areas, distributed beam losses around the machine, and the beam interacting with the residual gas inside the beam pipe. Electronic components and systems exposed to a mixed radiation field will experience at once all three different types of radiation damages: Single Event Effects (SEEs), damage from Total Ionizing Dose (TID) and Displacement Damage (DD), where in all cases, not only the particle type, but also the respective energy distribution are to be considered. One important example of the latter are latch-up errors (possibly destructive) where in the context of accelerator environment their cross section can still increase until energies in the GeV range, especially if high-Z materials are present near the device's sensitive region. In addition, for some devices the impact of thermal neutrons is not to be neglected; and when it comes to dose, pure gamma test measurements are partly not fully representative.

For the CERN accelerator sector, the control and the functioning of the Large Hadron Collider (LHC) requires many systems and equipment partly to be installed in radiation areas, such as power converters providing up to 13 kA current to the super conducting magnets, safety and monitoring electronics and actuators for discharging the superconducting coils, pumps for creating the required vacuum conditions in the beam pipe, in the magnets, and in the helium distribution line, cryogenic systems to reach the temperature of 4K, and many others. Moreover, depending on the functionality, each system is replicated 10, 100 or 1000 times along the LHC and its injections lines.

Within these constraints, the conception of full custom solutions down to the component level is often not possible and must be adopted according to each individual design limitations, defined by the electrical specifications on the one side and the harsh radiation environment on the other. Depending on the latter, in the context of accelerators, an equipment can thus be either a fully commercial system, or a custom development, based on hardened or qualified electronic components, or a mix of the two solutions.

Therefore, all exposed electronic systems have to be qualified for their radiation tolerance. The latter has to include a failure analysis and an estimation of the respective impact on accelerator operation. In this context, the device degradation due to cumulative effects, or its functional limitations due to single event failures, is not a limitation by itself, but must be quantified. In terms of respective design acceptance criteria, the performance degradation must not prevent the proper use of the component or the system up to its defined (and qualified) TID and DD targets, as well as the rate of SEE must remain sufficiently low in order to cause only a limited (and acceptable) number of stops of the accelerator, while also keeping as short as possible the consequent machine downtime.

Combining all accelerator operation, control and monitoring systems, the R2E project aims for an accelerator operation with a radiation induced 'Mean-Time Between Failures'(MTBF) greater than or equal to one week for nominal, ultimate and later high-luminosity operation conditions, therefore finally assuming a peak luminosity of ˜5×1034 cm-2s-1 allowing for an annual integrated luminosity of more than 200 fb-1.

In order to keep the overall failure rate under control and to reach the goal defined by the MTBF target, one requires a long-term radiation test and qualification strategy trimmed to the needs of the accelerator radiation

environment and its applications.
Further detailing the above listed constraints and requirements, this paper will present the criteria for choosing radiation test facilities, both standard facilities as well as a new CERN-based one (CHARM), the test strategy and procedure, with flow charts of the radiation tests to be performed, taking into account the type of the equipment, its individual list of required components, as well as the radiation levels of the area where it will be installed. The high radiation environment encountered at the CERN accelerator, the large number of electronic systems and components, as well as the actual impact of radiation induced failures on the overall accelerator operation, strongly differ from the environment and systems usually relevant for space applications. Additional constraints, but in some cases also simplifications, which have to and can be considered with respect to the test and monitoring standards, are respectively summarized.

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