Overview of the ATLAS Policy on Radiation Tolerant Electronics

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Abstract

The ATLAS sub-systems will integrate a very large number and variety of electronic boards which will be exposed to radiation ranging from a few krads and a few 10^{10} n/cm^2 to more than 10 Mrads and 10^{14} n/cm^2, and to energetic particles capable of producing SEE (Single Event Effects). The ATLAS technical co-ordination has developed a new policy on radiation tolerant electronics in collaboration with sub-systems. It provides guidelines for the pre-selection and for the qualification of all the commercial electronic components and all the radiation-hard ASICs that will be used in ATLAS, in order to make sure they will resist to the foreseen radiation constraints. This paper summarises the organisation chosen by ATLAS to carry out the radiation hardness assurance, the main guidelines given in the ATLAS Policy on Radiation Tolerant Electronics, and the tools available to apply this policy.

I. ORGANISATION

The Radiation Hardness Assurance Working Group (RHA-WG) was organised in 1999 in the frame of the ATLAS Technical Co-ordination, with the mission of developing and operating a coherent plan for radiation hardness assurance (RHA) in all the ATLAS sub-systems. The members of this working group are:

- RHA leaders from each ATLAS sub-system;
- ATLAS RHA co-ordinator;
- ATLAS Front-End Electronics co-ordinator.

This working group meets every 3-4 months; its progress reports are published in the ATLAS Radiation Hard Electronics Web Page [1].

II. ATLAS POLICY ON RADIATION TOLERANT ELECTRONICS

A. *Goals*

The first goal of this policy is the general safety of the ATLAS materials and of the persons working on the experiment. Therefore, all components or systems which can cause fire or induce high and long-term radioactivity levels through radiation effects are forbidden.

The second goal of this policy is to help ATLAS sub-systems to build electronics that will resist the radiation level foreseen during 10 years of operation. Therefore, this policy gives the radiation tolerant criteria, the radiation test methods, and the rules which apply for pre-selecting and for qualifying radiation tolerant COTS components or radiation hard ASICs before purchase.

The third goal of this policy is to help sub-systems to anticipate radiation problems in order to build electronics within the foreseen schedule.

B. *Procurement Strategy*

Table 1 summarises the main steps of the ATLAS strategy for procurement of radiation tolerant COTS components or radiation-hard ASICs.

Procurement Strategy for Radiation Tolerant COTS	
Step 1	Determine the Simulated Radiation Level (SRL)
Step 2	Calculate the Radiation Tolerance Criteria (RTC)
Step 3	Pre-select the generic component (standard tests)
Step 4	Qualify batches of components (standard tests)
Step 5	Purchase qualified batches

Procurement Strategy for Radiation Hard ASICs	
Step 1	Determine the Simulated Radiation Level (SRL)
Step 2	Calculate the Radiation Tolerance Criteria (RTC)
Step 3	Select rad-hard technology (guaranteed features)
Step 4	Develop a prototype ASIC
Step 5	Qualify ASIC radiation hardness (standard tests)
Step 6	Purchase batches of qualified ASICs

Table 1: Procurement Strategy for COTS and ASICs

C. *Simulated Radiation Levels*

The radiation constraints which will degrade electronic devices in the LHC environment are:

- Total Ionising Dose (TID, unit: Gray), which is responsible for oxide charge trapping producing threshold voltage shift and leakage currents in CMOS devices and gain decrease in bipolar devices;
- Non-Ionising Energy Loss (NIEL, unit: 1 MeV equivalent neutron per cm^2), which is responsible for displacement damage producing gain decrease in bipolar devices, threshold voltage shift in JFET, leakage current in PIN diodes, etc.
- Total fluence of hadrons having an energy higher than 20 MeV (unit: hadron per cm^2). These hadrons are responsible for various Single Event Effects (SEE) such as Single Event Upsets (SEU), Single Event Latch-up (SEL), Single Event Burnout (SEB), Single Event Gate Rupture (SEGR), etc.

These radiation constraints have been simulated using GEANT CALOR, for the various locations of electronics in each ATLAS sub-systems. The three types of Simulated

Radiation Levels (SRL) are summarised in Table 2. Tables giving SRL values are available on the Web [1].

Simulated Radiation Level	Unit
SRL_{tid}	Gray
SRL_{niel}	1 Mev equiv. neutron/cm^2
SRL_{see}	>20 MeV hadron/cm^2

Table 2: Simulated Radiation Levels

D. Radiation Tolerance Criteria

Three Safety Factors (SF) must be applied to the raw Simulated Radiation Levels to determine the Radiation Tolerance Criteria (RTC). These are summarised in Table 3. Tables giving SF values are available on the Web [1].

Safety Factor	Purpose
SF_{sim}	Represents inaccuracies in the simulations
SF_{ldr}	Represents low dose rate effects in TID tests
SF_{batch}	Represents variations of radiation tolerance from batch to batch and within batches

Table 3: Safety Factors

Inaccuracies in the simulations result from inaccuracies in the event generation models, in the transport models and in the physical description of the detector, and from limited statistics (especially in the external regions of the detector).

Low dose rate effect is an increase of the damage produced by TID on CMOS, JFET or bipolar devices when irradiation is applied at low rate. This effect increases when the dose rate decreases; it becomes significant for dose rates below about 0.01 rad/s, depending on the technology [2,3]. It concerns potentially all the electronics of LHC experiments and of the LHC machine, which will be irradiated at dose rates ranging from a few 0.01 rad/s (inner detectors) to less than 0.1 mrad/s (muon detectors).

Variation of radiation tolerance from batch to batch may result from process or equipment changes which do not affect the electrical features but which could degrade uncontrolled parameters such as radiation tolerance in standard technologies. Variation of radiation tolerance within batches may result from fluctuations of some technological parameters which are not under control in non radiation-hard technologies.

For TID and NIEL, the Radiation Tolerance Criteria (RTC) is obtained by multiplying SRL with the three safety factors:

- $RTC_{tid} = SRL_{tid} \times SF_{sim} \times SF_{ldr} \times SF_{batch}$;
- $RTC_{niel} = SRL_{niel} \times SF_{sim} \times SF_{ldr} \times SF_{batch}$.

For SEE, three types of Radiation Tolerance Criteria are defined (table 4):

RTC	Type of SEE	RTC Unit
$RTC_{see.s}$	soft SEE	soft SEE / s
$RTC_{see.h}$	hard SEE	hard SEE / s
$RTC_{see.d}$	destructive SEE	destructive SEE / s

Table 4: Radiation Tolerance Criteria for SEE

The values of these RTC_{see} must be defined by each ATLAS sub-system for each electronic component. They depend on the architecture in which the components are used and on the system requirements.

To avoid fire risks, components which are sensitive to destructive SEE are not allowed, unless a proven robust architectural solution protects the system against thermal destruction.

E. ATLAS Standard Radiation Test Methods

ATLAS standard test methods are derived from DOD or ESA test methods [4-6] for CMOS devices and from ref. [7] for bipolar or BiCMOS devices, with several adaptations that take into account the specificities of the ATLAS radiation environment.

Radiation test method for NIEL

Figure 1 and 2 summarise the test method for pre-selecting generic components and for qualifying batches of components that satisfy the NIEL Radiation Tolerance Criteria (RTC_{niel}).

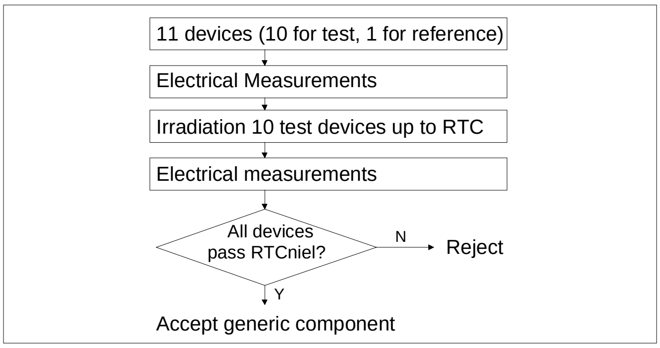

Figure 1: Pre-selection of generic components with respect to NIEL

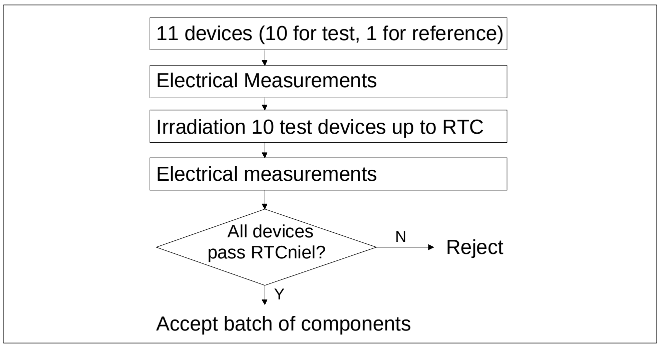

Figure 2: Qualification of batches of components w.r. to NIEL

Radiation test methods for TID

Figures 3 and 4 summarise ATLAS standard test methods for pre-selecting generic MOS devices and for qualifying batches of MOS devices that satisfy the TID Radiation Tolerance Criteria (RTC_{tid}).

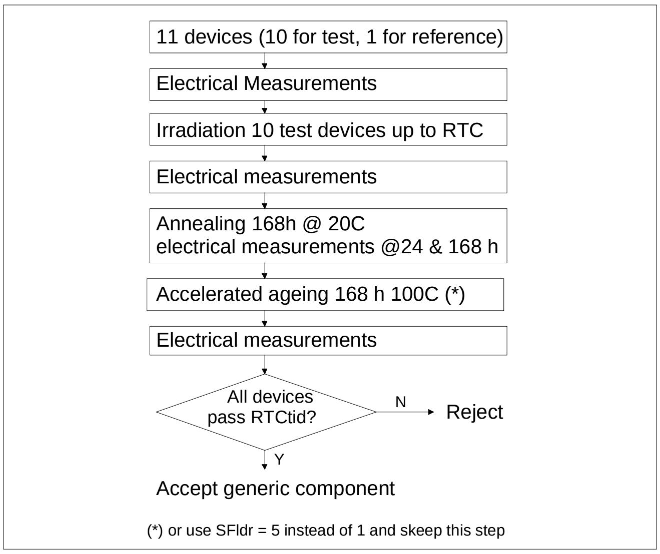

Figure 3: Pre-selection of generic CMOS with respect to TID

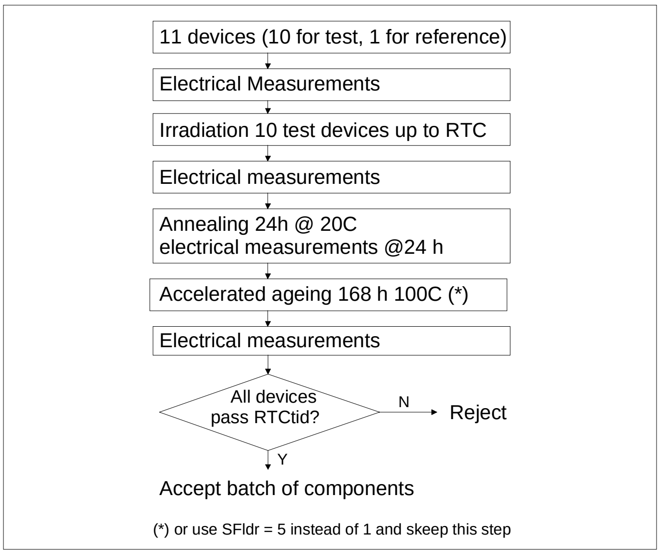

Figure 4: Qualification of CMOS batches with respect to TID

These test methods include an optional accelerated ageing that simulates the increase in damage produced by TID applied at low dose rate (such as in LHC experiments). This accelerated ageing enables one to set SF_{ldr} to 1 for RTC computation. Otherwise, if this accelerated ageing is skipped, SF_{ldr} must be set to 5 to represent low dose rate effects.

Figures 5 and 6 summarise ATLAS standard test methods for pre-selecting generic bipolar devices and qualifying batches of bipolar devices that satisfy the TID Radiation Tolerance Criteria (RTC_{tid}).

The pre-selection test method includes two optional steps. The first one is the determination of the worst temperature, i.e. the temperature at which the degradation of the component under irradiation is the highest. This determination is made by irradiating a few components at various elevated temperatures.

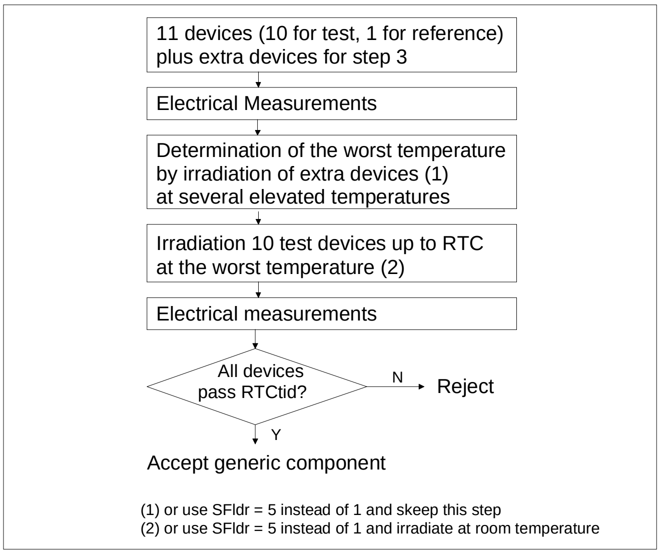

Figure 5: Pre-selection of generic bipolar devices w.r. to TID

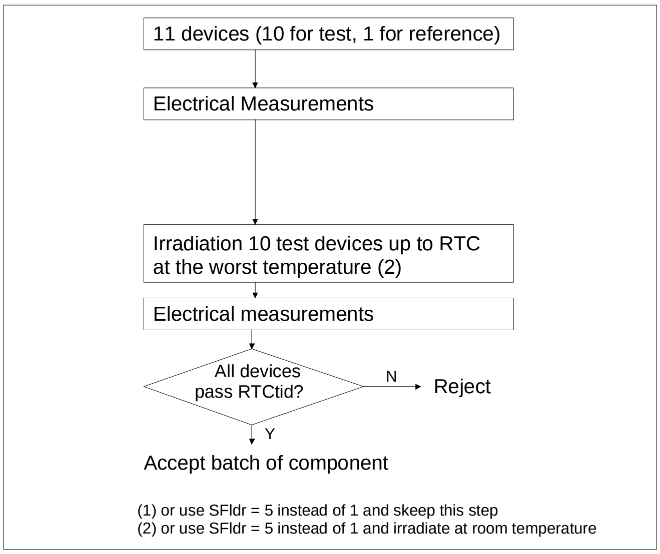

Figure 6: Qualification of batches of bipolar devices w.r. to TID

The second optional step is the irradiation of a full set of 10 test devices at the worst temperature using a medium or high dose rate. It simulates the effects of TID expected at low dose rate [7]. When these two optional steps are used, SF_{ldr} must be set to 1 for CRT computation. Otherwise, if these two optional steps are skipped, test devices must be irradiated at room temperature and SF_{ldr} must be set to 5 to represent low dose rate effects for RTC computations.

Radiation test methods for SEE

Two standard test methods can be used for selecting and qualifying integrated circuits that satisfy the SEE Radiation Tolerance Criteria (RTC_{see}): one is based on proton irradiation [6, 8], the other one is based on neutron irradiation [9]. We summarise in figure 7 the main steps of the proton-based SEE test method.

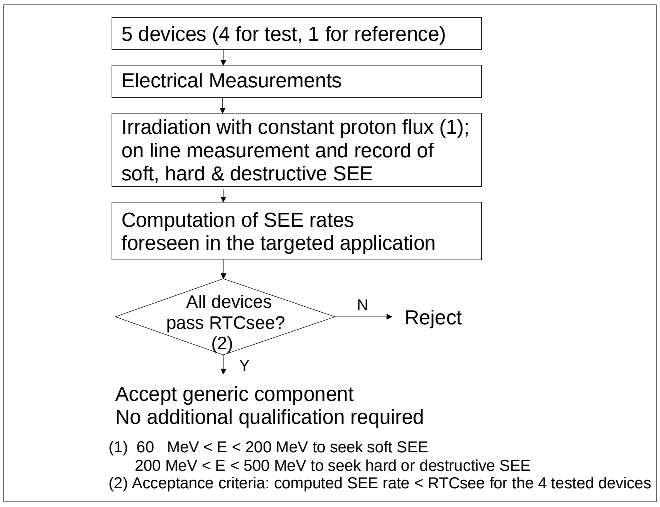

Figure 7: Pre-selection and qualification of integrated circuits with respect to SEEs

Protons with an energy comprised between 60 MeV and 200 MeV enable one to seek soft SEE as well as most of the hard and destructive SEEs. However, an *exhaustive* search for soft, hard and destructive SEEs requires protons with a higher energy (energy between 200MeV and 500 MeV).

III. TOOLS FOR RADIATION HARDNESS ASSURANCE

Several tools have been developed to help ATLAS sub-systems to carry out the radiation hardness assurance for their electronics:

- Two tutorial courses;
- Tables of simulated radiation levels and safety factors;
- ATLAS Policy on Radiation Tolerant Electronics;
- Lists of radiation test facilities;
- Agenda of ATLAS irradiation campaigns;
- ATLAS Radiation Tolerant Electronic Components Database;
- Templates of ATLAS Standard Radiation Test Reports;
- (…)

The tutorial courses are written to help ATLAS sub-systems and other LHC collaborations share a clear and common understanding of the effects of radiation on electronic components and circuits [10,11]. These two 90-minute courses are the first essential building blocks of the radiation hardness assurance. They were given in 1999 and 2000 in several ATLAS-member Institutes, in ATLAS Front-End Electronics meetings, and in a 3-day training on radiation effects on electronics organised by CERN in spring 2000 [12].

The tables of simulated radiation levels, the tables of safety factors and the document “ATLAS Policy on Radiation Tolerant Electronics” available on the ATLAS Radiation Hard Electronics Web Page are up to date and officially approved by ATLAS. Previous tables and previous documents remain available on the same web page as archive documents.

The lists of radiation facilities provide information on numerous gamma, x-rays, neutrons, protons, pions, and heavy ions facilities available for irradiation tests.

The agenda of ATLAS irradiation campaigns enables sub-systems to announce their irradiation planning and hence to co-ordinate their work together.

The ATLAS Radiation Tolerant Electronic Components Database enables the ATLAS sub-systems to record and share their radiation test results and hence to avoid any unnecessary duplication of tests. This database also helps sub-systems to standardise some electronic components. For each component, this database provides a brief description of the component, information on the manufacturer, on the technology, on the package, and copies of electrical data sheets and radiation test reports.

Templates of ATLAS Standard Radiation Test Reports enable ATLAS sub-systems to summarise the most relevant test results on a common form before entering them in the database.

All these tools are available on the ATLAS Radiation Hard Electronics Web Page [1].

IV. CONCLUSIONS

A Working Group was organised in the frame of ATLAS Technical Co-ordination in order to co-ordinate the efforts in the experiment and with other experiments (through RD49) in the field of testing and procurement of radiation tolerant or radiation hard components.

A tutorial course on radiation effects on electronic components and circuits was given in several ATLAS member Institutes and at CERN in order to share a clear and common understanding in this domain.

A Policy on radiation tolerant and radiation hard electronics was developed by ATLAS TC in collaboration with sub-systems and was approved by the Executive board of the experiment. It contains the ATLAS strategy for procurement of electronic components as well as the radiation test methods which are used for selecting and qualifying components.

New simulations of the radiation environment have been made to take into account recent changes in the detector.

A database for electronic components has been developed in order to centralise all the present and future information available on radiation hard or radiation tolerant devices.

A list of Radiation Facilities is available on the ATLAS Radiation Hard Electronics Web Page, as well as other tools mentioned above.

ATLAS is now in a situation in which everyone in each sub-systems speaks the same language, computes the radiation levels in the same manner and perform tests in the same way.

Sub-systems in collaboration with the RHA co-ordinator are currently running irradiation campaigns in order to pre-select radiation-hard and radiation-tolerant electronic components. Results will be summarised in standard test reports and shared within the experiment with the help of the database.

The next step for the ATLAS Radiation Hardness Assurance Working Group and for the sub-systems will be to apply the Radiation Hardness Assurance Policy on a large scale. The total number of components to be pre-selected and qualified is very large, and some of the radiation tests are not easy. It will be necessary to calibrate some radiation facilities, then to co-ordinate the preparation, operation and interpretation of the radiation tests within the sub-systems, to make sure that all the tests are made carefully and without error, and to decide together with the sub-systems when to order the pre-series and series batches of all the electronic components to be installed on the detector or in the cavern.

V. ACKNOWLEDGEMENTS

The ATLAS Radiation Hardness Assurance Working Group wish to thank Chris Parkman for the useful database he has developed for ATLAS, and Mike Shupe for the valuable simulations of radiation environment he has made for ATLAS.

VI. REFERENCES

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