FCC Special Technologies Workpackage
Task 11: Radiation Hardness Assurance (RHA)

Status Report

This document is a short status report of the Radiation Hardness Assurance Task for FCC as of June 2016.

G.Borghello, M.Brugger, M.Capeans, S. Danzeca, F.Faccio, R.Garcia Alia,
G.Gorine, A.Infantino, M.Moll, F.Ravotti

CERN

July 5th, 2016

Table of Contents

INTRODUCTION 3

STATUS OF RESOURCES 3

STATUS OF ACTIVITIES 4

TASK 1 Field conditions and radiation levels at FCC 4

TASK 2 FCC Qualification Protocols 5

TASK 3 Equipment needs for the accelerator, particle detectors and service systems 5

TASK 4 State of the art and development efforts on radhard components for HL-LHC 6

TASK 5 New Technologies 6

CONCLUSIONS 7

Introduction

Task 11 Radiation Hardness Assurance (RHA) addresses all activities undertaken to ensure that the electronics and materials developed for FCC perform to their design specifications after exposure to the FCC radiation environment. RHA deals with environment definition, part selection, part testing, radiation tolerant design, and FCC subsystems requirements. The reference document for the task can be found at EDMS FCC-ST-00001.

The RHA efforts have been divided in 5 different tasks, each linked to deliverables as shown in the table below.

FCC Task 11	Deliverables	Month	Due date
TASK 1 Field conditions and radiation levels at FCC	D1-1. Evaluation of FLUKA models' needs (environment and effects)	M6	Mar'16
	D1-2. FLUKA tuning for FCC (operational/layout options/requirements)	M12	Sep'16
	D1-3. Agreement on FCC target radiation field/levels	M14	Nov'16
TASK 2 FCC Qualification Protocols	D2-1. Define overall FCC qualification requirements as input to RHA	M12	Sep'16
	D2-2. Evaluation of current irradiation facilities and testing infrastructure	M20	May'17
TASK 3 Equipment needs for the accelerator, detectors, service systems	D3-1. Identification of technologies used at FCC with their expected radiation levels	M14	Nov'16
	D3-2. Catalogue of critical equipment (technology, supplier, function, etc.)	M18	Mar'17
TASK 4 State of the art and development efforts on radhard components for HL-LHC	D4.1 Evaluate HL-LHC VS FCC needs of rad hard components	M20	May'17
TASK 5 New Technologies	D5.1 Prototype status and definition of developments linked to technologies	M20	May'17
	D5.2 Radiation tester of advanced components/systems	M36	Sep'18
	D5.3 Radiation sensor	M40	Jan'19

Status of Resources

The table below shows FCC-funded personnel budgeted and committed. Resources have been filled according to timeline. A PJAS (L. Antunes Tambara) will join the team in the period 10/16-9/18 (collaboration agreement signed), and this will consume all personnel budget assigned to the Task.

Personnel	Budget (PM)	Committed @ June 2016	Affiliation	Remaining months
FELLOW	30	24 A.Infantino (from 1/2/16)	EN-EA	0
PJAS	30	6 m G.Borghello (1/1/16 – 30/7/16)	EP-ESE	24
PhD	60	36 G.Gorine EP-DT (from 1/11/15) 24 G.Borghello EP-ESE (from 1/8/16)	EP-DT EP-ESE	0

Existing CERN personnel in Task 11 at 5-10% level:

- EN Dept: M.Brugger (PL), Salvatore Danzeca, Ruben Garcia Alia, Francesco Cerutti, Anton Lechner, Maria Ilaria Besana
- EP Dept: Mar Capeans (PL), Federico Faccio, Federico Ravotti, G.Pezzulo, Michael Moll

The forecasted spending profile for materials (in kCHF) from now till end of 2018, as known today, is:

	Budget	Spending Profile								
		2016	2017				2018			
		Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
FLUKA/TCAD/Spice model development	**50**			25				25		
Evaluation of irradiation and testing infrastructure	**210**		20	20	20	80	20		40	
Development of a radiation tester	**60**			30				30		
Development of radiation sensor	**100**	10	10		50		10		10	
R&D on materials radiation damage	**50**		10		20		10		10	

An example of upcoming expenditures is listed below:

- Cost of EPFL-CMi clean room work for RDR and JNL-FET fabrication (machine renting, special processes, raw materials): 30K
- Irradiation campaigns outside CERN with ultra-high doses: 20K
- Testing/measurement equipment: 150k. Probe station for RDR characterization and equipment to characterize JNL-FET devices degradation: Deep Level Transient Spectroscopy and/or a Semiconductor Parameter Analyser.
- CC60 test stand: 30K
- Component reverse engineering studies: 20K
- Fabrication of test structures for micro-electronics characterization: 40k

Status of activities

Detailed presentations of the progress on the different areas of work are available in the INDICO page of the last Task Progress Meeting held on 22/6/16:
https://indico.cern.ch/event/539360/
A summary is presented hereafter.

TASK 1 Field conditions and radiation levels at FCC

Task driven by R. Garcia Alia (EN).
FCC-funded resources: A.Infantino, fellow.

Progress:
Work on FLUKA is well integrated with ongoing activities in the framework of R2E, and therefore the task was started using resources of the R2E project till the FCC-funded fellow

joined in Feb'16. With current status of simulations, we can give dose indications and shielding considerations and requirements. Current civil engineering design layout is not yet appropriate for known equipment needs. Need to maintain active on the field throughout the entire FCC design process. Generic studies (ongoing) will provide shielding and distance requirements, as well as overall target design levels.

Studies on radiation environment:
Experiments: available first results for the end-cap muons regions (few 10^{15} 1 MeV n_{eq} fluence and 0.4 MGy) highlight the challenges for the inner trackers and associated services where worst case expected for tracker close to the IP is ~500MGy.
Machine: first results available based on scaling factors (generic calculations). Considering the arc (only), the radiation levels are evaluated to be ~15 times higher as current peak LHC levels (increasing probability of SEE). This is a good starting point for studying possible "a-priori" relocation/mitigation solutions (dedicated alcoves, redundancy, etc). Currently focusing on generic studies (due to available layout limitations) and also updating the FLUKA model of the arc section in terms of tunnel (as in CE preliminary drawings), beam screen, optics. In addition, the FLUKA team has started the work on the overall Monte-Carlo model requirements.

TASK 2 FCC Qualification Protocols

Task driven by S. Danzeca (EN), R. Garcia Alia (EN) and F.Ravotti (EP).
FCC-funded resources: G.Gorine (EP), Doctoral student.

Progress
Work has started to qualify Irradiation Facilities for FCC. An inventory of relevant irradiation facilities available world-wide is being carried out and a reference database, developed in the context of AIDA2020 Project, is being populated with important input from the Task 11 team. In view of evaluating the need of in-house irradiation facilities for FCC equipment characterization, the GIF++ radiation field (16.65 TBq ^{137}Cs) has been characterized and measured with PH-RADMON based dosimeters. It results that FCC doses for muon detectors call for tests up to 100 kGy (10 years of detector operation) and at the current GIF++, this would require 22 years of not-stop testing. Work to propose new concepts of test facilities for FCC, and additional FCC-driven characterization of existing CERN facilities will follow.

Given the expected radiation levels in the machine and the large number of distributed electronic systems, work has started in order to develop a general qualification procedure applicable for COTS or hybrid (combined with radiation tolerant technology) systems.

TASK 3 Equipment needs for the accelerator, particle detectors and service systems

Task driven by S. Danzeca (EN)
FCC-funded resources: L. Antunes Tambara (as from autumn 2016)

Established links with several groups working in different aspects of FCC equipment. FLUKA team investigating on radiation levels near the interaction points, absorbers for beam dump, as well as RP studies.
Technology: Response on radiation of SC switches for kicker system based in SiCarbide MOSFETs, control architecture for beam dumps where there is quite many components to be characterized against radiation (eg SRAM-based FPGAs).

Radiation level calculations done for magnets and detectors can be used as starting point, and can be used as orders of magnitudes for categorizing different types of equipment radiation hardness levels.
SiC MosFETs promising for kicker technology, radiation hardness studies required.
Identified a technology study on a “Next-Generation System-on-a-Chip” to be used for future communication link and control projects. The studied Scalable Sensor Data Processor (SSDP) is under development with an established ESA/Gaissler/TAS collaboration. It is a next generation mixed-signal ASIC delivering in the same package high-performance data processing and reliable control. These are complemented by a diverse set of Input/Output interfaces, together with on- and off-chip data acquisition and conversion, a promising design concept for future accelerator and experiment application.
University and ESA collaborations established; layout frozen.
See also Task 4 below.

TASK 4 State of the art and development efforts on radhard components for HL-LHC

FCC-funded resources: G.Borghello 6m PJAS, and Doctoral student.

Progress
Carrying out studies on <u>total dose sensitivity of deep submicron CMOS technology</u>. Collaborative effort with EP-ESE partners: University of Padova (IT), Vanderbilt University (USA), EPFL (CH), INFN (IT).
The current LHC technology is 250nm. For LHC upgrades 65nm technology is being studied. At very high TID the 65nm MOS transistors have large performance degradation. Current degradation is due to isolation oxides, not to gate oxide. Started studies to understand radiation hardness of this technology supplied by different vendors.
Started to investigate the radiation response of 28nm MOS technology. Seen strong dependency on w/l transistor parameters; clear limitation to reach target radiation levels. New test chip with new test structures will be available soon. Test procedures and protocols in place.

TASK 5 New Technologies

FCC-funded resources: G.Gorine, Doctoral student

<u>Development of a Radiation Sensors for FCC</u>.
Analysis of state-of-the-art technologies for radiation measurement carried out, including performance evaluation of existent RADMON sensors at LHC. On this basis, it was identified the need of developing dosimetry technologies for MGy range.
An experimental program to assess RADFET usability and performance in harsh hadron field at FCC-levels was launched. First results expected in few months.
In parallel, started design and fabrication of very novel dosimetry sensors with the initial target of measuring and monitoring of the Displacement Damage in a mixed FCC-level radiation environment. The efforts are currently focused on the development of a solution based on metal nanostructures of nanometer thickness, nano-RDR (Radiation Dependent Resistance). The main expected features are: low cost, simple readout, CMOS-compatible fabrication allowing integration in more complex systems, miniaturized form factor, high radiation tolerance and high measurable fluence range. First prototype structures are being produced in collaboration with EPFL at CMi (Center of MicroNano Technology), and a deep

pre- and post-irradiation characterization will follow. A second option based on Junctionless FET is being explored aiming to target also other radiation effects such as Total Ionizing Dose, and potentially Single Event Effects.

Conclusions

Work on all areas defined for RHA has started. Currently there is a strong focus in background work to define the field conditions and radiation levels at FCC. The next step is the definition of qualification tests (protocols, doses, facilities) for critical components, and evaluate HL-LHC VS FCC needs, identifying common versus specific developments. Test equipment for the next testing phase has been identified and will be purchased shortly.
Currently Task 11 experimental line focus on understanding new technology trends and their radiation hardness. In particular, R&D on 28nm MOS technology for electronics can provide indications on radiation hardness of miniaturization trends. Exploration of metal nanostructures of nanometer thickness devices for MGy radiation dosimetry is a very novel and promising approach being developed.