Impacts of SEEs
LHC Performance Workshop
Chamonix 2009

R2E Taskforce
B. Bellesia, M. Brugger, A. Ferrari, D. Kramer, R. Losito,
S. Myers, M. Pojer, S. Roesler, M. Solfaroli, A. Vergara,
S. Weisz, T. Wijnands

with input from:
R. Assmann, A. Ballarino, J.C. Billy, S. Claudet, B. Dehning,
R. Denz, Q. King, M. Lamont, J. Lendaro, M. Moll, D. Perrin,
R. Schmidt, H. Thiesen, Y. Thurel, J. Uythoven, M. Zerlauth
Overview

• R2E 2008 Activities and Conclusions
• Example of UJ76/RR73,77 to illustrate the chosen analysis & evaluation approach
• Underground Areas – Expected Radiation & Prioritization
• Suggested Priority Classification of Equipment
• 1st Iteration on Machine Protection related Systems
• Performed Radiation Tests
• Implications for 2009
• What is needed for the mid/long-term
R2E 2008 Activities and Conclusions

- **Review** of available simulation data and respective iteration
- Split of **priorities** in short/mid/long-term
- **Loss assumptions** and scaling for coming years
- **FLUKA simulations** for most critical areas
- **Shielding studies** for most critical areas, discussion of [http://ab-div.web.cern.ch/ab-div/Meetings/r2e](http://ab-div.web.cern.ch/ab-div/Meetings/r2e)
- Study of possible temporary move of the betatron cleaning to P3
- **Prioritization** of underground radiation areas containing electronics
- **Monitoring** during start-up, successful comparison with simulations
- **Radiation Tests** and implications
- SEE related **shutdown activities** (UJ76/TZ76, RR73/77, UA63/67, UX85)
UJ76/RR73/77 Approach

- Early awareness of radiation levels
- Detailed analysis based on tracking studies (SIXTRACK) and cascade simulations (FLUKA) to estimate the distribution and maximum radiation doses and fluences
- Analysis of related uncertainties (assumptions, models, statistics, limitations)
- Inventory and location of installed electronics
- Study of consequences in case of failure
- Study of different solutions (shielding, relocation, combinations)
- Proposed solution outlined and discussed in respective ECR (LHC-EC-UJ76)
- Staged implementation approach to allow for additional measurements during operation
SEEs related 2008/9 Shutdown’s Activities

• IR7
  – RR73/77 installation of final shielding
  – TZ76 preparation
  – UJ76
    • UPS removal (from UJ76 into TZ76)
    • additional shielding wall to increase protection of safe room

• IR6
  – Shielding of ducts between tunnel and UA63/67

• IR8
  – UX85b installation of remote controllers

• Additional identified holes in shielding were already mostly closed before first start-up (e.g., geometer holes)
• Critical Areas: check for additional monitoring, iterations
Radiation Levels- Summary - Prioritized

• Current knowledge based on **simulations only**, thus detailed analysis and iteration required during early operation

• **Important uncertainties** due to assumptions going into loss terms (real integrated luminosity, distribution of losses, ...)

• **Priorities** assigned during 2008 according to
  – system sensitivity and criticality
  – uncertainty of loss assumptions (*e.g.*, UJ76)
  – possible short-term measures (*e.g.*, UA63/67)

• **Continuous evaluation – Prioritization (colour coding)**
  - Ongoing work during this shutdown
  - Highest priority for upcoming iterations/evaluations
  - Second priority, cross-check with measurements
  - Lowest priority, layout check and evaluation

• **Other color codes:**
  - areas which require additional calculations
  - analysis to be done
# Radiation Levels - Summary - Prioritized

**!!! Simulations Only !!!**

**!!! Loss Assumptions !!!**

<table>
<thead>
<tr>
<th>LHC Point</th>
<th>Area(s)</th>
<th>Radiation Levels</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Point 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UJ14, UJ16</td>
<td></td>
<td>1E9-1.1E10, 1.1E10-1.1E11, 1. - 10.</td>
<td>2</td>
</tr>
<tr>
<td>RR13, RR17</td>
<td></td>
<td>3E7-9E7, 1.5E8-4.5E8, 0.01-0.2</td>
<td>2</td>
</tr>
<tr>
<td>US15, USA15</td>
<td></td>
<td>1E6-1E7, 0.001-0.02</td>
<td>4</td>
</tr>
<tr>
<td><strong>Point 2</strong></td>
<td>UX25</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>US25</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td><strong>Point 3</strong></td>
<td>UJ33</td>
<td>1E4-2E6, 5E4-7E6, 1E-6-1E-3</td>
<td>4</td>
</tr>
<tr>
<td>UJ32</td>
<td>1E7-1E8, 1E8-1E9, &lt; 0.01</td>
<td>3</td>
<td>1.65E11m-1y-1, Beam-gas, very conservative beam-gas assumptions</td>
</tr>
<tr>
<td>RE38</td>
<td>2E5-1E7, 1E6-5E7, 5E-5-1E-3</td>
<td>3</td>
<td>1.65E11m-1y-1, Beam-gas, very conservative beam-gas assumptions</td>
</tr>
<tr>
<td><strong>Point 4</strong></td>
<td>UX45</td>
<td>5.0E+06, 1.5E+07</td>
<td>3</td>
</tr>
<tr>
<td><strong>Point 5</strong></td>
<td>UJ56</td>
<td>1E9-1.1E10, 1.1E10-1.1E11, 1. - 10.</td>
<td>2</td>
</tr>
<tr>
<td>RR53, RR57</td>
<td>3E7-9E7, 1.5E8-4.5E8, 0.01-0.2</td>
<td>2</td>
<td>70 fb-1, Luminosity, Beam-gas, full shielding assumed in calculations (last phase as in ECR)</td>
</tr>
</tbody>
</table>
## Radiation Levels - Summary - Prioritized

!!! Simulations Only !!!

!!! Loss Assumptions !!!

<table>
<thead>
<tr>
<th>LHC Point</th>
<th>Area(s)</th>
<th>Radiation Levels</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point 6</td>
<td>UA63</td>
<td>1E6-1E9</td>
<td>1E7-1E10</td>
</tr>
<tr>
<td></td>
<td>UA67</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UD62</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UD68</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>US65</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UX65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point 7</td>
<td>UJ76</td>
<td>1E7-1E9</td>
<td>5E7-5E9</td>
</tr>
<tr>
<td></td>
<td>RR73</td>
<td>1E7-1E8</td>
<td>5E7-5E8</td>
</tr>
<tr>
<td></td>
<td>RR77</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TZ76</td>
<td>&lt;1E8</td>
<td></td>
</tr>
<tr>
<td>Point 8</td>
<td>UX85b</td>
<td>5E8-2E9</td>
<td>1E9-1E10</td>
</tr>
<tr>
<td></td>
<td>US85</td>
<td>5E7-5E8</td>
<td>2E8-2E9</td>
</tr>
<tr>
<td>T12</td>
<td>UJ23</td>
<td>&gt;5E9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UA23</td>
<td>&lt;7E8</td>
<td></td>
</tr>
<tr>
<td>I18</td>
<td>UJ87</td>
<td>&gt;5E9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UA87</td>
<td>&lt;7E8</td>
<td></td>
</tr>
<tr>
<td>ALL</td>
<td>ARC</td>
<td>1E9-5E12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>REs</td>
<td>2E5-1E7</td>
<td>1E6-5E7</td>
</tr>
<tr>
<td></td>
<td>DS</td>
<td>1E9-5E12</td>
<td></td>
</tr>
</tbody>
</table>
Radiation Levels – Evolution

!!! Simulations Only !!!

!!! Loss Assumptions !!!

Needed Type of Electronics:

- SPECIAL DESIGN
- WELL TESTED
- TESTED COTS

High Energy Hadron Fluence ("20MeV") / [cm⁻² y⁻¹]

- UJ14, UJ16, UJ56
- RR13, RR17, RR53, RR57
- UJ33
- UJ76 (work ongoing)
- RR73, RR77 (work ongoing)
- RE38
- UX45
- UA63, UA67 (cons.!!!, work ong.)
- UA23, UA87 (prel.)
- UJ32
- UX85b (work ongoing)
- US85 (next iteration)

[Loss/Intensity-Scaling: M. Lamont]
Equipment Criticality Levels

Suggested colour coding according to equipment classes and respective implications:

- 1. Machine Safety Control
  - Beam Interlock System (BIC)
  - Damage related sub-systems (PIC, WIC, FMCM, BDS,...)

- 1.b. Systems whose input is important to assure machine protection
  - e.g., BLM

- 2. Systems whose dis-functionality leads to downtime or localized damage only
  - e.g., Power Converters, BTV

- 3. Impact on Beam Quality
  - e.g., Vacuum

- 4. Monitoring mainly
  - e.g., RAMSES (tunnel monitors)
Application to Machine Protection

Beam Interlock System

- Safe Beam Parameter Distribution
- LHC Devices
- Movable Detectors
- Beam Loss Monitors BCM
- Experimental Magnets
- Collimator Positions
- Environmental parameters
- Safe LHC Parameter
- Software Interlocks
- Sequencer
- Operator Buttons CCC
- LHC Experiments
- Transverse Feedback
- Beam Aperture Kickers
- Collimation System
- Special-BLMs
- Beam Dumping System
- Injection Interlock
- Timing System (Post Mortem Trigger)

- Powering Interlocks sc magnets
- Powering Interlocks nc magnets
- Magnet Current Monitor
- RF System
- Beam loss monitors BLM
- Beam Lifetime FBCM
- Access System
- Vacuum System
- Screens / Mirrors BTV

- Magnets
- Power Converters
- Monitors aperture limits (some 100)
- Monitors in arcs (several 1000)

- QPS (several 1000)
- Power Converters ~1500
- AUG
- UPS
- Cryo
- OK

- Doors
- EIS
- Vacuum valves
- Access Safety Blocks
- RF Stoppers

© R. Schmidt

4/2/2009

R2E Taskforce - Impacts of SEUs
What Sits Where – Critical?

Beam Interlock System

- Safe Beam Parameter Distribution
- LHC Devices
- Movable Detectors
- Beam Loss Monitors BCM
- Experimental Magnets
- Collimator Positions
- Environmental parameters

- Safe LHC Parameters
- Software Interlocks
- Sequencer
- Operator Buttons CCC

- Powering Interlocks sc magnets
- Powering Interlocks nc magnets
- Magnet CurrentMonitor
- RF System
- Beam loss monitors BLM
- Beam Lifetime FBCM
- Access System
- Vacuum System
- Screens / Mirrors BTV

- Monitors aperture limits (some 100)
- Monitors in arcs (several 1000)

- Screens
- Doors
- EIS
- Vacuum valves
- Access Safety Blocks
- RF Stoppers

[J. Uythoven]
- UA63 & UA67
- Ducts will be filled

© R. Schmidt
What Sits Where – Critical?

[J. Lendaro]
- TZ76, UJ33 -> ok
- UA23, 87 -> to be checked
- UJ14, UJ16, UJ56 -> problematic!

Beam Interlock System

Powering Interlocks sc magnets
Powering Interlocks nc magnets
Magnet Current Monitor
RF System
Beam loss monitors BLM
Beam Lifetime FBCM
Access System
Vacuum System
Screens / Mirrors BTV

Monitors aperture limits (some 100)
Monitors in arcs (several 1000)

Magnet
Power Converters

QPS (several 1000)
Power Converters ~1500
AUG
UPS
Cryo
OK

Doors
EIS
Vacuum valves
Access Safety Blocks
RF Stoppers

© R. Schmidt
What Sits Where – Critical?

- Beam Interlock System
  - Safe Beam Parameter Distribution
  - LHC Devices
  - Movable Detectors
  - Beam Loss Monitors BCM
  - Experimental Magnets
  - Collimator Positions
  - Environmental parameters

- Experimental Magnets
  - Collimator Positions

- Beam Interlock System
  - Safe LHC Parameter
  - Software Interlocks
  - Sequencer
  - Operator Buttons CCC
  - LHC Experiments
  - Transverse Feedback
  - Beam Aperture Kickers
  - Collimation System

- Powering Interlocks
  - sc magnets
  - nc magnets
  - Magnet Current Monitor

- Magnets
  - Power Converters

- Powering Interlocks
  - (several 1000)
  - Power Converters ~1500
  - AUG
  - UPS
  - Cryo OK

- Monitors aperture limits (some 100)
- Monitors in arcs (several 1000)

- Beam Dumping System
  - Special-BLMs
  - Injection Interlock
  - Timing System (Post Mortem Trigger)

- Doors
- EIS
- Vacuum valves
- Access Safety Blocks
- RF Stoppers

[M. Zerlauth]
- Surface, UAs, TZ76 -> ok
- UJ56 -> system redundancy ok, to be reviewed in terms of relocation

© R. Schmidt

4/2/2009 15R2E Taskforce - Impacts of SEUs
What Sits Where – Critical?

- Safe Beam Parameter Distribution
- LHC Devices
- Movable Detectors
- Beam Loss Monitors BCM
- Experimental Magnets
- Collimator Positions
- Environmental parameters
- Experimental Magnets
- Collimator Positions
- Environmental parameters
- Safe Beam Parameter Distribution
- LHC Devices
- Movable Detectors
- Beam Loss Monitors BCM
- Experimental Magnets
- Collimator Positions
- Environmental parameters
- Experimental Magnets
- Collimator Positions
- Environmental parameters

[ J. C. Billy ]
- all REs -> ok
- even points: UAs -> ok
- odd points: US15, UJ33, USC151 -> ok
- UJ76 -> solution foreseen

© R. Schmidt

4/2/2009
R2E Taskforce - Impacts of SEUs
Machine Protection

[R. Schmidt, M. Zerlauth]

- **Machine protection control** equipment doesn’t rely on standard communication – **hard links used where required**
- Electronics racks (controllers) are installed in **surface areas** and **certain underground areas** (UAs, USs, TZ76 and UJ56)
- One current concern is the BIC rack located in the **UJ56** (BIC, FMCM,...) where important radiation levels are expected (luminosity driven)
  - the design is redundant (fail safe except both units would fail at the same time), thus no direct impact on machine safety (dump would occur)
- The others are considered as radiation safe, with two ‘reminders’
  - **UA63/67**: ducts to be filled (this shutdown) thus maximum radiation levels substantially reduced
  - **UJ-UA23/87**: equipment close to UJs (e.g., access control rack), no early problem expected, possible impact due to injections on TED to be verified
- **protection control equipment** installed in the tunnel (e.g., interfaces) were tested and showed high radiation resistance
Machine Protection

• Further concern: **collimation racks** (for TCTs, TCLPs) in **UJ14/16 and UJ56**: options to be studied

• A closer look to what is in the UA:  
  – control of TCDQ position: **additional redundancy added**, will work similar as the BETS [see talk J. Uythoven]
  – BETS: problem with beam energy would lead to possible worst case accident, **sufficient redundancy**
  – Extraction kicker switches will be checked during operation, no problem expected for the UAs

• Energy extraction 13kA **switches**  
  [A. Vergara]
  – Located at some points, RRs, UAs (1st floor)
  – radiation levels in the RRs of IP1 and IP5 to be reviewed
  – more detailed analysis required

• Transfer line dump on downstream **TED**  
  [J. Uythoven]
  – UJ23/UA23, UJ87/UA87 radiation levels to be checked
  – general issue (not SEE): circulating LHC beam and affected BLM monitor

• Additional iterations ongoing through R2E/RadWG linked with MPWG
Recent Radiation Tests & Problems

Power Converters [Y. Thurel, Q. King]

- LHC60A-08V power part tests during 2008 were successful
- SEUs counted on FGC generic, auto-recovery worked
- FGC (special design) of the 60kA (network interface) failure is linked to the Xilinx CPLD, so far it can not be excluded that failure could also be non-radiation caused
- If radiation sensitivity is confirmed then ‘extended MicroFIP’ or similar solution possible for the LHC60A (within one year)
- For all designs, significant additional hardening possible already on software level
- Situation significantly more complicated (time required, costs) in case full redesign of convertors needed
  - Ok for 2009
  - Additional radiation tests (1 month) required at CNGS
Recent Radiation Tests & Problems

• New QPS devices to be installed in the tunnel (mid dipole only) [Reiner Denz]
  – tests with the presently installed QPS system were promising (no hardware failure, only software)
  – the new extended QPS device will be further modified
    • increased hardening concerning firmware (triple voting etc.)
    • power supplies (linear regulators etc.) including remote power cycle features
  – link to Field-bus: communication loss clears the ‘Power Permit’ condition for the corresponding circuit, i.e., an alarm is created, the run can continue but re-start is not possible anymore.
  – detection systems do not depend on the Field-bus communication with respect to detection/ protection
  – additional tests (March PSI, Summer CNGS)
    – Ok for 2009

• Solid state relays used for the HTS current lead heating system [Amalia Ballarino]
  – two different types were tested at CNGS and both failed after some days of operation -> analysis ongoing, no details yet
  – located in UJs, RRs (1st floor)
  – additional radiation tests foreseen in 2009
    – Ok for 2009

4/2/2009 R2E Taskforce - Impacts of SEUs
Implications on 2009 Operation

• Based on current knowledge: **no showstopper** for 2009 restart
• BIC (and collimation crates) in **UJ56** (also in UJ14/16) to be kept in mind
• Equipment and radiation levels in **US85** to be checked
• **Monitoring** of radiation levels, **evaluation** of loss assumptions and comparison with respective simulations
• **Iterations of areas/systems** to continue
  • Machine Protection related systems
  • R2E iterations scheduled for all areas (following the assigned priorities) before startup
  • Additional analysis required in case it’s decided to run through winter (possible short-term measures to be investigated)
• Additional **radiation tests** required (CNGS and elsewhere)
What we should do...

• **Review of areas**
  – scheduled Iterations: 1 every 4 weeks (R2E)
  – followed by a RadWG collecting detailed information of equipment/status/links/etc...
  – visits to be scheduled as from now
  – point owners collect/check global system information
  – integration drawings (racks, monitors,...)
  – review of monitor locations & settings
  – assignment of maximum fluence/dose values (based on simulations, scaling, applying uncertainties)

• **Data collection**
  – general document database [existing]
  – radiation levels & classifications (critical areas) [ongoing]
  – inventory of concerned equipment systems [missing]
    • Class
    • Racks
  – equipment details and inter-dependencies to be collected
    • *general problem not only for SEE* [missing]
  – consequences of equipment failure/malfunctioning [missing]
  – repair (replacement) implications [missing]
What else is needed...

• **Early ‘Learning’**
  – efficient Monitoring tool allowing for quick analysis during early operation (monitor locations, settings to be reviewed now!)
  – during start-up: concentrating on most important areas (UJ76, RR5, US85, UJ56,...)
  – Continued/additional simulation studies

• **Knowledge & Development**
  – improve exchange between experiments & machine
  – ‘SchoolDay’ to be organised

• **Radiation Tests & Facilities**
  – Coordinated radiation test campaigns (RadWG)
  – External facilities
  – New CERN facility?

• **Structure**
  – Organisational
  – Procedures
  – Supported (requested) by all concerned department & group leaders
1. **Policy** for Electronics installed in areas with elevated radiation levels (R2E)

2. **Evaluation** of Radiation Levels: simulations, monitoring, proposal of measures (R2E)

3. Structure to **implement** the Policy (RadWG)

4. **Radiation Tests** (RadWG)

5. **Control** (Point Owners)
Conclusions

• No imminent SEE related machine protection problems expected (identified so far!) during 2009 operation
• Concerns discovered for early operation - BIC and collimation racks installed in UJ56 (UJ14, 16)
• Further important impacts on operation to be expected (as soon as intensity/losses go up)
• Continuously updated priority list presented
• Weak links & Redundancy: information difficult to access
  – more detailed inventory needed on the mid/long-term
  – equipment classes, evaluations to be added first
• Related short & medium term actions discussed
• R2E approach presented:
  – iterations to tackle existing installations
  – evaluation/selection of implementations
  – mid/long-term structure proposed
Conclusions

• R2E objectives for 2009

  – Detailed review of areas
    (one by one, bi-weekly/monthly schedule)
  – Monitoring tool
    (required for efficient analysis of early operation)
  – Review of monitor locations and setting
  – Definition of Maximum Radiation Levels
    (per area, and ‘operational year’)
  – Additional simulation studies of areas
  – Organization of ‘SchoolDay’ for electronics installed in radiation areas
  – Definition of electronics policy for underground areas with radiation
  – Evaluation/Monitoring during start-up
  – Proposal of 2009/2010 shutdown activities
Backup
R2E Website & Related Database

- https://ab-div.web.cern.ch/ab-div/Meetings/r2e/
Monitoring Tool

• Important to efficiently understand radiation levels during early operation
• Collection of available monitor data, units, storage & access details
  – prepared ‘Definition Document’
• A staged implementation is followed starting from the simple and core objectives
  – post-mortem analysis
  – selection of available monitor data by area(s)
  – interface to existing logging tool (Timber, and other DBs not accessible through Timber) in order to obtain relevant data-files
  – unit conversion when available/needed
  – link to technical drawings for visualized monitor locations (where available)
• Important ingredients & first implementation
  – monitor inventory & locations updated/entered into LHC Reference Database
    • http://layout.web.cern.ch/layout/search.aspx
    • Radmon, BLM, RAMSES, BCM, ...
  – detector locations further put into technical drawings
Policy & Procedures
What Experiments Where Doing

• Radiation Tolerance Documents kept in dedicated Data Base
• Policy for Electronics Design to be installed in Radiation Areas
• All electronic systems are required to provide detailed information
  – General Information
  – Technical Data Sheet
  – Radiation Test Report
  – For COTS components data sheet from the manufacturer, as well as chosen approach (e.g., redundancy)
  – For ASICs, FPGAs datasheets/details from the collaboration author are required
• To be installed components go through a coordinator and/or respective working group
• Installation in underground areas only with approved permit (‘plaquette could be a nice idea’)
• Has to be top-down, department/groups to agree on procedure
Knowledge & Development

• R2E ‘SchoolDay’
  – jointly organised: PH/ESE – EN/STI – BE - ...
  – Combined Experiments/Machine lectures based on radiation to electronics related experience, development and solutions
  – Organised on 1-Day Basis outside CERN (no WiFi!)
  – Focused on one central subject
  – Participants: electronic developers, equipment designers (owners),... [restricted group]
  – 1\textsuperscript{st} Scheduled for
    • Theme: Design of electronics for radiation levels in the machine
    • Date: to be scheduled before summer
  – Possible repetition on various subjects
Radiation Test Requirements

• Need of irradiation facilities summarized in memo of ‘Working Group on Future Irradiation Facilities at CERN’ [15.12.2008]
  – http://www.cern.ch/irradiation-facilities

• Test facility for electronics is important part of it

• Partly required for existing equipment as amount of tests ideally to be performed would be both:
  – very costly if through external institutions
  – limited in terms of radiation field (mixed-field requirements)
  – too time consuming

• Certainly required for replacements and new developments

• Indispensable for all LHC upgrade related activities