Radiation Protection Aspects of the Commissioning and Operation of CERN High Energy Accelerator Mixed Field (CHARM) facility in the CERN East Experimental Area

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Description and Requirements

Construction

Radiation Protection Monitoring

Commissioning

Access Planning and Operational Dosimetry

Operation in 2015

CERN Shielding Benchmark Facility Upgrade
Motivation

- Objective of R2E project (Radiation2Electronics): \( \leq 0.5 \) dumps per fb\(^{-1}\)
- Radiation test for electronic equipment (power converters, electronic devices)
- CHARM project to provide test locations with well understood, typical mixed radiation fields (in addition to existing facilities CNGS, CERF, H4IRRAD, IRRAD)
- Space in CERN–PS East Experimental Hall available due to decommissioning of DIRAC experiment in 2013
- Design and construction during the Long Shut-down 1 (2013-2014)
Location
Parameters

- Proton beam from CERN–PS with 24 GeV/c on target
  - up to 5e11 protons/pulse
  - Pulse length 350 ms
- Three targets for CHARM to adjust intensity
  - Copper
  - Aluminum
  - Aluminum with longitudinal slits to reduce effective density
  - Diameter 8 cm, length 50 cm

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Number of spills per super-cycle (45.6 s)</th>
<th>Proton beam intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average</td>
</tr>
<tr>
<td>Nominal</td>
<td>2</td>
<td>2.2e10 p/s</td>
</tr>
<tr>
<td>Maximum</td>
<td>6</td>
<td>6.6e10 p/s</td>
</tr>
<tr>
<td>e-Cal</td>
<td>1</td>
<td>7.5e9 p/s</td>
</tr>
<tr>
<td>h-Cal</td>
<td>1</td>
<td>1.1e10 p/s</td>
</tr>
</tbody>
</table>
Integration – IRRAD & CHARM
Radiation Protection Assessment

- Radiation Protection Assessment during the design phase
  - Prompt radiation
  - Residual radiation
  - Air activation
  - Environmental impact
- presented at SATIF 12, 2014, Fermilab
Construction and Commissioning

- Construction in 2013-2014 during the Long Shut-down 1
- Close collaboration with integration team during the construction process
- Commissioning with tight cooperation of operation teams using a gradual approach
- Verification of shielding and residual ambient dose equivalent rates in dedicated measurement campaigns
CHARM Targets
Shielding Construction
Radiation Protection Monitoring

- AMF/AGM for prompt radiation
- IAM for residual radiation
- VMS for monitoring the release to the environment
- Mobile AMF/AGM during commissioning
- Supervision and data extraction/analysis via dedicated GUI
Radiation Protection Monitoring
Shielding with final RP Monitor placement
Commissioning without ventilation system

- Ventilation system had not been operational during start-up phase
  - No flush before access possible
  - No extraction during beam operations
    - Different build-up of the radionuclides (effective half-life changed)
- Reduction of average beam intensity or restriction on target choice as a function of the operation time to respect design constraint of $1 \mu$Sv committed effective dose due to inhalation for a 1 hour long access
Commissioning without ventilation system

Effective committed dose due to inhalation for 1 hour access - Irradiation with 2.2E10 p/s

- Cu Target / No cooling
- Cu Target / 1d cooling
- Al Target / No cooling
- Al Target / 1d cooling
- No Target / No cooling
- No Target / 1d cooling
Verification

- Permanently installed RP monitors
- Dedicated measurement campaigns including mobile RP monitors
- Comparison to Monte Carlo simulation results
Verification – Campaign 1
Verification – Campaign 2
Verification – Campaign 2
Verification – Campaign 3

Prompt Ambient Dose Equivalent Rate at 40 cm above top shielding

- Ambient Dose Equivalent Rate for $6.6 \times 10^9$ p/s ($\mu$Sv/h)
- Prompt Ambient Dose Equivalent Rate at 40 cm above top shielding
- Photon Measurement
- Neutron Measurement
- Total Measurement

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Verification – Induced Activation

- Residual ambient dose equivalent rates
  - Permanently installed RP monitors
  - Dose rate surveys
  - Measurement data collection for residual ambient dose equivalent rates benchmark (FLUKA/DORIAN) at the beginning of the winter technical stop 2015/16 (45 minutes up to 2 weeks)

- Activation samples
Access planning and operational dosimetry

- Procedure for target removal before access as a function of facility exploitation
- Flush by ventilation system before access
- Access planning and coordination is extremely important for efficient and optimized operation
- Operational dosimetry system linked with work planning tool and quick feed-back to guide optimization process
- Residual Radiation Survey

<table>
<thead>
<tr>
<th>Average Beam Intensity I (protons/h)</th>
<th>Required cool-down time before access</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Copper target</td>
</tr>
<tr>
<td></td>
<td>Mobile Shielding Retracted</td>
</tr>
<tr>
<td>I &lt; 9e13</td>
<td>3 hours</td>
</tr>
<tr>
<td>9e13 ≤ I &lt; 1.3e14</td>
<td>12 hours</td>
</tr>
<tr>
<td>1.3e14 ≤ I</td>
<td>24 hours</td>
</tr>
</tbody>
</table>
Residual Radiation Survey – Definition
Residual Radiation Survey – Example
Operation in 2015

- Operation period from April to November 2015
- Number of protons slightly below nominal design value
  - Beam attribution has been adapted for operation in 2016
- Air exchange rate of 6.7 volumes/hour

<table>
<thead>
<tr>
<th>Target type</th>
<th>Number of protons in 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum sieve</td>
<td>1.30e16</td>
</tr>
<tr>
<td>Aluminum</td>
<td>7.20e15</td>
</tr>
<tr>
<td>No target</td>
<td>2.38e14</td>
</tr>
<tr>
<td>Copper</td>
<td>2.71e17</td>
</tr>
</tbody>
</table>
Derived Design Goal on Air Tightness

![Graph showing the relationship between annual effective dose to members of the public (µSv/y) and air tightness (total air volumes per hour). The graph plots increasing dose with increasing air tightness.]
Effective dose to members of the public in 2015

- Airborne Release: 0.084 µSv/y
- Sky-shine 0.58 µSv/y
  - Calculations scaled by
    - number of protons per year
    - ratio of ambient dose equivalent rate on roof between measurements and FLUKA simulations
- Total 0.66 µSv/y
- Below design goal of 1 µSv/y

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Release Total (TBq/y)</th>
<th>Fraction</th>
<th>Eff. dose (µSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-11</td>
<td>0.33</td>
<td>0.14</td>
<td>0.017</td>
</tr>
<tr>
<td>N-13</td>
<td>0.79</td>
<td>0.35</td>
<td>0.030</td>
</tr>
<tr>
<td>O-14</td>
<td>0.08</td>
<td>0.04</td>
<td>0.002</td>
</tr>
<tr>
<td>O-15</td>
<td>0.99</td>
<td>0.44</td>
<td>0.013</td>
</tr>
<tr>
<td>Ar-41</td>
<td>0.06</td>
<td>0.03</td>
<td>0.005</td>
</tr>
<tr>
<td>Total predicted</td>
<td>2.28</td>
<td></td>
<td>0.075</td>
</tr>
<tr>
<td>Measured</td>
<td>2.54</td>
<td></td>
<td>0.084</td>
</tr>
</tbody>
</table>
CERN Shielding Benchmark Facility

- Combined facility of EN/EA, R2E and RP
- Characterization of the shielding properties of various materials
- Deep shielding penetration studies
- Detector calibration
- Detector inter-comparison
- Activation benchmarks
  - see presentation by E. Iliopoulou et al. on Wednesday
- Situated laterally above the CHARM target
  - Dedicated use for 1 week per year
  - Parasitic use of the radiation field emerging from the CHARM target during normal CHARM operation
CSBF Upgrade

Side View

Horizontal cut at 560cm height

Beam Target
Iron
Concrete
Marble

Shielding material test location block
Collimator filled by removable sample concrete block

Side Shielding for material test location block

Height (in addition to 120cm above floor level)
CSBF Upgrade

Side View
- Side Shielding for material test location block
- Shielding material test location block
- Collimator filled by removable sample concrete block
- Barite concrete

Top View
- Removable sample concrete block
- 10cm x 37cm
- 10cm x 10cm

Concrete
- 40cm
- 80cm
- 160cm
- 240cm
- 340cm
- 320cm
- 40cm

Iron
- 40cm

Marble
- 120 cm
- 240cm
- 320cm
- 40cm

Beams
Target

Height (in addition to 120cm above floor level)
CSBF Upgrade
CSBF Upgrade
CSBF Upgrade
CSBF Upgrade
Conclusions

- CHARM facility has been constructed and commissioned in 2014
- Shielding design, residual dose rate and air activation estimates have been verified
- CHARM (and IRRAD) fully operational for their design limits since December 2014
- Optimization for operational exploitation well advanced
- CERN Shielding Benchmark Facility upgraded in 2016
- On the agenda
  - Evaluation of CSBF run in 2016 and planning for 2017
  - Evaluation of residual dose rate benchmark data
Acknowledgments

- Experimental Area group
- Integration team
- IRRAD & CHARM operation teams
- Transport group
- Gamma spectrometry laboratory
Thank you for your attention!
Backup
<table>
<thead>
<tr>
<th>Description</th>
<th>Construction</th>
<th>RP Monitoring</th>
<th>Commissioning</th>
<th>Access</th>
<th>Operation 2015</th>
<th>CSBF Upgrade</th>
</tr>
</thead>
</table>

CSBF Upgrade

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RP Aspects CHARM Commissioning & Operations
CSBF Upgrade
CSBF Upgrade
CSBF Upgrade
CSBF Upgrade
CSBF Upgrade
Prompt Radiation – Design Goals

- **Area Classification:**
  - $3 \mu Sv/h$ (control rooms) or $15 \mu Sv/h$ (low occupancy area) at 40 cm outside from shielding walls for maximum average beam intensity
  - $2.5 \mu Sv/h$ outside of the hall for maximum average beam intensity
  - Optimization of shielding passages (Access chicanes, ventilation ducts, cable ducts)

- **Sky-shine:** $1 \mu Sv/y$ to members of the public (reference group) for nominal/maximum annual protons on target

- **Monitoring:** Define locations for area monitors

- **Shielding design:**
  - Re-use of existing concrete and iron blocks
  - Space constraints due to already existing facilities/crane

- **Monte Carlo simulations:** performed with **FLUKA**
  - Configuration management and synchronization with CAD integration model
Sky-shine
Sky-shine – Annual effective dose to members of the public

![Graph showing annual effective dose to members of the public for 3.3E17 p/y (µSv/y) versus distance from CHARM facility (m). The graph indicates a decreasing dose with increasing distance, with a value of 1.25 µSv/y at 1.25 m.](image)

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Residual Radiation – Design Goals

• Reduce ambient residual radiation
  • Optimization (ALARA)
  • More efficient exploitation of facility

• Marble cover for some wall parts and ceiling

• Target alcove
  • Target moved to alcove during access
  • Movable marble shielding to close alcove

• Studies for different shielding configurations to optimize procedures

• 100 $\mu$Sv/h for the Patch Panel area (most frequent access)

• Monte Carlo simulations: performed with FLUKA and DORIAN code
Residual DR after 200 days with 6.6E10 p/s and 1d of cool–down
Air Activation – Methodology

• Design goals
  1. Committed effective dose due to inhalation:
     \[ \leq 1 \mu Sv \text{ for 1 hour access} \]
  2. Effective dose to members of the public (reference group):
     \[ \leq 1 \mu Sv/y \]

• Radionuclide concentrations and release
  • Track-length spectra scored in air volumes
  • Radionuclide production yields by weighting of spectra with dedicated air activation cross-sections
  • Confinement characteristics (dynamic/static) and time evolution to obtain radionuclide concentrations
  • No filtering of the recirculated air has been taken into account
  • External effective dose and the internal committed effective dose by integrating over the 1 hour exposure time after a cool-down period of 30 minutes without flush before access
  • External effective dose to members of the public by dedicated Monte Carlo integration program (EDARA)
Air Activation – Access

East Area - Dynamic confinement

Dose for 1 hour access without flush (µSv)

- External
- Internal

- H-3
- Be-7
- Be-10
- C-11
- C-14
- N-13
- O-14
- O-15
- F-18
- Na-22
- Na-24
- Mg-27
- Mg-28
- Al-26
- Al-28
- Si-31
- Si-32
- P-32
- P-33
- S-35
- Cl-36
- Cl-38
- Cl-39
- Ar-37
- Ar-39
- Ar-41
- K-38
- K-40

Internal/External

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Air Activation – Access

East Area - Static confinement

Dose for 1 hour access without flush (µSv)

- External
- Internal

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RP Aspects CHARM Commissioning & Operations