FLUKA STUDIES OF DOSE RATES IN THE ATLAS STANDARD OPENING SCENARIO

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Motivation

• An extended period without beams in the Large Hadron Collider (LHC) at CERN is scheduled for 2024-2025. This stop in operations, known as Long Shutdown 3 (LS3), is required for the experiments, as well as the accelerator, to perform crucial consolidation and upgrade tasks.

• In particular, the ATLAS Inner Detector (ID) will be decommissioned and replaced by a new tracking system (ITk), allowing the experiment to collect 4000/fb.

• Given the location of the inner detector with respect to the beam pipe and the expected integrated luminosity up to LS3 of 300/fb, a detailed radiological assessment of the scheduled work is needed.
Aim

- Study using the Monte-Carlo particle transport code FLUKA version 2011.2c.5 and DPMJET-III:
  - The ambient dose equivalent rates in the ATLAS experimental cavern during future LS.
  - Estimate the expected radiation levels at the ITk during the High Luminosity LHC shutdown periods.

- Consider the detector configuration changes with the toolkit SESAME:
  - Various detector elements will be removed or displaced during LS, YETS or EYETS (Extended Year End Technical Stop) to facilitate the interventions.
  - This variation of detector geometry strongly influences the results of the simulation and needs to be taken into account.

1 $\mu$Sv = 0.1 mrem
Method: SESAME

- Simulating prompt radiation in the closed geometry, storing the nuclides produced on a file.
- Letting these nuclides decay in the open geometry after some transformations/displacements.
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SESAME prompt step

- The geometry corresponds to the operational closed scenario.
- The source is a $2 \times 7$ TeV colliding proton beam (half-crossing angle of 142.5 µrad). The total number of simulated proton collisions is 187 000.
- The magnetic field is switched on.
- The FLUKA physics parameters are the standard for activation studies:
  - The EM shower is off cause it is not particularly relevant for creation of isotopes and it is very time consuming.
- The information of the nuclides is stored with the SESAME routines in a binary file.
SESAME decay step

- The geometry is remodelled to match the standard opening scenario.
- The source consists of loading the information from the modified binary file with the nuclide information, where:
  - The nuclides belonging to regions that are transformed, change their position accordingly.
  - The nuclides from regions that are removed, are also removed.
  - The nuclides created in air, are discarded as the air is continuously flushed with fresh air during shutdown periods.
- The magnetic field is turned off.
- The EM shower is now on.
- Usual particle thresholds:
  - All particles thresholds set to 100 keV.
  - Low energy neutrons in 260 groups from 0.01 meV to 20 MeV.
  - EM shower cuts for transport and production of electrons: 50 keV, and gammas: 10 keV.
**SESAME decay step**

- The decay of the nuclides is scaled according to the irradiation profile provided by the Technical Coordinator of ATLAS (ultimate scenario estimates, August 2016).
  - Ion runs can be judged as cooling times due to their small impact in the activation.
  - A 75% of peak luminosity levelling is considered up to LS3.

  - The proton-proton inelastic total cross section is of 75 mb up to LS1 and 80 mb afterwards.
  - The irradiation is supposed to be delivered at the end of the proton run schedule, at the maximum luminosity (conservative scenario).
  - The ambient dose equivalent is scored in the region of interest:
    - $0 \leq R \leq 1500$ (150 bins).
    - $0 \leq \varphi \leq 2\pi$ (1 bin).
    - $0 \leq Z \leq 2500$ (250 bins).
Some regions materials are set to vacuum for decay purposes, to simulate different contributions from the components that are displaced.

Multiple runs: Sum up the scorings (after displacement).
FLUKA 1-step

• There is only one geometry: the closed scenario.
• The source is a $2 \times 7$ TeV colliding proton beam (half-crossing angle of 142.5 µrad). The total number of simulated proton collisions is 25 000 (6 times).
• One run per component (prompt and decay in a single step).
• The magnetic field is turned on in the prompt and off in the decay.
• The same physics cards than in the prompt step in the SESAME approach, but the EM shower is now on.
• Usual particle thresholds as from the decay step in the SESAME approach.
• The region of interest is extended to avoid artefacts in the superposition afterwards.
Comparison: SESAME vs. FLUKA 1-step

1. p-p collision
2. Creation of new particles
3. Propagation in the closed geometry
4. Activation in the material
5. Residual nuclides decay in the open geometry (transformation)
6. Scoring in the region of interest

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Comparison: SESAME vs. FLUKA 1-step

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4. Activation in the material
5. Residual nuclides decay with some materials set to vacuum in the closed scenario
6. Post-process contributions in an extended region of interest (transformation)
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VS.

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Comparison: SESAME vs. FLUKA 1-step

- General overestimation in FLUKA 1-step method for open geometries.

- Shielding effect in SESAME scheme for open geometries.

LS4 (28 days)
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LS4 (181 days)
2016 (28 days)

- 28 days of cooling time after the proton run:
  - At a radial distance of around 1-2 m from the beam line, it can be considered as controlled radiation area.
  - The remaining cavern is considered as supervised radiation area.
  - In order to mitigate the radioactive risk, and also to address any operational problems encountered near the beam pipe, a temporary shielding can also be placed.
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Results

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[Graph showing radiation levels with annotations]

- 14 TeV pp ATLAS Standard Opening Res. Dose Rate | 2010-2039, 4317 fb⁻¹ total

- Area up to 0.5 μSv/h
- Supervised radiation area (3 μSv/h)
- Simple controlled radiation area (10 μSv/h)
Benchmark

- Comparison of measurements taken in 2016 YETS.
- Good agreement but the underestimation might be due to some material missing in the FLUKA geometry description (ID and flanges).
Conclusions

• The SESAME approach is better as:
  o It still relies on FLUKA, it only provides tools to run the simulation.
  o It is not straightforward to transform and combine the scorings in case of rotations in the FLUKA 1-step, and also precision error can arise because of the displacements and the bin width mismatch.
  o It avoids the repetition of the nuclide production, that has to be done only once per closed geometry, and is very time consuming.
  o The results are validated according to some measurements taken in 2016 YETS.
  o The radiation field is more realistically described in the open scenario. Shielding regions can easily be added and the replacement of components can be considered faster.
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