

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
Laboratoire Européen pour la Physique des Particules
European Laboratory for Particle Physics

Occupational Health & Safety and Environmental Protection Unit

Summer Student Report
16 August 2019

Measurements and FLUKA simulations of aluminium, copper and steel activation at the CERN High energy AcceleRator Mixed field facility (CHARM)

A. Mufazalova Supervisor: E. Iliopoulou

Summary

As summer student at CERN, I have been working in the Radiation Protection group for 8 weeks. I worked with the FLUKA Monte Carlo simulation code using the Flair interface. The primary task of my project was to perform benchmark studies for the FLUKA code at the CHARM facility in the CERN East Experimental Area.

This task consisted of analyzing data taken in previous years, notably beam intensity related data for the dedicated operation of the CERN High energy AcceleRator Mixed field facility (CHARM) and also comparison with simulation data from FLUKA.

1 Introduction

The CERN High energy AcceleRator Mixed field facility (denoted CHARM) has been constructed in the CERN Proton Synchrotron (PS) East Experimental Area in 2014 to study radiation effects on electronic components. The facility receives a pulsed proton beam from CERN PS with a beam momentum of 24 GeV/c with $5{\cdot}10^{11}$ protons per pulse [1]. The maximum beam intensity is $6.6{\cdot}10^{10}$ p/s and the nominal beam intensity is $2.2 \cdot 10^{10}$ p/s [2, 3, 4].

Activation samples of aluminium, copper, steel and stainless steel were placed in the CHARM facility in September 2015. Monte Carlo simulations with the FLUKA code have been performed to estimate the activity for these samples.

This document describes the comparison between the estimated activity values from FLUKA and the activation of these samples placed in the CHARM facility measured by γ-spectrometry.

2 FLUKA Simulations and Measurements

An activation test was conducted by Radiaction Protection Group on the 9th of September in 2015. Four samples were irradiated at the CHARM facility for 1 week and measured by γ-spectrometry after 9 days of cooling. The samples were made from copper, aluminium, steel and stainless steel. The basic properties of the samples are listed in table 1.

Material	Maximum weight fraction (%)	Dimension (mm^3)	Mass (g)
aluminum 6060	Al, 97.94	50x50x5	25
copper ETP	Cu, 99.84	50x50x4	100
FE360C	Fe, 98.47	50x50x5	102
ST304	Fe, 63.35	50x50x6	120
	Cr, 24.43		

Table 1: Properties of the samples being irradiated at CHARM [5].

The proton beam from PS impacts on the CHARM target and produces a shower of particles which irradiates the samples. The prompt radiation for nominal beam intensity ($2.2 \cdot 10^{10}$ p/s) at CHARM is presented in figure 1.

FLUKA was used for the simulation of fluence of different particles. The FLUKA code is a Monte-Carlo simulation tool for the interaction and transport of particles and nuclei in matter. The simulation results were obtained by scoring the protons, neutrons, pions (positive and negative) and photons fluences spectra in activation sample volumes with FLUKA [6, 7]. The neutrons, pions, protons and photons fluence spectra for air and samples is presented in figures 2 – 3.

The fluence spectra that were obtained by FLUKA in air were then inserted in the ActiWiz3-Creator program where the given fluences from FLUKA were weighted with energy and particle type dependent nuclide production yields for the elements in the compound and summed up according to the abundances of the elements in the compound.

In the next step, ActiWiz applies the Bateman solution on each isotope by considering the irradiation and cooling pattern that was used for this experiment. The irradiation period was 7 days and was binned in 1 day long intervals taking also into account the 9 days cooling time. This provides the final activation results. The procedure of ActiWiz operation is described in detail in [8, 9, 10].

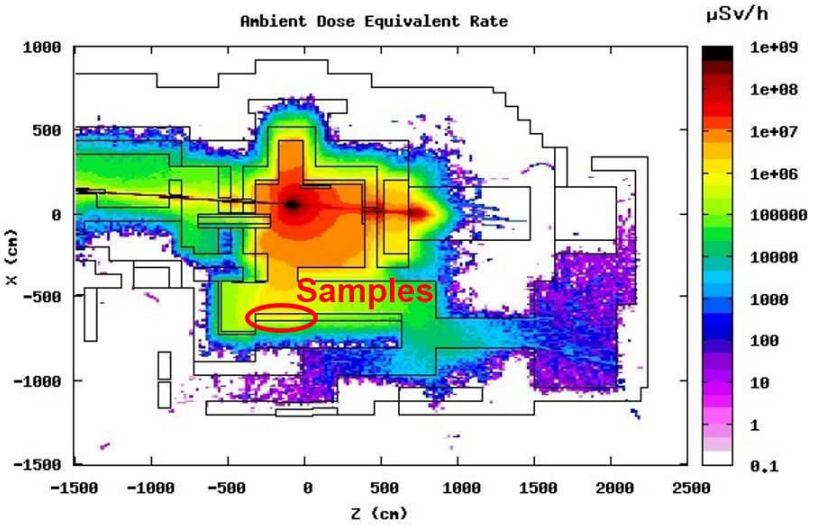


Figure 1: Prompt radiation at beam line level at CHARM for $2.2 \cdot 10^{10}$ p/s. The position of the samples is indicated in the red circle.

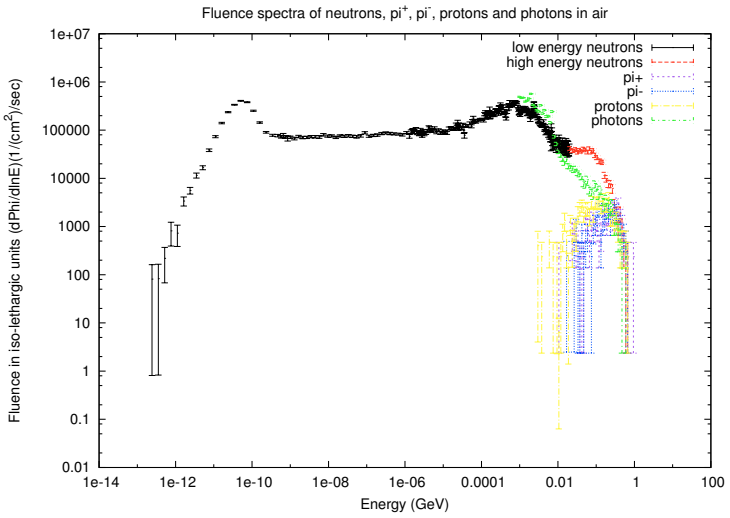


Figure 2: Fluence spectra for neutrons, pions, protons and photons predicted by FLUKA at the samples location.

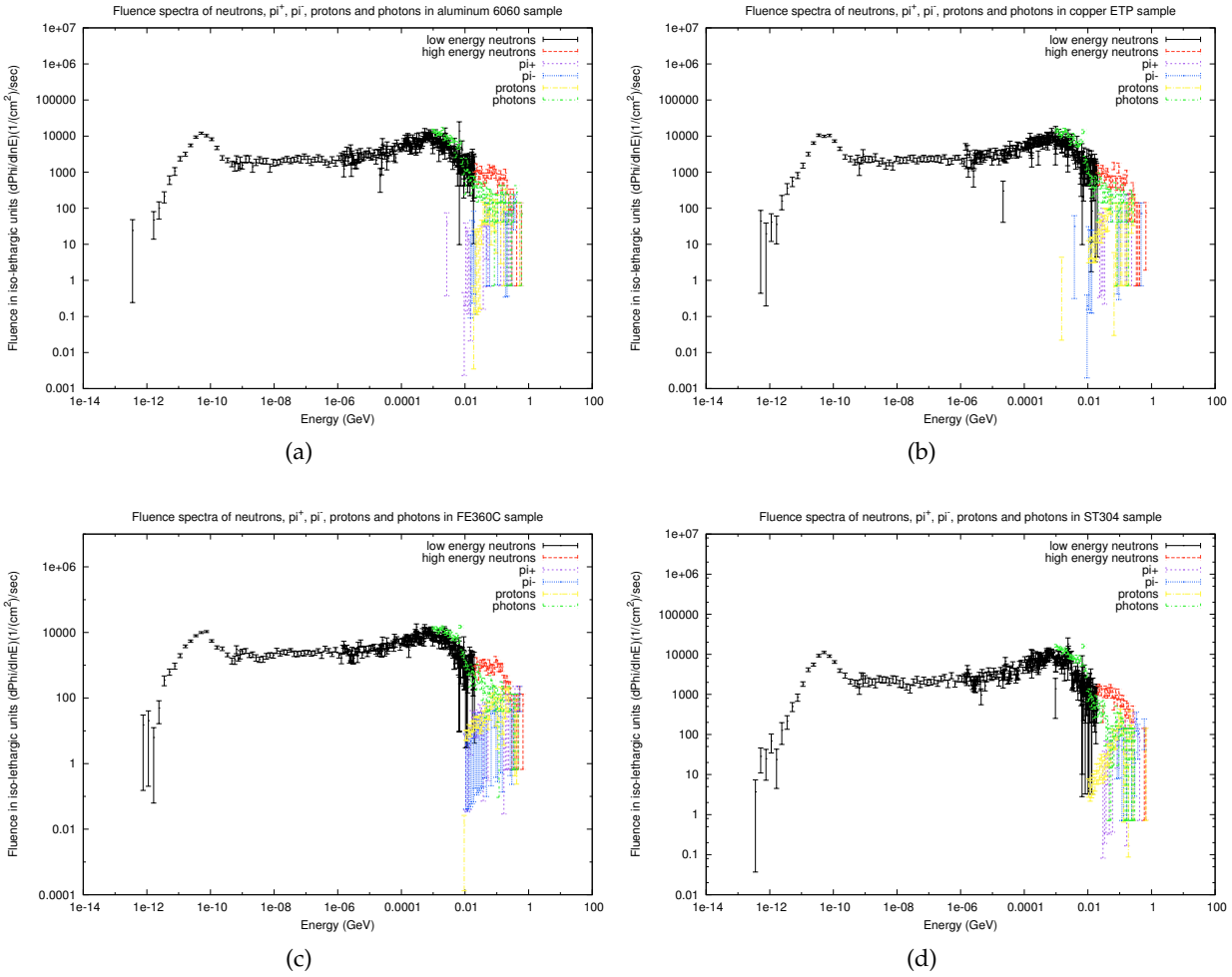


Figure 3: Fluence spectra for neutrons, pions, protons and photons predicted by FLUKA at the aluminum (a), copper (b), steel (c) and stainless steel (d) samples.

3 Results

The results are presented in tables 2- 5 and in figure 4 for all samples as ratios between predicted activities with FLUKA and ActiWiz calculations and the measured activities by γ-spectrometry for aluminium, copper, steel and stainless steel samples. The agreement between FLUKA and measurements is at a level of a factor of 2.

Radionuclide name	**Measured activity (Bq/g)**	**Predicted activity (Bq/g)**	**Ratio between predicted activity and measurememt**
Na-22	$0.21 \pm 16\%$	$0.10 \pm 8.9\%$	$0.49 \pm 18\%$

Table 2: Comparison between predicted activities and the γ-spectrometry measurements for aluminum 6060. Measured errors quoted at 1σ.

Radionuclide name	**Measured activity (Bq/g)**	**Predicted activity (Bq/g)**	**Ratio between predicted activity and measurememt**
Co-58	$1.90 \pm 5.3\%$	$2.15 \pm 5.6\%$	$1.14 \pm 7.8\%$
Cr-51	$0.62 \pm 17\%$	$0.40 \pm 14\%$	$0.62 \pm 23\%$
Co-57	$0.30 \pm 10\%$	$0.40 \pm 9.5\%$	$1.30 \pm 14\%$
Co-56	$0.21 \pm 7.0\%$	$0.27 \pm 11\%$	$1.30 \pm 13\%$
V-48	$0.13 \pm 8.4\%$	$0.17 \pm 21\%$	$1.30 \pm 22\%$
Mn-52	$0.23 \pm 5.2\%$	$0.15 \pm 16\%$	$0.65 \pm 17\%$
Fe-59	$0.18 \pm 12\%$	$0.10 \pm 9.0\%$	$0.51 \pm 15\%$
Mn-54	$0.095 \pm 13\%$	$0.089 \pm 12\%$	$0.94 \pm 18\%$
Co-60	$0.095 \pm 11\%$	$0.060 \pm 6.0\%$	$0.61 \pm 12\%$
Sc-47	$0.043 \pm 28\%$	$0.023 \pm 22\%$	$0.54 \pm 35\%$

Table 3: Comparison between predicted activities and the γ-spectrometry measurements for copper ETP. Measured errors quoted at 1σ.

Radionuclide name	**Measured activity (Bq/g)**	**Predicted activity (Bq/g)**	**Ratio between predicted activity and measurememt**
Cr-51	$5.0 \pm 8.3\%$	$6.5 \pm 6.6\%$	$1.3 \pm 11\%$
Fe-59	$1.3 \pm 3.7\%$	$2.5 \pm 3.4\%$	$1.8 \pm 5.0\%$
Mn-52	$1.8 \pm 2.7\%$	$2.3 \pm 8.6\%$	$1.2 \pm 9.0\%$
Mn-54	$2.0 \pm 5.1\%$	$2.2 \pm 6.9\%$	$1.1 \pm 8.6\%$
V-48	$1.1 \pm 3.3\%$	$1.6 \pm 11\%$	$1.5 \pm 12\%$
Co-60	$0.07 \pm 14\%$	$0.08 \pm 2.2\%$	$1.1 \pm 15\%$
Sc-44m	$0.08 \pm 22\%$	$0.07 \pm 17\%$	$0.9 \pm 27\%$
Sc-46	$0.088 \pm 13\%$	$0.094 \pm 9.5\%$	$1.1 \pm 16\%$
Sc-47	$0.13 \pm 16\%$	$0.10 \pm 13\%$	$0.73 \pm 21\%$
Sc-44	$0.04 \pm 29\%$	$0.07 \pm 17\%$	$1.75 \pm 33\%$
Co-58	$0.04 \pm 29\%$	$0.04 \pm 3.11\%$	$1.0 \pm 30\%$

Table 4: Comparison between predicted activities and the γ-spectrometry measurements for FE360C. Measured errors quoted at 1σ.

Radionuclide name	**Measured activity (Bq/g)**	**Predicted activity (Bq/g)**	**Ratio between predicted activity and measurememt**
Cr-51	$82 \pm 7.4\%$	$197 \pm 3.2\%$	$2.40 \pm 8.0\%$
Co-58	$2.60 \pm 5.9\%$	$3.70 \pm 3.5\%$	$1.50 \pm 6.9\%$
V-48	$1.50 \pm 4.3\%$	$2.50 \pm 7.0\%$	$1.60 \pm 8.2\%$
Co-60	$0.93 \pm 5.3\%$	$1.52 \pm 2.2\%$	$1.62 \pm 5.7\%$
Mn-52	$1.63 \pm 3.7\%$	$1.73 \pm 8.3\%$	$1.10 \pm 9.1\%$
Fe-59	$1.02 \pm 7.2\%$	$1.61 \pm 3.4\%$	$1.60 \pm 7.9\%$
Mn-54	$1.54 \pm 6.4\%$	$1.51 \pm 6.4\%$	$0.98 \pm 9.0\%$
Co-56	$0.36 \pm 9.2\%$	$0.55 \pm 20\%$	$1.55 \pm 22\%$
Sc-46	$0.20 \pm 13\%$	$0.19 \pm 5.5\%$	$0.93 \pm 14\%$
Sc-47	$0.33 \pm 21\%$	$0.23 \pm 7.6\%$	$0.70 \pm 22\%$
Co-57	$0.42 \pm 15\%$	$0.60 \pm 6.9\%$	$1.44 \pm 17\%$

Table 5: Comparison between predicted activities and the γ-spectrometry measurements for ST304. Measured errors quoted at 1σ.

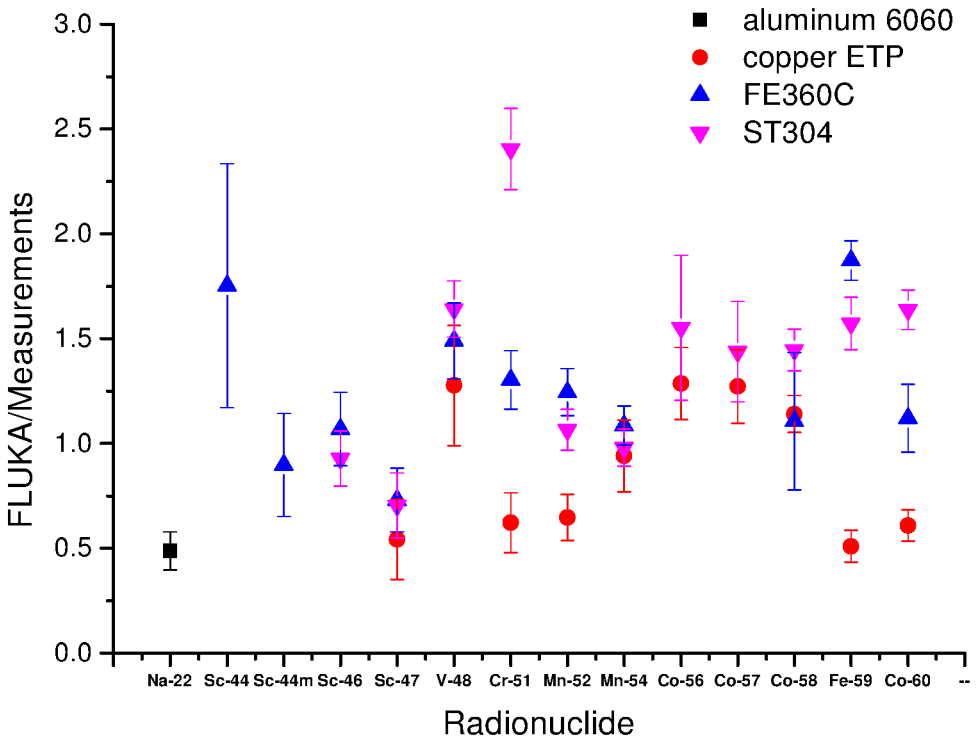


Figure 4: The ratio of predicted activities in the samples with FLUKA and the measured activities for aluminum, copper, steel and stainless steel samples.

4 Conclusions

An activation test has been conducted in September 2015 in the CHARM facility. Aluminium, copper, steel and stainless steel samples were placed on the wall of the CHARM facility access corridor. We wanted to benchmark FLUKA code at the CHARM facility, so for this reason I scored the fluence spectra at the sample location, in order to estimate the activities of the samples.

Then measured activities have been compared to these estimated values from FLUKA Monte Carlo simulations and ActiWiz3. The agreement is at a level of a factor of 2. This demonstrates that FLUKA is a very suitable tool for the simulation of the radiation field produced in the CHARM facility.

5 Acknowledgments

I would like to thank my supervisor E. Iliopoulou, R. Froeschl, R. Geyer and all the RP group for the support and communication. And also thanks to the Summer Student Programme team and Non Member States team for the best opportunity to be part of the CERN community.

References

[1] E. Iliopoulou, P.Bamidis, M. Brugger, R. Froeschl, A. Infantino, T. Kajimoto, N. Nakao, S. Roesler, T. Sanami, A. Siountas. *Measurments and FLUKA simulations of bismuth and aluminum activation at the CERN Shielding Benchmark Facility (CSBF). Nuclear Inst. And Methods in Physics Research*, pages 79–85, 2018.

[2] R. Froeschl. *Radiation Protection Assessment of the Proton Irradiation facility and the CHARM facility in the East Area*. Technical Report CERN–RP–2014–008–REPORTS–TN, EDMS 1355933, 2014.

[3] R. Froeschl, M. Brugger, S. Roesler. *The CERN High Energy Accelerator Mixed Field (CHARM) facility in the CERN PS East Experimental Area. Proceedings of SATIF12, NEA/NSC/R(2015)3, Batavia,Illinois, United States*, pages 14–25, 2014.

[4] R. Froeschl, E. Iliopoulou, M. Brugger, S. Roesler, F. Malacrida, M. Lazzaroni, J. Lendaro. *Radiation Protection Aspects of the Commissioning and Operation of the CHARM facility. Proceedings of SATIF 13, NEA/NSC/R(2018)2, Dresden, Germany*, pages 163–171, 2016.

[5] Doris Forkel-Wirth, Reiner Geyer, Chris Theis and Helmut Vincke. *Comparison of the radionuclide content of irradiated tesy samples with RAW/ActiWiz at Charm. Personal communication*, 2017.

[6] T.T. Bohlen et al. *The FLUKA Code: Developments and Challenges for High Energy and Medical Applications. Nuclear Data Sheets 120*, pages 212–214, 2014.

[7] A. Fassò, A. Ferrari, J. Ranft and P.R. Sala. *FLUKA: a multi-particle transport code*. Technical Report CERN-2005-10 (2005), INFN/TC-05/11, SLAC-R-773.

[8] C.Theis, H.Vincke. *ActiWiz 3- an overview of the concepts, architecture new features*. Technical Report CERN–RP–2016–117–REPORTS–TN, EDMS 1706010, 2016.

[9] C.Theis, H.Vincke. *Mass production of nuclide production data used in ActiWiz3 code*. Technical Report CERN–RP–2016–220–REPORTS–TN, EDMS 1761230, 2017.

[10] C.Theis, H.Vincke. *Implementation of an activation build-up and decay engine in ActiWiz*. Technical Report CERN–RP–2013–85–REPORTS–TN, EDMS 1312453, 2013.