Author(s): Gao, Zhihao; Solders, Andreas; Al-Adili, Ali; Cannarozzo, Simone; Lantz, Mattias; Penttilä, Heikki; Pomp, Stephan

Title: New design and simulation of the ion guide for neutron-induced fission products at the IGISOL facility

Year: 2023

Version: Published version

Please cite the original version:

Gao, Z., Solders, A., Al-Adili, A., Cannarozzo, S., Lantz, M., Penttilä, H., & Pomp, S. (2023). New design and simulation of the ion guide for neutron-induced fission products at the IGISOL facility. In C. M. Mattoon, R. Vogt, J. Escher, & I. Thompson (Eds.), ND 2022 : 15th International Conference on Nuclear Data for Science and Technology (284, Article 04011). EDP Sciences. EPJ Web of Conferences. https://doi.org/10.1051/epjconf/202328404011

EPJ Web of Conferences **284**, 04011 (2023)
ND2022
https://doi.org/10.1051/epjconf/202328404011

New design and simulation of the ion guide for neutron-induced fission products at the IGISOL facility

Zhihao Gao[1,*], *Andreas* Solders[1,**], *Ali* Al-Adili[1], *Simone* Cannarozzo[1], *Mattias* Lantz[1], *Heikki* Penttilä[2], *Stephan* Pomp[1], and *the IGISOL* team[2]

[1]Department of Physics and Astronomy, Uppsala University, BOX 516, 75120 Uppsala, Sweden
[2]Department of Physics, FI-40014 University of Jyväskylä, Finland

Abstract. Measurements of independent fission yield distributions in neutron-induced fission at high neutron energies are important for our fundamental understanding of the fission process, and are also relevant for reactor physics applications. So far, measurements of independent fission yields in proton-induced fission have been performed at the IGISOL facility at the University of Jyväskylä, using the Penning trap as a high resolving-power mass-filter. In order to also facilitate measurements of neutron-induced fission, a dedicated ion guide and a proton-to-neutron converter was developed. However, the first measurement indicates that fewer fission products than expected reach the Penning trap. To explore potential reasons and possible improvements, a simulation model was also developed and benchmarked. The benchmark showed that the model is able to reproduce the performance of the ion guide remarkably well and that the main reason for the low yield of fission products is the low collection efficiency of the ion guide.

Based on the benchmark, a new ion guide is being designed. In the new design, the positions of the uranium targets and volume of the ion guide have been changed to increase the collection of fission products. This results in a five-fold increase of the yield. However, the collection efficiency of the new ion guide still needs to be improved in order to achieve intensities of the extracted fission products that are large enough to allow for reasonable measurement times.

Because the volume of the ion guide is increased significantly, the extraction time of the ions is expected to be longer than that from the previous ion guide. Therefore, an electric field guidance system that consists of a combination of a stationary electric field and an RF-carpet is considered to be deployed. The stationary field, produced from a set of DC-ring electrodes, accelerates the ions towards the RF-carpet at end plate of the ion guide. The RF-carpet consists of a time-dependent field, produced from a radio-frequent structure of concentric rings, with a DC-component that guides the ions towards the exit hole in the center of the end plate. In this paper we present the current status of the simulations and design of the new ion guide.

1 Introduction

Independent fission yield distributions are a basic observable and are important in the understanding and modeling of the fission process. However, experimental data of complete independent yield distributions are scarce [1]. To facilitate measurements of the independent yields in neutron-induced fission at the Ion Guide Isotope Separator On-Line (IGISOL) facility, a proton-to-neutron converter (*pn*-converter) and a dedicated ion guide was developed and tested [2, 3]. In parallel, a multi-physics Monte Carlo simulation model for the ion guide was developed [4, 5] and benchmarked against γ-spectroscopy data [6]. According to the benchmark, only a small fraction of the fission products, about 0.9%, are stopped in the ion guide.

In the present work, with the aim of increasing the amount of extracted fission products, a new design of the ion guide is presented together with simulations of the system. The geometry of the ion guide, as well as the positions of the targets and the pressure and temperature of the helium gas, are different from those of the previous ion guide [6]. As the density of the helium gas is dependent on the temperature, the impact of the temperature on the collection efficiency is also studied.

To further increase the collection efficiency, as well as to reduce the extraction time of the fission products, an electric guidance system is implemented in the new design. This is inspired by the RF-system used in the CARIBU gas catcher [7] and the cryogenic stopping cell at GSI [8]. The guidance system, including a stationary electric field and a radio frequency field, has been calculated using the software COMSOL [9]. Under the electric guidance, trajectories of the charged ions in the ion guide are simulated with COMSOL. However, these simulations don't take the effect of the helium gas into account.

---

[*] e-mail: zhihao.gao@physics.uu.se
[**] e-mail: andreas.solders@physics.uu.se

2 New design and simulation

2.1 Simulation

Figure 1 shows an optional new design of the ion guide. In the simulation, the physics models and analysis procedures are the same as in the simulations of the previous ion guide [6]. However, in this new design, the diameter is increased from 60 mm to 250 mm and the length of the ion guide is increased from 70 mm to 300 mm. The dimensions are limited by the size of the IGISOL reaction chamber that is used to hold the ion guide. Two uranium targets of the same size as those used with the previous ion guide are used in the present simulation but their positions are changed in order to be closer to the *pn*-converter.

The pressure of the helium gas in the ion guide is reduced from 400 mbar to 150 mbar to eliminate the risk of sparking due to the electric field. The nominal temperature of the helium gas in the simulation is 260 K, which is considered the lowest temperature available without insulating the ion guide. To study the effect of the helium density on the stopping efficiency, different helium temperatures are compared. Results of the simulations with different parameters are presented in section 3.

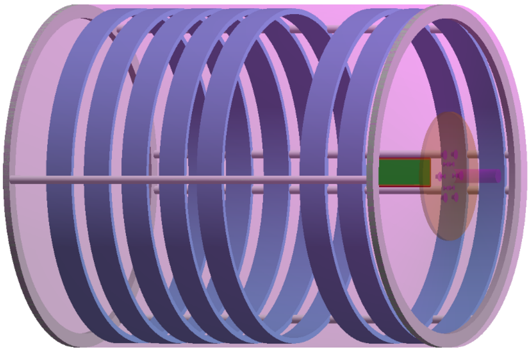

Figure 1. Geometry of the new design of the ion guide in the GEANT4 model. Green: uranium targets. Purple: Helium gas. Blue: DC cage. Red: Aluminum holders.

2.2 Electric fields

The AC/DC Module of COMSOL [9] is used to calculate the electric fields that will be implemented in the GEANT4 model. Figure 2 shows the obtained stationary field from the axial DC-ring electrodes, where the rings are drawn in wire frames to be able to see the electric field. The voltages of the rings from right to left are 5, 4.5, 3.5, 3, 2.5, 2 and 1.5 kV. There is a gap in between the second and third DC-ring, and a corresponding step in the voltages, in order to allow space for the uranium targets. In addition to the seven DC-rings, ten concentric ring electrodes at the end plate (to the left in Figure 2) of the ion guide provide an electric field to repel the ions and prevent them from hitting the exit wall.

In Figure 2, the electric field lines are drawn and the field strength is represented by the colors shown in the legend. The electric field strength is around 1.5×10^4 V/m. Later on these parameters will be optimized with respect to the collection efficiency of ions at the end of the ion guide.

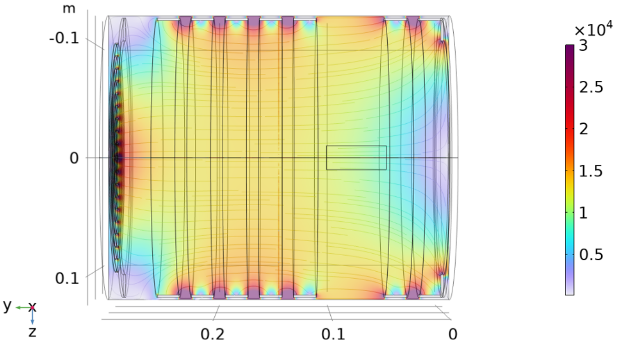

Figure 2. The calculated stationary electric field provided from the DC-rings and the concentric rings at the end plate in the ion guide by COMSOL. Colors represent the field strength in V/m.

The electric field is designed to center the ions on the axis of the ion guide and accelerate them towards the exit. As an example, Figure 3 shows the trajectories of ions with mass number A= 100 and ionic charge state +1 obtained with COMSOL. In this calculation the ions are emitted from the surface of the uranium target with an initial energy of 100 eV. These initial conditions correspond to a scenario where the ions, due to energy straggling, have lost most of their energy inside the target. The colors of the legend in Figure 3 show the velocities of the ions in m/s. Disregarding the helium gas, the ions arrive at the end plate of the ion guide in 5 μs and with kinetic energy at the keV scale. Compared to the previous ion guide, where the ion transport only relied on the flow of the helium gas, this corresponds to a reduction in the drifting time of several orders of magnitude, as expected. However, the COMSOL simulation disregards the effect of the helium gas, which is expected to increase the collection efficiency as well as the extraction time. In order to take the effect of the helium into account the electric fields will later be imported into the GEANT4 model.

The ions that arrive at the end plate after the transportation in the stationary field are assumed to have a very low energy because of the collisions with the helium gas. Figure 4 shows the geometry of the RF-carpet that consists of a RF-structure and the ten concentric ring electrodes (the rings at the end plate presented in Figure 3). The RF-structure has 200 rings with a width of 250 μm, to which an oscillatory potential at a frequency of 6.25 MHz, with a phase shift of π radians between consecutive electrodes, is applied. In addition, the ten ring electrodes at the end plate, having voltages 1.5 kV to 0.96 kV, provide a stationary field with a gradient towards the center hole. Near the RF-carpet, the ion transport is dominated by the combined fields which produces a time average force that transports the ions to the center exit hole. In Figure 4, the trajectories

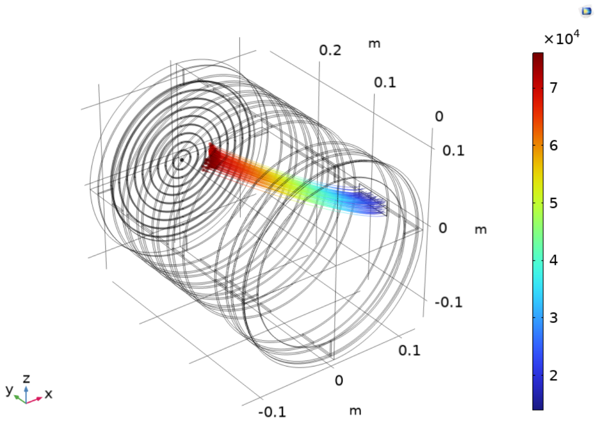

Figure 3. COMSOL: The trajectories of the charged ions in the stationary field during the first 5 μs, disregarding the helium gas. The colors indicate the velocities of ions in m/s.

shown are those of ions generated on a surface, 10 mm in front of the RF-carpet, at an energy of 0.5 eV. The ions are driven by the combined fields towards the exit hole, in the center of the end plate. However, in this simplified COMSOL model the helium gas is disregarded, which results in an acceleration of the ions instead of a slow mobility.

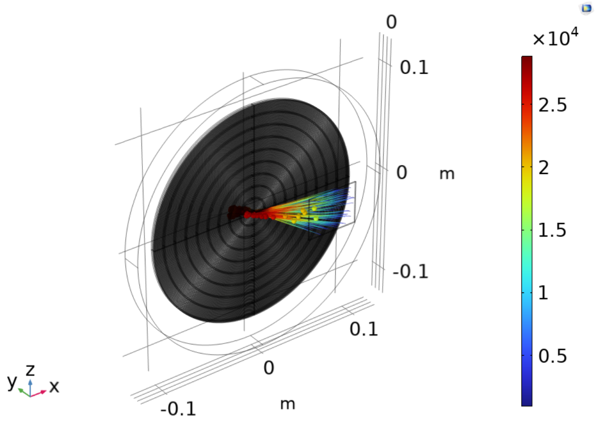

Figure 4. COMSOL simulation: The trajectories of the charged ions in the combined fields near the RF-carpet during the first 6 μs, disregarding the helium gas. The colors indicate the velocities of ions in m/s.

Table 1. Comparisons of the results from the simulations of the previous ion guide and the new design. The factor is the amount of FPs from the present simulation over the amount of FPs from the previous simulation.

	Temp (K)	Previous guide [6]	Present work	Factor
Amount of FPs	260	9.36×10^6	1.10×10^7	1.2
Stopping in the gas	260	8.10×10^4	4.07×10^5	5.0
Amount of FPs	220		1.10×10^7	1.2
Stopping in the gas	220		4.94×10^5	6.1
Amount of FPs	180		1.10×10^7	1.2
Stopping in the gas	180		6.10×10^5	7.5

3 Results and discussion

The amount of fission products generated from the uranium targets per second and the amount of fission products stopped in the gas are listed in Table 1, together with the simulation results of the previous ion guide [6]. Compared with those results, 1.2 times more fission products are generated in the uranium targets since the targets are closer to the *pn*-converter. In the simulation with a gas temperature of 260 K and a gas pressure of 150 mbar, the amount of fission products stopped in the gas is increased by a factor of 5 compared to the results of the previous ion guide. The main reason for the increase is the larger volume of gas.

By decreasing the temperature, as shown in Table 1, more fission products are stopped in the gas. This makes sense since the density of the helium gas increases with the decrease in temperature. However, to achieve temperatures below 260 K, such as 180 K, a cryogenic system would have to be developed. Such a system would make the operation of the ion guide more complex. At the same time, it would reduce the stopping volume of the ion guide due to the necessity of having double walls for insulation. Hence, further investigations are needed to evaluate the benefits of implementing such a system.

4 Outlook

The development of the simulation model is ongoing and the next step will be to implement the electric fields derived from COMSOL into the GEANT4 model. The effect of the helium gas on the ion transport in the field has to be included. Furthermore, the RF-carpet will be implemented in the model to simulate the transportation of the ions to the exit hole of the ion guide. The final step will be to optimize all of the parameters concerning the collection of fission products at the exit hole.

Also the influence of size and position of the uranium targets needs to be further investigated. On one hand the uranium targets should be positioned as close as possible to the *pn*-converter, on the other hand it has to be placed to optimize the stopping of the fission products. Further more, if cryogenic temperatures are to be implemented the necessity of having a double wall chamber will pose constraints on the minimum achievable distance between the converter and the target.

5 Acknowledgements

The computations were enabled by resources provided by the Swedish National Infrastructure for Computing (SNIC) at Uppmax partially funded by the Swedish Research Council through grant agreement no. 2018-05973.

This work was supported by the Swedish research council Vetenskapsrådet (Ref. No. 2017-06481), the European Commission within the Horizon 2020 Framework Programme through Fission-2019-SANDA (Project No. 847552), the Swedish Radiation Safety Authority (SSM), and the Swedish Nuclear Fuel and Waste Management Co. (SKB).

References

[1] H. O. Denschag *et al.*, *Compilation and Evaluation of fission Yield Nuclear Data*, (INTERNATIONAL ATOMIC ENERGY AGENCY, Vienna, 2000) 1168

[2] D. Gorelov *et al.*, Nucl. Instrum. Methods Phys. Res. B **376**, 46 (2016)

[3] A. Mattera *et al.*, Eur. Phys. J. A **53**, 173 (2017)

[4] A. Al-Adili *et al.*, Eur. Phys. J. A **51**, 59 (2015)

[5] K. Jansson *et al.*, Eur. Phys. J. A **53**, 243 (2017)

[6] Z. Gao *et al.*, Eur. Phys. J. A **58**, 27 (2022)

[7] G. Savard *et al.*, Nucl. Instrum. Methods Phys. Res. B **376**, 246 (2016)

[8] M. Ranjan *et al.*, Nucl. Instrum. Methods Phys. Res. A **770**, 87 (2016)

[9] *AC/DCModule User's Guide*, (COMSOL AB, Stockholm, Sweden. 2021) 82

[10] T. Eronen *et al.*, Eur. Phys. J. A **48**, 46 (2012)