

Accurate Fission Data for Nuclear Safety

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The Accurate fission data for nuclear safety (AIFONS) project aims at high precision measurements of fission yields, using the renewed IGISOL mass separator facility in combination with a new high current light ion cyclotron at the University of Jyväskylä. The 30 MeV proton beam will be used to create fast and thermal neutron spectra for the study of neutron induced fission yields. Thanks to a series of mass separating elements, culminating with the JYFLTRAP Penning trap, it is possible to achieve a mass resolving power in the order of a few hundred thousands. In this paper we present the experimental setup and the design of a neutron converter target for IGISOL. The goal is to have a flexible design. For studies of exotic nuclei far from stability a high neutron flux (10^{12} neutrons/s) at energies 1 - 30 MeV is desired while for reactor applications neutron spectra that resembles those of thermal and fast nuclear reactors are preferred. It is also desirable to be able to produce (semi-)monoenergetic neutrons for benchmarking and to study the energy dependence of fission yields. The scientific program is extensive and is planned to start in 2013 with a measurement of isomeric yield ratios of proton induced fission in uranium. This will be followed by studies of independent yields of thermal and fast neutron induced fission of various actinides.

I. INTRODUCTION

Fission product yields are an important characteristic of the fission process. In fundamental physics, knowledge of the yield distributions is needed for a better understanding of the fission process itself. For nuclear energy applications good knowledge of neutron induced fission product yields is crucial in many aspects, including criticality and reactivity calculations for reactor design, dosimetry and fission gas production for reactor safety and improved burn-up predictions [1]. For the management of the nuclear waste, i.e. depositories, reprocessing, transmutation and so on, as well as for Generation IV reactor concepts, good knowledge of the composition of the spent fuels is required. The inventory of fission products in a reactor determine the decay heat, both residual heat after reactor shut down and the decay heat from spent fuel. Typically, the decay heat is dominated by fission products for the first 50-80 years after extraction of spent nuclear fuel from a reactor [2].

The successful operation of nuclear power plants shows that the current knowledge of the underlying nuclear physics processes is generally sufficient. Predictions of macroscopic reactor parameters with model codes, as well

as calculations of the isotopic composition of spent nuclear fuel, are in reasonable agreement with reality. Nevertheless, more accurate nuclear data would improve the predictions of fuel compositions and hence both safety and fuel economy.

In a supplement to WRENDATA 93/94 - World Request List for Nuclear Data [3] the International Atomic Energy Agency (IAEA) concludes that for independent neutron induced fission yields practically all fissioning systems need to be further investigated and that it is recommended to measure the energy dependence of yields for neutron energies ranging from thermal to very high [4]. Other measurements are needed to improve model calculations of for example the even-odd effect of the fissioning nuclide. Independent fission yield measurements near symmetry are also needed to improve semi-empirical model parameters.

II. THE EXPERIMENTAL TECHNIQUE

The AIFONS project will use the upgraded IGISOL-JYFLTRAP facility at the accelerator laboratory of the University of Jyväskylä. With the Ion Guide Isotope Separator On-Line (IGISOL) technique high yields of fission products are selected and then mass separated in the Penning trap JYFLTRAP. This method has proven to be

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very useful for the determination of independent fission yields. So far experiments have been performed with 25 MeV protons on ^{232}Th and ^{238}U , with 50 MeV protons on ^{238}U and with 25 MeV deuterons on ^{238}U . These measurements are described in more detail elsewhere in these proceedings [5].

A. The IGISOL-JYFLTRAP Facility

The recent move of the IGISOL-JYFLTRAP facility to a new experimental area includes a general upgrade. An important addition is the new MCC30/15 cyclotron [6] that can provide protons in the 18 - 30 MeV energy range, and deuterons of 9 - 15 MeV. A beam current of up to 100 μA is expected, making it possible to consider high intensity neutron beams. In combination with the heavy ion K-130 cyclotron, up to 4000 beam hours per year could be delivered to IGISOL.

In the reaction chamber (Fig. 1) the beam from the cyclotron is impinging on a fissionable target. The ionized fission products leave the thin target and are retarded in a stream of noble gas. In this stream the ions are transported to a sextupole ion guide (SPIG) and accelerated for further transport down the beam line. The neutral gas is not affected by the electric field of the SPIG and is effectively pumped away between the SPIG rods. Thanks to the high ionization potential of the buffer gas, usually Helium, a large fraction of the ions are extracted from the reaction chamber as singly charged [7].

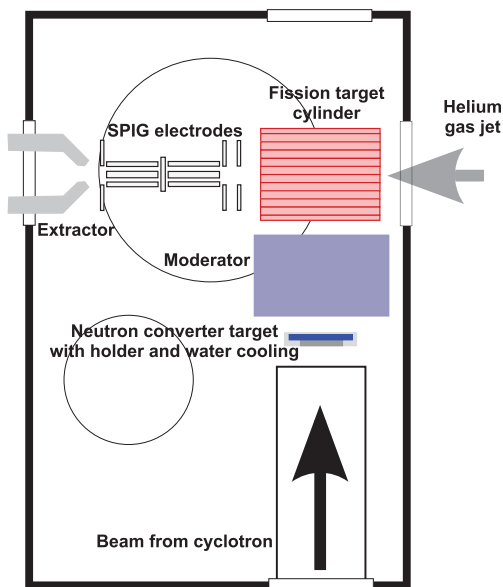


FIG. 1. Sketch of the reaction chamber with the proposed setup for neutron induced fission yield measurements. Not to scale.

The ions are accelerated to 30 keV and isobarically separated in a 55° dipole magnet with a mass resolv-

ing power of 500. In the RFQ buncher and cooler [8] the ions are accumulated and their energy spread is reduced, using buffer gas cooling, before they are further transported to the Penning trap system JYFLTRAP. In the purification part of JYFLTRAP the mass separated fission products are further cooled, and the magnetron orbits are expanded by applying a mass independent, oscillating dipole-field in the azimuthal plane. In a final step, a mass selective quadrupole-excitation is applied. This will resonantly re-center those fragments that has a cyclotron frequency

$$f_c = \frac{1}{2\pi} \frac{qB}{m},$$

that match the frequency of the quadrupole field. The fragments are then extracted from the trap through a 2 mm aperture which means that only the re-centered fragments will escape. These are finally detected and counted using an MCP detector. With this scheme a mass resolving power of more than 10^5 has been demonstrated [7]. For a detailed description of the purification process see for example reference [9].

B. The Neutron Converter Target

So far only proton induced independent fission yields have been investigated with the Penning trap technique. For the study of neutron induced fission a neutron converter target is being developed. As a first approach a design similar to the ANITA target [10] at The Svedberg Laboratory (TSL) was considered. This is a thick tungsten target producing a white neutron spectrum through the $\text{W}(p, \text{xn})$ reaction. To be competitive compared to other neutron facilities in the studies of nuclides far from the line of stability, the converter should deliver 10^{12} high energy neutrons (above 1 MeV) per second on the fission target. For this reason also beryllium was considered as target material. To estimate the neutron flux for different target options the Monte Carlo codes FLUKA [11, 12] and MCNPX [13] have been used. In Fig. 2 the obtained neutron spectra for 5 mm targets of tungsten and beryllium is plotted. From this beryllium was selected as the main option because of the higher neutron yield in the high energy regime.

For the studies of independent fission yields for nuclear power applications the neutron energy spectrum should preferably resemble that of nuclear reactors, either moderated light water reactors (LWR) or fast reactors. Alternatively, a close to mono-energetic spectrum could be used. In Fig. 2 simulated spectra from tungsten and beryllium with and without moderator is compared to typical spectra from LWR and fast breeder reactors. The conclusion from these simulations is to have a flexible design that can be adopted to different materials and thicknesses.

In order to benchmark the simulated neutron spectra and to try to resolve the discrepancies between the two

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