Surrogate Reaction and Fission Research at JAEA

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1. Introduction

Accurate nuclear data are vital input for design of advance nuclear reactors. Recently, a new technique called surrogate method is actively applied to measure neutron cross sections of nuclei for which sample is not available[1]. This method utilizes nucleon transfer reactions or inelastic scattering to populate excited nuclei which correspond to compound nuclei in neutron-induced reactions on a target nucleus having one-less neutron. Then, decay branching ratios to fission or capture channel is determined. In this way, it may become possible to measure neutron cross sections of unstable nuclei such as minor actinides and long-loived fission producets. In this presentation, a JAEA-based activity on the installation of equipments for the surrogate method and its physical justification will be explained briefly as well as status of research for fission reactions.

2. Method and Results of A Test Experiment

By using the surrogate method, we plan to determine primalily 1) fission cross sections, 2) capture cross sections, and subsequently 3) fission-fragment mass distributions and 4) number of prompt neutrons per fission, of minor actinides. Also, capture cross sections of LLFPs and some nuclei relevant to the s-process nucleosynthesis are in our scope. Therefore, our detection system must involve i) charged-particle detercters to identify the populated nuclear species and their excitation energies, ii) fission fragment detectors, iii) γ-ray detectors and iv) neutron counters. The system is shown schematically in **Fig. 1**. The charged particles are detected by silicon ΔE and E detectors, which will yield a signal such as shown in **Fig. 2**. This spectrum was taken in a test experiment for the ^{18}O + ^{238}U system as explained below. We can observe various isotopes of O, N and C (although not designated). They correspond to population of a series of U, Np and Pu isotopes as compound nuclei. Therefore, surrogate reactions based on heavy-ion projectiles have a certain advantage that they can populate many compound nuclei cimultaneously, while those based on light ions such as ^{3}He can populate less variety.

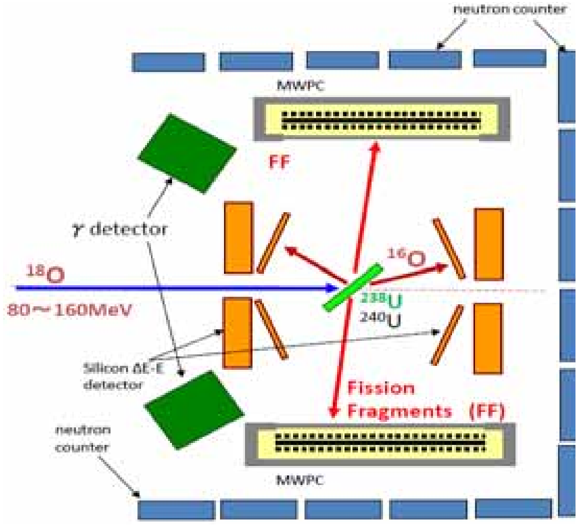


Fig.1 A schematic layout of the surrogate detection system under plan

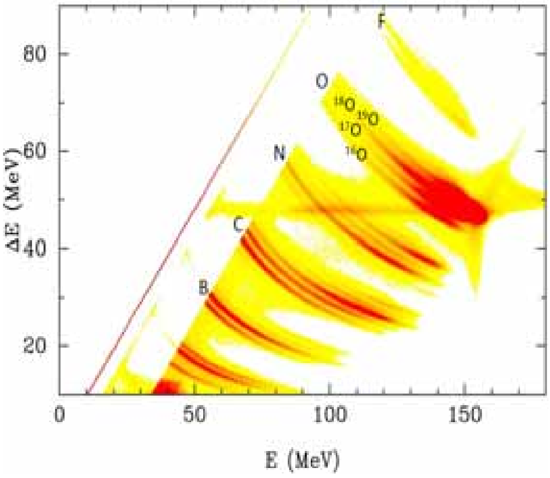
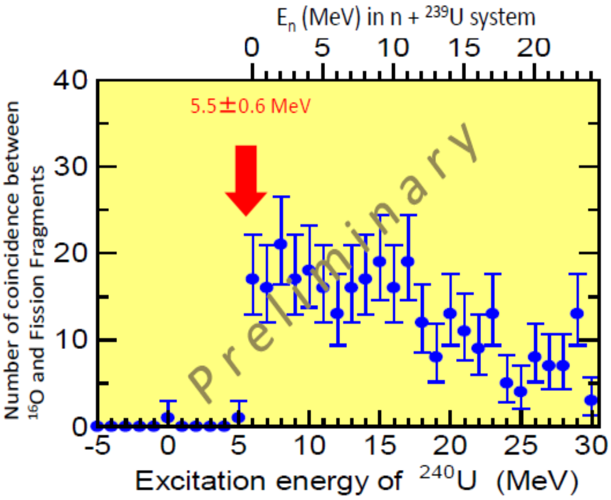


Fig.2 Charged-particle spectra obtained by a silicon ΔE-E deterctor

We carried out a text experiment to verify that the surrogate method based on heavy-ion projectiles can yield desired fission properties[3]. We have chosen the ^{18}O + ^{238}U system, for which we have enough experience in the in-beam γ-ray spectroscopy. The detecor consists of the silicon ΔE-E counter and the MWPC (multi-wire proportional counter for detection of fission fragments) of **Fig. 1**. **Figure 3** shows the number of coincidence events between ^{16}O ejectile and fission fragments as a function of the excitation energy of residues. We observe a clear threshold of 5.5 MeV, which coincides with the fission barrier of ^{240}U. This result therefore shows population of compound nucleus ^{240}U and decay of it to the fission channel. At the upper horizontal axis, equivalent neutron energy in the n+^{239}U system is indicated. We also observed fission fragment mass distribution (FFMD) from a number of residues. Some examples are shown in **Fig. 4**. All these FFMD data were observed for the first time (still preliminary though). Therfore, it was justified that the surrogate method based on the heavy-ion projectiles can yield a large variety of new data.



- **Fig.3** Number of coincidence events between ^{16}O and fission fragments for a ^{238}U(^{18}O,^{16}O) reaction[3]

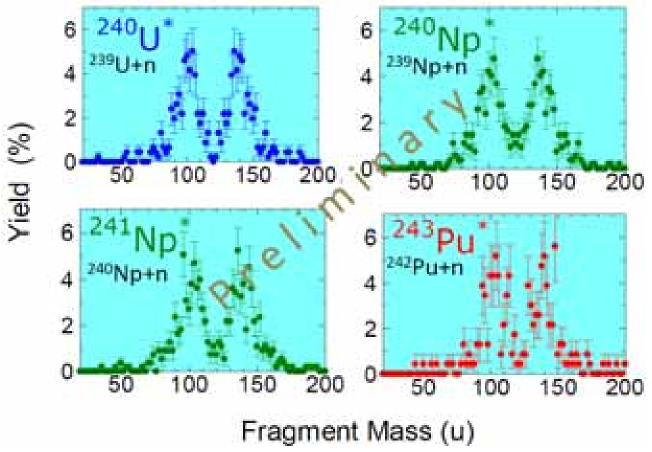


Fig.4 Prelimiary FFMD data from various residues measured by a surrogate reaction ^{238}U+^{18}O[3]. FFMDs from these nuclei were not observed in the past

3. Theoretical Studies

Theoretical investigations of the surrogate reactions are important since simple the decay branching ratio is sensitive to the spin and parity of the decaying nuclei. In other words, Weisskopf-Ewing approximation is not applicable to low-energy neutron reactions. Therefore we have to find condition under which the surrogate method really yields information which can be converted to desired neutron cross sections. Especially, the capture cross section may deviate by a factor of 5 or more due to the difference of spin distributions between neutron-induced and surogate reactions[2]. Recently, SC and Iwamoto have discovered a condition for the surrogate "ratio" method to work[4]. Surrogate ratio method requirs an existence of 2 pairs of neutron-induced and corresponding surrogate reactions. It was concluded that 1) the weak Weisscopf-Ewing condition defined in ref. [4] should be satisfied, 2) the 2 surrogate reactions should yield equivalent spin-parity distributions, and 3) the maximum spin populated by the surrogate reactions must not be too large (less than 10 hbar) compared to the neutron-induced reactions. It was demonstrated that even the capture cross section can be determined with an accuracy of around 10% if they are fulfilled. In ref. [4], however, the conditions 2) and 3) were simply assumed. Then, we verifed these conditions based on both quantal[5] and semi-classical[6,7] models in subsequent works. Details of these models will be published elsewhere[5,6].

3. Summary

We have an intensive plan at JAEA to develop experimental and theoretical tools to investigate surrogate reactions to determine neutron cross sections of unstable or rare nuclei. The project started under financial support from MEXT. I wish to notice that some variations of the method, such as the inverse kinematics, projectile fragmentation and even some other methods would be possible as a surrogate method and in some cases they would be very useful. We are wokring on the direction as well.

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