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Nuclear physics with fast neutrons at LANSCE/WNR: GEANIE and FIGARO

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Abstract. GEANIE is an array of 26 HpGe detectors used to study nuclear reaction dynamics and structure following reactions with high-energy ($1 < E_n < 200$ MeV) neutrons, for both basic and applied research projects. Studies have included the measurement of *(n,xn)* partial cross sections as a function of E_n for a variety of nuclei, particularly actinides. More recently, studies of *n*-induced fission-fragment distributions and nuclear structure in the actinide region have been started. A second beam line and experimental station (FIGARO) have been set up to complement and extend this program. Research conducted on this second beam line includes the use of conversion electron spectroscopy to explore nuclear structure, using the University of Pittsburgh ICEBall II array.

INTRODUCTION

Spectroscopic studies of reactions between nuclei and fast neutrons can provide information on both nuclear structure and nuclear reactions. Of particular applied interest are the measurements of both partial and total fast neutron-induced reaction cross sections with a variety of nuclei, especially actinides, for the DoE stockpile stewardship program as well as other applications.

There is also considerable basic physics interest in such reactions. Since *(n,xnypzα)* reactions preferentially populate relatively low spin states, detailed studies of these reactions can provide information on both the reaction mechanism and the nuclear structure involved. Such studies are useful for improving detailed reaction models, including the description of nuclear level densities. In this paper we will present the current status and recent results of the program at LANSCE/WNR to measure the properties of neutron-induced reactions by spectroscopic means.

LANSCE/WNR

The Weapons Nuclear Research (WNR) facility, part of the Los Alamos Neutron Science CEnter (LANSCE), provides a "white" spectrum of neutrons from spallation of 800 MeV protons on a thick tungsten target. Six beam lines are available for a variety of defense, industrial and basic science measurements, with the experimental target positions typically 20-30 m from the spallation target. The proton beam structure consists of numerous micropulses 1.8 μs apart, contained in macropulses typically 625 μs wide, at a rate of up to 120 Hz. The overall duty cycle is 6-8%. The pulsed nature of the beam allows the time-of-flight determination of the incident neutron energy on an event-by-event basis. Figure 1 shows the neutron flux spectrum at WNR for the GEANIE flight path.

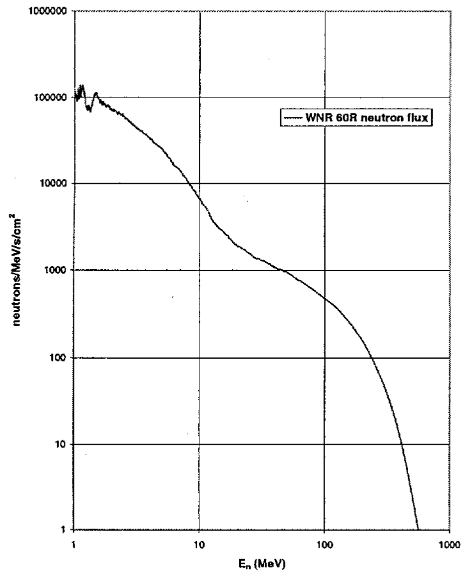

FIGURE 1. The neutron flux spectrum at WNR for the GEANIE flight path. Other flight paths have similar neutron flux spectra.

The GEANIE array consists of 26 high-purity germanium detectors for γ-ray spectroscopy; 11 of these are LEPS detectors for low-energy γ-rays (up to 1 MeV), and twenty of these, including all the LEPS, are Compton suppressed. It is based on the HERA array from LBNL, with the addition of the LEPS detectors.

A second beam line is currently being reconfigured to expand this program and relieve the beam time pressure on GEANIE. It can accommodate both Ge and neutron detectors, and has recently been used to explore the use of conversion electron detection at WNR. FIGARO is described in another submission to this conference[1], though a description of the electron detection experiment will be presented below.

^{238}U(*n,xn*) RESULTS FROM GEANIE

The GEANIE array has typically been used in "singles" mode to accurately measure yields of individual γ-rays, and hence to determine partial γ-ray cross sections. The partial cross sections of individual γ-rays are determined as a function of incident neutron energy by measuring the γ-ray yield, corrected for computer deadtime, attenuation in the target, internal conversion, and the absolute efficiency of the array. The incident neutron flux is monitored using ^{235}U and ^{238}U fission foils[2].

The extraction of γ-ray yields from "dense" spectra, in which literally thousands of discrete lines can be identified, can of course be problematic. An elaborate and versatile peak-fitting routine has been developed for this purpose[3], and the resulting fits to the data give reliable yields for all of the cases studied. Nonetheless, doublets and triplets, etc., need to be considered on a case by case basis; the excitation functions provided by the incident neutron spectrum at WNR allow the separation of doublets from different reaction channels.

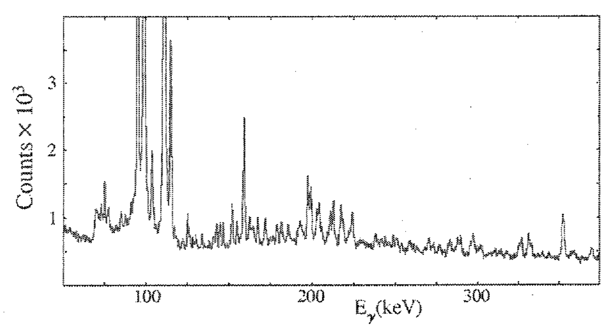

FIGURE 2. Total γ-ray spectrum for n + ^{238}U, for $1 < E_n < 100$ MeV. Note the density of γ-ray lines.

Figure 2 shows a sample γ-ray spectrum, and figure 3 shows some partial cross section results from reactions with ^{238}U as a function of incident neutron energy. The data in the top panel are ground-band transitions in ^{238}U, populated by *(n,n')* reactions. The second, third and fourth panels are lighter U isotopes populated in *(n,xn)* reactions, and the bottom panel contains a sample transition in ^{100}Zr, a fission fragment. The accompanying lines are predictions from the pre-equilibrium plus Hauser-Feshbach reaction code GNASH,[4,5] which includes a description of the γ-ray decay of the residual nuclei. The detailed comparison of GNASH with data of this type has improved the nuclear structure input to GNASH, resulting in better fits to individual γ-ray transitions.

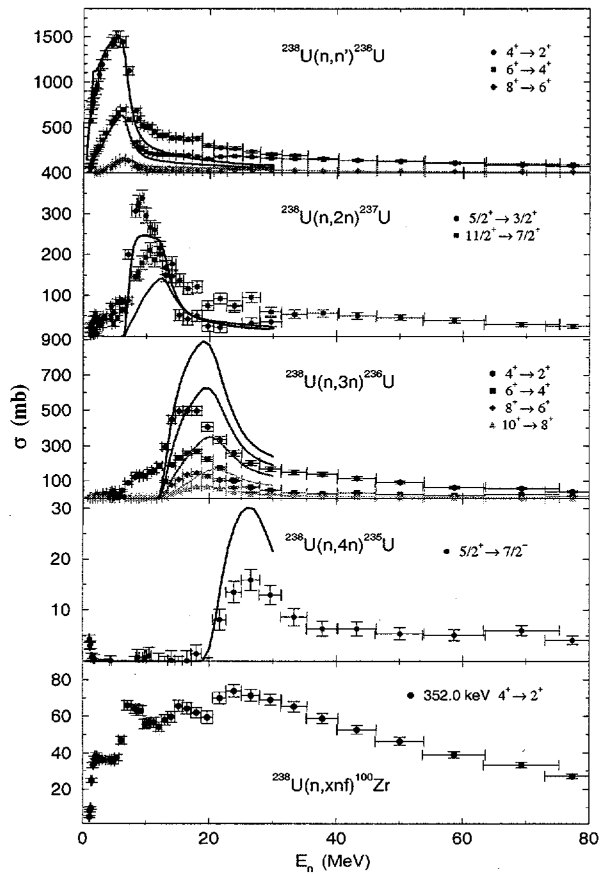

FIGURE 3. Partial cross sections measured at GEANIE. Shown are various transitions from the *(n,n')* [top], *(n,xn)* [middle three], and one fission fragment line from *(n,xnf)* [bottom]. Solid lines are GNASH calculations[5] for the same transitions. In addition to γ-ray background, contaminant lines are subtracted from the yields, where known.

^{239}Pu(*n,2n*)^{238}Pu CROSS SECTION

The ^{239}Pu(*n,2n*)^{238}Pu cross section has been one focus of our research. Previous measurements have given inconsistent results below 14 MeV, resulting in a large uncertainty in the evaluated cross section. The combination of WNR and GEANIE using the technique of measuring partial γ-ray cross sections has been applied to this problem.

Figure 4 shows a preliminary result for the ^{239}Pu(*n,2nγ*) partial cross section, for the 6^+ to 4^+ transition in ^{238}Pu (top, left), and for the sum of five independent transitions (bottom, left). The resulting total cross sections, using GNASH calculations of the proportion which feeds through the measured transitions, are shown on the right. These results indicate that using as many independent transitions as possible provides a better estimate of the total cross section. The ^{239}Pu(*n,2n*)^{238}Pu cross section has now been accurately measured as a function of incident neutron energy from threshold to over 50 MeV.

OTHER PROJECTS AND FUTURE DIRECTIONS

In addition to the examples presented above, GEANIE has been used for a variety of other research projects. These include studies of states populated in spallation neutron-induced reactions with ^{92}Mo[ref. 6], ^{235}U*(n,xn)* partial cross sections[7], the distribution of fission fragments for *n*-induced fission on ^{235}U[ref. 7], and ^{238}U[ref. 8] and *(n,2n)* partial cross section measurements on a variety of isotopes of interest for applications such as stockpile stewardship and Accelerator Transmutation of Waste (ATW). In addition, future experiments will explore actinide spectroscopy via *(n,xn)* reactions and *n*-induced fission fragment distributions.

CONVERSION ELECTRON SPECTROSCOPY AT WNR

Internal conversion represents an increasing contribution to the decay of nuclear states as atomic number increases. Conversion electron spectroscopy is therefore an appealing technique to study actinide structure. In typical, charged-particle induced reactions, the profuse production of atomic electrons and x-rays supplies a large background for conversion electron detectors. For neutron-induced reactions, however, this background should be considerably reduced. Moreover, *E*0 transitions can only be observed via electron detection, and such observations have provided significant information on β bands[9] and 0^- bands[10] in U isotopes.

In order to test the feasibility of conversion electron detection at WNR, we set up the University of Pittsburgh ICEBall II detector array[11] on the FIGARO beam line to look for *E*0 and other converted transitions following neutron reactions with ^{238}U. ICEBall II consists of six SiLi detectors with mini-orange focusing magnets; it has a peak efficiency of 14% at 400 keV. Despite the reduced background from the target, we encountered a significant background for scattered neutrons.

Improved shielding was successful at reducing this background, and further improvements in shielding are planned. Analysis of the data is in progress, though to date only continuous, not discrete, electrons from the ^{238}U target have been identified.

ACKNOWLEDGMENTS

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REFERENCES

1. Zanini, L., et al., these proceedings.
2. Wender, S.A., et al., *Nucl. Instr. and Meth.* **A336**, 226 (1993).
3. Younes, W., to be published.
4. Young, P.G., Arthur, E.D., and Chadwick, M.B., LANL Report LA-12343-MS (1992).
5. Chadwick, M.B., personal communication.
6. Garrett, P.E., et al., *Phys. Rev.* **C62**, (2000) 014307; Garrett, P.E., et al., *Phys. Rev.* **C,** in press.
7. Younes, W., et al., to be published.
8. Fotiades, N., et al., to be published; Ethvignot, T., et al., to be published.
9. Janssens, R. V. F., et al., Phys. Lett **90B** (1980) 209; W. Z. Venema, et. al., Phys. Lett. **156B** (1985) 163.
10. Zeyen, P., et al., Z. Phys. **A328** (1987) 399.
11. Saladin, J.X., et al., to be published; see also Metlay, M.P., Saladin, J.X., Lee, I.-Y., and Dietzsch, O., *Nucl. Instr. and Meth.* **A336**, 162 (1993).

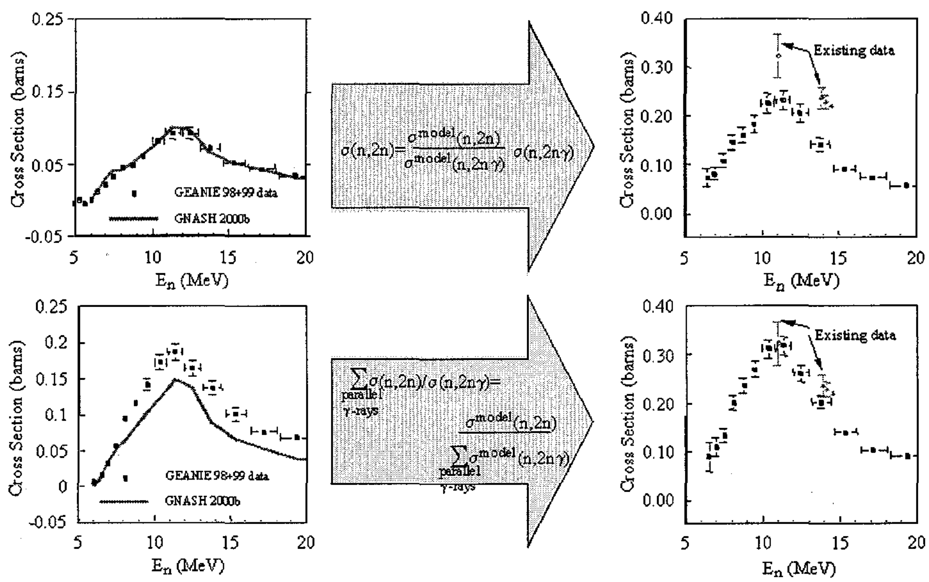

FIGURE 4. Preliminary partial ^{239}Pu(*n,2n*) cross sections extracted for the 6^+ to 4^+ transition in ^{238}Pu (top left) and a sum of five independent transitions in ^{238}Pu (bottom left). Extracted total cross sections for the transitions (right top and bottom) using GNASH calculations.