Determination of Neutron Cross Sections
and Resonance Parameters for the Osmium
Isotopes 186, 187, and 188, ^{205}Tl , ^{32}S , the
Stable Tellurium Isotopes and of the 82
keV Inelastic Cross Section for ^{238}U

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Abstract

This report covers a period of intense professional activity. During the past twelve months the work supported by DOE contract No. DE-AS02-76ER02696 has resulted in three publications in the referred literature, two invited and three contributed papers, and the submission for publication of two more papers. (Reprints or preprints of all are enclosed with this report.) These publications span all three aspects of the Denison/ORNL collaborative research program: nuclear physics, astrophysics and reactor technology. We have contributed to our understanding of the nucleon-nuclear interaction by demonstrating a connection between the resonance structure revealed by the high energy resolution neutron cross section measurements and the average nuclear potential. Our measurements of the capture cross sections of the isotopes of Osmium have made possible the most reliable estimate of the age of the chemical elements so far achieved. Finally, in response to official requests, we have measured the ^{238}U inelastic neutron scattering cross section near 82 keV (near the peak of the fast reactor neutron spectrum) and the capture cross sections of ^{101}Ru , ^{103}Rh and ^{105}Pd isotopes which, because of their high fission yields and large capture cross sections, are important poisons in fast reactors.

I. Introduction

A national laboratory facility such as the Oak Ridge Electron Linear Accelerator (ORELA) should provide data pertinent to a spectrum of physics questions. This past year's research efforts by the Denison University/ORNL collaboration has been especially satisfying because we have achieved that goal. Our data and associated analyses have had impact on:

1.) Fast Reactor Technology:

In response to the need to understand observed degradation in the fast breeder reactor, we have measured the neutron inelastic scattering cross section of ^{238}U at 82 keV (near the peak of the reactor neutron spectrum). It is interesting that both coupled-channels and statistical model calculations agree well with our result which is also in good agreement with the ENDF/B-V evaluation. However, the calculations predict significantly lower cross sections in the range 85-140 keV than does ENDF/B-V. Thus, while the result of our work affirms the ENDF/B-V evaluation at 82 keV, the question of the correct energy dependence up to the next inelastic threshold remains unanswered, and we recommend additional experimental work using our technique.

Our measurements of the capture cross sections of ^{101}Ru , ^{103}Rh and ^{105}Pd have provided much needed data in understanding the effects of these fission-produced isotopes on the neutron flux in the keV energy region.

2.) Nuclear Theory:

We have demonstrated the connection between the resonance structure of the high energy resolution ORELA neutron cross section data and the optical model of the nucleon-nucleus interaction.

3.) Astrophysical Theories of Nucleosynthesis:

Our measurements of the ^{186}Os and ^{187}Os capture cross sections have allowed us to estimate the age of the chemical elements as (10.6 ± 2.2) years, the most reliable estimate so far proposed.

II. Fast Reactor Technology

A. $^{238}\text{U}(n,n')$ Cross Section at 82 keV

Collaborators: R. R. Winters, N. W. Hill, R. L. Macklin,
J. A. Harvey, D. K. Olsen, and G. L. Morgan

An important process by which the fast reactor neutron flux can be degraded is by inelastic neutron scattering particularly to the excited states of the ground state rotational band in ^{238}U . Using a novel combination of a pulsed neutron source and a thick iron filter to select 82 keV neutrons within each pulse, we have measured this cross section near the peak of the fast reactor neutron spectrum. Our value $\sigma_{nn'} = 381 \pm 21$ mb is in good agreement with the ENDF/B-V evaluation and with two other theoretical calculations, a coupled-channels calculation by J. Jary and a level-statistical calculation by Frohner. Above 82 keV (but below the 150 keV second excited state threshold), the calculations and other measurements differ from the ENDF/B-V evaluation, tending to lower cross section. As we point out in the enclosed preprint, " ^{238}U Inelastic Neutron Scattering at 82 keV", the shape of the ENDF/B-V evaluation near threshold does not follow the $E_{\text{ex}}^{-1/2}$ dependence expected from the neutron penetrability components of the neutron transmission factors. However, the calculations by Jary and by Frohner do have this simple dependence, perhaps a hint that the ENDF/B-V evaluation rises too rapidly in the range 80 keV to 150 keV. We suggest a measurement using our technique, a filtered

neutron pulsed beam, to measure the inelastic cross section at 128 keV, the next prominent window in the iron filter.

B. A New Neutron Detector

Collaborators: R. R. Winters, N. W. Hill, D. J. Horen and G. L. Morgan

In order to accomplish the measurement described in section II A, a new detector, a NE110 plastic scintillator view with three photomultiplier tubes operating in a majority logic mode was developed. This detector has good efficiency for detecting neutrons down to 10 keV or lower while offering almost absolute insensitivity to gain shifts. The detector is described in the preprint, "Majority-Logic NE-110 Detector for keV Neutrons", which is included with this report

C. Reactor Poisons

Collaborators: R. L. Macklin and R. R. Winters

Of significant concern in the calculation of fuel loads for fast breeders are the effects of neutron capture by such fission products as ^{101}Ru , ^{103}Rh and ^{105}Pd . These capture cross sections in the keV neutron energy near the peak of the fast reactor neutron spectrum have been measured and sent to the National Center for Nuclear Cross Section Data.

III. R-matrix Resonance Parameters and the Optical Model

Collaborators: R. R. Winters and C. H. Johnson

The optical model potential (OMP) continues to be an important link between experimental and theoretical neutron physics. The imaginary part

of the (OMP) describes particle-core excitations which can be strongly dependent on the incident particle energy. We have measured the neutron total cross section for $^{32}\text{S} + n$ and extracted via the R-matrix formalism two functions, the external R-function and the external strength function (for details see C. H. Johnson and R. R. Winters, Phys. Rev. C 21 (1980), reprints included with this report). These functions can be calculated using the OMP by varying the well depths to fit the observed functions. The resulting imaginary well depths for s- and p-wave incident neutrons over 0.025-1.1 meV are approximately half as deep as reported by other workers at higher energies. This may be an indication that few particle-core excitation modes are open below 1.1 meV in $^{32}\text{S} + n$. In addition the spherical OMP real well depths which we used in our work are parity dependent which we interpret as indication of nuclear deformation and the opening of associated collective state excitations.

IV. $^{186,187,188}\text{Os}(n,\gamma)$ Cross Sections and Galactic Nucleosynthesis

Collaborators: R. R. Winters and R. L. Macklin

Don Clayton pointed out over a decade ago the importance of the $^{187}\text{Re} \xrightarrow{\beta} ^{187}\text{Os}$ ($\tau_{y2} = 40 \times 10^9$ yr.) as a measure of the duration of the building of the chemical elements in our galaxy. As difficulties with the few alternative nucleosynthetic chronometers have been demonstrated, Re/Os appears even with its significant problems to offer the best opportunity of understanding the scenerio of nucleosynthesis. Our work has resolved one of the most difficult problems, the apparently low ratio of 30 keV capture cross sections

$R \equiv \frac{{}^{187}\bar{\sigma}(n,\gamma)}{{}^{186}\bar{\sigma}(n,\gamma)}$ derived from semi-empirical estimates and the one previously existing measurement by Browne and Berman. As a result of through discussions with Browne, their work was re-evaluated and brought into good agreement with our result $R = 0.50 \pm 0.02$. Hence, using a standard model for r-process nucleosynthesis, we estimate the duration of nucleosynthesis as $(10.4 \pm 2.5) \times 10^9$ years and as the implied age of the universe about 17×10^9 years, in fair agreement with the estimates by Sandage, but almost a factor two larger than the recently reported value by De Vaucouleurs et al.

V. Conclusion

Working full-time at ORNL during the initial phase of the current contract period has provided impetus to the completion of much (90%) of the proposed research, but has also suggested experiments to satisfy certain continuing data needs. Moreover, sufficient data has been acquired over the past two years to provide ample challenges for the primary investigator as he returns to teaching (2/3 full-time) at Denison. It is particularly satisfying to report that a senior physics major has already involved himself in the research program and will accompany the primary investigator to ORNL to participate in an experiment during January 1981. The best expression of appreciation to the U.S. DOE and to ORNL is my commitment to continued dedication to the collaborative research program; it keeps me professionally alive.