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Recent Capture Cross Section Data from ORELA Above 2.6 keV

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Recent Capture Cross Section Data

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Abstract

Neutron capture by natural rhodium (^{103}Rh) and enriched stable isotopes of ruthenium (100-104) and palladium (104-110) were measured at the Oak Ridge Electron Linear Accelerator pulsed neutron facility. Average pure isotope cross sections from three to several hundred keV were derived. The neutron flux shape was determined relative to ENDF/B V standard $^6\text{Li}(n,\alpha)$ and $^{235}\text{U}(n,f)$ cross sections below and above 70 keV respectively. Strength functions were adjusted to fit the data by least squares. The ^{101}Ru fission product would appear to cause less poisoning than ^{105}Pd or ^{103}Rh in plutonium fueled fast reactors.

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Introduction

^{101}Ru , ^{103}Rh and ^{105}Pd through a combination of strong neutron capture and high fission yield are among the most important stable isotopes in regard to the poisoning effect in fast reactors. The even stable isotopes in this mass range are also significant neutron absorbers. Evaluations of the microscopic cross sections^{1,2} have had to rely on fragmentary experimental results (except for ^{103}Rh) or average statistical properties of nuclei in the general mass range.

Experimental Technique

Enriched samples of ^{100}Ru , ^{101}Ru , ^{102}Ru , ^{104}Ru , ^{104}Pd , ^{105}Pd , ^{106}Pd , ^{108}Pd and ^{110}Pd were measured at 40 meters from the Oak Ridge Electron Linear Accelerator pulsed neutron source. A natural ^{103}Rh metal sample was included in the study. Prompt capture gamma rays were observed with C_6F_6 based liquid scintillators which have a low sensitivity (10^{-3} - 10^{-4}) for scattered neutrons and give negligible neutron moderation. Both time-of-flight and pulse height were recorded for the first pulse (if any) recorded after a neutron burst. By weighting each event as a function of the pulse height, an unbiased estimate of the total gamma energy is obtained. As the excitation energy of the compound nucleus after neutron capture is well known, this leads directly to the number of neutrons captured during a measurement. The time-of-flight resolution is adequate to resolve a hundred or so resonances per isotope in the few keV neutron energy range. The analysis of individual resonance peaks is reported separately.^{3,4}

The neutron flux was monitored by a thin (0.5 mm) ^6Li glass scintillator half a meter upstream from the sample. While the absolute cross section was determined at 4.9 eV using the saturated resonance technique, we must rely on an efficiency vs energy curve for the flux monitor at high energy. This has been recently redetermined relative to the $^{235}\text{U}(n,f)$ ENDF/B V standard cross section.⁵

Cross Sections

The enriched isotope sample yields (corrected for measured backgrounds, dead time losses, gamma energy loss in each sample, etc.^{3,4}) were linearly combined to derive pure isotope yields.³ These were then corrected for average resonance self-protection and multiple scattering of neutrons within each sample to give average isotopic cross sections. Table I summarizes the cross sections averaged over various energy regions, and the figures show them as histograms. Uncertainties in cross section are estimated at 4-5% up to 100 keV or so, increasing to perhaps 10% at the highest energies reported for each isotope.

Analysis

Average cross sections up to about 110 keV in quarter keV steps were well represented by strength functions S^0 , S^1 , S^2 and $\bar{\Gamma}_\gamma/D_0$ through least squares adjustment. For the even isotope capture data it was found necessary to adopt a fixed value of the s-wave strength function S^0 (see Table II). At higher energies competition from inelastic scattering is seen as a reduction in capture above most inelastic thresholds. Hauser-Feshbach codes may be able to fit the higher energy data also, but this has not been done.

Discussion

Cross section agreement with prior evaluation and data adjustments^{1,2} is good except for ^{102}Ru which we find 5% to 40% lower at various energies. Two more recent values for $^{103}\text{Ru}(n,\gamma)$ at 520 ± 80 keV and 720 ± 80 keV⁶ are about 20% below ours. Below about 10 keV for the even isotopes studied the cross section is best represented by single resonance parameters.^{3,4} In the higher energy region around 100-200 keV where fast reactor spectra peak, the highest cross section appears to be for ^{105}Pd , followed by ^{103}Rh and ^{101}Ru . The lower ^{101}Ru capture is attributable both to radiative strength (28% below ^{105}Pd) and the lower threshold for competition by inelastic scattering (~ 130 keV vs ~ 300 keV for ^{103}Rh or ^{105}Pd). For a plutonium fuelled fast reactor this would predict ^{105}Pd as the leading fission product poison. For a fast reactor with much ^{233}U or ^{235}U fission, the lower mass ^{101}Ru might become most significant.

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Table I. Histogram of the Average Neutron Capture Cross Sections

E_n keV	^{100}Ru mb	^{101}Ru mb	^{102}Ru mb	^{103}Rh mb	^{104}Ru mb	^{104}Pd mb	^{105}Pd mb	^{106}Pd mb	^{108}Pd mb	^{110}Pd mb
3										
4	748.6	2652.6	703.5	2639.5	411.2	747.0	2452.1	1124.5	1029.6	869.5
6	575.5	2074.1	510.0	2524.9	533.4	1172.8	2380.0	900.5	869.1	817.7
8	586.5	1880.6	476.2	1902.4	529.9	958.6	2014.7	891.9	699.6	707.9
10	460.1	1746.2	443.3	1793.2	350.7	978.2	1816.7	709.7	751.8	726.8
15	339.9	1512.3	355.2	1687.4	292.5	712.5	1695.2	564.0	569.4	446.0
20	342.4	1299.2	269.9	1408.3	239.2	604.8	1504.4	568.8	482.9	385.3
30	220.3	1127.6	222.1	1193.7	186.4	499.6	1279.4	435.1	385.7	271.7
40	191.6	933.4	164.0	950.9	143.4	411.8	1093.8	362.3	304.9	246.9
60	147.3	762.6	128.9	805.6	113.6	330.2	930.1	270.0	248.7	196.6
80	127.0	610.4	107.5	662.4	92.8	259.2	771.5	221.6	205.7	146.9
100	103.4	526.2	95.5	547.2	83.1	221.9	668.5	192.8	178.2	135.3
150	91.5	441.2	86.6	457.9	74.8	194.6	575.0	172.9	153.9	123.8
200	80.2	342.4	83.1	370.0	73.6	176.6	485.1	156.9	146.8	115.0
300	81.4	277.7	79.3	315.9	70.7	169.9	422.9	153.5	142.4	110.9
400	81.3	196.5	79.3	228.4	61.9	159.1	299.5	149.0	141.2	100.9
500	86.9	149.1	78.1	166.3	41.8	166.5	219.4	161.3	122.1	70.4
600	78.2	123.3	60.1	137.1	38.9	159.8	174.6	132.1	95.6	
700	64.0	101.6		125.7	37.6	126.0	152.1	117.7		

Table II. Least-Squares-Adjusted Strength Functions and Average Neutron Capture

Strength Function	^{100}Ru	^{101}Ru	^{102}Ru	^{103}Rh	^{104}Ru	^{104}Pd	^{105}Pd	^{106}Pd	^{108}Pd	^{110}Pd
$10^4 S^0$	(0.58) ^a	0.59 ± 0.04^b	(0.55)	1.04 ± 0.13	(0.52)	(0.50)	0.50 ± 0.02	(0.50)	(0.50)	(0.50)
$10^4 S^1$	6.5 ± 0.9	6.1 ± 0.4	5.0 ± 0.7	7.9 ± 0.7	5.7 ± 0.9	6.65 ± 0.59	5.80 ± 0.29	6.70 ± 0.62	5.91 ± 0.62	8.05 ± 0.91
$10^4 S^2$	1.2 ± 0.3	2.1 ± 0.5	0.94 ± 0.25	2.3 ± 0.7	0.57 ± 0.20	1.77 ± 0.44	2.90 ± 0.52	1.65 ± 0.36	1.51 ± 0.35	1.47 ± 0.24
$10^4 \Gamma_\gamma/D_0$	3.47 ± 0.15	101.3 ± 2.7	3.24 ± 0.15	59.5 ± 2.3	2.63 ± 0.11	9.11 ± 0.37	140.5 ± 3.8	7.35 ± 0.28	6.60 ± 0.28	4.40 ± 0.15
$\bar{\sigma}(\text{mb})^c$ (30 keV)	209	1011	189	1072	163	447	1189	382	345	264
		1097 ^d	314 ^d	984 ^d	177 ^d		1178 ^d			

a. Values in parentheses were assumed and not adjusted to the data by least squares.

b. Standard deviations derived from the fluctuations in the data by the fitting code are shown. The effect of overall uncertainties in cross section is not included. Correlation coefficients among the three adjusted parameters for the three even targets were less than 0.80 in absolute magnitude. For the four parameter sets of the odd targets values ranged up to 0.92.

c. The 30 keV average capture cross sections are those predicted from our fitted strength functions. Systematic uncertainties are estimated at 4% (Ru and Rh), and 5% (Pd).

d. Calculated value from Reference 1.

Figure Caption

Average neutron capture cross sections as histograms and fitted curves from least squares adjusted strength functions for samples of a) $^{100,101}\text{Ru}$, b) ^{102}Ru and ^{103}Rh , c) ^{104}Ru and ^{104}Pd , d) $^{105,106}\text{Pd}$, and e) $^{108,110}\text{Pd}$. The vertical arrows indicate thresholds for inelastic neutron scattering which often shows significant competition with neutron capture.

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