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REACTOR PRODUCTION AND CHARACTERIZATION OF CADMIUM-109

R. E. Lewis
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REACTOR PRODUCTION AND CHARACTERIZATION OF CADMIUM-109

R. E. Lewis and T. A. Butler

Isotopes Division

MAY 1968

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CONTENTS

	Page
Abstract	1
Introduction	1
Experimental	2
Reactor Irradiations	2
Recovery, Purification, and Assay of ^{109}Cd	2
Results	4
Cadmium-109 Cross Section	4
Cadmium-108 Cross Section	5
Characterization of ^{109}Cd Products	5
Conclusions	7

REACTOR PRODUCTION AND CHARACTERIZATION OF CADMIUM-109

R. E. Lewis and T. A. Butler

ABSTRACT

Two methods for production of ^{109}Cd were examined: neutron irradiation of enriched ^{108}Cd and natural silver. Effective neutron capture cross sections were determined to be 1.1 and 700 barns for ^{108}Cd and ^{109}Cd nuclides, respectively. The specific activity and the purity of the ^{109}Cd products obtained by both methods of preparation are compared.

The achievable specific activity of ^{109}Cd is greater when enriched ^{108}Cd is used as target material; however, traces of ^{115m}Cd produced from ^{114}Cd in the target material limit the usefulness of the product. Cadmium-109 prepared from silver is free of other radionuclides of cadmium.

The rate of production of ^{109}Cd from enriched ^{108}Cd and from natural silver and the chemical recovery and purification processes for each method of production are described.

INTRODUCTION

The long half-life (453 ± 2 d)[1] and low energy gammas (0.022 and 0.088 Mev) make ^{109}Cd especially attractive for use as a low photon energy radiographic source[2] material. In this as well as other applications, such as autoradiography[3,4] and mass, density, or thickness gaging,[5,6] high radionuclidic purity and high specific activity are desirable characteristics. Cadmium-109 is ordinarily produced by the reactor irradiation of enriched ^{108}Cd targets by the $^{108}Cd(n,\gamma)^{109}Cd$ reaction, but can be produced by neutron irradiation of natural silver in a reactor to produce ^{109}Cd by the reactions:

$$^{107}Ag(n,\gamma)^{108m}Ag \xrightarrow[\beta^-]{2.4\ min} {}^{108}Cd(n,\gamma)^{109}Cd.$$

The purpose of this work was to determine the effective reactor production rates of ^{109}Cd from enriched ^{108}Cd and from normal silver targets and to characterize the resultant products with respect to specific activity, isotopic composition, and radiochemical purity. In the course of this study, the cross section for the $^{108}Cd(n,\gamma)^{109}Cd$ reaction was confirmed because of wide variation in reported values,[7-10] and the previously unreported cross section for the $^{109}Cd(n,\gamma)^{110}Cd$ reaction was determined.

EXPERIMENTAL

Reactor Irradiations

Targets of enriched ^{108}Cd and natural silver were irradiated in the Oak Ridge Research Reactor (ORR). The enriched ^{108}Cd had an isotopic composition of 0.6% ^{106}Cd, 68.6% ^{108}Cd, 10.4% ^{110}Cd, 5.4% ^{111}Cd, 6.5% ^{112}Cd, 2.4% ^{113}Cd, 5.1% ^{114}Cd, and 1.1% ^{116}Cd. The target materials, CdO and 1-mil natural silver foil, were encapsulated in quartz ampules for irradiation. The thermal neutron flux was monitored with ^{59}Co (cross section, 37 barns). The results are given in Table 1.

Recovery, Purification, and Assay of ^{109}Cd

The ^{109}Cd produced from enriched ^{108}Cd contained small amounts of ^{60}Co, ^{65}Zn, ^{110m}Ag, and ^{115m}Cd. The impurities (exclusive of ^{115m}Cd) were effectively removed by chromatographic separation on a Dowex 50-X8 cation-exchange column. The cadmium and impurities were adsorbed on the resin from 0.1 M HCl solution. The cadmium was then selectively eluted with 50 ml of 0.2 M HCl (>95% chemical recovery).

Table 1. Experimental Yield of ^{109}Cd from Enriched ^{108}Cd and Natural Silver

Target, mg	Irradiation time,[a] days	^{109}Cd yield, mc	Neutron flux	$\bar{\sigma}$, barns[b] $^{108}Cd(n,\gamma)^{109}Cd$
CdO (68.6% ^{108}Cd)				
29	180	76.3	2.75×10^{14}	1.34
29	540	53.1	2.20×10^{14}	0.94
25	531	63.8	2.80×10^{14}	1.29
56	858	124.6	2.20×10^{14}	1.19
Natural Silver				
100	160	8.6	2.08×10^{14}	0.91
100	848	89.4	2.57×10^{14}	1.24
100	848	88.6	2.57×10^{14}	1.23
			average	1.1 ± 0.2 (S.D.)

[a]Days actually exposed to neutron flux, represents 80% of total time in reactor.

[b]The calculations of the effective cross sections of the $^{108}Cd(n,\gamma)^{109}Cd$ reaction were carried out on the Control Data 1604-A Computer using the ISOSEARCH computer code.[11] Corrections were made for the 700-b cross section of the $^{109}Cd(n,\gamma)^{110}Cd$ reaction.

The ^{109}Cd prepared from natural silver contained curie quantities of ^{110m}Ag and ^{111}Ag which were separated by solvent extraction. The irradiated silver target was dissolved in 25 ml of 8 M HNO_3, and the solution was contacted with 25 ml of 30% O'O'O'triisooctylphosphothionate-70% hexane. The organic phase extracts >99% of the silver and <0.1% of the cadmium.[12,13] The phases were separated and the extraction was repeated twice to remove the residual silver. The aqueous phase was washed twice with 25 ml of hexane to remove traces of the organic extractant and then evaporated to ~5 ml; 10 ml of 12 M HCl was added and the solution was heated to remove the HNO_3. The HCl solution was then evaporated to ~3 ml and diluted with distilled water to 0.1 N HCl. This solution was passed through on a column (8 mm by 15 cm) of Dowex 50-X8; the ^{109}Cd and the radionuclidic impurities sorb on the column. The ^{109}Cd was selectively eluted with 50 ml of 0.2 M HCl (>95% chemical recovery).

The ^{109}Cd products were assayed using a 200 channel gamma-scintillation spectrometer with a 3- x 3-in. NaI(Tl) crystal. The millicurie content of the sample was determined by gamma-ray spectrometry using a branching ratio of 0.039 (refs. 1,14) gamma photons of 0.088-Mev energy per disintegration. The specific activity of ^{109}Cd was determined by radiochemical analysis of a known weight of cadmium.

RESULTS

Cadmium-109 Cross Section

Three samples, each 1.12 mc of carrier-free ^{109}Cd produced by the cyclotron reaction $^{109}Ag(p,n)^{109}Cd$, were irradiated 7.37 days in a reactor neutron flux of 1.8×10^{14} n/cm^2.sec. The ^{109}Cd activity, corrected for

losses by radioactive decay, decreased on the average by 8.8 ± 1.3% of the original content indicating that the average value for the effective cross section of the $^{109}Cd(n,\gamma)^{110}Cd$ reaction is 700 ± 100 barns.

Cadmium-108 Cross Section

The experimental yields of ^{109}Cd from enriched ^{108}Cd and natural silver are shown in Table 1. From these data, the effective cross section of the $^{108}Cd(n,\gamma)^{109}Cd$ reaction is 1.1 ± 0.2 barns and is in fair agreement with a value of 1.41 ± 0.35 barns[10] reported by Mangal and Gill.

Characterization of ^{109}Cd Products

Cadmium-109 prepared from enriched ^{108}Cd also contains ^{115m}Cd due to the $^{114}Cd(n,\gamma)^{115m}Cd$ reaction. The purity of ^{109}Cd with respect to ^{115m}Cd depends on the amount of ^{114}Cd in the enriched ^{108}Cd target. In the ^{108}Cd sample used in this study, the ^{114}Cd content was 5.1%; after irradiation, the ^{115m}Cd activity was 12% of the ^{109}Cd activity.

The ^{109}Cd prepared from natural silver was found to be free of other cadmium radionuclides. Before purification, the irradiated target contained ^{109}Cd, ^{110m}Ag, and ^{111}Ag radionuclides, but the silver was readily separated from the cadmium by chemical processing.

The isotopic compositions of the ^{109}Cd products prepared from enriched ^{108}Cd and natural silver are compared in Table 2.

Table 2. Comparative Isotopic Compositions of Radiocadmium Produced by Reactor Irradiation of Enriched Cadmium-108 and Natural Silver

Mass number	Isotopic composition of radiocadmium, %	
	From natural Ag	From enriched ^{108}Cd
106	None	0.50
108	36.4	67.77
109	0.046[a]	0.1[a]
110	61.5	11.35
111	<2.0	5.42
112	<0.2	6.42
113	<0.2	<0.05
114	<0.2	7.50
116	<0.2	0.99

[a]Calculated from specific activity determination. The specific activity of the product obtained from enriched ^{108}Cd was 2.46 curies/g and that obtained from natural silver was 1.17 curies/g.

CONCLUSIONS

The specific activity of ^{109}Cd produced from enriched ^{108}Cd is greater for a given irradiation time and neutron flux than that of ^{109}Cd produced from natural silver. The specific activity of ^{109}Cd produced from enriched ^{108}Cd at a neutron flux of 2-2.7 x 10^{14} n/cm^2.sec is limited to ~2.5 curies/g of cadmium. The specific activity of ^{109}Cd produced from natural silver in the same neutron flux is limited to ~1.5 curies/g of cadmium because the rate of production of ^{110}Cd from ^{109}Ag is greater than the rate of production of ^{108}Cd from ^{107}Ag. The use of ^{107}Ag enriched to ~95% as the target material would increase the specific activity of ^{109}Cd to ~3 curies/g.

The yield of ^{109}Cd from the enriched ^{108}Cd target is greater for a given irradiation time and neutron flux than the yield from natural silver because the production of ^{108}Cd from ^{107}Ag proceeds by successive neutron captures. However, the cost of enriched ^{108}Cd (~$10.00/mg of 60-70% ^{108}Cd) compared with the cost of natural silver may make the irradiation of silver more economically desirable for production of multicurie quantities of ^{109}Cd.

The ^{109}Cd prepared from natural silver is preferred over that from enriched ^{108}Cd for use in radiography or for mass, density, or thickness gages because it is free of other radionuclides of cadmium.

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