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Production of Iron Nuclides in Thermal, Fission, and 14.1-MeV Neutron Sources

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PRODUCTION OF IRON NUCLIDES IN THERMAL,

FISSION, AND 14.1-MeV NEUTRON SOURCES

by

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ABSTRACT

The $^{56}Fe(n,2n)^{55}Fe$, $^{54}Fe(n,p)^{54}Mn$, and $^{54}Fe(n,\alpha)^{51}Cr$ cross sections at 14.1 MeV were measured. Also determined were the production of n,γ, n,p, and n,α reactions on iron due to degraded fission neutrons and n,γ production on iron in a thermal neutron source.

I. INTRODUCTION

A joint Los Alamos Scientific Laboratory (LASL)-McClellan Central Laboratory (MCL) experiment to determine the $^{56}Fe(n,2n)^{55}Fe$ and $^{54}Fe(n,p)$ ^{54}Mn cross sections at 14.1 MeV,relative to excitation functions used in interpretational work, was run under MCL calibration number 7804. As part of this joint experiment, the production of ^{55}Fe and ^{59}Fe due to n,γ reactions in iron were measured in fission spectrum and thermal neutron sources. Besides iron and manganese, atom ratios for several other neutron-induced activities were measured. Two types of iron foils were used in the experiments: (1) a very high purity Armco Fe (2) a 348 stainless steel. Irradiation of these two materials in a thermal flux allowed an estimate of the purity of the Armco Fe. The results are presented in sections based on the neutron source used for foil activation. Interpretation of results and conclusions are discussed in section V.

II. THERMAL NEUTRON IRRADIATION

On 20 March 1978 a 0.55-gram Armco Fe and a 0.27-gram 348 stainless steel foil were irradiated for 10 minutes in the LASL Omega West reactor thermal column rabbit, R-2, at a flux of approximately 6 x 10^{12} n/cm^{2}sec with a Cd ratio of 17.5. The foils were mounted on standard LASL counting plates and measured on Ge(Li) detectors #45 and #75. The Armco Fe foil was then sent to MCL,where it was also Ge(Li) counted. After whole-foil measurements, the foil was dissolved and nominal 10-mg samples of iron were mounted in standard MCL x-ray counting geometry. ^{55}Fe was measured on these chemically pure iron samples.* The results of all the measurements on both the Armco Fe and 348 stainless steel foils are presented in Table I. The Mn impurity in the Armco Fe foil was determined from this portion of the experiment to be 0.0014% by weight. Cr, Co, and Ni impurities were also observed with Ni being the highest:0.019% by weight.

III. BIG-10 CRITICAL ASSEMBLY IRRADIATION

On April 10-12 1978 two Armco Fe and two 348 stainless steel foils were irradiated at the Big Ten critical assembly at LASL. The total irradiation time of 2280 min produced a fluence of 10^{16}n/cm^2. The four foils were measured at LASL

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* The chemical purification used is outlined in the Appendix.

Table I

THERMAL NEUTRON IRRADIATION RESULTS

ARMCO Fe WEIGHT - 558.2 mg

Nuclide	LASL Atoms/mg Fe	MCL Atoms/mg Fe	Decay Constant (day^{-1})
^{55}Fe	----	5.589×10^{9} [a]	0.0006802
^{59}Fe	1.52×10^{8}	1.596×10^{8} [a]	0.01551
^{56}Mn	7.77×10^{6}		6.442
^{60}Co	8.74×10^{7}	8.30×10^{7}	0.000360
^{65}Ni	1.48×10^{5}		6.539
^{51}Cr	2.13×10^{5}		0.02493
	348 Stainless Steel Weight - 276.0 mg		
	LASL Atoms/mg Target		
^{59}Fe	1.01×10^{8}		0.01551
^{56}Mn	1.02×10^{10}		6.442
^{60}Co	2.10×10^{9}		0.000360
^{65}Ni	4.80×10^{7}		6.539
^{51}Cr	4.71×10^{9}		0.02493

[a]Separated sample measurements on historic basis.

via GeLi detector #75 prior to two of the foils being sent to MCL. The results of these measurements are presented in Table II.

IV. 14.1-MeV COCKROFT-WALTON IRRADIATION

On 21 March 1978 an Armco Fe, 348 stainless steel and 5 Al monitor foils were irradiated at the LASL Cockroft-Walton air-cooled target for 886.1 min. A standardized 90° angle between beam and sample with a stand-off distance of 2 cm produced an irradiation with 14.1-MeV neutrons. The prime Al monitor foils were placed at 10.0 cm. Using an $^{27}Al(n,\alpha)^{24}Na$ cross section of 122.3 mb, the average fluence measured in the Armco Fe foil was $2.098 \times 10^{13} c/cm^2$; the average fluence measured in the 348 stainless steel foil was 1.915×10^{13}. An apparent $^{27}Al(n,\alpha)^{24}Na$ cross section of 123.3 mb was obtained using the associated particle (α) monitor confirming a typical irradiation within customary experimental errors. The iron and stainless steel foils were measured on GeLi detectors #45 and #75 at LASL and then they were sent to MCL. The results of the LASL and MCL measurements are presented in Table III.

V. Based on the results presented in Tables I through III and the monitor foil measurements discussed in section 2, the cross sections and nuclide production from iron presented in Table IV were determined.

Table II

BIG-10 CRITICAL ASSEMBLY IRRADIATION RESULTS

ARMCO Fe WEIGHT 579.1 mg

Nuclide	LASL Atoms/mg Fe		MCL Atoms/mg Fe	AFTAC Atoms/mg Fe
	Foil 1	Foil 2	Foil 2	
^{55}Fe	---	---	7.751×10^{7}	7.828×10^{7}
^{59}Fe	1.526×10^{6}	1.546×10^{6}	1.574×10^{6}	1.432×10^{6}
^{54}Mn	8.02×10^{7}	7.98×10^{7}	6.261×10^{7}	5.823×10^{7}
^{51}Cr	8.69×10^{5}	8.47×10^{5}	9.656×10^{5} [a]	
^{58}Co	3.82×10^{5}	3.60×10^{5}	4.031×10^{5} [a]	

348 Stainless Steel Weight

Nuclide	LASL Atoms/mg Target		MCL Atoms/mg Target [a]
	Foil 1	Foil 2	Foil 2
^{59}Fe	1.058×10^{6}	1.038×10^{6}	1.129×10^{6}
^{54}Mn	5.306×10^{7}	5.340×10^{7}	5.747×10^{7}
^{51}Cr	1.162×10^{7}	1.162×10^{7}	1.319×10^{7}
^{57}Co	2.848×10^{5}	2.858×10^{5}	3.250×10^{5}
^{58}Co	1.325×10^{8}	1.375×10^{8}	1.486×10^{8}
^{60}Co	2.80×10^{6}	2.97×10^{6}	3.33×10^{6}

[a]Whole-foil measurements on absolute basis.

Table III

14.1-MeV COCKROFT-WALTON IRRADIATION RESULTS

ARMCO Fe WEIGHT 547.4 mg

Nuclide	LASL Atoms/mg Fe	MCL Atoms/mg Fe	AFTAC Atoms/mg Fe
^{55}Fe	----	7.264×10^{7} [a]	7.336×10^{7}
^{54}Mn	4.37×10^{6}	3.710×10^{6} [a]	3.65×10^{6}
^{51}Cr	1.048×10^{6}	1.176×10^{6}	
^{58}Co	2.53×10^{4}	2.48×10^{4}	

348 Stainless Steel Weight 277.2 mg

	LASL Atoms/mg Target	MCL Atoms/mg Target[b]
^{54}Mn	5.49×10^{6}	5.61×10^{6}
^{51}Cr	9.37×10^{6}	9.86×10^{6}
^{57}Co	8.42×10^{6}	9.27×10^{6}
^{58}Co	5.33×10^{6}	5.71×10^{6}

[a]Separated samples measurements on historic basis.

[b]Whole-foil measurements on absolute basis.

Table IV

IRON CROSS SECTIONS AND PRODUCTION RATE RATIOS

14.1 MeV - LASL Cockroft-Walton with $^{27}Al(n,\alpha)^{24}Na$ monitor

$^{54}Fe(n,p)^{54}Mn^{a}$ $\sigma_{14.1}$ = 260 mb versus 357 evaluated

$^{54}Fe(n,p)^{54}Mn^{b}$ $\sigma_{14.1}$ = 350 mb

$^{54}Fe(n,p)^{54}Mn^{d}$ $\sigma_{14.1}$ = 331 mb

$^{56}Fe(n,2,)^{55}Fe^{a}$ $\sigma_{14.1}$ = 349 mb versus 441 evaluated

$^{54}Fe(n,\alpha)^{51}Cr^{b}$ $\sigma_{14.1}$ = 89 mb

$^{54}Fe(n,\alpha)^{51}Cr^{d}$ $\sigma_{14.1}$ = 79.4 mb

$$^{54}Mn/^{55}Fe = \frac{0.0584}{0.9168}\ \frac{260}{349} = 0.0475$$

$$^{51}Cr/^{54}Mn = \frac{89}{260} = 0.342$$

Degraded fission spectrum - LASL BIG-10 critical assembly

$$\frac{\sigma\ ^{54}Fe(n,p)^{54}Mn^{a}}{\sigma\ ^{58}Fe(n,\gamma)^{59}Fe^{a}} = 2.6 \qquad \frac{^{54}Mn}{^{59}Fe} = \frac{0.0584}{0.0031}\ 2.16 = 40.7$$

$$\frac{\sigma\ ^{54}Fe(n,\gamma)^{55}Fe^{a}}{\sigma\ ^{58}Fe(n,\gamma)^{59}Fe^{a}} = 2.79 \qquad \frac{^{55}Fe}{^{59}Fe} \geqslant \frac{0.0584}{0.0031}\ 2.79 \geqslant 52.6 \ (\Rightarrow 54.7 \text{ for BIG-10})$$

$$\frac{\sigma\ ^{54}Fe(n,\alpha)^{51}Cr^{b}}{\sigma\ ^{54}Fe(n,p)^{54}Mn^{a}} = 0.0166 \qquad \frac{^{51}Cr}{^{54}Mn} = 0.0166$$

Thermal - LASL Omega West reactor

$$\frac{\sigma\ ^{54}Fe(n,\gamma)^{55}Fe^{a}}{\sigma\ ^{58}Fe(n,\gamma)^{59}Fe^{a}} = 2.06^{c} \qquad \frac{^{55}Fe}{^{59}Fe} = \frac{0.0584}{0.0031}\ 2.06 = 38.8$$

[a]"AFTAC" historical atom scale.
[b]MCL "absolute" atom scale Ge(Li).
[c]The accepted value for this result is 1.96 (BNL-325).
[d]LASL "absolute" atom scale Ge(Li).

APPENDIX

The iron foils were dissolved in concentrated hydrochloric acid (HCl), containing a few drops of concentrated nitric acid (HNO_3). The solution was diluted to known volume with two molar HCl and aliquots were taken for iron and manganese analyses. Manganese carrier plus microgram quantities of cobalt, chromium, and nickel were added to each aliquot. Each aliquot was taken to low volume, diluted with six molar HCl, and extracted with diethyl ether. The organic phase containing iron was back-extracted with water, precipitated as the hydroxide, dissolved in concentrated HCl and adsorbed on a Dowex 1 x 8 (50-100 mesh) ion exchange column. Iron was eluted with dilute HCl, precipitated as the hyroxide, and mounted by electroplating on a platinum disk.

The aqueous phase containing the manganese was converted from HCl to an HNO_3 medium. Manganese was then precipitated as manganese oxide (MnO_2), dissolved in HCl, scavenged with cobalt, copper, nickel, and iron sulfides, and then precipitated as manganese sulfide from basic medium. The precipitate was dissolved in dilute HNO_3, filtered, and then precipitated as manganese ammonium phosphate ($MnNH_4PO_4$), which was ignited to convert to manganese pyrophosphate ($Mn_2P_2O_7$) for mounting.