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COMPUTED 14 MeV PARTIAL NEUTRON CROSS-SECTIONS OF ^{55}Mn FOR TRACE ELEMENTAL ANALYSIS OF HUMAN BLOOD AND HAIR

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The partical cross-sections of ^{55}Mn like (n, n'); (n, p); (n, α); $(n, 2n)$; (n, np); $(n na)$; (n, pn); $(n, 2p)$; $(n, p\alpha)$; $(n, \alpha n)$: $(n, \alpha p)$ and $(n, 2\alpha)$ with 14 MeV neutrons have been computed here, using diffused edge, spin-dependent optical model potential parameters. Recent shell-dependent Newton's level density formula has been used here for the computation of level densities. The computed partial neutron cross-sections are in good agreement with the available experimental values around 14 MeV neutron energy. The computed cross-sections (n, p) and (n, α) are quite suitable for trace elemental analysis of biological samples like hair, blood and if possible adrenals, aorta, ovaries, pancreas, prostate, lymph nodes, spleen, testes, liver, kidey, brain, heart, lung, skeletal muscle, bone, skin etc. The induced beta or gamma activity for ^{55}Mn (n, p) ^{55}Cr* and ^{55}Mn (n, α) ^{52}V* with T1/2 = 3.6 min and 3.75 min respectively, per gram of the above biological samples per unit neutron flux have been computed and tabulated here.

Key Words : Partial Cross-sections; Trace Elemental Analysis; Biological Samples; Human Hair and Blood; Optical Model Potential; Neutron Flux-induced Activities

INTRODUCTION

AT 14 MeV neutron energy, primary partial reaction cross-sections like (n, n'); (n, p); (n, α) are quite prominent. Partial secondary reaction cross-sections like $(n, 2n)$; (n, np); $(n, n\alpha)$; (n, pn); $(n, 2p)$; $(n, p\alpha)$; $(n, \alpha n)$; $(n, \alpha p)$ and $(n, 2\alpha)$ are significant and some have fairly large cross-sections. All primary and secondary partial cross-sections are listed in Table I. For the computation of these cross-sections, the compound nucleus theory based on Fermi gas and evaporation models with optical model potential has been used. These computed partial cross-sections can be used to estimate the value of induced β or γ-activity per unit neutron flux per gram of various biological samples of humans for trace

TABLE I

Computed ^{55}Mn Partial Reaction Cross-Sections for 14 MeV Neutrons

Sr. No.	Nuclear Reaction	Q-Valve (MeV)	Computed Cross-sections (mbs)	Available Experimental Cross sections (mbs)
1.	^{55}Mn (n, n') ^{55}Mn	0	1245.3	—
2.	^{55}Mn (n, 2n) ^{54}Mn*	−10.227	232.1	—
3.	^{55}Mn (n, np) ^{54}Cr*	− 8.068	430.2	—
4.	^{55}Mn (n nα) ^{51}V*	− 7.936	~ 0	—
5.	^{55}Mn (n, p) ^{55}Cr*	− 1.810	48.68	43 ± 7
6.	^{55}Mn (n, pn) ^{54}Cr*	− 6.246	1.47	—
7.	^{55}Mn (n, 2p) ^{54}V*	−12.460	~ 0	—
8.	^{55}Mn (n, pα) ^{51}Ti*	− 7.800	~ 0	—
9.	^{55}Mn (n, α) ^{53}V*	− 0.630	43.02	34 ± 5
10.	^{55}Mn (n, αn) ^{52}V*	− 7.311	< 1	—
11.	^{55}Mn (n, αp) ^{51}Ti*	− 8.995	~ 0	—
12.	^{55}Mn (n, 2α) ^{48}Sc*	− 9.366	~ 0	—

elemental analysis of hair, blood (serum, RBC) samples in human subjects and aborted foetuses and cadavers in clinical research.

The body of a normal man is estimated to contain a total of 12–20 mg Mn, Underwood.[1] Manganese is distributed widely throughout the tissues and fluids without any notable concentration in any particular location and with a comparatively little variation among organs or species or with age in the body. Underwood,[1] has listed the Mn concentration in man tissues in ppm on fresh basis as adrenals 0.20, aorta—0.19, heart 0.23, Pancreas—1.21, Prostate—0.24, spleen—0.22, liver—0.68. brain—0.20 ± 0.03, kidney—1.30 ± 0.5, lung—2 ± 00.3, muscle—0.04 ± 0.007, ovaries—0.7 ± 0.3, nodes—1.1 ± 0.6 and testes—0.1 ± 0.04. Casey ane Robinson[2] gave concentration of manganese (μg/g) in human foetal tissues, liver—4.26 ± 1.57, kidney—2.36 ± 0.52, brain—1.58 ± 0.23, hair—1.29 ± 0.34, lung—1.24 ± 0.43, skeletal muscle—0.67 ± 0.16 and bone—2.25 ± 0.54. It is apparent from the above data that liver, kidney, bone and pancreas carry higher Mn concentration than other organs and the muscle are among the lowest in this element of the tissues in the body.

Prasad[3] the Mn content in whole blood ranges from 8.44 ± 2.73 to 9.84 ± 0.4μg/litre and in serum concentration is 1.242 ± 0.2μg/litre and the level in red cells is 23.57 ± 1.2μg/litre. Serum manganese is increased following acute coronary conclusion. An increased concentration of manganese in red cell has been observed in patient with rheumatoid arthritis.

Gibson[4] and Soythes[4] reported the changes in hair manganess levels with the age in normal children in ppm as Neonates; (just born)—0.19, 1 month—0.80, 3—months—0·94, 6 months—0.52 and 0—15 years—0.56. But according to Collipp *et al.*[5] the concentration of manganese in the hair of normal new born infants was found to increase significantly from 0.19μg/g at birth to 0.965μg/g at six weeks of age and 0.685μg/g at four months when they were fed infant formula feed. There was an insignificant increase to 0.330μg/g at age 4 months in breast fed infants. After this age there was a slow decline in hair manganese to 0.268μg/g in normal children at age of 8 years and 0.434μg/g in learning disabled hyperactive children. It was noted that hair manganese concentration level in infants rises in first 3 months but decline in the next three months. The rise in hair manganese level may result from a redistribution after birth derived from the body stores.

Underwood[1] has informed that chronic manganese poisoning occurs among miners, working with manganese ores. Excess manganese enters the lungs as oxide dust and also enters the body *via* the gastrointestinal tract from the contaminated environment. Manganese poisoning is characterized by a severe psychiatric disorder resembling schizophrenia, followed by a permanently crippling neurological disorder clinically similar to Parkinson's disease.

Manganese deficiency in man has been reported in association with vitamin K deficiency.[3] Metabolism of manganese is also abnormal in thyroid disease. A decrease in serum cholesterol, triglyceride and phospholipids was also noted in the manganese-deficient human subject, the decrease was corrected by manganese the supplimentation. Iyenger[6] reported that the estimated range of adequate and safe intake of manganese is 2.5mg per day per adult.

Calculations, Results and Discussion

Wadhwa and Mohindra[7] have described the formulae for theoretical computation of primary and secondary reaction cross-sections, which are based on compound nucleus model using the optical model potential parameters given by Mani *et al.*[8] for proton and neutron penetrabilities. For alpha-induced inverse reaction cross-sections, Huizenga and Igo[9] listed the inverse reaction cross-sections. Shell-dependent level density formula due to Newton as discussed by Wadhwa, Manocha and Mohindra[10] has been used here for these computations. The formulae used for secondary cross-sections based on the evaporation theory, have been reported earlier by Wadhwa and Mohindra.[7] The gamma ray emission has been ignored in competition to the particle emission in these computations. The *Q*-values and separation energies tabulated by Wapstra and Bos[11] have been used. The computed partial reaction cross-sections at 14 MeV neutron energy are listed in Table I alongwith a few available experimental cross-sections of Borman *et al.*[12] for comparison and these are in fairly good agreement.

The induced β-activity[13,14] in micro-Curies per unit neutron flux per gram of the biological samples containing ^{55}Mn for the experimental investigations is given by the relation :—

$$\frac{0.693 \times \text{Number of atoms of Mn} \times [\sigma(n,p) \text{ or } \sigma(n,\alpha)\ (\text{cm}^2)] \times \text{Isotopic abundance}}{3.7 \times 10^4 \times T^{1/2}\ (\text{seconds})},$$

where $T^{1/2}$ is the physical half life of the residual nuclei $^{55}Cr^*$ ($=3.6$ min) and $^{52}V^*$ ($=3.75$ min). This gives very nearly the saturation activity of the radioactivity produced in 6 or 7 half lives.

Out of various possible reactions listed in Table I, the reactions ^{55}Mn (n, p) $^{55}Cr^*$ with $\sigma(n, p) = 48.68$ mbs and ^{55}Mn (n, α) $^{52}V^*$ with $\sigma(n, \alpha = 43.02$mbs are the most suitable for the ^{55}Mn trace elemental analysis of the human biological samples. The computed induced β-activities of human biological samples are listed in Tables II to V. The computed activities in micro-Curies per gram per unit neutron flux seem sufficient for the experimental investigations with 14 MeV neutron generator having fluxes of the order of 10^8 to 10^{10} neutrons per cm^2 per second.

TABLE II

Computed induced β-activity for ^{55}Mn (n, p) $^{55}Cr^*$ and ^{55}Mn (n, α) $^{52}V^*$ in fresh human samples

Sl. No.	Organ or Tissue	Manganese (ppm)	Induced β-activity produced (μC/Unit flux/g)	
			(n, p) reaction	(n, α) reaction
1.	Adrenals	0.20	9.245×10^{-18}	7.843×10^{-18}
2.	Aorta	0.19	8.783×10^{-18}	7.451×10^{-18}
3.	Heart	0.23	10.632×10^{-16}	9.02×10^{-18}
4.	Pancreas	1.21	55.932×10^{-18}	47.453×10^{-18}
5.	Prostate	0.24	11.094×10^{-18}	9.412×10^{-18}
6.	Spleen	0.22	10.170×10^{-18}	8.628×10^{-18}
7.	Liver	1.68	77.658×10^{-18}	65.885×10^{-18}
8.	Brain	0.20 ± 0.03	$(9.245 \pm 1.387) \times 10^{-18}$	$(7.843 \pm 1.177) \times 10^{-18}$
9.	Kidney	1.30 ± 0.50	$(60.093 \pm 23.113) \times 10^{-18}$	$(50.982 \pm 19.609) \times 10^{-18}$
10.	Lung	0.20 ± 0.03	$(9.245 \pm 1.387) \times 10^{-18}$	$(7.843 \pm 1.177) \times 10^{-18}$
11.	Muscle	0.04 ± 0.007	$(1.849 \pm 0.324) \times 10^{-18}$	$(1.569 \pm 0.025) \times 10^{-18}$
12.	Ovaries	0.70 ± 0.30	$(32.358 \pm 13.868) \times 10^{-18}$	$(27.452 \pm 11.765) \times 10^{-18}$
13.	Nodes	1.10 ± 0.60	$(50.848 \pm 27.735) \times 10^{-18}$	$(43.139 \pm 23.530) \times 10^{-18}$
14.	Testes	0.10 ± 0.04	$(4.623 \pm 1.849) \times 10^{-18}$	$(3.922 \pm 1.569) \pm 10^{-18}$

In humans, gross-deficiency in many of the trace elements are highly unlikely whereas marginal deficiencies might be quite widespread subsequently raising the question of their impact on various chronic diseases, organ damage, due to changes in specific proteins etc. The marginal deficiencies of excess which can occur frequently, often escape recognition. Sophisticated procedures are required for their identification. Therefore, there is pressing need to develop a reliable and simple diagnostic procedure to assess the trace element nutritional status of individuals, which can be done by monitoring the trace element like Mn profiles in suitable clinical samples. Also, for fission and fusion reactors, these computed partial cross-sections listed here can play useful role in several nuclear designs, radiation damage and shielding problems at low energies in the range of 5 to 20 MeV.

TABLE III

Computed induced β-activity for ^{55}Mn (n, p) $^{55}Cr^*$ and ^{55}Mn (n, α) $^{52}V^*$ In human foetal tissues (dry matter)

S. No.	Tissue	Manganese content (μg/g)	Induced β-activity Produced (μC/Unit flux/g) (n, p) reaction	(n, α) reaction
1.	Liver	4.26 ± 1.57	(196.919 ± 72.573) × 10^{-18}	(167.064 ± 61.571 × 10^{-18}
2.	Kidney	2.36 ± 0.52	(109.091 ± 24.037) × 10^{-18}	(92.552 ± 20.393) × 10^{-18}
3.	Brain	1.58 ± 0.23	(73.036 ± 10.632) × 10^{-18}	(61.963 ± 9.02) × 10^{-18}
4.	Heart	1.29 ± 0.34	(59.630 ± 15.717) × 10^{-18}	(50.59 ± 13.334) × 10^{-18}
5.	Lung	1.24 ± 0.43	(57.319 ± 19.877) × 10^{-18}	(48.629 ± 16.863) × 10^{-18}
6.	Skeletal Mucle	0.67 ± 0.16	(30.971 ± 7.396) × 10^{-18}	(26.276 ± 6.275) × 10^{-18}
7.	Bone	2.25 ± 0.54	(104.006 ± 24.962) × 10^{-18}	(88.238 ± 21.177) × 10^{-18}

TABLE IV

Computed induced β-activity for ^{55}Mn (n, p) $^{55}Cr^*$ and ^{55}Mn (n, α) $^{52}V^*$ in human hair

S. No.	Age	Manganese content μg/g	Induced β-activity produced (μC/Unit flux/g) (n, p) reaction	(n, α) reaction
1.	Neonates (b)	0.19	8.783 × 10^{-18}	7.451 × 10^{-18}
2.	1 month (b)	0.80	36.98 × 10^{-18}	31.374 × 10^{-18}
3.	6 Weeks (a)	0.965 ± 0.39	(44.607 ± 18.028) × 10^{-18}	(37.844 ± 15.295) × 10^{-18}
4.	3 Months (b)	0.94	43.452 × 10^{-18}	36.864 × 10^{-18}
5.	4 Months (a) (infant feed)	0.685 ± 0.26	(31.664 ± 12.09) × 10^{-18}	(26.864 ± 10.196) × 10^{-18}
6.	4 Months (a) (breast fed)	0.330 ± 0.15	(15.254 ± 6.934) × 10^{-18}	(12.942 ± 5.883) × 10^{-18}
7.	6 Months (b)	0.52	24.037 × 10^{-18}	20.393 × 10^{-18}
8.	9 Months (a)	0.587 ± 0.35	(26.811 ± 16.179) × 10^{-18}	(23.02 ± 13.726) × 10^{-18}
9.	3 Years (a)	0.398 ± 0.21	(18.392 ± 9.707) × 10^{-18}	(15.608 ± 8.236) × 10^{-18}
10.	7/10 years Normal (a)	0.268	12.388 × 10^{-18}	10.510 × 10^{-18}
	,, Disabled (a)	0.434	20.062 × 10^{-18}	17.020 × 10^{-18}

(a) Collipp *et al.* (3)
(b) Gibson (4)

For the measurement of such activities, one can use online system for the gamma rays accompanying the beta emission which starts detecting automatically as the 14MeV neutron beam is switched off. A high resolution Ge(Li) detector for gamma rays of about 60 cc volume with multi-chemical analyser and associated electronic circuity will be ideal. One can also use e. g., for counting betas by any beta detector Si(Li) or G.M. counter with thin window. The hair

TABLE V

Computed induced β-activity for ^{55}Mn (n, p) $^{55}Cr^*$ and ^{55}Mn (n, α) $^{52}V^*$ In dry tissues of children who died as a result of marasums, marasmic kwashiorkor, kwashiorkor and from other causes (controls)

S. No.	Organ or Tissue	Manganese content (μg/g)	Induced β-activity (μC/Unit flux/g (n, p) reaction	Induced β-activity (μC/Unit flux/g (n, α) reaction
Marsums				
1.	Liver	6.3 ± 1.8	(291.218 ± 83.205) × 10^{-18}	(247.067 ± 70.591) × 10^{-18}
2.	Heart	3.1 ± 0.9	(143.298 ± 41.603) × 10^{-18}	(121.573 ± 35.295) × 10^{-18}
3.	Muscle	2.1 ± 0.4	(97.073 ± 18.49) × 10^{-18}	(82.356 ± 15.687) × 10^{-18}
4.	Skin	2.0 ± 0.3	(92.45 ± 13.868) × 10^{-18}	(78.434 ± 11.765) × 10^{-18}
Marasmic-Kwashiorkor				
1.	Liver	6.1 ± 4.0	(281.973 ± 184.9) × 10^{-18}	(239.224 ± 156.868) × 10^{-18}
2.	Heart	2.8 ± 0.6	(129.43 ± 27.735) × 10^{-18}	(109.808 ± 23.53) × 10^{-18}
3.	Muscle	2.2 ± 0.3	(101.695 ± 13.868) × 10^{-18}	(86.277 ± 11.765) × 10^{-18}
4.	Skin	1.8 ± 0.8	(83.205 ± 36.98) × 10^{-18}	(70.591) ± 31.374) × 10^{-18}
Kwashiorkor				
1.	Liver	3.8 ± 1.3	(175.655 ± 60.093) × 10^{-18}	(149.02 ± 50.982) × 10^{-18}
2.	Heart	3.7 ± 0.9	(171.033 ± 41.603) × 10^{-18}	(145.103 ± 35.295) × 10^{-18}
3.	Muscle	4.2 ± 0.9	(194.145 ± 41.603) × 10^{-18}	(164.711 ± 35.295) × 10^{-18}
4.	Skin	5.2 ± 2.0	(240.37 ± 92.45) × 10^{-18}	(203.928 ± 78.434) × 10^{-18}
Controls				
1.	Liver	7.1 ± 0.8	(328.198 ± 36.98) 10^{-10}	(278.441 ± 31.374) × 10^{-18}
2.	Heart	7.1 ± 2.7	(328.198 ± 124.808) × 10^{-18}	(278.441 ± 105.886) × 10^{-18}
3.	Muscle	4.8 ± 1.3	(221.88 ± 60.093) × 10^{-18}	(188.242 ± 50.982) × 10^{-18}
4.	Skin	3.1 ± 0.4	(143.298 ± 18.49) × 10^{-18}	(121.573 ± 15.687) × 10^{-18}

samples can be prepared by making thin pallelets of hair-ash for both beta or gamma activities. The blood samples can be taken in thin plastic capsules for measuring only the gamma rays.

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