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Expected yield of iodine-123 radionuclides from trillium isotopes in the intermediate energy range (20-100) MeV for protons.

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Abstract :

In medical applications, radionuclides are categorized as either diagnostic or therapeutic based on their decay characteristics. Radioactive ^{123}I is one such nuclide; it is a gamma radioactive isotope employed in the diagnostic imaging of thyroid tissue. With a half-life of 13.22 hours, various production methods were explored, such as cyclotron usage for proton irradiation of selected trillium isotopes (^{123}Te, ^{124}Te, ^{125}Te). This research aims to investigate the most favorable interactions and energies to achieve the best outcomes. Reaction cross sections were derived from the TENDL-2021 nuclear data library. The stopping power and total isotope production calculations employed different software tools, namely SRIM and MATLAB, after interpolating data based on established experimental results from international laboratories. It was determined that the ^{124}Te(p,2n)^{123}I reaction is ideal for ^{123}I production and the optimal proton energy range for producing ^{123}I is Ep = (20-100) MeV, which aligns with previously published findings.

Keyword: Radionuclides, Isotopes, Cross-Section, Stopping Power.

الناتج المتوقع لنويدات اليود 123 المشعة من نظائر التريليوم في نطاق الطاقة المتوسطة (20-100) مليون إلكترون فولت للبروتونات

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مستخلص :

في التطبيقات الطبية، يتم تصنيف النويدات المشعة إما تشخيصية أو علاجية بناءً على خصائص اضمحلالها. المشع ^{123}I هو أحد هذه النويدات؛ وهو أحد نظائر غاما المشعة المستخدمة في التصوير التشخيصي لأنسجة الغدة الدرقية. مع عمر نصف قدره 13.22 ساعة، تم استكشاف طرق إنتاج مختلفة، مثل استخدام السيكلوترون لتشعيع البروتون لنظائر التريليوم المختارة (^{123}Te ، ^{124}Te، ^{125}Te). ويهدف هذا البحث إلى دراسة التفاعلات والطاقات الأكثر ملاءمة لتحقيق أفضل النتائج. تم استخلاص المقاطع العرضية للتفاعل من مكتبة البيانات النووية TENDL-2021. استخدمت حسابات قدرة الإيقاف وإجمالي إنتاج النظائر أدوات برمجية مختلفة، وهي SRIM و MATLAB، بعد استيفاء البيانات بناءً على النتائج التجريبية المثبتة من المختبرات الدولية. تم تحديد أن تفاعل ^{124}Te(p,2n)^{123}I مثالي لإنتاج ^{123}I وأن نطاق طاقة البروتون الأمثل لإنتاج ^{123}I هو Ep = (20-100) MeV، والذي يتوافق مع النتائج المنشورة مسبقًا.

الكلمة المفتاحية : النويدات المشعة ، النظائر ، المقطع العرضي ، قوة الايقاف.

1-Introduction

Prior research in this domain includes a study conducted by K. Kondo, R. M. Lambrecht, and A. P. Wolf [1], who discovered that using the ^{124}Te (p, 2n) ^{123}I reaction on ultra-highly enriched ^{124}Te is an effective and cost-efficient method for producing high-purity ^{123}I via cyclotrons with minimal particle energies. Additionally, a study by Rıdvan Unal and Ufuk Akcaalan[2] focused on bombarding isotopes $^{123\text{-}124\text{-}125}$Te with protons to generate radioisotopes $^{123\text{-}124}$I, commonly utilized in medical applications. The study found that the production of ^{123}I can be achieved through a highly enriched ^{124}Te(p,2n)^{123}I reaction, resulting in a significant level of on-target enrichment.

The ongoing advancement of nuclear medicine is reliant on the availability of radionuclides. With increasing cancer rates, various methods have been developed to create radionuclides for diagnostic and therapeutic purposes[3]. One such nuclide is ^{123}I, which undergoes decay through electron capture.

$$^{123}_{52}I + ^{0}_{-1}e \rightarrow ^{123}_{51}Te + \gamma \quad \dots\dots..(1)$$

The ^{123}I isotope has a half-life of 13.2 hours, primarily emitting 159-keV photons with an abundance of 83.4%, making it ideal for gamma camera imaging. This isotope is better suited for regular nuclear medicine imaging procedures, such as examining the thyroid, due to its reduced internal impact on patients. When dealing with ^{123}I, gamma rays are generated, and these gamma radiations are discharged from the ^{123}I nucleus as highly energetic rays with extremely short wavelengths.

Gamma rays possess the ability to penetrate the human body without making tissues radioactive, but they can cause significant harm to human tissues and are the primary reason for radiation illness. In the case of isotope ^{123}I, its short half-life ensures that tissues are not exposed to an excessive amount of gamma rays. Occasionally, isotopes ^{124}I and ^{125}I are also utilized in medical practices[4]. Isotope ^{123}I releases a minimal amount of high-energy emissions[5]. Moreover, this low-energy isotope emits numerous electrons upon its breakdown, but it does not inflict severe damage to cells[6].

Furthermore, ^{123}I plays a significant role not just in SPECT-type thyroid examinations but also in cardiac studies and monitoring hormone metabolism, such as adrenaline in the heart muscle. This assists in acquiring and ultimately selecting more precise diagnoses, leading to improved treatments for patients with arrhythmias or coronary artery issues.

Moreover, ^{123}I is becoming increasingly vital in neurological research, particularly when tracking patients with suspected Parkinson's disease and differentiating Alzheimer's disease from dementia cases[7]. There is considerable potential for growth and development in these latter two areas. The objective of this study focused on presenting trustworthy nuclear interactions between protons and trillium isotopes within the energy range of (20 – 100) MeV, consequently enhancing the dependability of the existing literature database.

2-Experimental

The data on cross-sections (C.S) of target elements was gathered to assess their productivity and effectiveness. The TENDL-2021 Nuclear data library[8] provided the cross-sectional information for reactions $^{123}Te(p,n)^{123}I$, $^{124}Te(p,2n)^{123}I$, and $^{125}Te(p,3n)^{123}I$. The energy range was finely divided into 2 MeV steps, covering 20 to 100 MeV.

As charged particles travel through matter, they lose energy by ionizing atoms and causing excitation [9]. Stopping power (SP) is the average loss of energy per unit path length dE/dx. It varies based on the projectile's charge, velocity, and target material [10,11]. SP (E), measured in MeV/(mg/cm²), represents the term dE/dx at a specific energy E and is calculated using a specific formula [12].

$$S_P(E)=\frac{dE}{dX} \quad \ldots\ldots\ldots\ldots 2$$

Where:

dE : the differential loss in energy.

dx : the differential distance travelled by the particle.

The determination of stopping power employed the Zickler formula, in accordance with the SRIM[13]. By utilizing cross-section data, stopping force, and relevant energies, a sufficiently thick target with one atom per molecule results in a yield referred to as target thickening yield. This is computed using MATLAB software (7.8 2009a), as derived from the subsequent equation [14]:

$$y = \frac{N_L H}{M} I(1 - e^{-\lambda t} \int_{E_1}^{E_2} (\frac{dE}{d(\rho X)})^{-1} \sigma(E) dE \ldots. (3)$$

Where

Y : activity (in Bq) of the product.

NL : Avogadro number.

H : isotopic abundance of the target nuclide.

M : mass number of the target element.

I : projectile current dE/d(ρx) is the stopping power.

Σ (E) : (C.S) cross section at energy E.

3-Results And Discussion

In order to understand the nuclear reaction mechanism, we must examine the theoretical cross-sectional data of three different models, namely ^{123}Te (p,n)^{123}I, ^{124}Te(p,2n)^{123}I, and ^{125}Te(p,3n)^{123}I. For the most effective outcome, a thorough investigation of all potential production methods is essential in order to select the best energy range and reaction. It is evident that nuclear data holds significant value in this respect.

As demonstrated in Figure 1, by comparing these reactions' cross-sections, it is apparent that the ^{124}Te(p,2n)^{123}I reaction is most suitable for creating ^{123}I. Furthermore, it reveals that the most effective proton energy range for generating ^{123}I falls between Ep = (20 – 100) MeV. This observation aligns with previously published findings [1, 2].

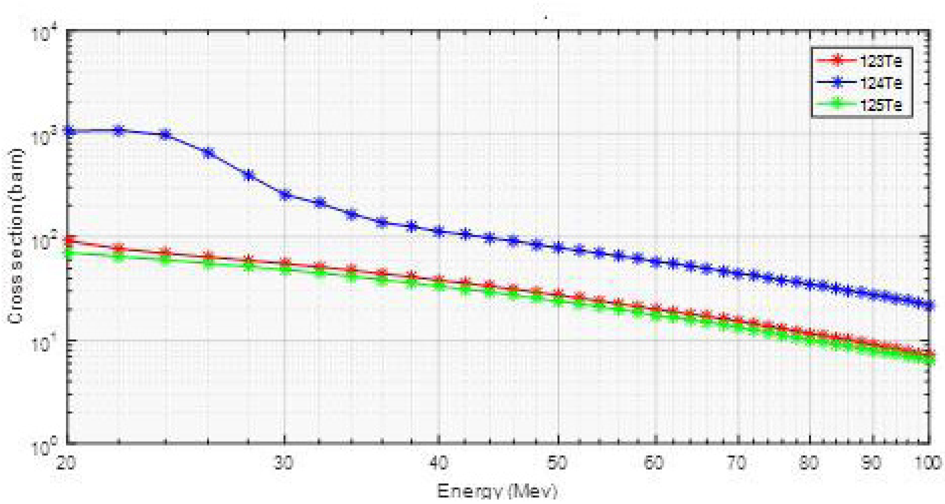

Fig. 1 Excitation function of the ^{123}Te(p,n)^{123}I,^{124}Te(p,2n)^{123}I,^{125}Te(p,3n)^{123}I process

The energy stopping capacity between 20KeV and 100MeV has been determined using the SRIM code. The overall stopping ability for the trio of reactions correlates with the energy of the incoming proton. It experiences a swift increase when maximizing minimal energy, and then it tapers off as energy levels rise. High-energy particles undergo a minuscule energy loss, represented by dE/dx. This is evident in Figure 2.

Fig.2 illustrates the proton stopping capacity for targets ($^{123-124-125}$Te) within the energy range (20-100)MeV.

The substantial

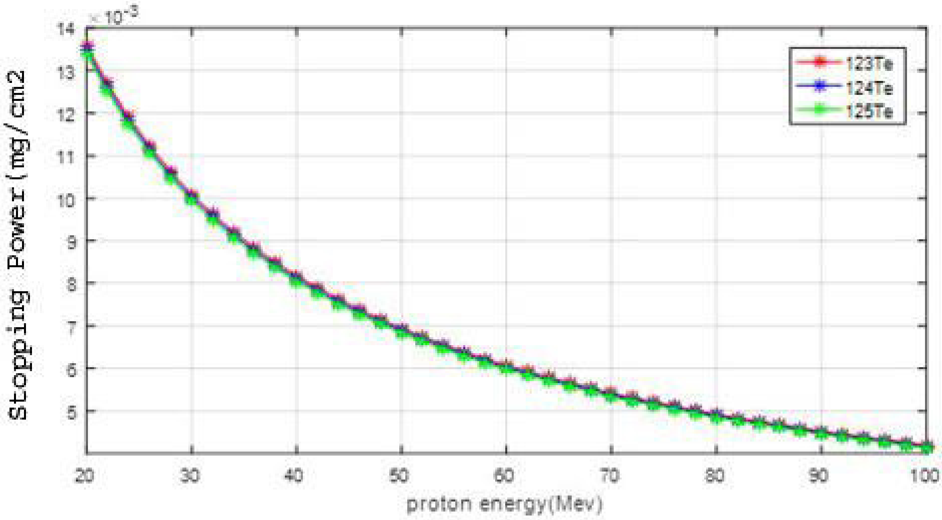

Fig.2 The stopping power of a proton for targets ($^{123-124-125}Te$) at the energy range (20-100)MeV

The MATLAB program was employed to assess the yield for three distinct reactions. As illustrated in Figure 3, the $^{124}Te(p,2n)^{123}I$ reaction demonstrates a higher yield production compared to the other two reactions.

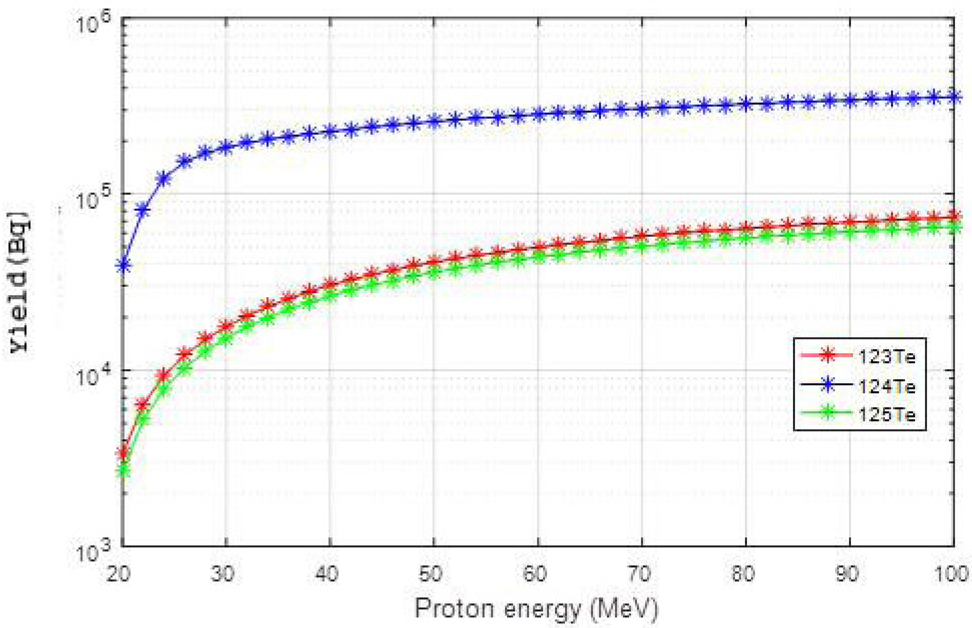

Fig. 3 The yields as a function of incident proton energy on $^{123-124-125}Te$

4-Conclusions

In the production of medical radionuclides using a cyclotron, analyzing cross-section data is crucial, as it involves not just the required interactions for calculating the integrated yield, but also other competing reactions. This study extensively evaluates all available and relevant proton-trillium reaction data for producing ^{123}I, as demonstrated in Table 1. Tellurium serves as the initial element in the reaction and is one of the target material options used to obtain ^{123}I. The most suitable pathway for this process is the reaction $^{124}Te(p,2n)^{123}I$, based on its yield.

Table. 1 Data for reaction $^{123}Te(p,n)^{123}I$, $^{124}Te(p,2n)^{123}I$, $^{125}Te(p,3n)^{123}I$

E (Me)	C.S (barn) ^{123}Te	C.S (barn) ^{124}Te	C.S (barn) ^{125}Te	Sp MeV/(mg/cm) ^{123}Te	Sp MeV/(mg/cm) ^{124}Te	Sp MeV/(mg/cm) ^{125}Te	Y (Bq) ^{123}Te	Y (Bq) ^{124}Te	Y (Bq) ^{125}Te
20	91.2528	1052.9	71.075	0.01359	0.01348	0.01337	3358	39065	2659
22	77.4722	1078.1	64.894	0.01269	0.01259	0.01249	6411	81890	5258
24	69.6786	966.11	60.16	0.01191	0.01182	0.01172	9336	122761	7824
26	64.1641	654.23	55.932	0.01123	0.01114	0.01105	12192	152118	10355
28	59.5866	398.19	52.074	0.01063	0.01054	0.01046	14994	171003	12844
30	55.4448	255.86	48.433	0.01009	0.01001	0.00994	17741	183778	15281
32	51.6122	210.93	45.026	0.00963	0.00956	0.00948	20419	194814	17656
34	47.7797	165.99	41.619	0.00922	0.00914	0.00907	23012	203894	19951
36	44.3372	137.38	38.617	0.00883	0.00876	0.00869	25522	211734	22173
38	41.2849	125.09	36.021	0.00849	0.00842	0.00835	27954	219167	24330
40	38.2325	112.80	33.425	0.00817	0.0081	0.00804	30295	226129	26410
42	35.8344	105.09	31.373	0.00789	0.00783	0.00777	32565	232838	28429
44	33.4363	97.371	29.321	0.00762	0.00756	0.00750	34758	239277	30384
46	31.2622	90.570	27.4293	0.00738	0.00732	0.00726	36878	245467	32274
48	29.3123	84.684	25.697	0.00715	0.00709	0.00704	38927	251436	34100
50	27.3624	78.797	23.964	0.00693	0.00687	0.00682	40902	257169	35857
52	25.7314	74.298	22.609	0.00674	0.00669	0.00663	42811	262726	37562
54	24.1005	69.798	21.255	0.00655	0.0065	0.00645	44650	268094	39210
56	22.6192	65.677	19.94	0.00638	0.00633	0.00628	46422	273284	40799
58	21.2877	61.932	18.665	0.00622	0.00617	0.00612	48134	278303	42323
60	19.9562	58.187	17.39	0.00606	0.00601	0.00596	49780	283143	43782
62	18.9808	55.359	16.589	0.00592	0.00588	0.00583	51382	287854	45205

E (Me)	C.S (barn) ^{123}Te	C.S (barn) ^{124}Te	C.S (barn) ^{125}Te	Sp MeV/(mg/cm) ^{123}Te	Sp MeV/(mg/cm) ^{124}Te	Sp MeV/(mg/cm) ^{125}Te	Y (Bq) ^{123}Te	Y (Bq) ^{124}Te	Y (Bq) ^{125}Te
64	18.0054	52.532	15.788	0.00579	0.00574	0.00569	52938	292431	46592
66	17.0609	49.828	14.99	0.00566	0.005612	0.00557	54446	296870	47938
68	16.1474	47.247	14.193	0.00554	0.00549	0.00545	55905	301171	49241
70	15.2338	44.666	13.397	0.00542	0.00537	0.00533	57311	305327	50497
72	14.4665	42.579	12.693	0.00532	0.00528	0.00523	58671	309363	51710
74	13.6992	40.491	11.989	0.00522	0.00518	0.00514	59984	313274	52877
76	12.9818	38.537	11.315	0.00512	0.00508	0.00504	61252	317068	54000
78	12.3142	36.715	10.671	0.00502	0.00498	0.00494	62478	320755	55080
80	11.6466	34.894	10.028	0.00492	0.00488	0.00484	63662	324329	56116
82	11.1260	33.445	9.6044	0.00484	0.0048	0.00476	64811	327812	57124
84	10.60544	31.997	9.1812	0.00476	0.00472	0.00469	65925	331199	58104
86	10.0849	30.5485	8.7580	0.00468	0.00464	0.00461	67002	334488	59054
88	9.56428	29.100	8.3349	0.00460	0.00457	0.00453	68041	337675	59974
90	9.0437	27.652	7.9117	0.00452	0.00449	0.00445	69041	340757	60863
92	8.66078	26.549	7.6199	0.00446	0.00442	0.00439	70012	343758	61731
94	8.27786	25.446	7.3281	0.00439	0.00436	0.00432	70954	346678	62578
96	7.89494	24.343	7.0362	0.00433	0.00429	0.00426	71866	349513	63404
98	7.51202	23.240	6.7444	0.00426	0.00423	0.0042	72747	352260	64208
100	7.1291	22.138	6.4525	0.0042	0.00417	0.00413	73595	354917	64989
102	6.88558	21.351	6.2043	0.00415	0.00411	0.00408	74426	357513	65749
104	6.64206	20.564	5.956	0.00409	0.00406	0.00403	75238	360047	66489
106	6.39854	19.778	5.7077	0.00404	0.00401	0.00397	76030	362516	67207
108	6.15502	18.991	5.4595	0.00398	0.00395	0.00392	76803	364919	67904
110	5.9115	18.205	5.2112	0.00393	0.0039	0.00387	77555	367254	68578
112	5.77014	17.631	4.9993	0.00388	0.00385	0.00382	78298	369542	69232
114	5.62878	17.058	4.7874	0.00384	0.00381	0.00378	79031	371782	69865
116	5.48743	16.485	4.5754	0.00379	0.00376	0.00373	79754	373973	70479
118	5.34607	15.912	4.3635	0.00375	0.00372	0.00369	80468	376113	71070
120	5.20471	15.338	4.1516	0.00370	0.00367	0.00364	81171	378202	71640
122	4.99285	15.045	4.1215	0.00366	0.00363	0.00360	81853	380273	72212
124	4.78099	14.751	4.0914	0.00362	0.00359	0.00357	82513	382326	72786
126	4.56912	14.458	4.0613	0.00358	0.00356	0.00353	83150	384359	73362
128	4.35726	14.164	4.0312	0.00354	0.00352	0.00349	83765	386374	73910
130	4.1454	13.870	4.001	0.00351	0.00348	0.00345	84356	388368	74520

E (Me)	C.S (barn) ^{123}Te	C.S (barn) ^{124}Te	C.S (barn) ^{125}Te	Sp MeV/(mg/cm) ^{123}Te	Sp MeV/(mg/cm) ^{124}Te	Sp MeV/(mg/cm) ^{125}Te	Y (Bq) ^{123}Te	Y (Bq) ^{124}Te	Y (Bq) ^{125}Te
132	4.05056	13.389	3.8224	0.00347	0.00344	0.00342	84940	390312	75079
134	3.95572	12.907	3.6438	0.00344	0.00341	0.00338	85515	392205	75618
136	3.86088	12.426	3.4652	0.00340	0.00338	0.00335	86082	394045	76135
138	3.76604	11.944	3.2866	0.00337	0.00334	0.00332	86641	395832	76631
140	3.6712	11.463	3.10796	0.00334	0.00331	0.00328	87191	397564	77104
142	3.55688	11.228	3.101	0.00331	0.00328	0.00325	87729	399275	77581
144	3.44257	10.993	3.09399	0.00328	0.00325	0.00322	88254	400967	78061
146	3.32825	10.758	3.0870	0.00325	0.00322	0.00319	88767	402637	78544
148	3.21394	10.523	3.0800	0.00322	0.00319	0.00317	89267	404286	79031
150	3.09962	10.288	3.0730	0.00319	0.00316	0.00314	89753	405913	79521
152	3.08691	10.04	2.9175	0.00316	0.00314	0.00311	90241	407515	79990
154	3.0742	9.7915	2.7620	0.00314	0.00311	0.00308	90732	409089	80437
156	3.06148	9.5434	2.6065	0.00311	0.00308	0.00306	91224	410637	80863
158	3.04877	9.2953	2.451	0.00308	0.00306	0.003033	91719	412158	81268
160	3.03606	9.0472	2.2955	0.00306	0.00303	0.003007	92215	413649	81649
162	2.95058	8.8394	2.2909	0.00303	0.00301	0.00298	92702	415119	82033
164	2.8651	8.6317	2.2863	0.00301	0.00298	0.00296	93178	416566	82419
166	2.77962	8.424	2.2818	0.00299	0.00296	0.00294	93643	417988	82807
168	2.694136	8.21628	2.27718	0.00296	0.00294	0.00292	94098	419386	83198
170	2.60866	8.0086	2.2726	0.00294	0.00292	0.00289	94542	420760	83591
172	2.52317	7.8008	2.2680	0.00292	0.00289	0.00287	94974	422108	83986
174	2.43769	7.5931	2.2635	0.0029	0.00287	0.00285	95395	423429	84383
176	2.35221	7.3854	2.2589	0.00288	0.00285	0.0028	95804	424724	84782
178	2.26673	7.1777	2.2543	0.00286	0.00283	0.00281	96201	425991	85183
180	2.18125	6.97	2.2498	0.00284	0.00281	0.00279	96586	427231	85587
182	2.11786	6.9238	2.1748	0.00282	0.00279	0.00277	96962	428470	85979
184	2.05448	6.8774	2.0999	0.0021	0.00278	0.00275	97329	429709	86360
186	1.99109	6.8311	2.0249	0.00278	0.00276	0.00272	97687	430948	86730
188	1.92770	6.7848	1.95	0.00276	0.0027	0.00272	98036	432185	87089
190	1.86432	6.7385	1.8751	0.00274	0.00272	0.0027	98376	433423	87436
192	1.80093	6.6922	1.8001	0.00273	0.00271	0.00268	98706	434661	87772
194	1.73754	6.646	1.7252	0.00271	0.00269	0.00267	99027	435897	88096
196	1.67415	6.5997	1.6502	0.00269	0.00267	0.00265	99337	437134	88407
198	1.61077	6.5534	1.5753	0.00267	0.00265	0.00263	99639	438369	88707
200	1.54738	6.5071	1.5004	0.00266	0.00263	0.00261	99931	439604	88994

5. References

1. K. Kondo, R. M. Lambrecht and A. P. Wolf, "123I production for radiopharmaceuticals XX. Excitation functions of the 124Te(p,2n)123I and 124Te(p,n)124I reactions and the effect of targe enrichment on radionuclidic purity" Int. J. Appl. Radiat. Isot. 28, (1977). 395–401
2. R. Unal and U. Akçaalan, "The Reaction Cross Sections for 124,125Te(p,xn)123,124I and 123,124Te(d,xn)123,124I" European Journal of Science and Technology, (18) (2020). 958-963
3. S. Frangos and JR. Buscombe Why should we be concerned about a "g"? Eur J Nucl Med Mol Imaging. 46:519, (2019). https:// doi. org/ 10. 1007/ s00259- 018- 4204-z
4. J.T. Lane; A.D. Meyers. "Radioactive Iodine Uptake Testing". Medscape" (January 17, 2013).
5. H. Ziessman, J. O'Malley and J. Thrall Nuclear Medicine The Requisites, **Book** • Fourth Edition • ٢٠١٤
6. V. R. Narra, R. W. Howell, R. S. Harapanhalli, K. S. Sastry, and D. V. Rao. "Radiotoxicity of some iodine-123, iodine-125 and iodine-131-labeled compounds in mouse testes: implications for radiopharmaceutical design. Journal of Nuclear Medicine", 33(12), (1992). 2196-2201.
7. P. Ávila, J. Camilo, et al. Factibilidad de producción de 123" I en la instalación Ciclotrón-Radiofarmacia de Bariloche.PhD Thesis. Universidad Nacional de Cuyo, 2018.
8. TENDL Nuclear data library(2021); (https://tendl.web.psi.ch/tendl_2021/tendl2021.html)
9. F.A. Mettler, Jr., M.D. and A.C. Upton, M.D. Medical Effects of Ionizing Radiation, Grune & Stratton, Inc., Orlando, Florida, (1995).
10. A.S. Naeem, physics and Engineering of Radiation Detection, Queen's University, Kingston, Ontario, , (2007),118-120.
11. Y.H. Song, and Y.N. Wang, "Effect of ion-nucleus sizes on the electric stopping power for heavy ions in solids", Nucl. Instr. and Meth. in Phys. Res. B 135, (1998),124-127.
12. D.D. Sood, A.V.R. Reddy and N. Ramamoorthy; "Fundamentals of Radiochemistry", IANCAS Publications, Ch8, (1995), P136.

13. J.F.Ziegler, J.P. Biersack, U. Littmark. 1985. The Stopping and Range of Ions in Matter. New York: Pergamon
14. *S.M. Qaim*, Nuclear data for medical applications: An overview. Radiochim. Acta 89, (2001),189.