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Short Research Article

Study of activation cross sections of deuteron-induced reactions on erbium for applications†

F. TÁRKÁNYI[1,*], A. HERMANNE[2], S. TAKÁCS[1], F. DITRÓI[1], B. KIRÁLY[1], M. BABA[3], T. OHTSUKI[3], S. F. KOVALEV[4] and A. V. IGNATYUK[4]

[1] Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI), Debrecen, Hungary
[2] Vrije Universiteit Brussel (VUB), Brussels, Belgium
[3] Tohoku University, Sendai, Japan
[4] Institute of Physics and Power Engineering, Obninsk, Russia

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Introduction

The use of compounds and biomolecules labeled with radionuclides of rare-earth elements is a fast growing field in therapeutic nuclear medicine. These radionuclides are currently produced by (n,γ) caption in a nuclear reactor, but to obtain high specific activity or end products at the no carrier added level, usually alternative production routes utilizing charged particle-induced processes are required.

Our systematic study of proton- and deuteron-induced nuclear reactions shows that it is worthwhile to investigate the deuteron-induced reactions because in the heavy mass region the (d,2n) process is more productive than the (p,n). Here, we report on the production of Tm and Er radioisotopes by (d,x) reactions on erbium target. Among the reaction products the ^{165}Tm → ^{165}Er, ^{169}Er, ^{167}Tm, ^{170}Tm and ^{171}Er → ^{171}Tm radionuclei have been gained interest in therapy.

Experimental

The excitation functions were measured by the stacked foil technique up to 40 MeV. Commercial Er foils were stacked with Ti and Al monitor foils. Irradiations were done at the external beam of the cyclotrons of the VUB and of the Tohoku University. The measured ^{nat}Er(d,x)^{166,167}Ho, ^{163,165,166,167,168,170,171}Tm, ^{169,171}Er cross sections were compared to theoretical effective cross sections calculated by means of the computer code ALICE-IPPE. No experimental results were found in the literature for cross sections of deuteron-induced reactions on erbium.

Results and discussion

Thick target yields calculated from our fitted cross sections give reliable estimations for production of medically relevant radioisotopes of high radionuclide purity by using highly enriched mono-isotopic targets.

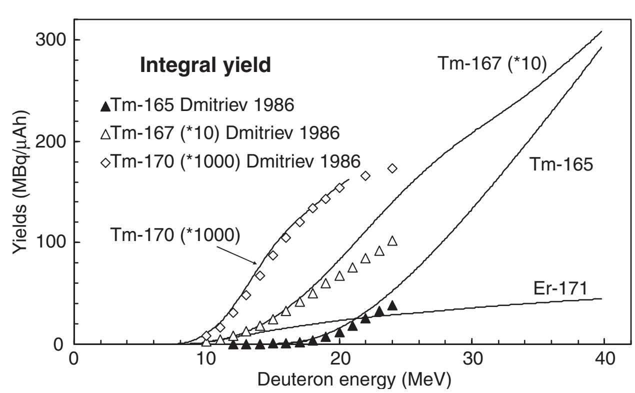

Figure 1 Integral yields of the ^{165,167,170}Tm and ^{171}Er calculated from the measured excitation functions.

*Correspondence to: F. Tárkányi, Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI), Debrecen, Hungary. E-mail: tarkanyi@atomki.hu

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Table 1 Comparison of reactor and accelerator production of $^{167,170,171}Tm$ and $^{165,169}Er$

Isotope	Nuclear reactor	Cyclotron
^{165}Er	$^{164}Er(n,\gamma)^{165}Er$ $\sigma_{th} = 13\,000$ mb carrier added	$^{165}Ho(p,n)^{165}Er$, $\sigma_{max} = 150$ mb $^{165}Ho(d,2n)^{165}Er$, $\sigma_{max} = 600$ mb $^{166}Er(p,2n)^{165}Tm \rightarrow {}^{165}Er$, $\sigma_{max} = 1200$ mb $^{166}Er(d,3n)^{165}Tm \rightarrow {}^{165}Er$, $\sigma_{max} = 320$ mb no carrier added
^{169}Er	$^{168}Er(n,\gamma)^{169}Er$ $\sigma_{th} = 2000$ mb carrier added	$^{168}Er(d,p)^{169}Er$, $\sigma_{max} = 300$ mb no carrier added
^{167}Tm	$^{168}Yb(n,2n)^{167}Yb \rightarrow {}^{167}Tm$ $\sigma_{14\,MeV} = 1900$ mb no carrier added	$^{167}Er(p,n)^{167}Tm$, $\sigma_{max} = 500$ mb $^{166}Er(d,n)^{167}Tm$, $\sigma_{max} = 20$ mb $^{168}Yb(p,2n)^{167}Lu \rightarrow {}^{167}Yb \rightarrow {}^{167}Tm$, $\sigma_{max} = 1200$ mb, no carrier added
^{170}Tm	$^{169}Tm(n,\gamma)^{170}Tm$ $\sigma_{th} = 105\,000$ mb carrier added	$^{170}Er(p,n)^{170}Tm$, $\sigma_{max} = 130$ mb $^{170}Er(d,2n)^{170}Tm$, $\sigma_{max} = 120$ mb no carrier added
^{171}Tm	$^{170}Er(n,\gamma)^{171}Er \rightarrow {}^{171}Tm$ $\sigma_{th} = 6000$ mb no carrier added	$^{170}Er(d,n)^{171}Tm$, $\sigma_{max} = 10$ mb $^{170}Er(d,p)^{171}Er \rightarrow {}^{171}Tm$, $\sigma_{max} = 300$ mb no carrier added

The integral yields for $^{165,167,170}Tm$ and ^{171}Er calculated from the measured excitation functions are shown in Figure 1 in comparison with the directly measured data of Dmitriev.[1]

The comparison of the cross section data of reactor and accelerator routes for $^{167,170,171}Tm$ and $^{165,169}Er$ is given in Table 1. The cross sections of proton-induced reactions in Table 1 were obtained from the available experimental data and by using the ALICE-IPPE code. According to Table 1 among the charged particle-induced reactions, the (p,2n) and (d,2n) reactions provide the highest yields.

^{169}Er and ^{171}Tm can be produced at cyclotrons only by deuteron-induced reactions. The theoretical description needs further improvements especially for (d,p) and (d,2n) reactions (breakup process). The total amount of $^{165,169}Er$ and $^{167,170,171}Tm$ produced at a nuclear reactor is significantly larger than the expected amount produced via charged particle-induced reactions at a cyclotron (Table 1). However, the reactor produced products are only of low specific activity except ^{171}Tm.

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