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R.Arlt, V.A.Bystrov, W.Habenicht, E.Herrmann
V.I.Raiko, H.Strusny, H.Tyrroff

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Introduction

The spallation reaction induced by high energy protons is well suited to produce nuclei with a deficit of more than 10 neutrons. For nuclear spectroscopical investigations of a certain type of nuclei it is necessary to isolate the activity taken under consideration by chemical and isotope separation steps.

The aim of this paper is to describe a production method for the radioactive isobars of elements having the first ionization potential lower than 6.5 eV. The activities can be obtained without any chemical separation. For this purpose an electromagnetic isotope separator equipped with a surface ionization ion source has been used [1-3]. The short-lived activities produced have been investigated on the YASNAPP-facility [2].

General Considerations

As is well known, some of the spallation products can be released from irradiated targets, if a sufficiently high temperature is applied [4].

The release behaviour of different elements depends on their boiling points[5]. Heating an irradiated target in the above-mentioned ion source, the evaporated radioactive atoms become ionized on the glowing surface. According to the Saha-Langmuir formula the ionization efficiency depends on the first ionization potential of these atoms as well as on the ionizer material and temperature. In this way, using

the target materials listed in Table I, one could obtain ions of all Rare Earth (RE) elements or the Alkaline and Alkaline Earth elements, respectively. After electromagnetical separation of these ions, isobars are collected on a certain mass position. To identify the activities in the isobaric samples it is possible to make use of the different physical properties of the elements such as the boiling points, the first ionization potentials or characteristic X -rays.

As an illustration, the surface ionization efficiency for *Rb* and *Sr* calculated as a function of the ionizer temperature accepting $\phi = 5.43$ eV for the work function is presented in Fig. 1. As could be seen, the yield ratio $\eta(Sr) : \eta(Rb)$ may change several times when the ionizer temperature is varied. Thus it is possible to distinguish between the radiation emitted from nuclei of these elements.

In Fig. 2 a qualitative estimation of the activity of RE nuclides after isobaric separation is given. The activity of the nuclei, having a deficit of 10 neutrons depends on the cross section σ_{-10n} of the spallation reaction *Ta(p;xp;yn)*RE with 660 MeV protons /6/, as well as on the surface ionization efficiency η for $\phi = 5.9$ eV /3/, and on the part D of the spallation products, evaporated from the target. The values of D have been obtained from the data for the release of RE-activities out of graphite targets /5/. If the activation time is long compared with the half-lives and the separation time is short enough to be neglected, then the activities of the different RE isotopes may be considered to be proportional to $\eta\ \sigma_{-10n} D = C(Z)$.

In Fig. 2 the C-value of the RE isotopes in an isobaric sample, which has a deficit of 9, 10 and 11 neutrons, is shown. Isobars with a half-life of about 10 minutes are connected by dashed lines.

Experimental Results

Isobars from a Zirconium-Niobium Alloy Target

After irradiation on the external proton beam of the Dubna synchrocyclotron (E_p = 660 MeV, $I_p = 10^{11}$ p.sec^{-1} cm^{-2}), the zir-

conium-niobium alloy target (0.1 g) has been placed in the evaporizer of the above-mentioned ion source[3]. The separation has been performed at two different experimental conditions:

I - at about half of the maximum temperature of the ionizer (power applied to the source ≃ 180 watts);

II - at maximum temperature of the ionizer (power applied to the source ≃ 300 watts).

Figure 4 (upper part) shows parts of the γ -spectra measured on mass position $A = 81$ for both conditions. The transition $E_{\gamma 1} = 88$ keV belongs to the decay of ^{81m}Rb ($T_{1/2} = 32$ min) and the transitions $E_{\gamma 2} + E_{\gamma 3} = 147.8 + 153.4$ KeV belong to ^{81}Sr ($T_{1/2} = 29$ min)[7,8]. The quotient of the γ -intensity ratios for these transitions taken for both temperatures is equal to:

$$\left(\frac{I_{\gamma 1}\ (Rb)}{I_{\gamma 2} + I_{\gamma 3}\ (Sr)}\right)_I \ : \left(\frac{I_{\gamma 1}\ (Rb)}{I_{\gamma 2} + I_{\gamma 3}\ (Sr)}\right)_{II} \simeq 10$$

This is in qualitative agreement with the calculated results shown in Fig. 1.

A New Isotope $^{77}_{37}Rb_{40}$

When the zirconium-niobium target was treated as described above a new β - -activity on the mass positior. $A = 77$ with half-life $T_{1/2} = 3.9 \pm 0.1$ min has been discovered.

To identify this activity its γ- spectrum with the characteristic ray $E_{\gamma 4} = 66.55$ KeV has been measured. (See Fig. 4 lower part). Then the intensity of this transition has been compared with the intensity of $E_{\gamma 1} = 88$ KeV for both temperatures of the ion source. (See the previous part of the paper). Taking into account the different half-lives it has been possible to obtaine the following relation:

$$\frac{(I_{\gamma 1}\ (Rb)\ )_I}{(I_{\gamma 1}\ (Rb)\ )_{II}} \simeq \frac{(I_{\gamma 4}\ (A=77))_I}{(I_{\gamma 4}\ (A=77)\ )_{II}} \simeq 1$$

whilst the intensity ratio for the γ -transitions belonging to Sr equals to 1/10.

From this fact it follows, that the γ -transition $E_{\gamma 4}$ =66.55 KeV belongs to the decay of the new activity ^{77}Rb ($T_{1/2}$=3.9 ± 0.1 min.). Studying the chemical behaviour of the new activity it has been established that, it is possible to coprecipitate it together with $RbClO_4$, but not with $SrSO_4$. Also the grow up of the daughter activity ^{77}Kr ($T_{1/2}$ =1.2 h) in samples closed with an adhesive tape [x] supports the identification of the new isotope /9/.

In Table 2 the first spectroscopical data for ^{77}Rb are listed. The 66.55 KeV γ -transition is in coincidence with E_γ=178.9 KeV. We propose, that the recently reported activity ^{77m}Kr(E_γ = 68 KeV, $T_{1/2}$ =2.8 ± ± 1 min) belongs to ^{77}Rb /7/.

Production of Rare Earth Isobars

Heating an activated Ta -target (0.4 g) in the ion source RE isobars with 133 ≤ A ≤ 170 have been obtained on the collector of the isotope separator. In Table 3 some of the analyzed activities are listed. The identification has been accomplished by means of characteristic γ -lines and half-lives. The fact that the samples with mass numbers A = 139, 140, 141 and 143 contained mainly Sm and Eu agrees with the considerations made in the second part of this paper. Figure 5 shows a γ -spectrum of the isobaric sample with a mass number A = 139. The spectrum contains transitions which belong to the decay of ^{139}Nd (30 min), ^{139}Pm (4 min) and Sm (2.5 min).

For all spectroscopic measurements $Ge(Li)$ spectrometers have been used and the data have been processed by means of a CDC-1604-A computer /10/

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[x] All isobaric samples have been collected on aluminized polyester tapes, so that the beam was hitting the organic side.

Conclusions

The described isobaric separation method for spallation products enables one to investigate isotopes with a half-life of about 2-3 minutes in an off-line mode. Using a larger amount of target material this method could be successfully applied to on-line facilities for studying shorter-lived activities.

Acknowledgement

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Table I
Ionization potentials and boiling points of the elements produced by spallation in some target materials

target material	spallation-products	ionization potentials/eV	Boiling points/°C
Ta	Rear Earths	$6.19 \leq Ie \leq 5.43$	$1427 \leq BP \leq 3470$
Th	Ra	5.27	
	Fr	3.93	
La	Ba	5.21	1640
	Cs	3.89	690
Zr-Nb	Sr	5.69	1380
	Rb	4.17	688
Ti	Ca	6.11	1440
	K	4.34	760
Si	Mg	7.64	1107
	Na	5.14	892

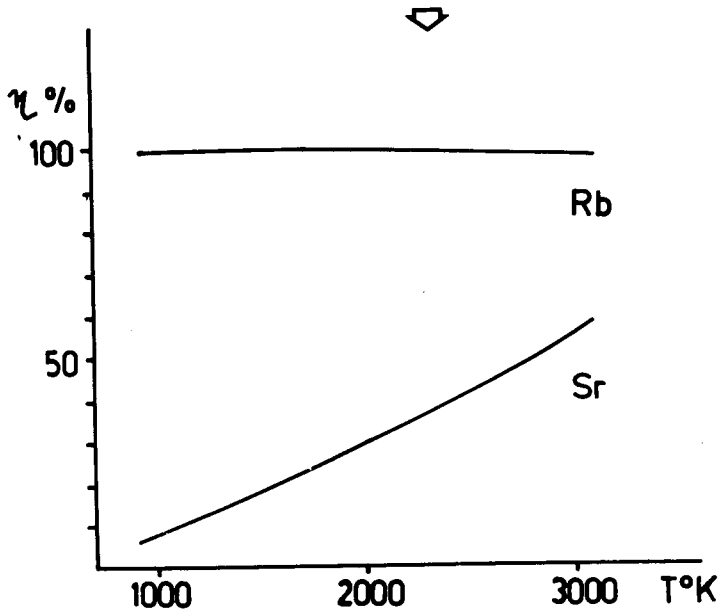
Table 2
Energy and intensity of gamma rays emitted by the beta decay of $^{77}_{37}Rb_{40}$

E_γ /KeV	Δ E/KeV	I_γ /rel.un.	Δ I/rel.un.
66.55	0.06	100	15
150.1	0.3	7.5	1.0
178.9	0.2	37.7	4.0
244.4	0.5	2.3	0.5
254.3	0.5	3.1	0.6
393.5	0.2	13.0	1.5

Table 3
Identified isotopes in the rare earth isobars obtained from a tantalum target

Mass number	Identified isotopes and half-lives	Ref.
135	135Pr (27 min), 135Nd (15 min)	/11/
139	139gNd (30 min); 139mNd (5.5 h); 139gSm (2.5 min) 139gPm (4 min)	/12/
140	140Sm (14.5 min); 140mPm (5.8 m)	/12/, /13/
141	141mSm (22.5 min); 141gSm (9.5 m) 141Pm (20.9 min)	/12/, /13/
143	143gSm (8.8 min); 143 Eu (2.6 m)	/12/

Fig. 1. Calculated surface ionization efficiency for *Rb* and *Sr* as a function of the ionizer temperature with ϕ = 5.43 eV.



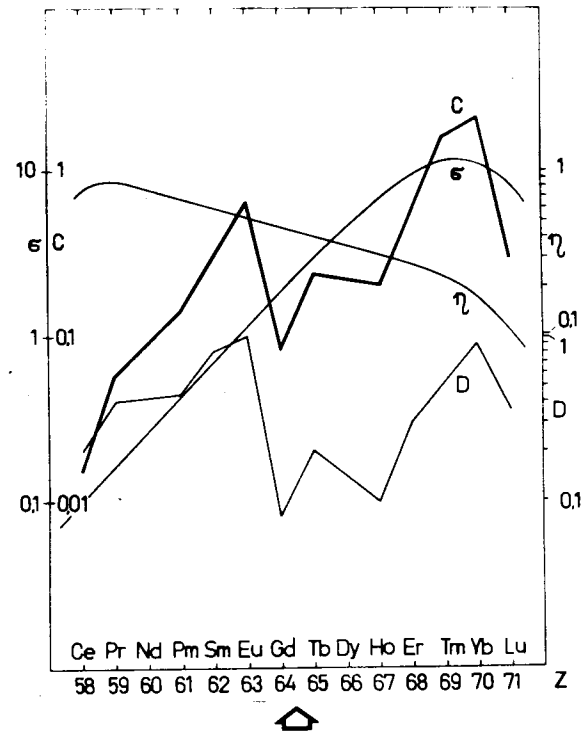


Fig. 2. Value $C = \eta\sigma_{-10n}$ *D* as a function of *Z*. *C* is proportional to the activity of the nuclei of rare earth isotopes, having 10 deficient neutrons.

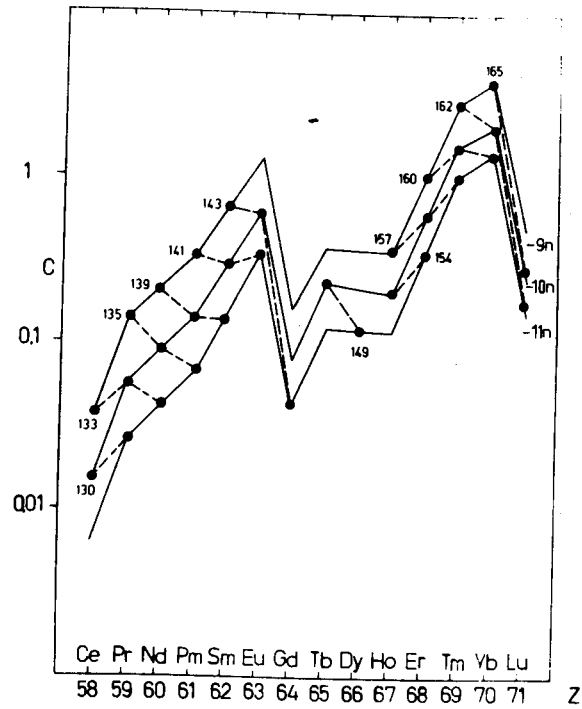


Fig. 3. C -value of the rare earths on the collector of the isotope separator having 9, 10 and 11 deficient neutrons. The dotted lines indicate isobars of different elements.

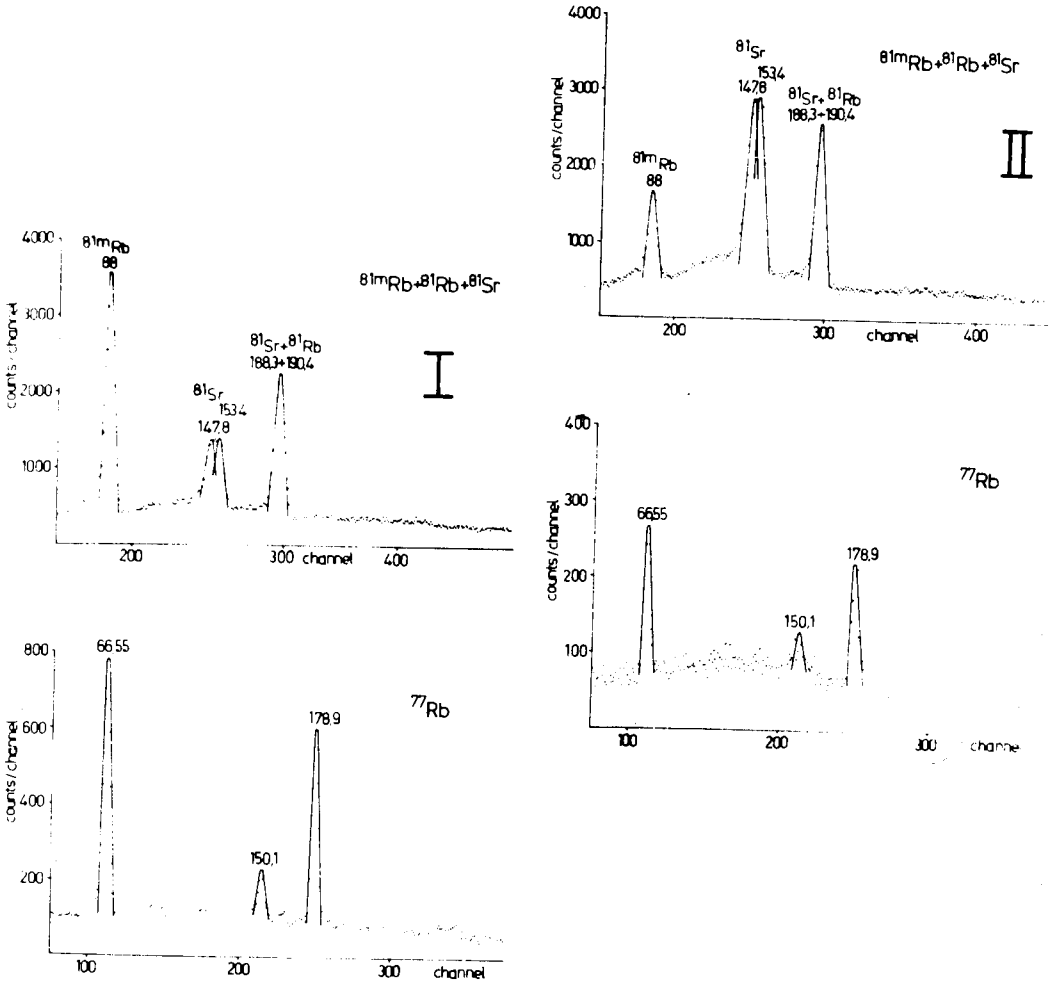


Fig. 4. Parts of γ -spectra measured of samples collected on the mass positions $A = 81$ (upper part) and $A = 77$ (lower part). The spectra in part I are obtained for the ion source power $P_I \simeq 180$ watts, the spectra II - for $P_{II} \simeq 300$ watts.

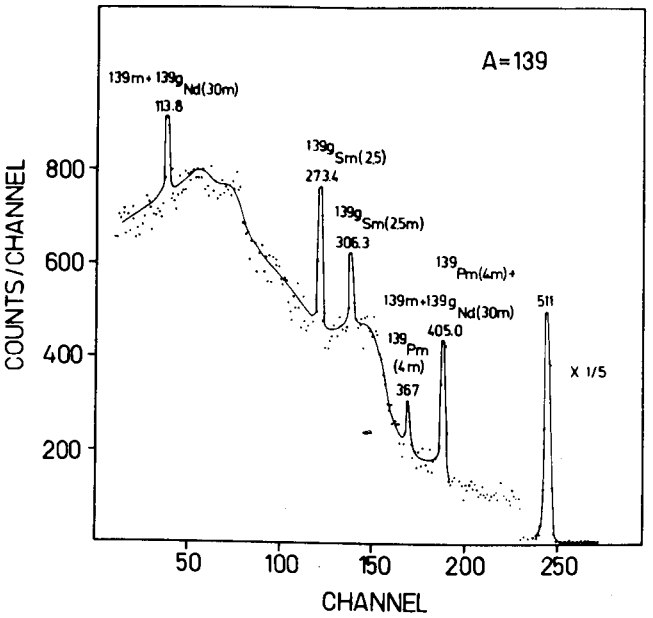


Fig. 5. γ **-spectrum for the** $A = 139$**-isobars.**