RADIOACTIVE BEAMS FOR MATERIAL ENGINEERING

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The application of the radioactive nuclei beams for the diaggnostic of wear and corrosion in mechanical devices is discussed. The intense 7Be beam production at the cyclotron is described. Some examples of applications for car industry are presented.

1. Introduction

The radioactive nuclei beams became already a powerful tool of modern nuclear physics. Normally new effective technique of fundamental research finds soon its way in applications. There are serious grounds to predict that RNB will not be the exception.

The reliability of modern industrial equipment, transportation systems, power plants, etc,is strongly influenced by such degradation processes as wear and corrosion.Consequently, the development of effective methods of measurement and monitoring of these processes is of great importance. One of the most promising methods of non-destructive methods is so called radionuclide technique. Its main feature is the creation of a thin radioactive layer under the investigated surface by irradiation of the object by protons with the energyof about 10 MeV. The method occurred to be very effective in the study of wear of metallic parts of machines /1/.

However, some large classes of important materials, such as elastomers, polimers, rubber cannot be investigated in this fashion. The first reason is that it is very difficult to produce the radioactivity with necessary properties in synthetic materials. The second one is that these materials normally suffer strongly from the radiation damadges.

The usage of the secondary radioactive beams could provide the solution of the problem. The idea is to implant the nuclei having convenient radioactivity to the desired depth of the detail under study.

2. 7Be beam

The requirements for the secondary nuclei can be briefly summarized as follows :

a) $T_{1/2}$ > 1 day, b) $M_\gamma/T_{1/2}$ where M_γ is the number of gammas per decay, c) range $\lesssim$ 0.1 mm, d) large productive cross-section, e) low cost of a projectile, f) little radiation damadge of the material.

These demands are contradictory in many aspects, and only a limited number of nuclides could be considered. Some of them together with required intensities are presented in Table 1 (for rough estimate one may take the minimum accumulated activity 0.04 MBq and maximum irradiation time 1 day).

Table 1. Required intensities

Projectile	Intensity
7Be	$3*10^7$
22Na	$2*10^7$
48Sc	$3*10^4$
52Mn	$8*10^4$

All these secondary beams can be produced with rather large cross-sections either in (p,n)-reactions (including the inverse kinematic conditions) or in the fragmentation process. However, economical and radiation damadges considerations leave for the practical utilization only 7Be which is by no means the best nuclide from some other points of view.

The main nuclear parameters of 7Be are : $T_{1/2}$ = 53 d, E_γ= 478 keV, M_γ= 0.1. The range of 100 μm is achieved at the energy 30 MeV.

Three methods of obtaining of 7Be beam have been tested or discussed.

1) Heavy ions (14N) fragmentation /2/,

2) (p,n)- or (p,α)- reactions in the inverse kinematic conditions /3,4/,

3) Off-line production of 7Be sample and postacceleration /5/.

The practical applications were done at Kurchatov cyclotron using the method 2).

3. Kurchatov cyclotron 7Be irradiation facility

Its principle is shown in Fig.1

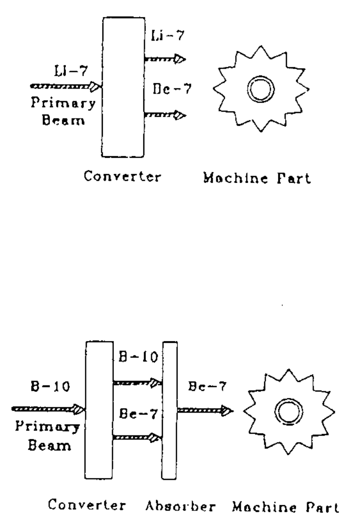


Fig. 1: The principle of Be-7 recoil implantation for the radioactive surface labelling of synthetic materials.

Two well-known nuclear reactions : 7Li(p,n)7Be and 10B(p,α)7Be, were used for 7Be production. The inverse kinematics allowed to increase the cross-section in the laboratory frame and to get the angular distributions strongly peaked forward. In both cases thick hydrogen-containing targets (converters) were used providing continuous spectra of the secondaries. For low intensity experiments a monoenergetic beam was obtained by magnetic fragment separator MASE. The parameters of the 7Be beams are given in Table 2.

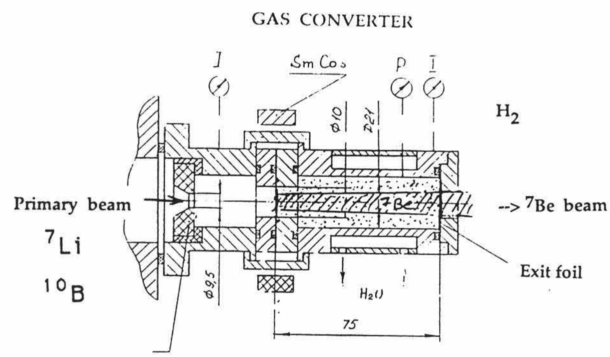
Table 2. Parameters of 7Be beams

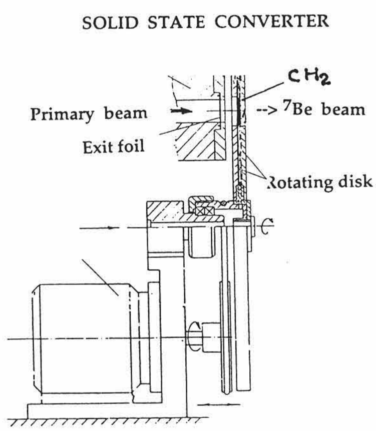
No	Primary beam E, MeV	Primary beam I, μA	Reaction	7Be beam E, MeV	7Be beam I, sec^{-1}	7Be beam Beam spot, cm^2	Type of converter
1	70	0.2	H + 7Li	0 - 28	$1*10^9$	2.5	gas
2	50	0.2	H + 7Li	0 - 25	$3*10^8$	0.1	polyethylen
3	59	0.2	H + 10B	0 - 42	$2*10^8$	1.5	gas
4	59	0.2	H + 10B	0 - 28	$7*10^7$	2.0	gas+absorb.
5	59	0.1	H + 10B	0 - 25	$1*10^7$	0.1	polyet.+absorb.
6			H + 7Li	monoen.	$1*10^6$	0.1	MASE

The choice of the primary beam depends on the sensitivity of the material under study to the radiation damadges induced by it.The 7Li beam provides an order of magnitude larger intensity of the secondaries but in this case it is impossible to clean out the 7Be nuclei by simple means. On the other hand, 10B projectiles can be stopped by the absorber, while 7Be nuclei penetrate through it.

Different types of converters were used. Their choice depends on the pecularities of the irradiation conditions, especially on the required dimensions of the beam spot.The schematic drawing of the two most frequently used types of the converters is shown in Fig.2. One of them containes pure hydrogen, the other is made of polyethylen.

Normally for wear studies the uniform energy distribution of the implanted radioactivity is required. The usage of thick converters together with the energy variation solves this problem rather easily.





4. Some examples of 7Be beam applications

Some results of the tests of the irradiated machine parts were given in /3/. A summary of some iradiation characteristic follows :

1) Gear wheel (polyamid), working surface of teeth - 20 cm^2 , effective implantation depth (EID) - 20 μm, 7Be dose - $2.3*10^{12}$.

2) Crankshaft seal (viton), inner working surface - 0.3*50 cm^2, EID - 20 μm, 7Be dose - $1.9*10^{12}$.

3) Belt (polyamid), implanted area - 2 marks of diameter 1.3 cm on the working surface, EID -20 μm, 7Be dose - $2.5*10^{12}$ each.

The complete set of the tests was done by KfK group in cooperation with the AUDI company and Firma Hess, Ingolstadt /5/. The results demonstrated good applicability of the method to the wear diagnostics of synthetic materials.

5. Future developments

Three main directions of future research seems to be important.

1) Construction of the superconducting solenoid for separation 7Be nuclei from the primary 7Li beam.

2) Detailed study of radiation damadges in various classes of synthetic materials under different irradiation conditions.

3) Usage of the monoenergetic beams.

References

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