BE-7 BEAMS FOR WEAR STUDIES OF PLASTICS, ELASTOMERS AND CERAMICS

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1. INTRODUCTION

RTM is known since 1960's and is widely used for tribological studies of a large variety of constructing materials.

Unfortunately, this technique can not be applied directly for low atomic number materials (plastics, elastomers and some ceramics) as no suitable nuclear reactions for their activation by charged particles are known. The problem can be solved by the Radioactive Nuclei Implantation (RNI) into the area of interest of a machine part.

One of the most attractive nuclei is ^{7}Be. It is the lightest relatively long-lived one with the halflife of 53.3 days, that decays emitting almost monochromatic gamma-rays with energy 478 keV suitable for RTM application.

2. BE-7 BEAMS PRODUCTION

^{7}Be beams were obtained in a number of laboratories. However, the vast majority of investigators obtained a spectrometric ^{7}Be beams for fundamental studies in the fields of nuclear and astrophysics. Such beams were not intense enough for commercial application in RNI.

Up to 1990 ^{7}Be beams with the highest intensity reported were obtained in Michigan ($4*10^{6}$ sec^{-1}) [1].

To increase ^{7}Be beams intensity the evaluation of the applicability of $H(^{10}B,^{7}Be)$ nuclear reaction, as well as optimization of various targets were performed.

Let's consider the desired parameters of such targets.

First, a machine part's area of interest may have rather small dimensions, so ^{7}Be beam must be specified by a small cross section. The same time an angular distribution of a secondary ^{7}Be beam produced as in $H(^{7}Li,^{7}Be)$ as in $H(^{10}B,^{7}Be)$ nuclear reactions is wide due to kinematics of a nuclear reaction itself and due to multiple scattering in the body of target. Therefore, to obtain ^{7}Be beam with minimum cross section one should decrease the length of a target.

Second, a target should be thin not to stop low energetic ^{7}Be beam in a target material. From the other hand a target should be thick enough to obtain an intense ^{7}Be beam.

Third, to increase the intensity of the secondary ^{7}Be beam one must increase the intensity of the primary beam and/or the hydrogen content of the target material. The same time there are limitations concerned with the target material thermoresistance.

Thus, a design of an optimized target is a rather complicated problem.

A pure hydrogen gas target can be used as well as a solid (TiH_2, polyethylen etc.) or liquid (H_2O) ones.

Further we shall call a target as a "converter", because primary (^{7}Li or ^{10}B) beam is converted into ^{7}Be beam in it.

We considered several possible converters. In this work we would like to present two types of it - the pure hydrogen gas converter and the polyethylen converter.

The converters can be applied as for ^{10}B, as for ^{7}Li primary beams.

Table 1 presents the parameters of the produced ^{7}Be beams.

Table 1. Parameters of ^{7}Be beams

No	Primary beam Energy [MeV]	Primary beam Intens. [pμA]	Nuclear reaction	^{7}Be beam Energy [MeV]	^{7}Be beam Intens. $[c^{-1}]$	^{7}Be beam Cross sec. $[cm^{2}]$	Converter
1	70	0.2	$H(^{7}Li,^{7}Be)$	0-28	$1*10^{9}$	2.5	gas
2	50	0.2	$H(^{7}Li,^{7}Be)$	0-25	$3*10^{8}$	0.1	polyethylen
3	59	0.2	$H(^{10}B,^{7}Be)$	0-42	$2*10^{8}$	1.5	gas
4	59	0.2	$H(^{10}B,^{7}Be)$	0-28	$7*10^{7}$	2.0	gas with ^{10}B absorber
5	59	0.1	$H(^{10}B,^{7}Be)$	0-25	$1*10^{7}$	0.1	polyethylen with ^{10}B absorber

Unfortunately, ^{7}Be beams leaving converters are not "clean". A wide spectrum of particles (the primary beam, hydrogen recoil nuclei, neutrons, alpha-particles, etc.) are emitted from the converters too. Primary beams are the most intense of them.

If the beam intensity is higher than some predetermined level, the influence of this beam on the material to be irradiated can lead to irreversible changing of physical and chemical properties of the material. So, it may be necessary to suppress the primary beams with minimum loss of ^{7}Be beam in the region of implantation.

For $H(^{10}B,^{7}Be)$ nuclear reaction it is enough to install a simple foil absorber between the converter and a sample to be implanted. But in this case the loss of ^{7}Be beam intensity can be about 70 % (see Table 1).

This approach can be applied for $H(^{7}Li,^{7}Be)$ reaction, because ^{7}Li nuclei have the larger range, than ^{7}Be nuclei have. In this case magnetic separation can be used.

A main principle of such separation is as follows. In the initial part of a separator ^{7}Li and ^{7}Be beams are defocused. As ^{7}Li and ^{7}Be beams have the different angle divergence (determined by the kinematics of $H(^{7}Li,^{7}Be)$ reaction for ^{7}Be beam and by scattering of ^{7}Li beam in the converter), and magnetic rigidity (determined by energies and charge states of ^{7}Be and ^{7}Li beams after the converter), in the separator ^{7}Be beam cross section is larger than the cross section of ^{7}Li beam . The ^{7}Li beamstop is installed in the point characterized by the minimum $^{7}Li/^{7}Be$ cross section ratio. Then, the ^{7}Be beam is focused and after the separator is implanted into the sample. Thus, ^{7}Li beam is suppressed with minimum loss of ^{7}Be beam.

The parameters of ^{7}Be beams passed through the installations based on a system of quadruple magnets and on a superconductive solenoid were estimated. The estimations yielded the advantages and disadvantages of such installations.

The cheap and relatively simple quadruple magnets system is rather ineffective as only 5-10% of ^{7}Be nuclei will reach the exit of such a separator.

In a superconductive solenoid about 40-70 % of ^{7}Be nuclei will reach the exit, but it is rather complex and expensive system.

The feasibility study of a separator design is being discussed now. Building of a separator should allow to increase ^{7}Be beam intensity up to $5*10^{8}$ s^{-1} while its cross section being not more than 1.0 cm^{2}. The same time ^{7}Li beam intensity is expected to be about the same value of magnitude as ^{7}Be beam intensity is.

3. EXAMPLES OF ^{7}BE BEAMS APPLICATION

The main requirements for ^{7}Be implantation are the homogeneous distribution of ^{7}Be nuclei in the area of interest and the value of implanted ^{7}Be activity sufficient for quality wear measurements.

Table 2 presents the results of ^{7}Be implantation in real machine parts performed at Kurchatov Institute cyclotron.

Table 2. Examples of ^{7}Be implantation

No	Machine part Material	Shape and size of implanted area	Effective depth of implantation	^{7}Be dose
1	Gear wheel, Polyamid	Working surface of teeth, 20 cm^{2}	20 μm	$2.3*10^{12}$
2	Crankshaft seal, Viton	Inner working surface, 0.3*50 cm^{2}	20 μm	$1.9*10^{12}$
3	Belt, Polyamid	2 marks _ 1.3 cm on the working surface	20 μm	$2.5*10^{12}$ each

These parts were treated using the pure hydrogen gas converter irradiated by ^{10}B beam. The absorber after the converter was installed. It was specified by the requirement of the full ^{10}B beam suppression. For homogeneous irradiation of an area of interest a rotatory and reciprocating motions of parts were used.

The complete set of tests was applied by KfK in cooperation with the company AUDI A.G. and the material test institute Firma Hess, Ingolstadt [2-3].

The results of the tests proved the applicability of ^{7}Be implantation of RTM ON-LINE diagnostics of plastics and elastomers.

4. REFERENCES

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