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INSTALLATION FOR IRRADIATION OF THIN FOILS BY HALO PROTON BEAM ON IHEP ACCELERATOR

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Abstract

The halo of proton beam arises due to proton elastic and coulomb scattering on the internal target. On 70 GeV IHEP accelerator (U-70) halo contains up to several percent of proton beam.

It was shown by Monte Carlo method [1-3] that on thin target (0.05-1 g/cm^2 foils) each halo proton crosses the foil specimen up to 10^3 – 10^5 times before it will be lost during U-70 cycle. The radiation damage level in foil specimens at 10^{20} crossings was estimated at about 0,17 dpa (displacement per atom).

Accumulation of hydrogen and helium atoms during exposure was calculated for iron, nickel and chromium specimens.

Some factors limiting the rate of accumulation of radiation damage and ways for its solutions are discussed.

Simple installation with various material foils as targets is described together with the first proton exposure results of copper foils.

It is important, that foils irradiation by beam halo may be provided independently out of the main U-70 physical program.

As concluded, radiation damage level compared with results got during one year research nuclear reactors can be accumulated during one U-70 run (one month).

INTRODUCTION

The materials radiation damage studies are caring up as usual on research nuclear reactors.

The given paper is devoted to study of possibilities and conditions for creation of high levels of radiation damage in samples of metals at circulating proton beam of 70 GeV IHEP accelerator. The choose range (0.05-1 g/cm^2 foils) of testing materials as a thin targets ensure multiple intersection of sample by each proton during one accelerator circle. It corresponds to multiple growth of proton fluence, that incident on thin internal target and, consequently, an increase in the dose on the sample. The high radiation levels in local specimen area may be created even at low intensity of circulating proton beam.

SIMULATION OF PROTONS CIRCULATION INSIDE VACUUM CHAMBER

The length of the main accelerator ring is 1480 m. Accelerated to the final energy, the proton makes $n \sim 4 \cdot 10^5$ revolutions during one cycle of the accelerator during the duration of the maximum of the magnetic field (2 s). When internal target (specimen) is in the beam the number of revolutions are decreased by nuclear interactions and coulomb and elastic scattering to large angles.

However, for a thin target, the number of passes through the target can be still significant $n \sim 10^3$ and higher.

Simulation results of this process by Monte Carlo method for various materials are given in table 1.

Table 1. The Number of Passes – n vs. Target Materials and Their Thickness

Target	$\lambda_{nuclear}$, cm	Target thickness, microns		
		10	50	100
		n. the number of passes		
		$\times 10^4$	$\times 10^3$	$\times 10^3$
Al	35	3,45	7,00	3,50
Fe	17	1,70	3,40	1,70
Cu	15	1,50	3,00	1,50
Ti	21	2,10	4,20	2,10
V	20	2,00	4,00	2,00
Cr	19	1,90	3,80	1,90
Ni	16	1,60	3,20	1,60
Zr	13	1,30	2,60	1,30

Theoretically, all the protons of the beam ($\sim 5 \cdot 10^{13}$ proton/circle) can go through the target many times. For example, the number of passes through the copper target with a thickness of 50 microns is $1.5 \cdot 10^{17}$ proton/circle or $4 \cdot 10^{22}$ proton/month. The main limit of this value is radiation heating.

INSTANTANEOUS RADIATION HEATING OF THIN TARGET

In our estimation we assume that the value of instantaneous radiation heating should not exceed $0.3 \cdot T_{melt}$.

For this aid the maximal limitations on the proton beam intensity were calculated and are given in the table 2.

Table 2. Proton Beam Intensity That Corresponds Target Heating up to $0.3 \cdot T_{melt.}$

element	$0.3 \cdot T_{melt.}$, ^{0}C	Maximal intensity, proton/circle vs. target thickness		
		10 micron	50 micron	100 micron
Al	198	$2{,}5 \cdot 10^{11}$	$1{,}3 \cdot 10^{12}$	$2{,}5 \cdot 10^{12}$
Fe	460	$6{,}3 \cdot 10^{11}$	$3{,}2 \cdot 10^{12}$	$6{,}3 \cdot 10^{12}$
Cu	325	$4{,}6 \cdot 10^{11}$	$2{,}3 \cdot 10^{12}$	$4{,}6 \cdot 10^{12}$
Ti	540	$7{,}2 \cdot 10^{11}$	$3{,}6 \cdot 10^{12}$	$7{,}2 \cdot 10^{12}$
V	516	$7{,}0 \cdot 10^{11}$	$3{,}5 \cdot 10^{12}$	$7{,}0 \cdot 10^{12}$
Cr	549	$6{,}9 \cdot 10^{11}$	$3{,}5 \cdot 10^{12}$	$6{,}9 \cdot 10^{12}$
Ni	436	$6{,}1 \cdot 10^{11}$	$3{,}0 \cdot 10^{12}$	$6{,}1 \cdot 10^{12}$
Zr	570	$8{,}3 \cdot 10^{11}$	$4{,}2 \cdot 10^{12}$	$8{,}3 \cdot 10^{12}$

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Of course, thermal diffusion must be taken into account if the process is long-lasting in time. To use more high intensities of the circulating beam, it is necessary to work out additional measures for cooling the targets during their irradiation.

EVALUATION OF RADIATION DAMAGE IN TESTING SPECIMENS

Results of the main radiation effects calculation in thin layers of natural iron, chromium and nickel substances are obtained in [4] and presented in table 3.

Table 3. Values of displacement per atom (in dpa units), hydrogen and helium atoms accumulation (in appm units) in exposed thin target of natural iron, chromium and nickel substances. Calculation [4] was made for incident fluence 10^{20} protons /см^2. Proton energy is 70 GeV.

metal	*dpa*	H *appm*	He *appm*
iron	0,170	930	122
chromium	0,138	840	116
nickel	0,201	1030	132

Thus on results from table 3 the accumulation velocities of hydrogen and helium atoms per 1 dpa are ~5100-6100 appm (atomic part per million) and ~650-840 appm, accordingly.

EXPERIMENTAL INSTALLATION

Installation includes itself: target (40x40 мм^2 foils), permanent device of target drive, beam monitor, temperature monitor and semiconductive gamma spectrometer [6].

The layout of the target in the radial focusing magnet of accelerator ring is shown on fig.1.

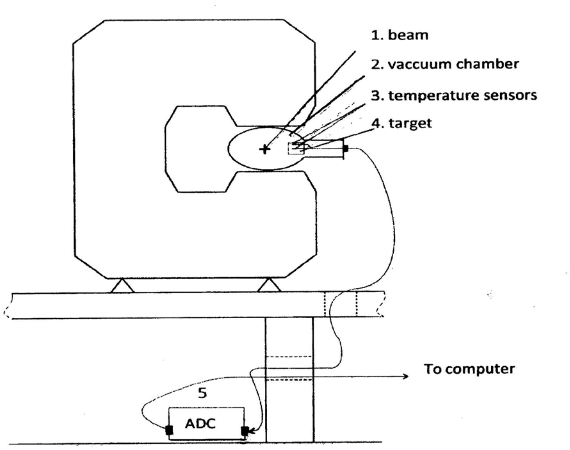

Figure 1: The layout of the target in the radial focusing magnet of the accelerator ring: 1 – beam, 2 - vacuum chamber, 3- temperature sensors, 4 - target, 5 – ADC.

The amplitude-digital convertor (ADC) is located under a magnet and protected from radiation by concrete floor overlapping.

The device of target drive [5] by which the target is introduced into the vacuum chamber of the accelerator, provides two types of displacements: slow and fast.

The slow moving unit allows setting the coordinate of target in the vacuum chamber in a range of ±60 mm relative to the central orbit in the horizontal plane and ±10 mm relative to the median plane in the vertical direction.

The fast movement unit in each cycle of the accelerator provides the movement of the target from a position outside the aperture of the vacuum chamber into the working position. The device moves the target only when the maximum energy of the accelerated beam is reached and sets it to the given coordinate without loss of the circulating beam itself. The accuracy of the target exit into the working position is ± 0.2 mm.

MONITORING

Monitoring of the total intensity of the circulating proton beam was carried out by the systems of the main control panel of the U-70 accelerator. That part of the intensity of the proton beam that hits the target was monitored separately. This monitoring was carried out on the secondary radiation generated by protons on the target. For this purpose we used a scintillation Cherenkov radiation detector installed at the end of the through channel in the lateral shield of the accelerator and aimed at the target.

The monitor was calibrated at the beginning of the accelerator run, when a known value of the intensity of the proton beam was been dropped onto the our target, but all other targets were turned off. Energy of proton beam was 50 GeV. The calibration curve for the copper target is shown in Fig. 2.

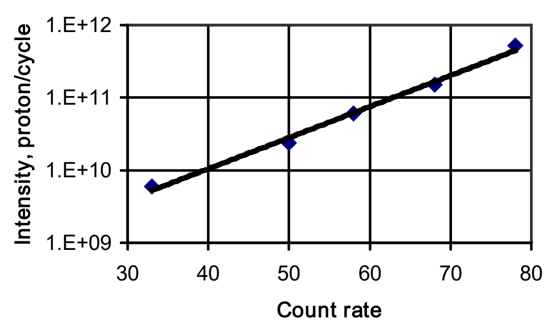

Figure 2: Calibration curve of the beam intensity monitor on a copper target.

The integral number of intersections of a copper target by protons was determined on the number of Na^{22} nuclei induced in the aluminum monitor foil. The monitor foil has the same transverse dimensions as the target, but an order of magnitude thinner and is installed direct behind it. The cross section of the monitor reaction $_{13}Al^{27}(p,3p,3n)_{11}Na^{22}$ for the proton energy Ep = 50 GeV was taken to be σ = 10.6 mb. The counting of monitor foils was carried out on a semiconductor gamma spectrometer [6].

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MEASUREMENT OF TEMPERATURE TARGET

The temperature platinum sensor from Heraeus Sensor Technology encased in a 4.0 x 2.2 x 0.9 mm ceramic capsule was selected. The sensor scale covers the full temperature range from -200 ° C to +850 ° C.

The length of the communication line from the temperature sensors to the measuring amplifier was 8 m. Measuring electronics in combination with temperature sensors and real communication lines were preliminarily tested on a laboratory bench in order to minimize electromagnetic interference and background noise. Before the beginning of irradiation measuring electronics was placed under a concrete floor at a distance of 2.5 m from the base of the magnet. The bulk of iron magnet and the mass of concrete floor were serve as an additional radiation protection of electronics (Figure 1). The photo of the target prepared for irradiation is shown in Fig. 3

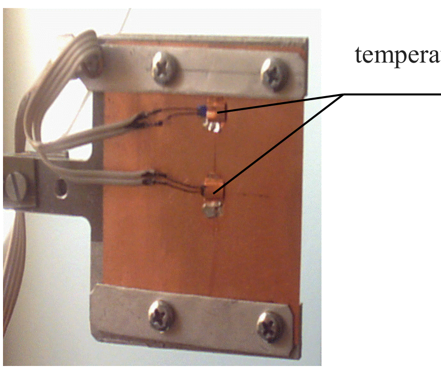

Figure 3: Placement of platinum temperature sensors on the target.

IRRADIATION OF SAMPLES

Copper was chosen for the experiment, since the change in its physical properties at high radiation levels is well known in the literature. As a material for testing targets pure electrolytic copper in the form of a thin foil was taken.

The irradiation regime for the experiment was selected with a target without temperature sensors. During the adjustment of the operating mode of our target, one of the foils was accidentally overheated by a proton beam (the photo in Fig. 4). Therefore, all other targets used for irradiation were equipped with temperature sensors.

The experiment itself was carried out for two runs of the U-70 accelerator. In the first run, a 50 μm copper target was irradiated, and in the second run a 100 μm copper target was irradiated. The number of passed proton targets was determined from monitor aluminum foils after the end of the irradiation.

During the first irradiation, $2.5 \cdot 10^{18}$ protons passed through the copper target with the 50 μm thickness and during the second irradiation $1 \cdot 10^{18}$ protons passed through the copper target with the 100 μm thickness. The error in determining the number of protons did not exceed ± 10%.

The average intensities of the beam for the both targets were $5.4 \cdot 10^9$ proton /cycle with an error of ~ 20% for both exposures.

Consequently, the experimental number n of intersections by protons of a copper target 50 μm thick in one cycle was n = 2020, and for 100 μm target n = 880. This result agrees with the calculated data for copper in Table 1.

The temperature at the controlled target points at an average intensities of $5.4 \cdot 10^9$ proton/cycle did not exceed 40 ^{0}C.

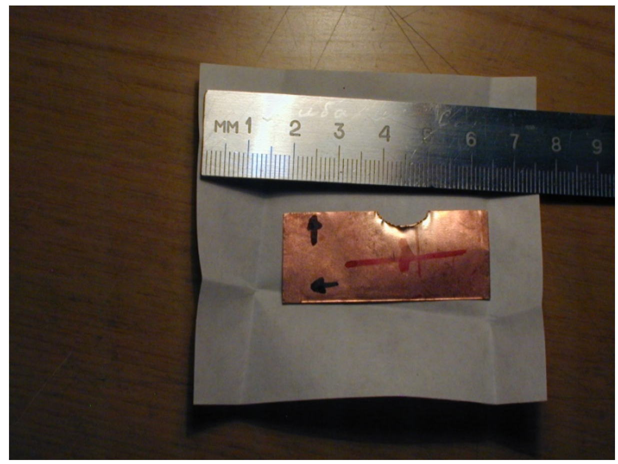

Figure 4: Photo of a target superheated by proton beam in the choice of the irradiation regime.

CONCLUSION

The technique of irradiation of thin metal samples on a circulating beam of 50 GeV protons U-70 has been worked out to obtain high levels of radiation damage in units of displacements per atom (up to ~1 dpa and above). An installation with a device for monitoring the intensity of the beam on the sample under investigation and measuring the temperature of sample heating during irradiation was realized. On the basis of experimental data, the attainable number of intersections (n) of a thin sample by a proton beam n ~ 10^3 times per cycle was confirmed.

To continue the development of this direction, it is necessary to solve the issues of cooling the samples during irradiation and to work out a technique for measuring the damage density in irradiated samples to predict changes in their physical properties.

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