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EXPERIMENTAL RESEARCH AND WORK DEVELOPMENT ON THE HELIUM IONS LINAC

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The paper provides a brief summary of the experimental research carried out at the present time at the materials science complex developed at the NSC KIPT. The main directions for the development of the work carried out have been determined. The complex is based on a linear accelerator of helium ions. The features and advantages of the accelerating structure of the accelerator, which is based on the principle of APF, are described. A technique was developed and irradiation of candidate materials for the divertor and the first wall of the TNR was carried out. The damageability of the irradiated samples could create from 3 to 80 dpa.

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INTRODUCTION

The 4 MeV helium ions linac [1] was developed, manufactured and put into operation at NSC KIPT. Accelerator was planned to be used as a pre-stripping section for the linac LUMZI. Using the main section possibility to accelerate the helium ion beam to energy of 8.5 MeV/nucl., development of work at LUMZI was supposed to be carried out in the direction of obtaining medical radioisotopes.

For objective reasons, these works were stopped. The development of work on the creation and research construction and candidate materials for nuclear power plants (NPP) led to the study the possibility using the helium ions linac in this area.

As a result of nuclear reactions, occurring in the NPP materials, fission products are formed. Special mention should be made the helium, the accumulation of which strongly affects radiation swelling, high-temperature and low-temperature radiation hardening and embrittlement, radiation-accelerated creep, erosion [2 - 7], etc. To date, insufficient experimental data on the behavior of helium in materials have been obtained.

Experiments to study the effect of helium formed during irradiation in NPP are long and rather complicated. In this regard, the introduction of helium into structural materials is carried out by helium ions bombardment in an accelerator. The purpose of this work is justification to use the 4 MeV helium ions LINAC for simulation processes, occurring in nuclear and thermonuclear reactors materials.

1. HELIUM IONS LINAC

A detailed description of the calculations, structure design and helium ion accelerator parameters are presented in previous publications [8]. The main parameters and distinctive features of the accelerator as a helium ion beam source to simulate the effect of TNR radiation fields on the divertor and the reactor first wall materials are below.

At the present time research is being carried out at the new pre-stripping section POS-4 developed at the NSC KIPT (Fig. 1). The interdigital (IH) accelerating structure operates on a modified alternativ phase focusing (APF) with a step change in synchronous phase (φ_s).

The φ_s step change along the accelerating period the structure makes it possible to obtain a good acceleration rate while maintaining beam stability.

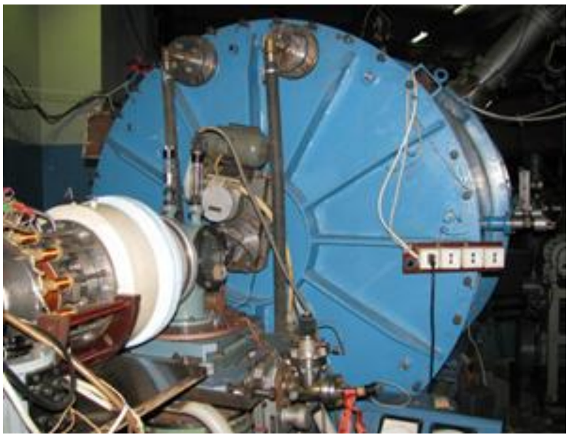

Fig. 1. Helium ions linac POS-4

The beam simultaneous radial and phase stability in APF is achieved by alternating sections with φ_s negative and positive values. Under certain conditions the beam simultaneously ensure the longitudinal and phase stability during the acceleration process is possible.

The advantages of this structure in the ion energies considered range are its small size, high acceleration rate, and high electrodynamic characteristics, which ensure the operation stability and RF power supply economical mode [9].

The accelerator channel consists of 6 focusing periods and one phasing accelerating gap. Each focusing period contains accelerating gaps with large φ_s absolute values to ensure maximum capture of particles in the acceleration mode. The gap with φ_s zero has the maximum acceleration rate. The accelerating gaps with an increasing HF field amplitude in the grouping section to compensate the drop in focusing rigidity with increasing particle energy, are used. The main linac parameters are shown in Table.

The main helium ions linac parameters

Input ion energy	30 keV/u
Output ion energy	975 keV/u
Operating frequency	47.2 MHz
Growing accelerating field	85 kV/cm
Total acceleration rate	1.6 MeV/m
Cavity length	2395 mm
Number of accelerating cells	32
Cavity diameter	107.5 cm
Pulsed current of accelerated ions	1…1.5 mA
Pulse repetition rate	5 Hz

2. TECHNIQUES AND EXPERIMENT

The research was carried out according to the following scheme. The samples were irradiated with helium ions in an accelerator. The accelerated ion beam energy and current, irradiation time, total fluence, and the sample temperature were controlled during the irradiation. The exit of the accelerator with a transport line and an irradiation chamber is shown in Fig. 2.

Fig. 2. Accelerator output:
1 – linear accelerator outlet; 2 – valve; 3 – Faraday cup; 4 – focusing triplet; 5 – induction transient sensor; 6 – chamber for irradiation of samples; 7 – turbomolecular pump; 8 – chamber with phosphor

After a certain radiation dose was reached, the profiles of helium occurrence in the sample and the profiles of damage were calculated. The SRIM program for materials of a given type and chemical composition has been used. In total, about a hundred metal, semiconductor and ceramic samples were irradiated. The maximum sample temperature and radiation dose were, respectively, 800°C and 10^{18} ion/cm^2. The irradiated materials damage level, depending on the energy and time, was in the range 3…80 dpa.

The research elaboration consists in the development of techniques and the structural materials characteristics study during and after their irradiation. Thermal desorption, microstructure, electrophysical characteristics (surface and volume resistance, capacitance and dielectric constant), ultrasonic and frictional characteristics are investigated.

The main attention to samples of zirconium (Zr), tungsten (W1), austenitic and martensitic steels (EP-450, EI-993), ceramics (TiO_2, Al_2O_3), as well as semiconductors (GaAs, InP) and graphite. was given. All samples before irradiation were thoroughly prepared. The irradiated surface of each sample, both before and after irradiation, was recorded on a digital camera using a microscope. The maximum resolution of the photographs was 16 pixels in 1 μm. Some experimental results and photographs of samples, as an illustration, are below. In subsequent publications more complete description the obtained results will be given.

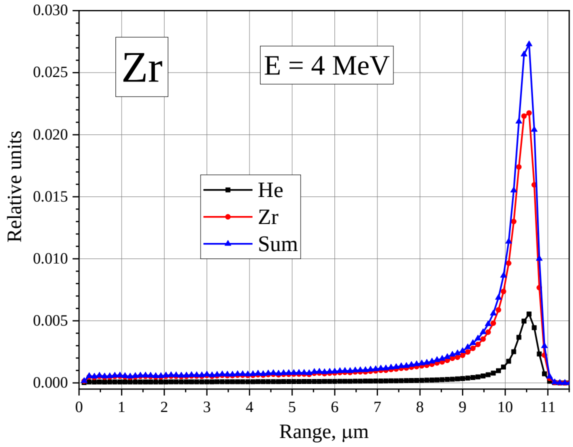

Fig. 3. Damageability profilogram zirconium sample

The irradiated zirconium sample damageability profilogram shows Fig. 3. Irradiation was carried out on a helium ions linac. The energy of the accelerated helium ions beam is 4 MeV, the dose is $1.1 \cdot 10^{15}$ part./cm^2. All calculations were performed taking into account displacement cascades. The main contribution to damage (83.4%) is made by zirconium atoms, which are formed in a cascade of displacements, 16.6% of displacements are created by a helium beam.

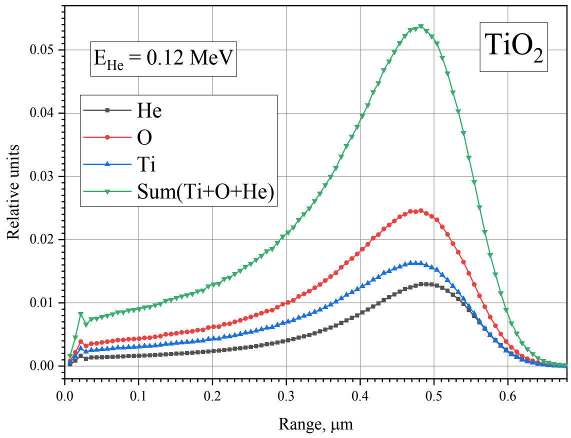

Fig. 4. The damageability graph a two-component material (titanium dioxide)

Fig. 4 shows a graph the damageability a two-component material (titanium dioxide) irradiated with a helium beam with an energy 4 MeV. The radiation dose is $1.12 \cdot 10^{18}$ part./cm^2. Calculations of the damageability of a TiO_2 sample, Fig. 4, presented on the basis of experimental data, show that the contribution to damage is distributed as follows: helium – 22%, oxygen – 46%, titanium – 32%. Consequently, the contribution from the main elements of the sample material with allowance for the cascade of displacements is 3-4 times greater than from the helium beam.

Figs. 5, 6 shows the profiles of occurrence and damageability a multicomponent sample of alloy W1, irradiated with a helium beam with energy 0.12 MeV. The radiation dose is $1.12 \cdot 10^{18}$ part./cm^2.

At the depth of run, tungsten has a maximum occurrence, as the main element of the W1 alloy, the next is helium, followed by all the alloy elements in accordance with the percentage.

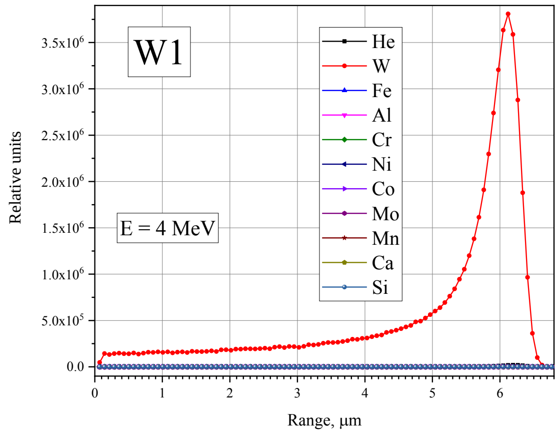

Fig. 5. The profil of occurrence a multicomponent sample of alloy W1

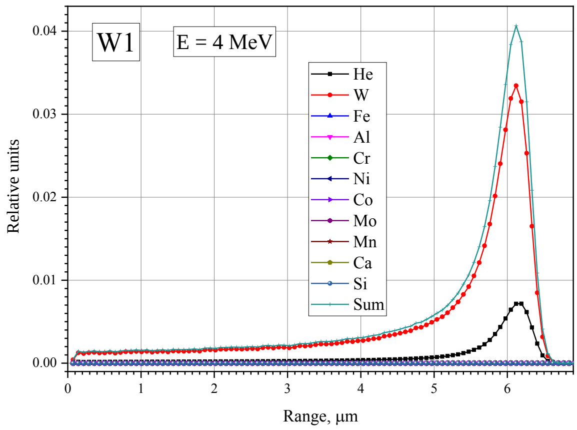

Fig. 6. The profil of damageability a multicomponent sample of alloy W1

Tungsten alloy damageability profilogram is shown in Fig. 6. As in the case of one- and two-component samples, the maximum damage occurs due to displacement cascades. The main contribution is made by tungsten, as the main element of the W alloy.

The W and steel EI-993 irradiated samples surfaces photographs are below.

Fig. 7 shows an image of the W surface after irradiation with 120 MeV helium ions without heating the sample. Dose is $1.1 \cdot 10^{18}$ part./cm^2. The picture clearly shows the formation of gas bubbles on the irradiated surface of the sample – “blistering”.

The steel EI-993 sample surface photograph is shown on Fig. 8. The experimental conditions are the same as for a tungsten sample. The sample top layer exfoliation is clearly visible here. Obviously, in this case, the so-called “flaking” takes place. Both cases are typical destruction examples of the first wall and the TNR divertor materials upper layer.

Fig. 7. The surface of the irradiated sample of the tungsten alloy W

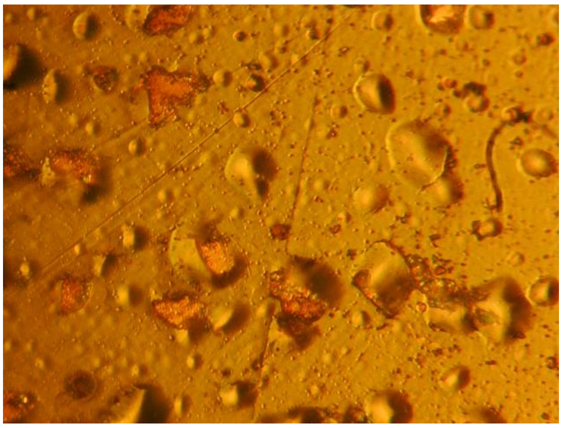

Fig. 8. The steel EI-993 irradiated sample surface

At present, an experimental setup has been created to study the frictional properties of a ceramic-metal pair after irradiation with helium ions in the temperature range of 200…700°C. A significant part of further experimental research will be devoted to the study the electrophysical characteristics ceramic materials. There are also plans to study the behavior ferrite-martensitic steels and tungsten samples under the influence a helium ion beam and powerful plasma flows in a wide range of temperatures, doses and thermal loads. In the course of these studies, the transmission acoustic waves through irradiated samples will be of great interest.

CONCLUSIONS

The methods and experimental data presented in this work make it possible to speak of their prospects for studying changes in the properties of structural materials during the operation of a nuclear power plant. The experimental results obtained in the development of the work, the directions which are described in the article, can be very useful for work on the creation and study of new materials for such NPP units as fuel rods, the first wall and the TNR divertor.

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ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ И РАЗВИТИЕ РАБОТ НА ЛИНЕЙНОМ УСКОРИТЕЛЕ ИОНОВ ГЕЛИЯ

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Приведено краткое изложение экспериментальных исследований, проводимых на материаловедческом радиационном комплексе, разработанном в ННЦ ХФТИ. Комплекс базируется на линейном ускорителе ионов гелия. Описаны особенности и преимущества ускоряющей структуры, в основу которой положен принцип переменно-фазовой фокусировки (ПФФ). Определены основные направления развития исследований. Разработаны методики и проведены облучения разного типа конструкционных и кандидатных материалов для дивертора и первой стенки ТЯР. Повреждаемость облученных образцов в экспериментах создавалась в пределах 3…80 сна.

ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ ТА РОЗВИТОК РОБІТ НА ЛІНІЙНОМУ ПРИСКОРЮВАЧІ ІОНІВ ГЕЛІЮ

І.М. Оніщенко, О.В. Мануйленко, Б.В. Зайцев, С.М. Дубнюк, А.П. Кобець, А.І. Кравченко, К.В. Павлій, В.М. Решетніков, В.А. Сошенко, С.С. Тішкін, О.В. Журавльов, В.Г. Журавльов

Наведений короткий виклад експериментальних досліджень, проведених на матеріалознавському радіаційному комплексі, розробленому в ННЦ ХФТІ. Комплекс базується на лінійному прискорювачі іонів гелію. Описані особливості та переваги прискорюючої структури, в основу якої покладений принцип змінно-фазового фокусування (ЗФФ). Визначені основні напрямки розвитку досліджень. Розроблено методики та проведені опромінення різного типу конструкційних матеріалів та кандидатних матеріалів для дивертора і першої стінки ТЯР. Пошкоджуваність опромінених зразків в експериментах створювалася в межах 3…80 сна.