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Review of some RIAR developed and improved procedures for post-irradiation examination

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Review of some RIAR improved and developed procedures for post-irradiation examination

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Abstract

Methods of post-irradiation examination (PIE) carried out in the SSC RF RIAR hot chambers are continuously extended and improved. In particular, it is concerned with methods used in examination and investigation of irradiated structural, fissionable and absorbing materials.

Brief characteristics are presented:

- methods for post-irradiation mechanical examination of zirconium claddings of VVER and RBMK fuel elements to be simultaneously affected by various damage factors;

- EPMA method used to study Xe output from UO_2 pellets;

- SIMS method used to study Ho distribution and Gd, Dy, B isotopes along cross-section of absorbers and fuel elements;

- MS method used to study He content in the stainless steel samples.

Introduction

In-pile and post-irradiation examinations (PIE) are carried out in the SSC RF RIAR involving five thermal, intermediate and fast research reactors (MIR, RBT-6, RBT-10, CM-2, BOR-60), 50 hot chambers and 100 boxes.

Along with standard methods of test and investigation RIAR continuously develops the original methods and extends the scope for use of standard research equipment.

Thus, it allows more complete evaluating and forecasting the reliability of materials and structures used in nuclear reactors.

1. Development of procedures for mechanical testing of zirconium claddings.

The series of mechanical procedures for testing the irradiated fuel pin claddings of the VVER and RBMK-type reactors has been developed and performed in hot cells. The procedures were designed for simulation of a whole complex of thermal, corrosion and mechanical effects on fuel pin claddings in both reactor operation conditions of steady-state and power maneuvering.

These procedures involve the following features:

- testing temperature up to 500°C;
- mechanical (without welding) face sealing of specimens under testing;
- cladding filling under internal gas or hydraulic pressure up to 150 MPa at loading rate from 0.01 to 1 MPa/s;
- containment of iodine vapors by cladding in testing;
- cycling the hydraulic internal or external pressure at frequency of ≤1 cycle/min;
- sample loading of simultaneous axial tensile strain up to 10^4H;
- maintaining of predetermined tangential and axial stress within 1to2;
- cycling of axial tensile loading at frequency of ≤1 cycle/min.

Scheme and results of some regimes for mechanical testing of zirconium claddings are presented in Figs. 1 and 2.

2. EPMA method used to study Xe output from UO_2

Method defining Xe output from UO_2 is based on the comparison of Nd and Xe distributions along cross-section radius of the VVER-1000 irradiated fuel pin.

Nd forms a solid solution in UO_2 by replacing positions of fissioned U atoms, i.e. it accumulates at the place of its formation. Nd migration and separation from UO_2 are negligible. Xe separation from UO_2 is considerably dependent on a temperature in the studied point of fuel pin cross-section.

Measurements were performed on specimens prepared for metallographic analysis with using the standard instrument MAP-3 and shielded micro-cell installed in it. The specific Xe radiation was recorded in a depth of about 1 μm. The current probe made up from 1.5 to 3.0 mA. The diameter of probe was within 30 to 50 μm. The measurements at the "point" continued for 80 s.

The developed method was used to study UO_2 gas separation depending on Δ_{ql} at the power jumps (Figs.3 and 4). The error of measurement makes up 15% at a burnup of B≥30 MW·days/kg U.

3. SIMS method used to study the distribution of burning-up isotopes on cross-section of elements

SIMS-method was carried out at RIAR on the base of standard secondary-ionic mass-spectrometer MC7202M suitable for operation with irradiated specimens. Investigations can be carried out with specimens of standard shape prepared for metallographic analysis.

Under study of absorbing element sample (vibropac B_4C powder in steel cladding of d x δ =10 x 0.5 mm) the Ar^+ions of 8 keV energy were used as primary ions. The current of primary ionic beam made up 0.1 mkA at diameter of ≈15μm. In this case ionic maps with resolution of 100x100 points were obtained. The scanning of a map lasted ≈15 min. The ionic images were recorded in the absorbed current (Ar^+) and secondary ions (^7Li, ^{12}C, ^{56}Fe, ^{52}Cr, ^{10}B, ^{11}B).

The isotopic composition of boron was also measured in "points" on cross-section of specimen after preliminary decontamination of surface with ionic beam. The spacing of measurement points was 200 μm.

The obtained results are given in Fig.5.

In studying the sample of another type absorbing element (Dy_2TiO_5 vibropac powder in steel cladding) the Ar^+ ions of 10 keV energy were used as primary ions. The beam current of primary ions was 0.8 mkA and diameter of ≈50 mkm. The relative Ho content and atomic concentration of Dy isotopes in the "point" on the sample radius were measured after preliminary surface decontamination with ionic beam. The points of measurement were spaced at 200 μm.

The results obtained are demonstrated in fig.6.

SIMS method was used in measurement of Gd-isotopic composition in the sample cut from irradiated fuel element (vibropac oxide fuel of 8% gadolinium oxide content involved in zirconium cladding of dxδ=9.1x0.65 mm).

The results obtained are demonstrated in Fig.7.

4. Mass-spectrum analysis used for study of He accumulation in stainless steels.

The procedure was realized at RIAR on the base of standard mass-spectrometer МИ-1201 used in operation with irradiated samples.

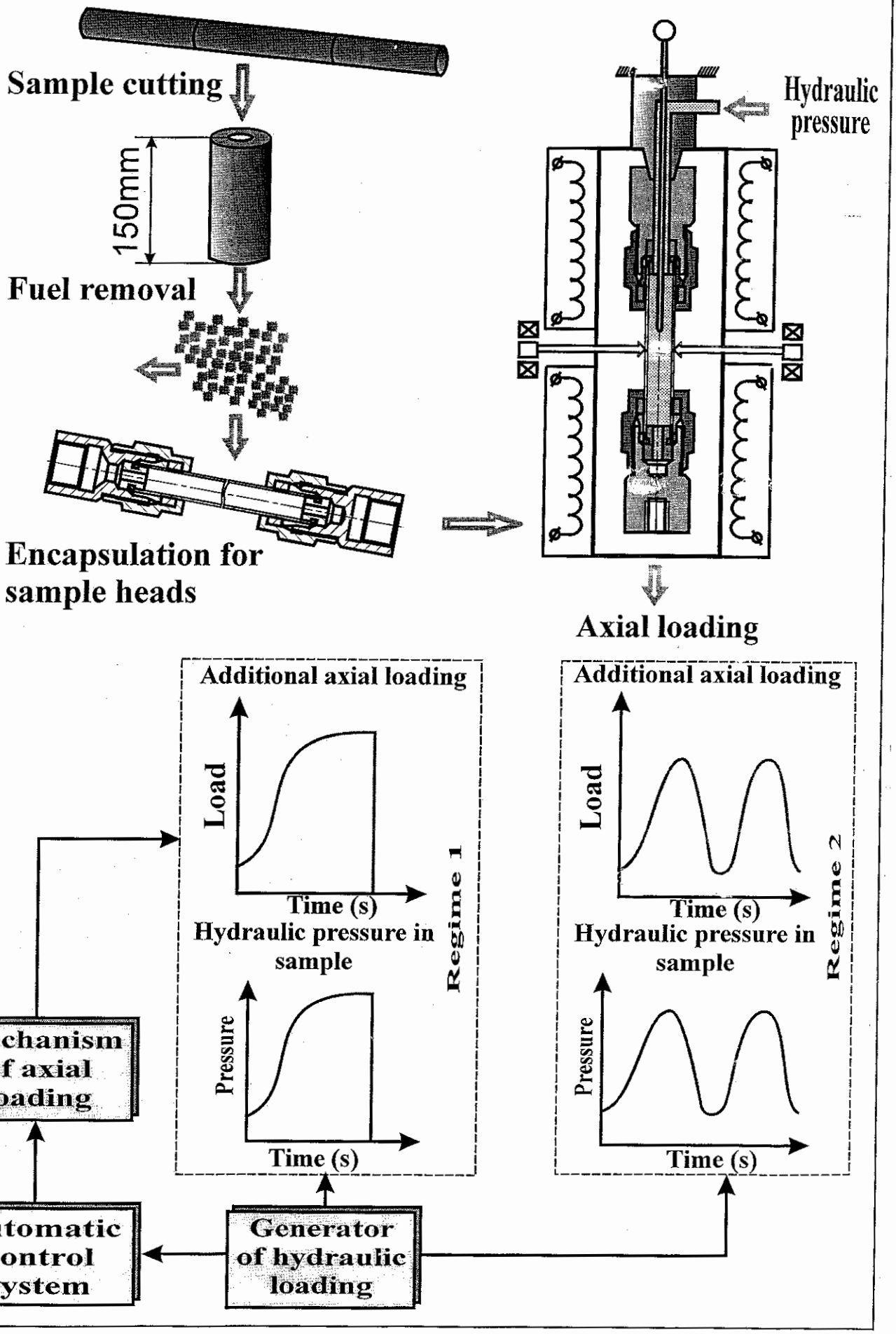
Irradiated stainless steel samples of ≈30 mg mass were placed in the tantalum crucible which was located in the quartz capsule connected to the vacuum chamber. The quartz capsule with gas-mark (^3He) and mass-spectrometer were united with the chamber too.

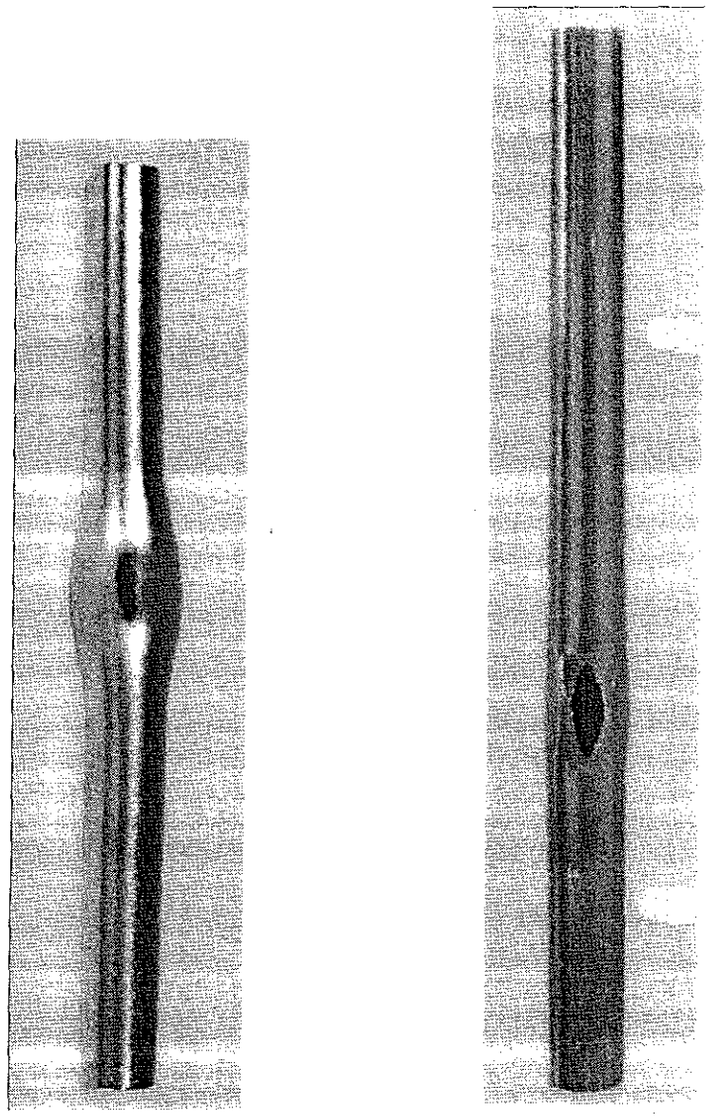
A sample was heated up to melting with using the inductor of high-frequency generator. The gas probe containing the gas phase extracted from the sample at T=2100 K and the gas-marker, i.e. the mixture of ^4He+^3He were subjected to mass-spectrometric analyses.

A high sensitivity of facility (minimum amount of analyzed gas of $\approx 10^{-10}$ mole) allows the measurement of ^4He containing in the stainless steel in the range of 1 to 500 ppm.

The ^4He content (with confidence probability of P=0.95) of N_A=276±36 ppm and N_B=21.0±3.4 ppm was measured in two A and B stainless steel 316 samples, mass of 33.3 mg (m_A) and 20.2 mg (m_B) after irradiation under different conditions.

Fig.1 Testing of spent VVER fuel pin cladding by internal hydraulic pressure





A B

Fig.2 . Appearance of Zr-cladding damaged by:
A – internal hydraulic pressure;
B – internal hydraulic pressure and axial tensile loading. (⇒ more axial strain, less radial strain)

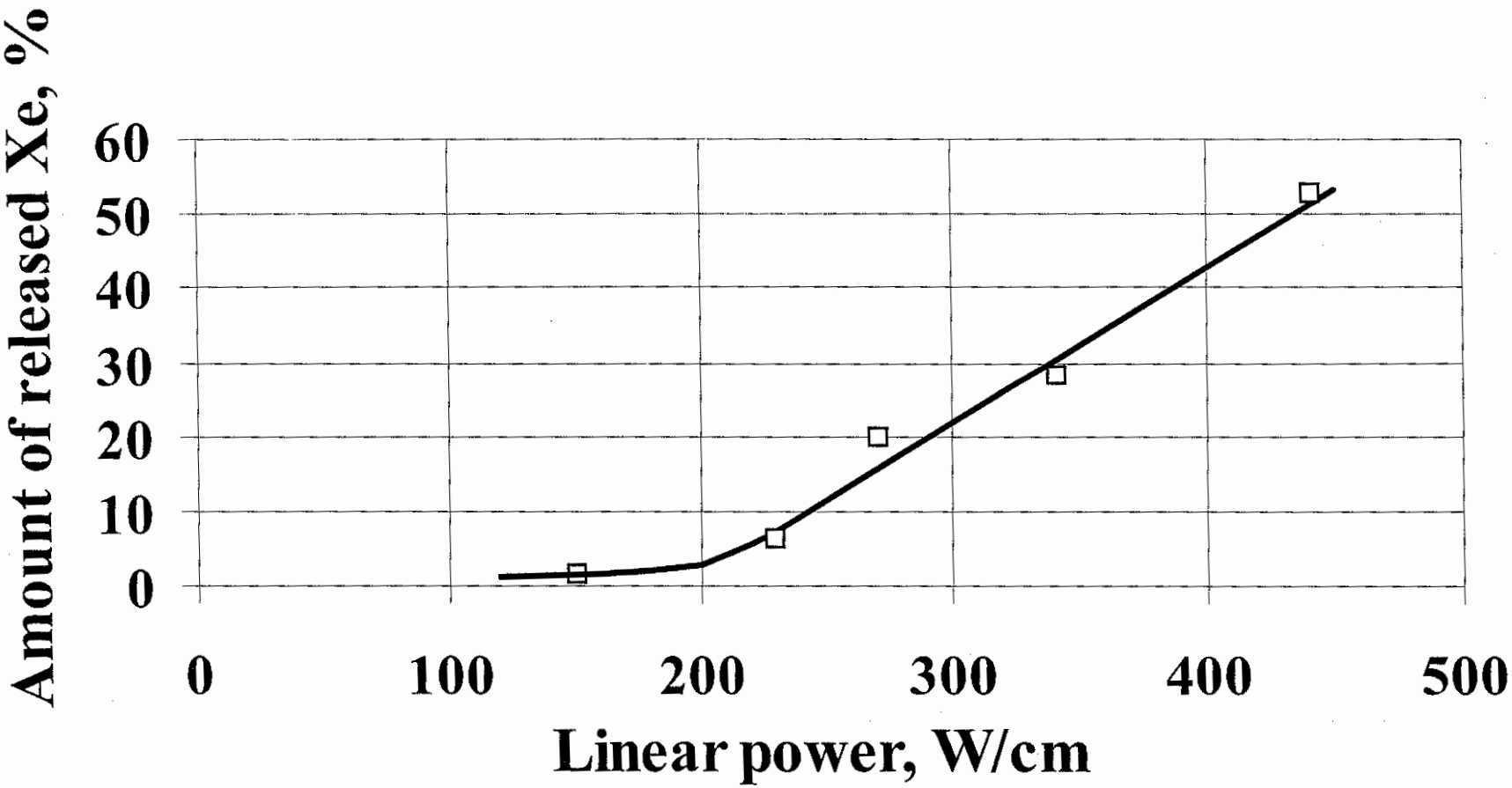


Fig.3 Output of gas fission products as a function of linear power

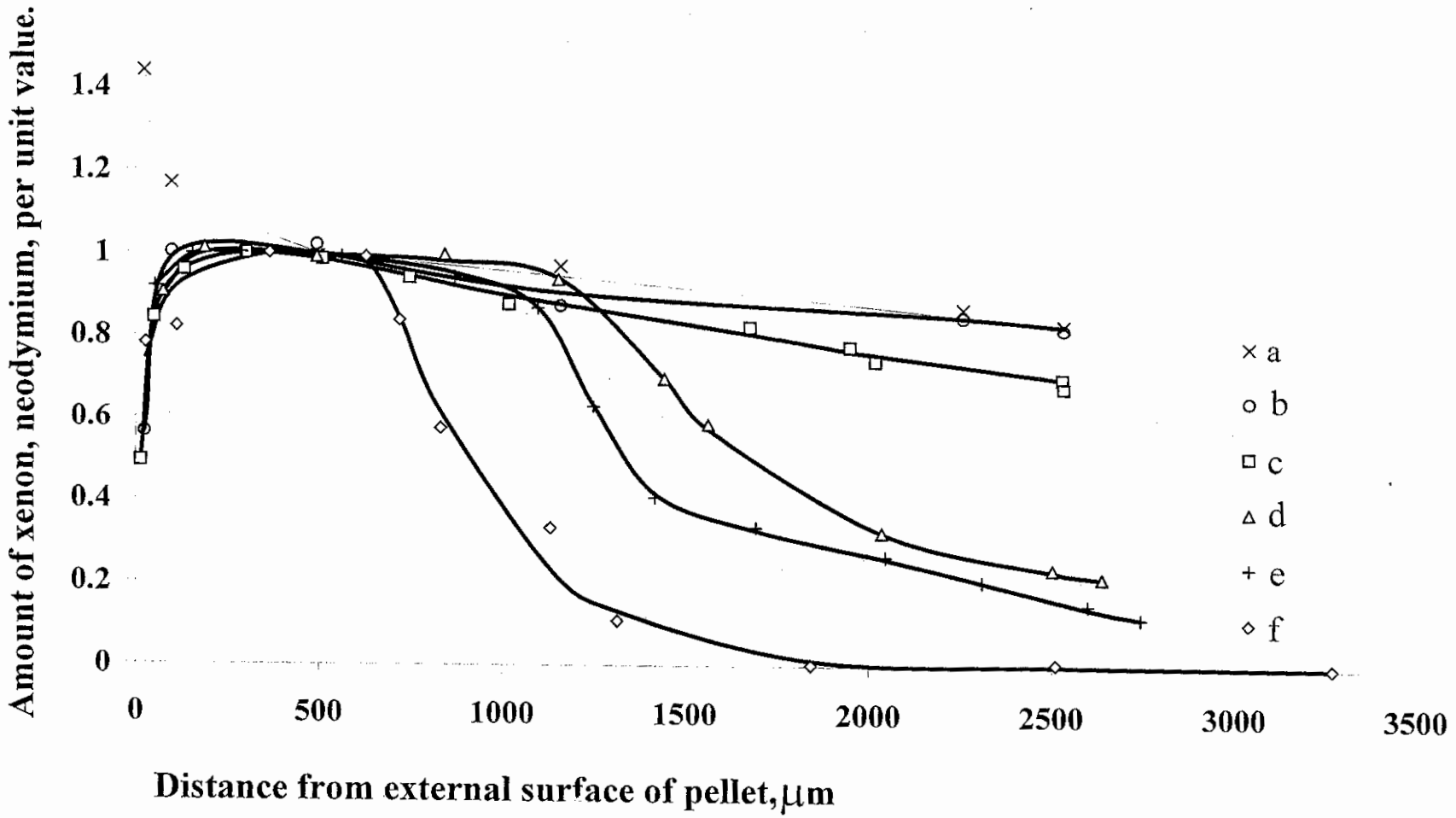
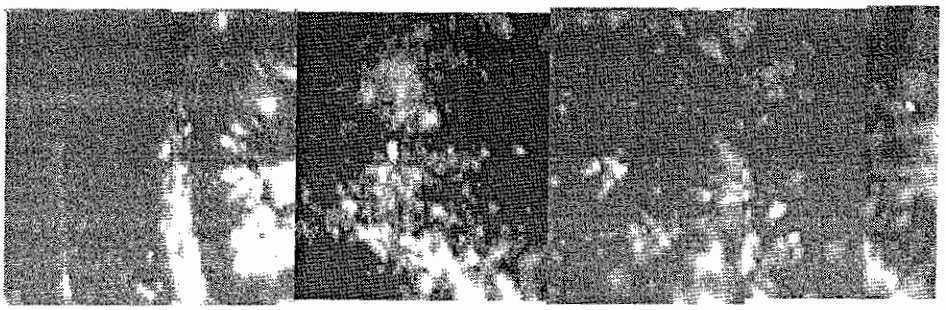
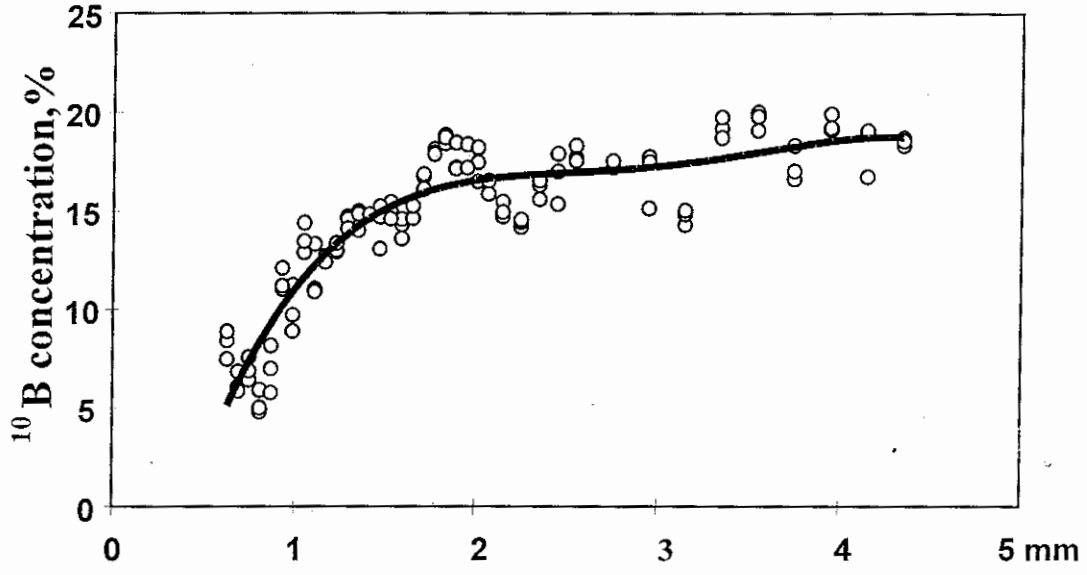


Fig.4.Distribution of neodymium (a) and xenon (b-e) on radius of pellets at linear power of (b)-150,(c) - 230, (d)-270, (e)-340, (f)-445 W/cm



A



B

Fig.5 Distribution of ^{10}B content on radius of B_4C sample
A – "ionic (B^{10})" picture
B – measured in "points"

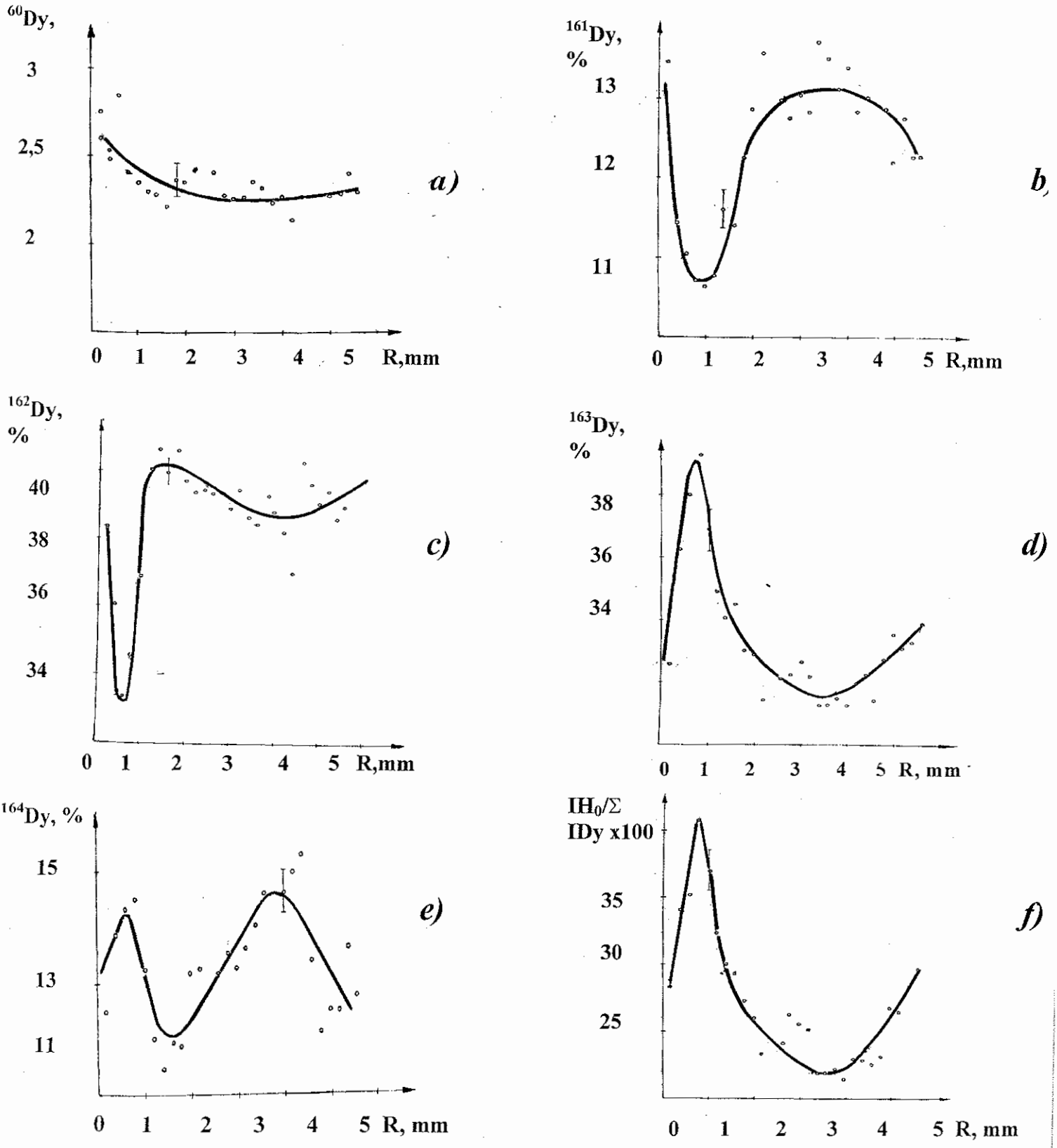


Fig.6 Distribution of dysprosium (a-d) and holmium (f) on radius of Dy_2TiO_5 irradiated sample .

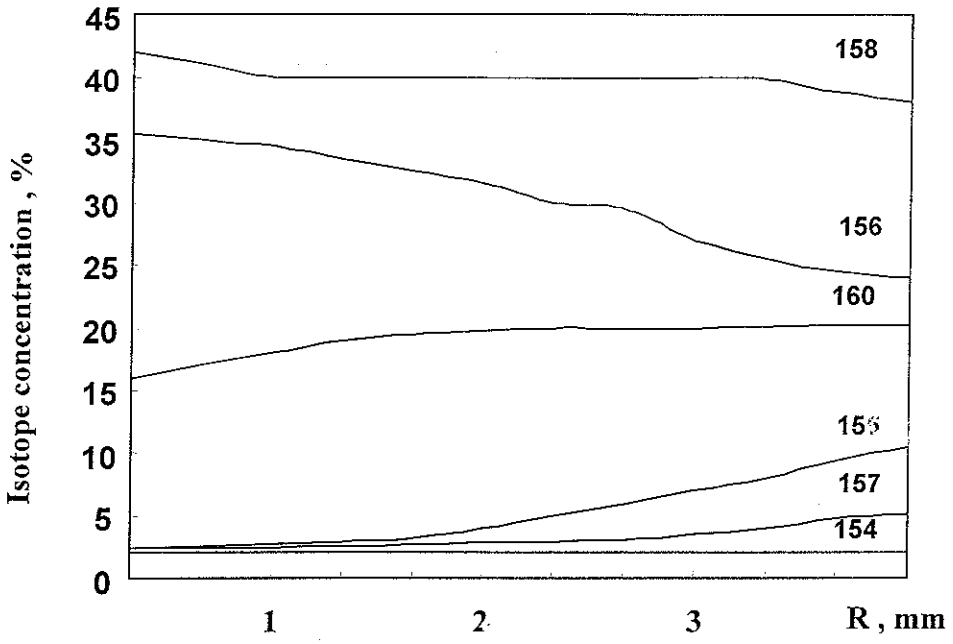


Fig.7 Distribution of gadolinium isotopic content on radius of UO_2 +Gd_2O_3 irradiated sample.