RIAR Hot Cells Material Testing Complex.
Methodical Possibilities

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Abstract

The RIAR material science complex was commissioned at the beginning of 1964. For more than 40-year period of existence of the material science complex several generations of its main and auxiliary research equipment have changed. The specialists have gained great experience in conducting examinations of irradiated materials, methods that are the most suitable for investigation of such materials have been selected. Current methodical possibilities of RIAR Material testing complex represented in this report.

***Keywords:* Material science, methodical possibilities, secondary ion mass spectrometry, nuclear reactors, mechanical properties, electron microscope**

Research Institute of Atomic Reactors is the largest hot laboratory in Russia. The RIAR material science complex that was commissioned at the beginning of 1964 was created to solve the following main tasks:

- organization and conducting of material science investigations prior to and after irradiation of fuel elements, fuel assemblies, control rods, fuel, absorber and structural materials of the cores of various purpose and other materials and products of nuclear engineering;
- conducting of investigations in the field of radiation damage physics;
- conducting of investigations to validate long-term storage of spent nuclear fuel, develop utilization technologies of irradiated materials and products;
- physical modeling of behavior of core materials and elements for nuclear reactors;
- development of techniques for post-irradiation examination;
- organization and conducting of material science supervision of the Institute and NPP reactors;
- development and manufacture of irradiation rigs, fuel and absorbing compositions, fuel elements, fuel assemblies and control rods, accumulation targets of radiation sources and other products of nuclear engineering;
- development of process equipment and production processes of reactor materials;
- development of production processes of transuranium elements (TUE) and alloys on their basis, study of their properties;
- widening of application scope of the developed technologies, materials and products in all branches of industry;
- participation in the development and implementation of federal and branch scientific-technical programs;

For more than 40-year period of existence of the material science complex several generations of its main and auxiliary research equipment have changed. The specialists have gained great experience in conducting examinations of irradiated materials, methods that are the most suitable for investigation of such materials have been selected.

RIAR Material testing complex houses 64 hot cells and 60 heavy-duty boxes and consists of three buildings:

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- for non-destructive analysis of full-scale fuel rods and fuel assemblies (measurements of fuel rod parameters; visual examinations; gamma scanning; vortex-current defectoscopy, etc);
- for destructive analysis (burn-up, fission products release; gamma scanning; metallography and micro-hardness; density and porosity; thermal conductivity and electric resistance; X-ray analysis; dilatometry; TEM, SEM, EPMA, AES, SIMS; mechanical testing (tensile, compression, bending, impact, etc.);
- for technological engineering programs;

There are two large hot cells in the first building (these big hot cells designed for operations with full-scale fuel assemblies for commercial reactors are 7.5 m long, 4.0 m wide and 7.2 m high) and five hot cells of the smaller size. These five hot cells are 5.0*1.8*2.6 m in size.

The scheme of the second building approximately can be divided into eight sections intended for:

- mechanical tests;
- dismantling of capsule assemblies, fuel assemblies and other irradiated products;
- x-ray and element-fractographic examination;
- metallography examination;
- production of gamma-, beta- and neutron sources;
- investigation of physical-mechanical properties and TEM-examination;
- study on the damage nature and local element - isotopic composition of irradiated specimens;
- study of the element composition of irradiated specimens by the microprobe analysis.

Mechanical testing area.

The most commonly used techniques of determining mechanical properties in our hot laboratory are:

- Definition of hardness of irradiated specimens of structural materials (steels);
- Technique for growing preliminary fatigue crack in compact specimens and Charpy-type specimens;
- Technique of post-irradiation examination of crack resistance based on the three-point bending test of specimens manufactured from technological channels and control rod channels of the RBMK-type reactors;
- Technique of remote instrumented impact toughness tests;
- Measurement technique of mechanical property characteristics during tension of annular specimens made from thin-walled steel and alloy tubes;
- Measurement technique of mechanical property characteristics during tension of annular specimens made from thin-walled zirconium alloy tubes;
- Test technique of irradiated specimens to determine fracture toughness of material for the RBMK reactor channel tubes;
- Technique for definition of growth rate of fatigue crack during cyclic loading of 0.5 C(T)-type compact specimens
- Technique for definition of short-term mechanical properties of irradiated materials;
- Bending test technique at decreased room temperature and elevated temperatures;
- Technique for definition of creep and long-term strength of irradiated materials;
- Technique for definition of crack resistance parameters of irradiated zirconium alloys during three-point bending test of specimens (5x5x35 mm) with a fatigue crack;
- Measurement technique of crack resistance parameters of cladding tube (5.8x0.5 mm diameter) material using a composite flat specimen;
- Estimation technique of dynamic toughness using Charpy specimens with a fatigue crack during testing at the instrumented impact testing machine with falling weight;
- Comprehensive techniques for tensile test of cladding materials;
- Techniques based on resonance-acoustic method for definition of elastic constants of materials.

The schemes of two RIAR facilities for tubular specimen testing are given in Fig. 1.

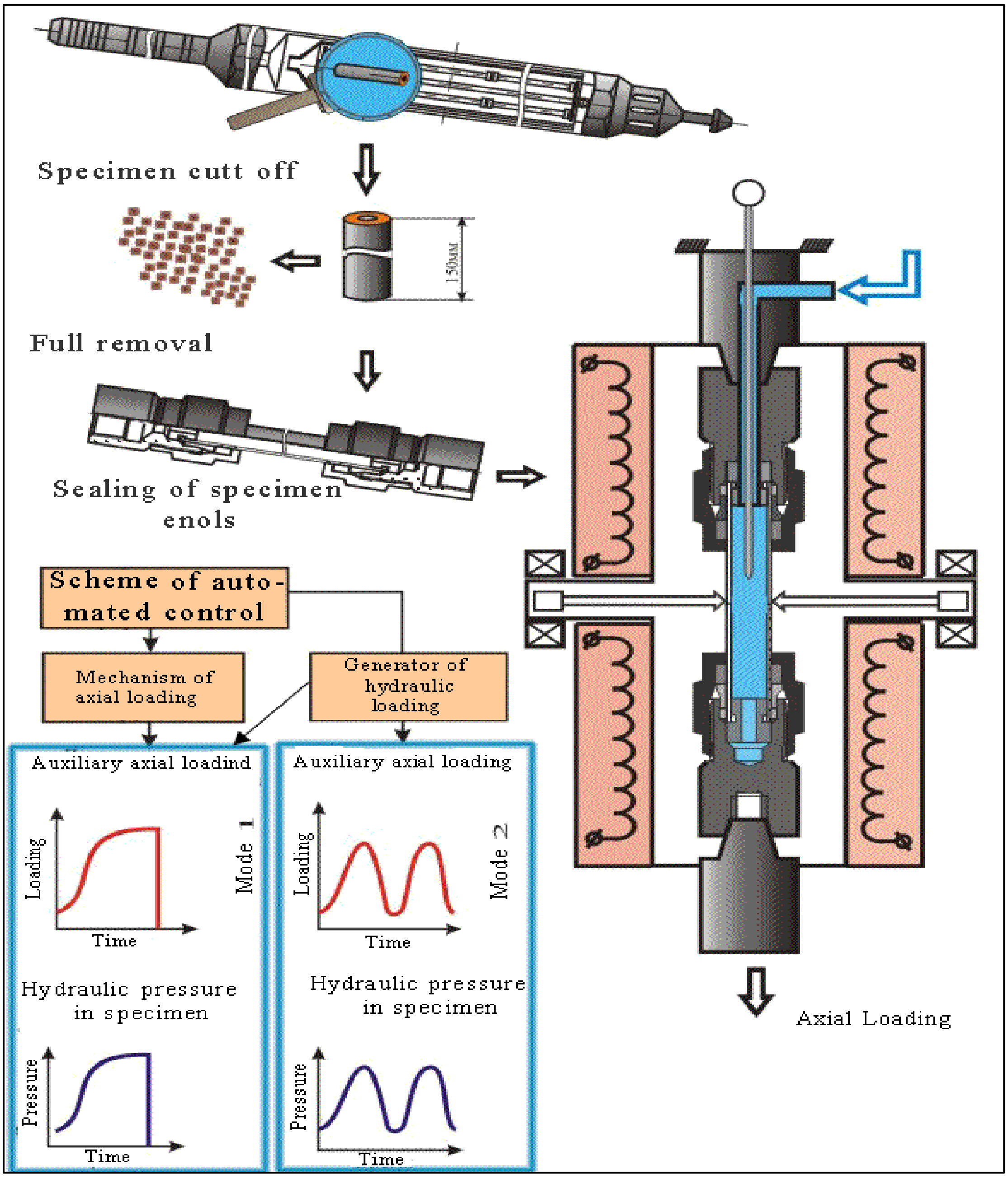


Fig. 1a: Scheme of the facility for tubular specimen testing under biaxial stress condition

The first facility (Fig.1a) is intended for testing of tubular specimens under biaxial stress condition. The facility allows to obtain the mechanical properties of the specimens cut off from the spent fuel rod cladding with the specified relation of circumferential and axial stress. Here, the state of the specimen surface and dimensions of its central part are not changed. The second facility (Fig.1b) is intended for stress corrosion cracking testing of the tubular specimens including stress cycling. The facility allows testing the cut off from the spent fuel rod cladding specimens without changing of the state of the specimen surface and dimensions of its central part. Gas is pressurized into the specimen inner cavity with corrosion-active medium.

Additional information about mechanical testing in RIAR material testing complex are presented in report [1].

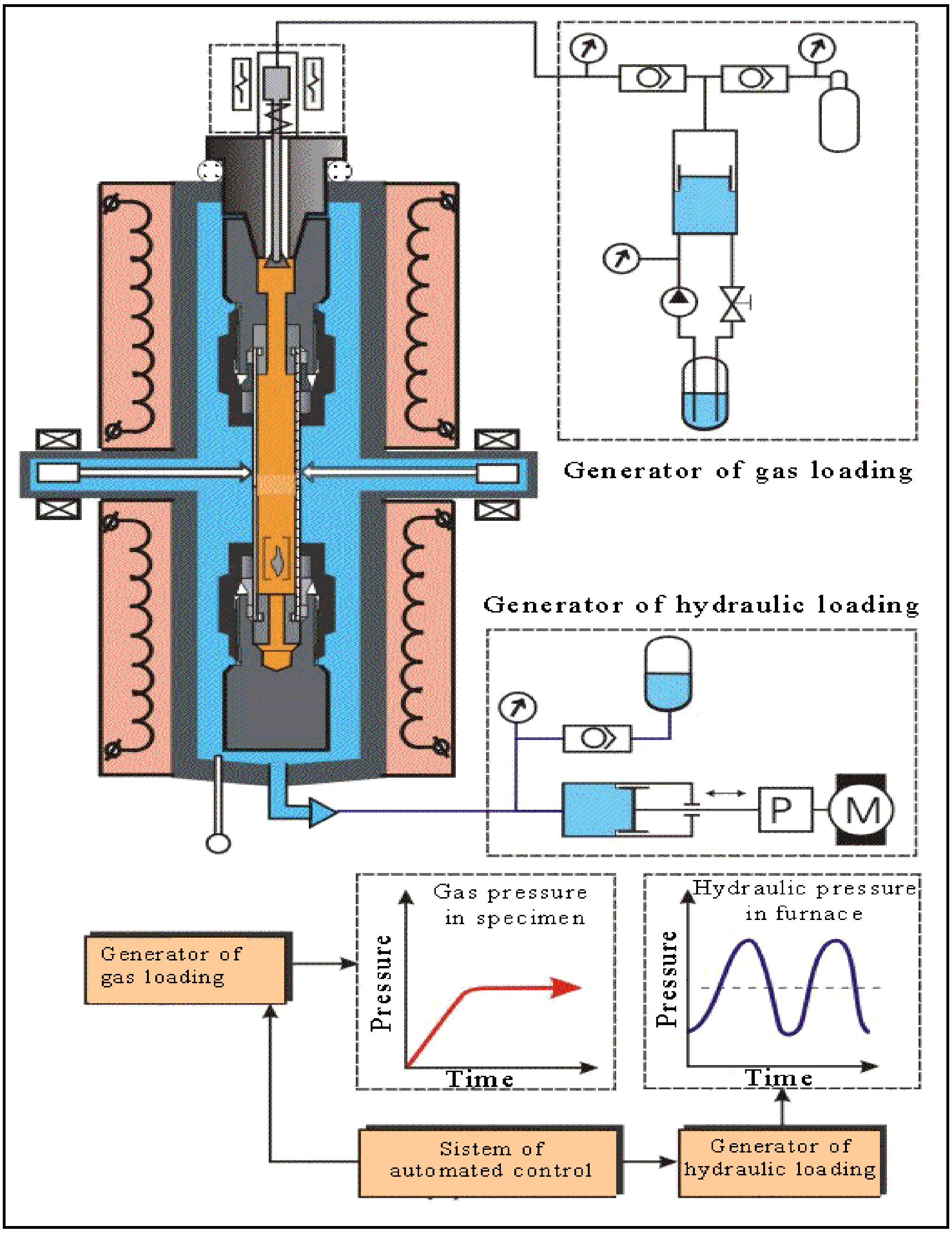


Fig. 1b: Scheme of the facility for tubular specimen testing - stress corrosion cracking testing of the tubular specimens including stress cycling. The facility allows to test the cut off from the spent fuel rod cladding specimens.

X-ray and element-fractographic examination area.

We have two x-ray remote handling diffractometers DARD and one scanning electron microscope Phillips XL 30 ESEM-TMP in this area.

Technical characteristics of the remotely controlled diffractometers do not differ from those of the general-purpose ones:

- accuracy of diffraction angle measurements ($d\theta = 0.0050$)
- power of X-ray tube (2.5kW)
- maximum diffraction angle ($2\theta = 164^0$).

Technical characteristics of the remotely controlled scanning electron microscope Phillips XL 30 ESEM-TMP and some examples demonstrating the microscope possibilities are resulted in [2], [3].

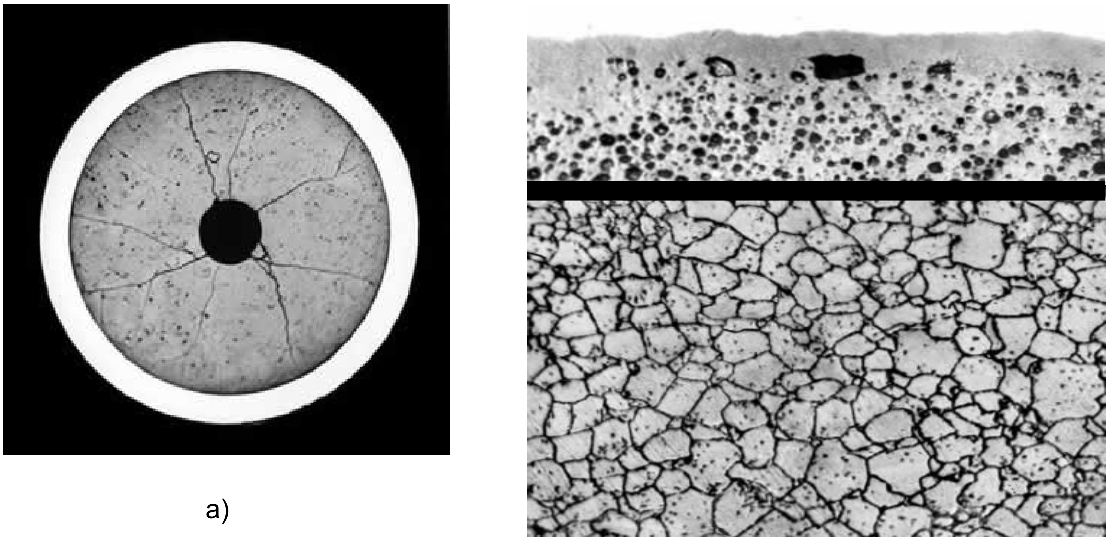
Metallographic examinations area.

The hot cells for metallographic analysis are equipped with:

- UMSD, MIM-7, MIM-8, MIM-10 and MIM-15 microscopes;
- micro-hardness meters PMT-3 and PMT-6,
- polishing machines and other auxiliary equipment:
- microscopes MMD-1M.

Irradiated specimens are examined in the hot cells by remotely controlled equipment.

Some examples of macrostructure and microstructure received on these microscopes are resulted in Fig.2.

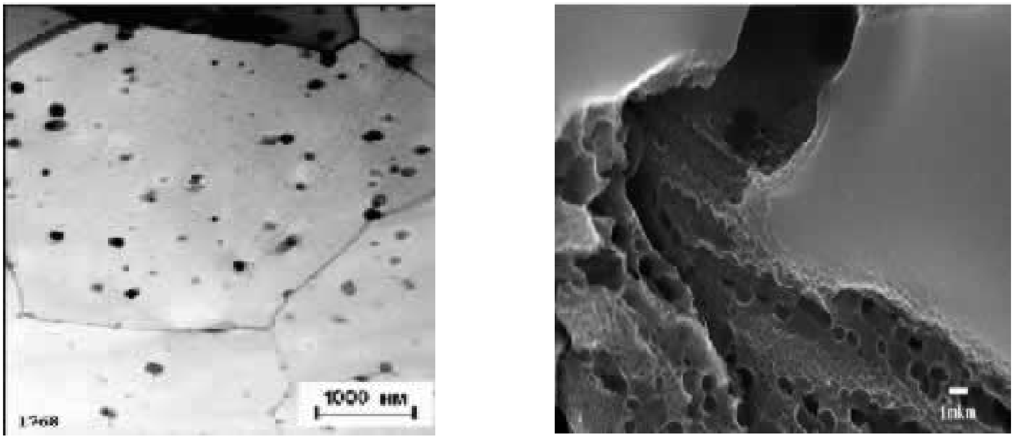


a) b) c)

Fig.2. Macrostructure of the transverse cross-section of the VVER-440 reactor fuel rod (a), microstructure of the pellet central part (b), rim-layer (c).

TEM-examination area.

There are two transmission electron microscopes in this are: JEM 2000 FX II and EM-125. Images obtained by JEM 2000 FX II microscope in the transmission mode and in the scanning mode are resulted in Fig. 3.



a) b)

Fig.3. Images obtained by JEM 2000 FX II microscope in the transmission mode (a) and in the scanning mode (b)

Surface element - isotopic composition examination area.

There are two differential scanning auger electron spectrometers: ESO-3 and ESO-5, one scanning electron microscope and one secondary ion mass-spectrometer MS-7202M in this area. Usually we use the techniques from this area for examinations of the isotope and elemental surface composition, for example, for the grain boundary surface elemental composition of the different alloys, for elemental and isotope composition of any corrosion surfaces, sometimes for the examinations of the isotope and elemental composition of the cross-sections of any absorbing and fuel elements. Some results of such examinations are adduced in [4, 5].

Microprobe examination area.

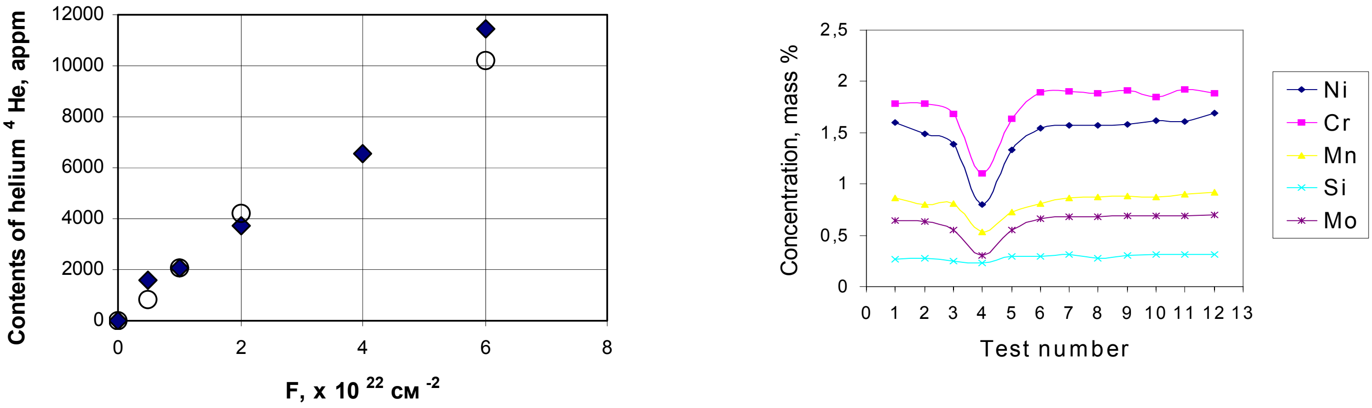
There are X-ray micro analyzer MAR-4 and laser atomic-fluorescent analyser LAFA-1 in the hot cell of this area. Technical characteristics of the remotely controlled micro analyzer MAR-4 do not differ from those of the general-purpose ones.

Laser atomic-fluorescent analyser LAFA-1 is intended for local spectral qualitative analysis of elemental composition (from hydrogen to californium).

And there are many other facilities in RIAR Hot Laboratory:

- Mass-spectrometer MI-1201. MI-1201 is designed for determination of helium content in alloys;
- Emission plasma spectrometer "Spectroflame Modula S". It is intended for qualitative elemental analysis of water solutions of different materials (more than 70 elements);
- Gas Analyzer OH-900. The ELTRA gas analyzer is intended for determination of oxygen and hydrogen concentration in steels, zirconium, and other irradiated materials.

Some examples of these facilities application are represented in Fig. 4.



a) b)

Fig.4. a - helium contents in irradiated beryllium (MI-1201);
b - impurities distribution in vessel steel weld (emission plasma spectrometer "Spectroflame Modula S"

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