NON-DESTRUCTIVE TESTING OF FUEL ELEMENTS FOR NUCLEAR REACTORS

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Abstract: It is possible to mark out two scopes of non-destructive testing which are most important and specific to nuclear power.

- The testing of nuclear fuel elements (NFE) and nuclear fuel assemblies (NFA) in process of their production;
- Material engineering researches of NFE and NFA before and after their using in reactor.

Significant growth of NFE and NFA production and increase of their quality requirements raises the necessity of development the new devices generation for non-destructive testing during production process, and examination after using them in reactor facility. In creation of such devices and monitoring systems and their use there were take part as the specialized enterprises, engaged in development of the equipment, and the enterprises manufacturing NFE and NFA. For monitoring of various parameters there have been used a wide spectrum of the methods based on various physical principles: radiation methods, a method of eddy currents, optical methods, etc.

Introduction: The nuclear power now plays an essential role in generating of electricity in many countries of the world. In a number of countries generating of an electricity at nuclear power plants makes more than 50 per cent (Lithuania - 81,5%, France - 78,2 %, Belgium - 60,1%). Russian nuclear power plants produce 13,6 per cent of all generated electricity in Russia, though in the European part of the Russian Federation this percentage makes already more than 30 per cent.

Ensuring of reliable and safe operation of the nuclear power plants is the central problem of nuclear power engineering. In particular it depends on quality of nuclear fuel and process equipment for fuel manufacture. Solving of this problem is directly connected to application of non-destructive testing and diagnostics.

Results: It is possible to mark out two most important and specific to nuclear power scopes of non-destructive testing.

1. The testing of nuclear fuel elements (NFE) and nuclear fuel assemblies (NFA) in process of their production;
2. Material engineering researches of NFE and NFA before using and after using in reactor.

Conditions of NFE and NFA operation in active zones of reactors at nuclear power plants are rather heavy. They are influenced with high temperature, significant pressure, very high level of radiation, thermal pressure, corrosion and chemical interaction of the fissionable substance, the shell and the coolant. In this connection especially great demands are made to NFE quality.

Means for non-destructive quality assurance of NFE and their components, used in process of their production, should have not only high traditional characteristics, but also meet a number of special requirements - to provide rational full automatic operation and to possess high stability to influence of destabilizing factors, rational disposition on production sites, a coordination with transport streams of production unit and a control system of manufacture.

In process of NFE production it is carried out the quality assurance of initial materials, powders, crude and sintered fuel pellets, shells and trailer details, the welded seams of assembled NFE and NFA.

A lot of the destructive and non-destructive methods regulated by special normative documents are applied to quality assurance of NFE and their components in process of manufacture. At the modern automated NFE production factory the priority have the non-destructive methods of quality inspection. So, for example, from the general number of testing operations (from 25 up to 50 for NFE of various types of reactors) a destructive quality inspection make only 10-20 per cent, and 80-90 per cent are the non-destructive methods of quality assurance.

Despite of significant distinctions in methods of testing, to the means, used for fuel elements quality assurance, the following general demands are made:

- Testing means over the majority should be directly connected to the process equipment, or should be built in production process; считывание
- Productivity, power supply of testing means should be coordinated, and also questions of metrology and reliability of display of testing results should be solved.

Thus, testing devices get features of complex automatic technical systems, which incorporate the transport ways providing feeding of a product for the testing, reading of an index (marks) of a product, comparison of the measured value from a field of the tolerance, the monitoring of technical and metrological serviceability of the equipment, representation of results of the testing, etc.

Within several decades one of the main developers of means of non-destructive testing of fuel elements and their parts is Russian National Technical Physics and Automation Research Institute (Moscow) [2]. Together with enterprises-coauthors such as MSZ (Machine Building Factory), NZHK (Novosibirsk Factory of Chemical Concentrates), All-Russian Non-Organic Materials Research Institute, Open Society SVERDNIIHIMMASH, etc. have been realized programs of creation aggregated system for fuel elements non-destructive testing (ASNK-T) and equipped with devices for non-destructive testing the various types of the fuel elements. So for fuel elements of reactors VVER-1000 on the basis of uniform scientific and technical principles the following devices have been developed, manufactured, tested and put into operation:

1. Device for the testing of completeness a fuel core.
2. Device for the testing of geometrical sizes.
3. Device for the pressure of helium inspection.
4. Device for the surface contamination monitoring.

Wide methodical, metrological and functional features based on developed concept ASNK-T have allowed for the first time to solve essentially new problems, essentially influencing on quality of technology and an opportunity of its automation.

For the automated modular production line of the third generation for manufacture of fuel elements for RBMK-1000 and RBMK-1500 reactors have been created the systems of non-destructive testing and automatic inspection.. The system of non-destructive testing is the set of automatic positions of the inspection providing noncontact measurement of the most crucial parameters of products, and includes the following devices:

Device for tightness inspection of welded seams. Device for testing of details alignment.

Device for inspection of length of the compressed part of a clamp and compensating volume.

Device for testing of extent of welded seams. Device for inspection and control of products etching. Device for testing of length, diameter and straightforwardness of products. Device for inspection of individual and total backlashes between pellets in fuel element. Device for inspection of presence of screen pellets. Device for inspection of a surface contamination of products. Device for weight measurement of shells with stopper plugs as well as of assembled fuel elements.

ASNK-T aggregated system supports also means of automation. That fact has allowed to create the automatic control system of the line for production of RBMK fuel elements as the microprocessor complex constructed on an uniform technical basis with non-destructive testing devices. These devices provide automatic inspection of:

Fitting-out of shells with pellets;
Dedusting and pressurization of products;
Inserting of screen pellets;
Inserting of a clamp;
Alkaline processing and anodizing of products.

Concept ASNK-T is realized also in creation of the local information system providing gathering, processing and representation of the full information on manufactured RBMK fuel elements, and also serviceability of the production equipment.

Significant growth of NFE and NFA manufacture and rise in demands to their quality arouse the necessity of development the new generation of devices. It is necessary to note among them the device for inspection of a surface contamination of fuel element, the device for the pressure of helium inspection, the device for automatic density measurements of fuel pellets, updating of the device for the completeness a fuel core testing.

It has been demanded the further development and serious automation of measurement methods used earlier in a large-lot production, and for some of them - replacement for more perfect. So, for example, specially developed modifications of gamma-absorption method for a quality testing of the sintered smooth fuel pellets density have allowed noticeably raise both accuracy, and productivity of the testing device. Fig.1 shows the device of new generation developed in VNIITFA for the diameter and density testing of sintered nuclear fuel pellets.

Fig. 1. The device for diameter and density testing of sintered fuel pellets.

Application of gamma-absorption method instead of radiographic testing of backlashes in fuel cores of fuel elements has allowed automate all testing operations, reduce the time of testing at 15-20 time, and noticeably raise its efficiency and profitability. A number of the devices providing the testing of backlashes and length of a fuel core in fuel elements of various type is created and is used in the industry. The Fig, 2 shows one of such devices.

Fig. 2. The device for testing of backlashes in a fuel core.

It is necessary to note, that a difficult component of development of such measuring system is creation of metrological maintenance. For this purpose special standard samples of enterprise (SSE) with the normalized metrological characteristics of controllable parameters are developed, according to requirements of normative and technical documentation and features of measuring systems for testing of backlashes of a fuel core in fuel element (simultaneous measurement of 8 parameters, rapidity of measurements, operation in an automatic mode).
During many years the various organizations were solving the problem of the measurement of internal pressure in VVER type fuel elements. Some modifications of such device are used, however, works on their modernization do not stop. The researches have shown that the device for the inspection of internal pressure developed by VNIITFA possesses by the widest range of measurements. Fig. 3 shows experimental variant of this device.

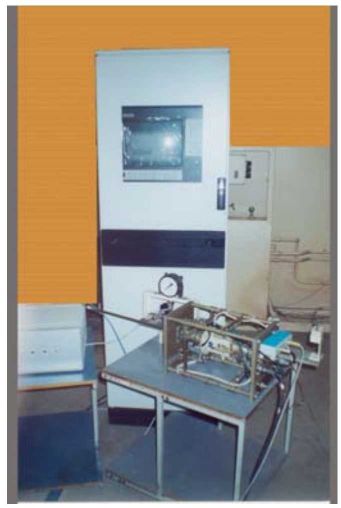


Fig. 3. The device for inspection of internal pressure in fuel element.

VNIITFA researches have created some modifications of devices for inspection of superficial contamination, including the devices intended for use in conditions of a three-zoned production system for the testing of fuel elements with high background fuel (Fig. 4). Now this direction is actively developing with using a new element base and namely the essentially different detectors of ionizing radiations.

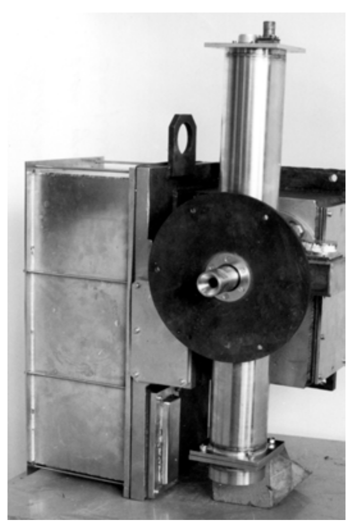


Fig. 4. The detector unit of device for inspection of superficial contamination of fuel elements

The essential work on creation and use of means for non-destructive testing is conducted on Novosibirsk Chemical Concentrates Factory by manufacture of nuclear fuel elements for various types of reactors [3]. It is necessary to note the use of ***ultrasonic methods*** in the decision of such problems, as:

- The testing of welded connections of stopper plugs in fuel elements, executed by a method of electron beam welding;
- The testing of stratification of an fuel elements shell;
- Technical diagnostics of the equipment used by fuel elements manufacture;

Radiation methods for:

- The radiographic testing of welded connections of stopper plugs in fuel elements, executed by a method of electron beam welding;
- The radiographic testing of separate units of equipment used by manufacture of fuel elements;
- The radiographic testing of fuel elements of research reactors;
- Gamma-absorption technique for the inspection of a fuel core in fuel element,
- Gamma-absorption technique for density measurements of fuel pellets;
- Measurement of thickness of coverings with use of back scattering of gamma-radiation.

Methods of eddy currents for:

- Determination of a fuel core position and its properties for fuel elements of reactors VVER-440 and VVER-1000;
- The testing of a covering defects;
- Detection of superficial defects.

It is possible to note the last developments used at this enterprise:

- X-ray devices for introscopy;
- The X-ray tomography device for the testing of the connections executed by an electron beam welding;
- The automatic transfer line for the testing of cylindrical products over connections executed by a method electron beam welding and butt-welding.

The essential and productive activity on creation of devices and systems on the basis of radiation techniques is conducted on the Electrostal Machine Building Factory (Open Society MSZ). So for example, it is described [4] the experience of development and introduction of X-ray TV-monitoring system MU115F, developed together with firm PHILIPS INDUSTRIAL X-RAY, for quality assessment of the fuel core in the fuel elements for reactors VVER-440. The system operates in structure of the industrial automated line. Processing and the analysis of X-ray images, detection and estimation of defects are made using PC. Productivity of the testing is 81 elements per hour. Metrological certification of system has been carried out with the help of the specially developed standard samples.

The trends of development of modern means for the testing and diagnostics of the spent nuclear fuel (nuclear fuel elements and fuel assemblies) in hot laboratories are defined by the necessity of the following problems solving:

- Supervising researches of the spent fuel both with a normal (scheduled) outcome of operation and with supernumerary end;
- Development of concepts of reactors of new generation with the increased safety;
- Increases of competitiveness and licensing of fuel.
- The primary goals of postreactor researches of the spent fuel are solved with use of a set of installations and stands of hot laboratory, which are typical for the majority of the material engineering centers [5]:
- Installation of visual-optical survey;

- Device for measurement of fuel elements length, length of the control and protection means and the nuclear fuel assemblies (NFA);
- Device for measurement of the sizes and forms of NFA cover;
- Device for measurement of external diameter of rods;
- Device for measurement of fuel elements volume;
- Device for measurement of a backlash "fuel - shell";
- Installation of X-ray radiography;
- Device for rods gamma-scanning;
- Installation for definition of free volume, pressure and structure of gases under the shell;
- The workbench for bend tests of NFA.

Besides receipt of material engineering information methods of non-destructive testing allow to optimize selection of the most representative products and their sites for the subsequent destructive testing.

As a rule, these installations are remote intrachamber scanning mechanisms with gauges (detectors) of the various functional purpose controlled with the help of micro- or minicomputers. The new generation of the installations actively developed now, is based on use of PC.

Material engineering diagnostics of the spent fuel status condition in hot laboratories mainly bases on results of researches of some NFE parameters before and after its irradiation in a reactor. An example of this problem decision is the use of gamma-scanning methods and the use of computer tomography in devices for determination of fuel distribution. Fig. 5 shows device for the testing of not irradiated NFE allowing to receive the distribution of a fissionable material, its total contents in the testing NFE along its length, as well as to carry out tomography testing over the chosen NFE sections.

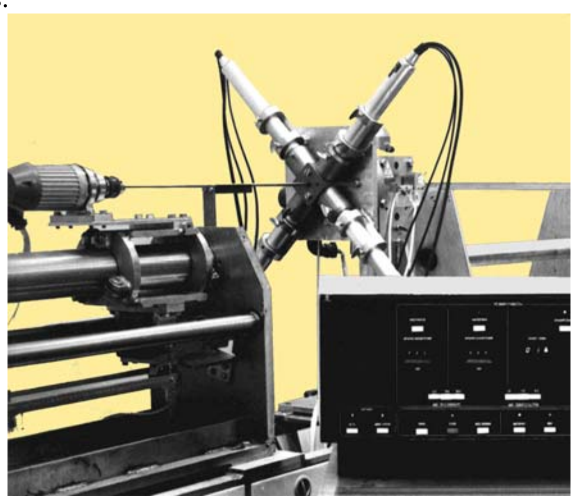
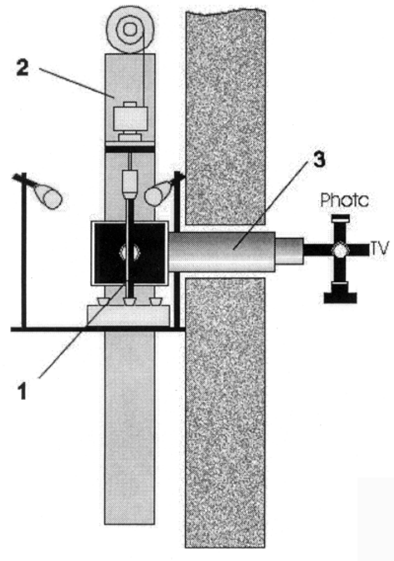


Fig. 5. Device for determination of the fissionable material distribution in nuclear fuel element.

When set aside the details of all the devices in the hot chambers, we shall choose only a few devices developed in the NIIAR (Fig. 6) for NFE after reactor testing.



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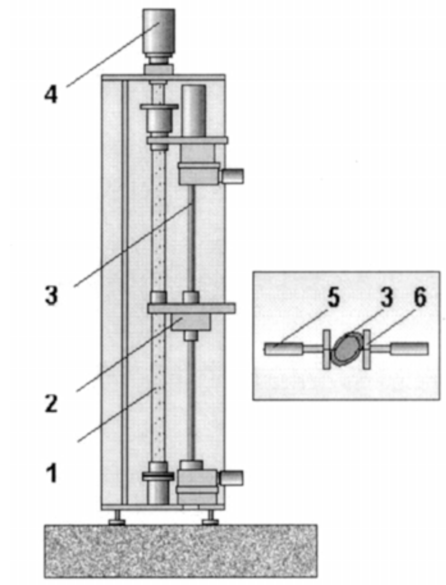

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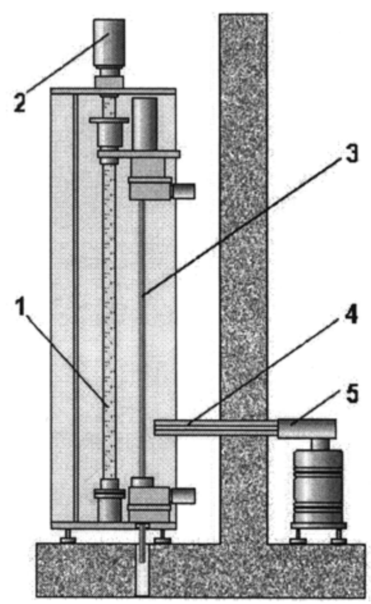

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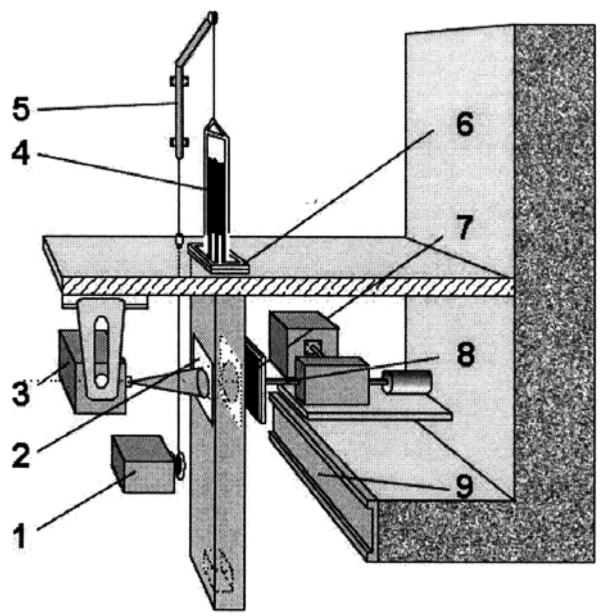

d)

Fig. 6. Devices for NFE after reactor testing.

a) Device for visual survey of NFA and NFE;

1 – the inspected product, 2 - device for NFE moving and rotation, 3 - periscope.

b) Device for measurement of external diameter and NFE flaw detector;

1 - conducting screw with a magnetic ruler, 2 - block of gauges, 3-NFE, 4-engine of moving of the measuring carriage, 5-converter of linear moving, 6-measuring tips.

c) Device for NFE gamma-scanning;

1- conducting screw with a magnetic ruler, 2-engine for NFE moving, 3-NFE, 4-collimating system, 5-detector.

d) Installation for X-ray radiography of NFEs;
1- lever hoist reducer, 2-window, 3 - X-ray tube, 4 – suspender with NFEs, 5-console crane, 6-shaft 7 - cartridge with a film, 8 - film conveyor, 9 - guide arm for the cartridge.

Device for visual survey of NFA and NFE (Fig. 7a) allows keep the image on a film or on the videotape, it is supplied with systems of readout of coordinate of a researched site. The device for measurement of external diameter and eddy current flaw detection of NFE (Fig. 7b) allows to determine an external diameter by a contact method with an error ±0,01 mm, and flaw detector with harmonious excitation allows to detect defects which minimal sizes make 10 % from thickness of a shell. The device for NFE gamma-scanning (Fig. 7c) allows to carry out researches of distribution of fissionable products along the fuel core, it can be estimated the burning out, energy liberation and factors of non-uniformity of energy liberation in NFEs. Data of installation for X-ray radiography (Fig. 7d) for research of integrity of the fuel core allow to detect breaks in the fuel core in width up to 0,5 mm.

Modern research problems of the spent fuel are connected to engineering diagnostics of NFA, as constructive element in the active zone which is a subject to various influences (dynamic, thermal, radiation, etc.). Simulation of similar influences in natural reactor conditions extremely dangerous and consequently is not practically applied. However good tool equipment allows carry out these simulation experiments in shielded chambers safely.

Conclusions: In conclusion it is necessary to note, that only by use of updating methods in instrumentation and namely - system approaches to designing, high degree of automation, wide use of computer facilities and a robotics, dataway-modular methods of the equipment construction – it was possible a creation of industrial means of non-destructive quality assurance for nuclear power.

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