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EXPERIENCE OF DEVELOPMENT OF THE METHODS AND EQUIPMENT AND THE PROSPECTS FOR CREATION OF WWER FUEL EXAMINATION STANDS

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Abstract

The report presents the basic methods and equipment developed for inspection of the fuel elements and fuel assemblies in the spent fuel pools. It considers their characteristics and results of the tests under laboratory and experimental fuel examination stand conditions. In particular, the following techniques are presented: visual inspection, measurement of the geometrical dimensions, definition of the form change in fuel assemblies and fuel elements, detection of the failed fuel elements, etc. The experience of the experimental fuel examination stand operation is generalized. The concept of the creation of the WWER-440 and WWER-1000 FA and FE inspection stands is presented. The concept is based on the modular principle which runs as follows. A set of the basic functional blocks is being developed based on which it is possible to make such a stand configuration which is necessary to fulfil the specific program of the examination at the particular nuclear power plant.

1. INTRODUCTION

Within the frame of the program for development of the stands for WWER and RBPC (Reactor Big Power Channel) spent fuel inspection the experimental inspection stands were developed and manufactured. The basic methods for non-destructive examination of fuel elements and FAs were improved, the detectors and executive mechanisms were examined, the design techniques were checked. The report presents the experience of the methods and equipment creation for irradiated fuel inspection in the spent fuel pools and the concept for creation of stands for WWER-440 and WWER- 1000 FA examination.

2. EXPERIMENTAL INSPECTION STANDS

To test the equipment and to work out the inspection methods using the fuel element and FA models in the laboratory a special stand was developed (Fig. 1) [1]. The stand represents a frame construction of 9 m in height. Along two vertical guides the carriage with a mobile table moves. There are detectors and devices for FA examination on it. The FA model is established in a jack. The FA is rotated and the carriage is moved by the engines located on the control board. The mobile table on the carriage is moved by the submersible step by step engine.

The examination of the following methods were carried out at the stand:

- visual inspection by TV camera;
- eddy current testing of the fuel elements of the FA peripheral line by pancake coil;
- measurement of the oxide film thickness;
- measurement of the peripheral fuel element diameter and gaps between them;
- measurement of FA geometrical sizes (cross sizes, bowing size and twisting corner, length);
- detection of leaky fuel elements in FA.

Various detector blocks and facilities were also tested at the stand.

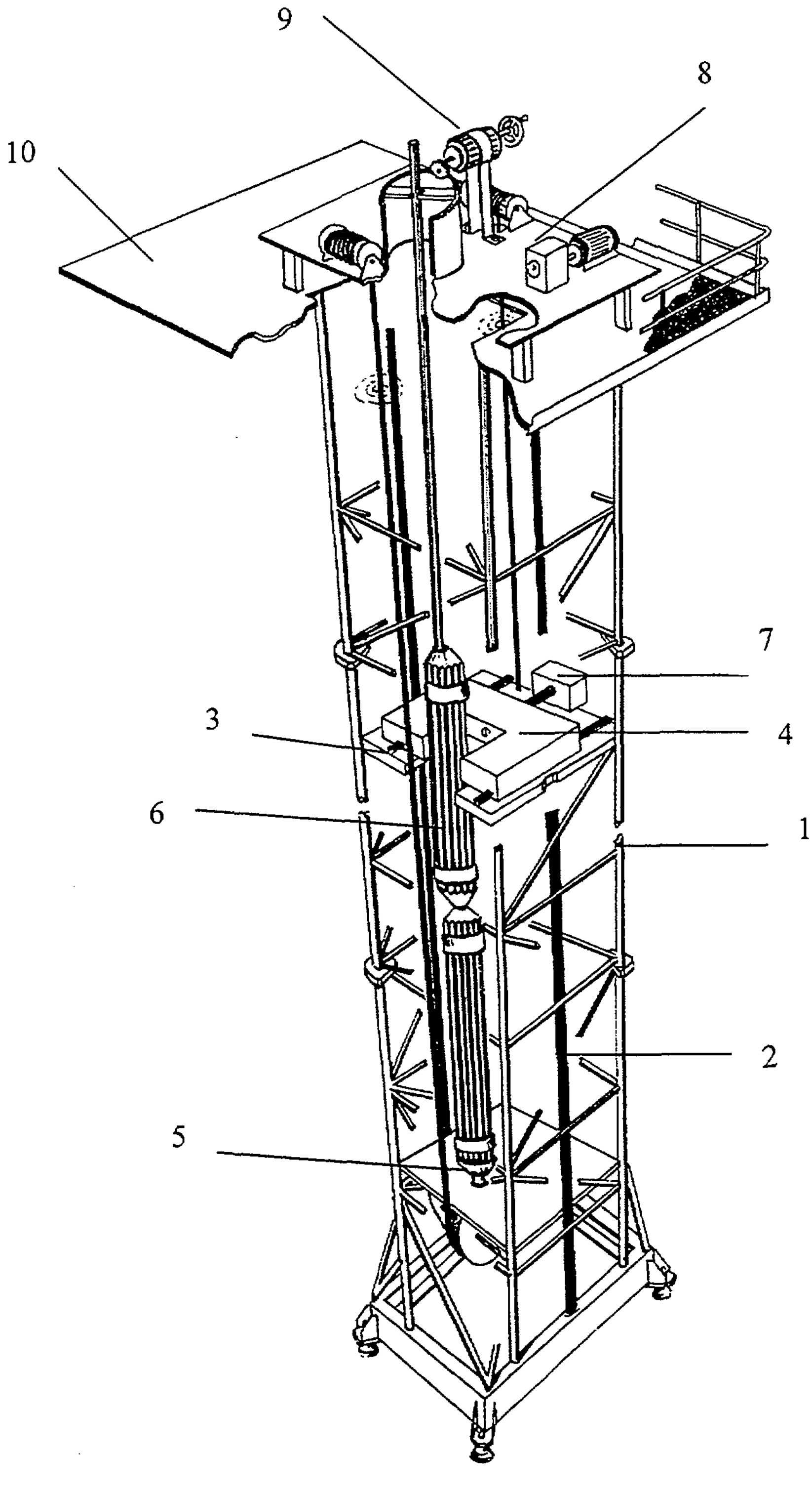


FIG. 1. Laboratory inspection stand.
1 - frame construction; 2 - guide; 3 - carriage; 4 - mobile table with detectors; 5 - FA support; 6 - FA; 7 - table driver; 8 - driver of carriage and FA support; 9 - FA rotating driver; 10 - servicing platform.

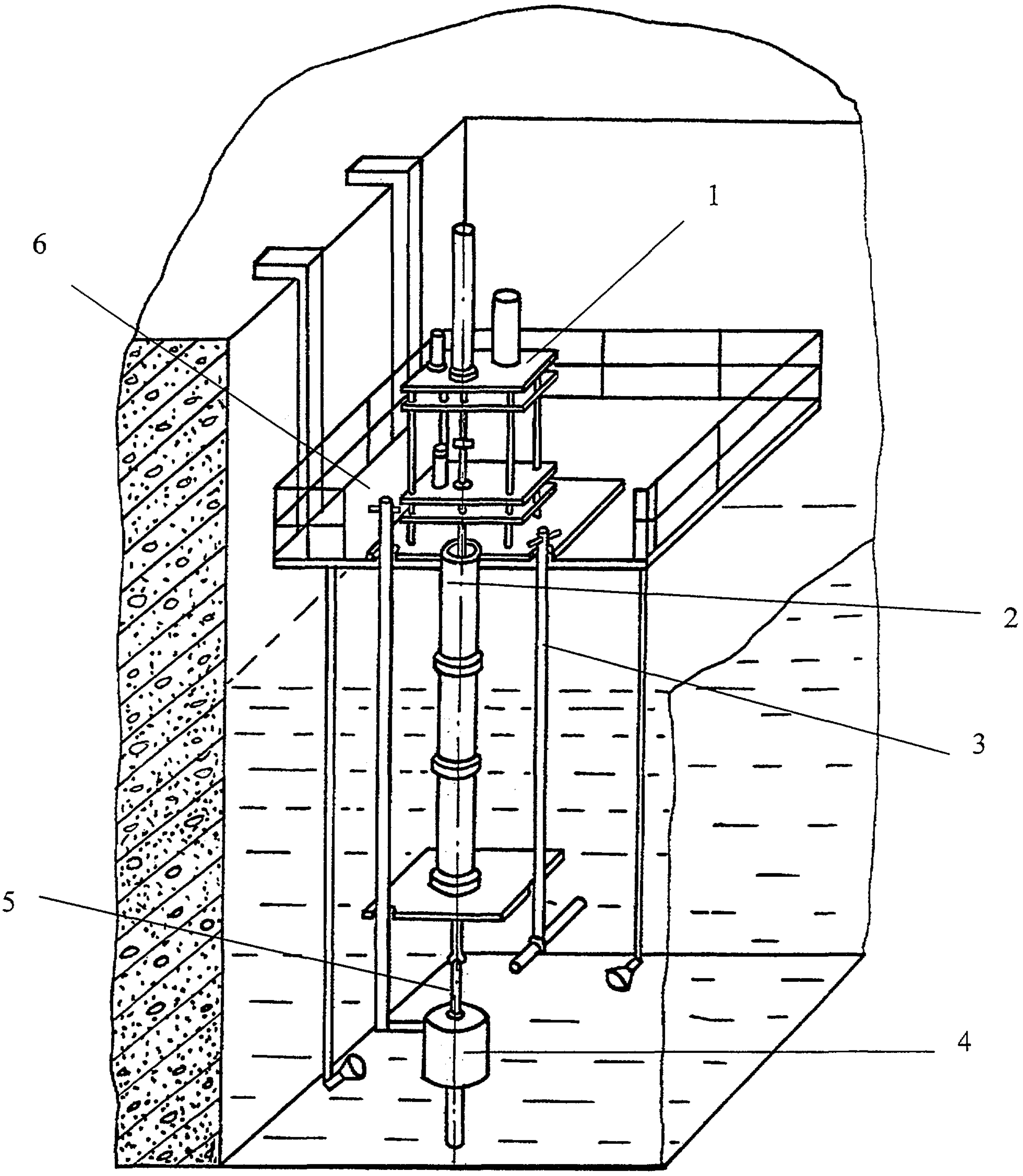


FIG. 2. Inspection stand for examination WWER type model FEs.
1 - fuel element transport mechanism; 2 - guide; 3 - TV camera mounting boom; 4 - probe unit; 5 - fuel element; 6 - servicing platform.

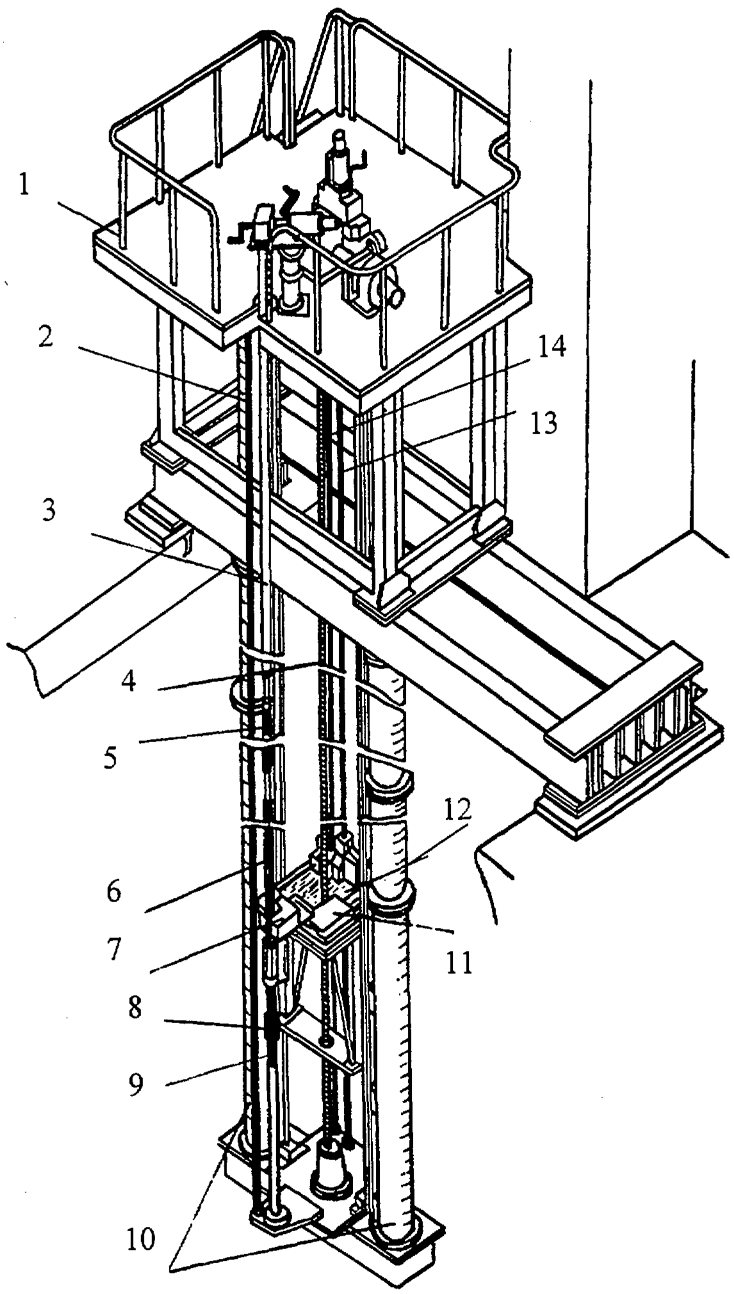


FIG. 3. FA inspection stand.
1 - servicing platform; 2 - ruler; 3 - FA holder; 4 - screw; 5,6 - FA;
7 - block with detectors; 8 - glass; 9 - test sample; 10 - column with guides;
11 - table; 12 - carriage; 13,14 - bars.

To improve methods for single fuel element examination the inspection stand for WWER type model fuel elements irradiated in the research MIR reactor was developed [2,3]. The stand (Fig. 2) represents the assembly construction consisting of the mechanism of fuel element moving and rotation, cylindrical guide, bars with TV camera and bars with measuring detector block. The stand design allows to carry out its quick installation and dismantling. Installation and the set-up of the measuring equipment takes from four till six hours.

The following NTD methods are applied at the stand:

- fuel element visual inspection;
- dimension measurement;
- eddy current testing;
- leak testing of fuel rods.

By the present time more than 50 WWER model fuel elements have been inspected at the stand.

Experimental inspection stand for RBPC FAs (Fig. 3) represents a suspension construction the basic elements of which are two columns of 300 mm in diameter [4]. The guides are attached to them. The carriage moves along them by means of a pair of screw and nut. On the carriage there is a table of two-co-ordinate moving. The measuring block with detectors are set on the table. The table is moved due to rotation of two bars transmitting a twisting moment from the drivers to the executive mechanisms.

All electric drivers are in the top part of the stand on the control board. The examined FA is brought into the stand sideways and fastened to the hanger. The FA bottom part is fixed in the special glass to avoid side moving. The bottom part of the glass simulates a small site of the FA and it is a calibration assembly for setting-up and checking of the detectors for dimensions measurement, devices for defectoscopy and visual inspection. The total stand height is 18 m, the cross dimensions are 1.5 x 1.9 m. The examination techniques of the stand is similar to those of the laboratory stand.

The stand was mounted in 1988 on the II block of Ignalina NPP and it is currently used to monitor the FAs unloaded from the reactor, i.e. the FA visual inspection is carried out by means of TV camera. According to it the primary information on the fuel elements and their state is obtained.

The stand to improve the method using a full-scale WWER-1000 FA model was also developed.

3. INSPECTION METHODS

The conventional methods of non-destructive examination of fuel elements and fuel assemblies in hot cells such as visual inspection, dimension measurement, eddy current testing were adapted for under water work in the spent fuel pools. The new methods being never used before in hot cells were developed. They are ultrasonic methods of leaky fuel element detection and methods for determination of change in form of the rod cluster control assemblies (RCCA).

3.1. Method of reconstruction of cross-section form WWER-1000 FA RCCA

The necessity to monitor change in form of RCCA is caused by the attempt to prolong their operation on the one hand and by providing the required level of safe reactor operation on the other hand.

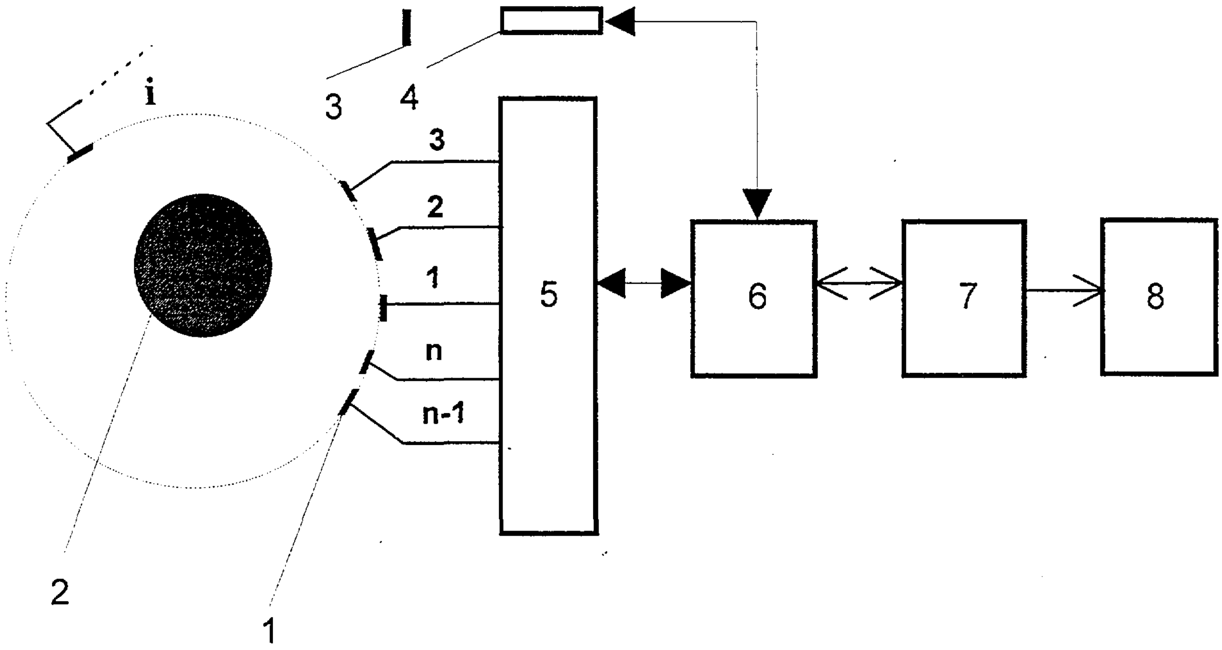


FIG. 4. Ultrasonic testing (UT) inspection principle.
1 - UT transducer; 2 - tested rod; 3,4 - device for correction sound velocity;
5 - switching device; 6 - UT channel; 7 - computer; 8 - printer.

During operation of RCCA two principal defects can appear [5]:

1. RCCA cladding tube external wear due to:

   - friction of FA guide tubes and RCCA at their vertical moving;
   - vibration of RCCA under the influence of coolant flow.

2. Cladding cracking of RCCA in the side of the bottom end due to swelling of the absorbing material under the influence of the irradiation and vibration.

The method was developed to identify the type of the cladding wear, to determine the maximal wear depth and to measure the rod cross size due to the swelling of the absorbing material.

The measuring device represents a ring, the inner diameter of which is 23 mm and outer diameter is 45 mm, inside of which RCCA under examination is located (Fig. 4). The outer diameter of the device is limited by the distance between the absorbing rods in the cluster.

Along the perimeter of the inner ring 104 ultrasonic detectors are located, which are connected to the measuring and computing system through the switching device.

The detectors operate in echo-pulsing mode, i.e. radiate ultrasonic waves in the direction of the RCCA surface and register them after reflection. Based on the obtained time of signal arrival and the sound velocity in water the distance from every detector to the RCCA surface is determined, and by means of specially developed algorithms the form of the RCCA cross-section is restored.

To correct sound velocity in water the method of the reference channel is used. From time to time it determines the sound velocity based on time of wave distribution from the detector of the reference channel to the reflector located at a particular distance from the detector.

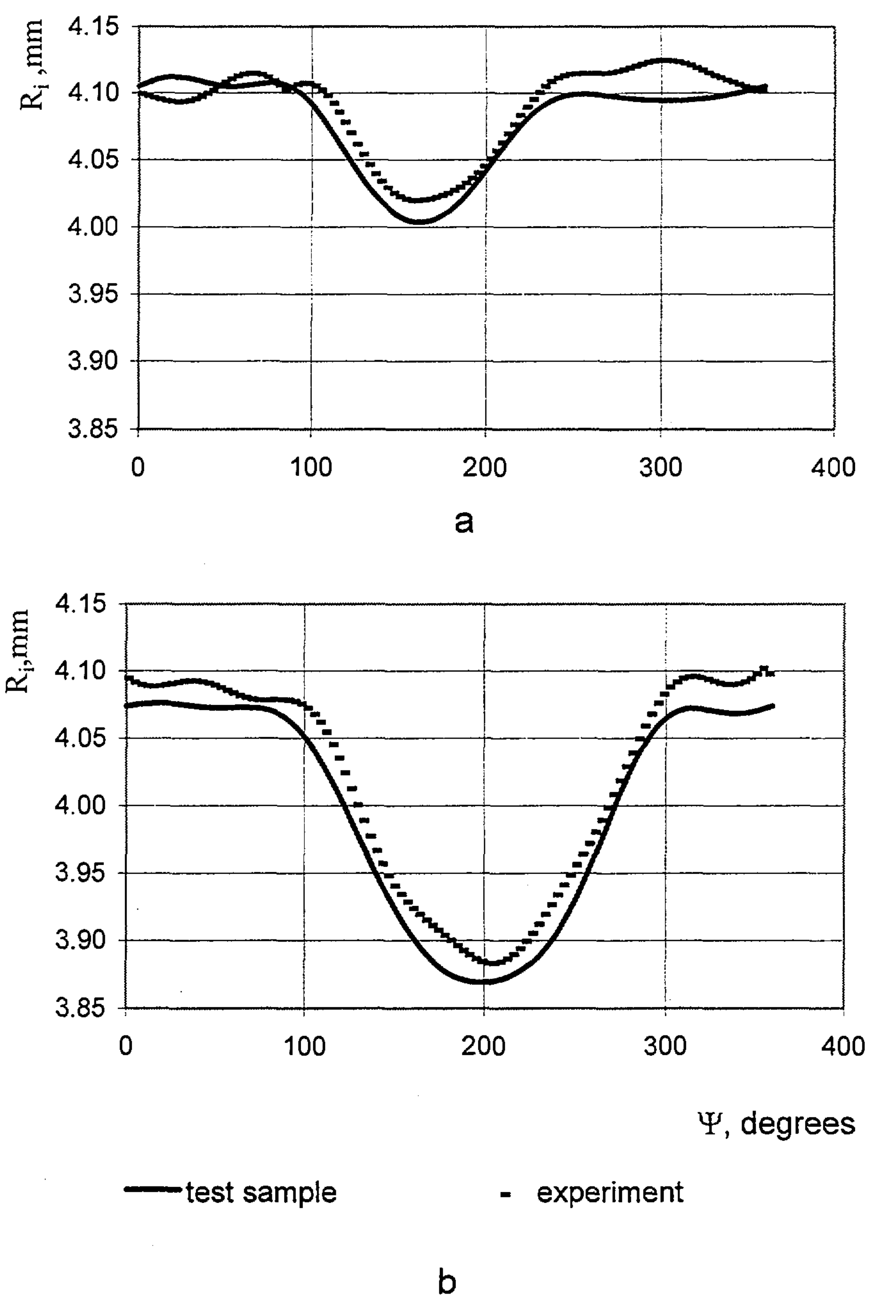
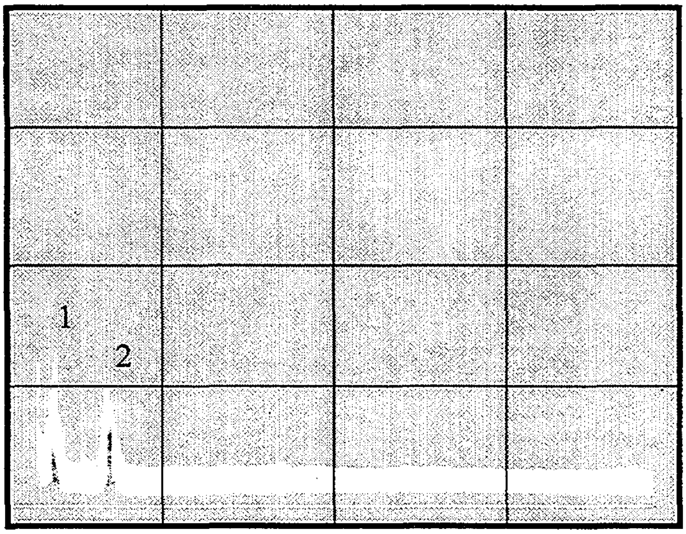


FIG. 5. Dependence of radius on the angle for the test samples.

The method was examined on the cylindrical rod test samples and test samples with imitation of worn RCCA cladding. Figures 5 a and b present dependences of radius of two test samples with maximal wear of 97 μm and 202 μm, respectively on the angle. It gives good conformity of the restored figure with the initial one. The accuracy of determination of maximal wear depth of the test samples is about 0.03 mm. The accuracy of determination of the material loss is about 2%. The given method can be applied for determination of the change in form of WWER fuel element cross-section.

a



b

FIG. 6. Examples of signals for sound (a) and leaky (b) WWER claddings at wave generation on the lateral surface:
1 - transmitter pulse; 2 - "useful" signal; 3 - multiple signals.

3.2. Methods for detection of leaky fuel elements in WWER-440 and WWER-1000 FA

Detection of the leaky fuel elements in FA is based on detection of water under the leaky fuel element cladding. The water under the cladding is detected by ultrasonic methods [6,7]. In the cladding the waves of certain type are generated. At wave propagation in the cladding their decay occurs due to energy radiation into environment. If there is water under the cladding, the additional easing of waves occurs and reduction of the wave amplitude testifies that fuel element is leaky.

According to the way of wave generation in the cladding the ultrasonic methods can be divided into two classes. The first one is generation and detection of waves on the lateral surface of the cladding. At that thin probes with emitter and receiver of ultrasonic waves are inserted into the space between the fuel elements in FA. The method of firm BBR and method EXO-330 belong to them [6].

The second method is generation and detection of waves on the fuel element top plug applied by firm Fragema [7]. The ultrasonic detector operated in a mode of radiation-reception is set on the plug. The wave is propagated along the fuel element cladding and detected by the same detector after reflection from the bottom plug.

The design of the WWER-1000 FA does not allow to use methods where the thin probes with detectors are inserted into the space between the fuel elements in FA, since the guide tubes of the RCCA block the gaps between the fuel element rows in FA. Therefore to detect the leaky fuel element in the WWER-1000 FA the method is applied, at which the monitoring is carried out from the side of the fuel element top plugs.

For WWER-440 FAs the monitoring can be carried out by all three methods after FA shroud tube removal.

Calculating and experimental examination of methods are carried out, the conditions of wave generation in WWER fuel element Zr claddings are determined. The basic parameters and specifications of methods are determined.

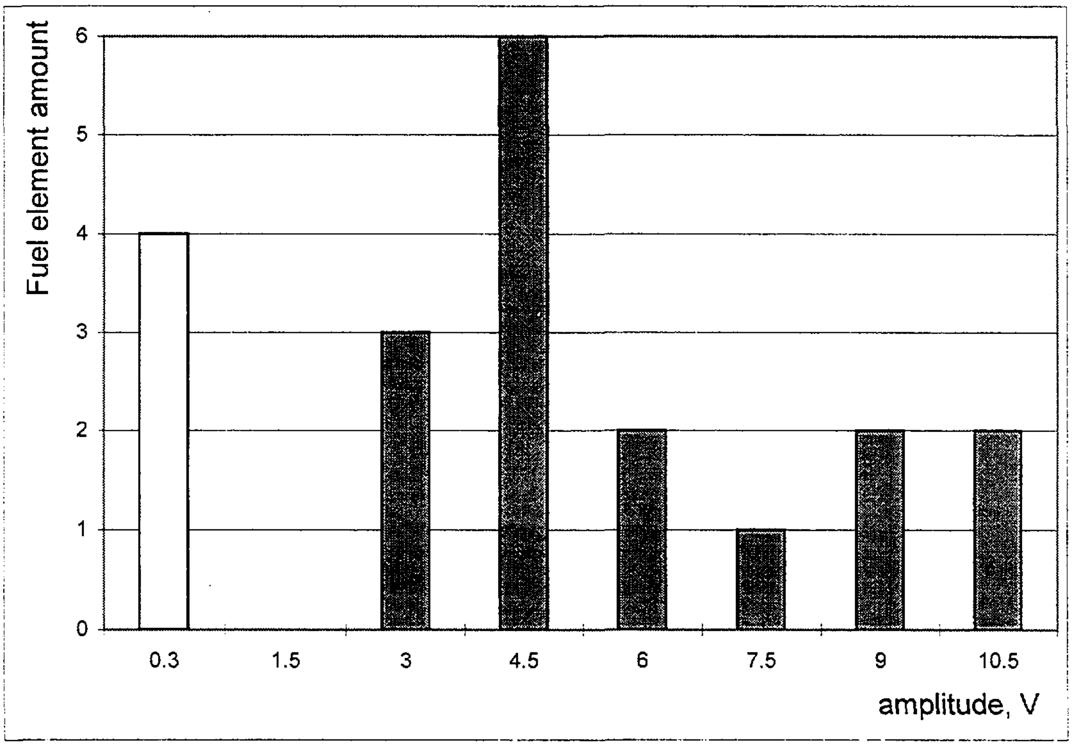
The efficiency of leaky fuel element detection was checked using the laboratory test samples and irradiated WWER fuel elements.

Figure 6 presents the characteristic signals for a sound and leaky cladding at wave generation on the lateral surface. Signal 2 corresponds to the wave going from emitter to receiver. The wave amplitude for the sound cladding is several times more than for the leaky one.

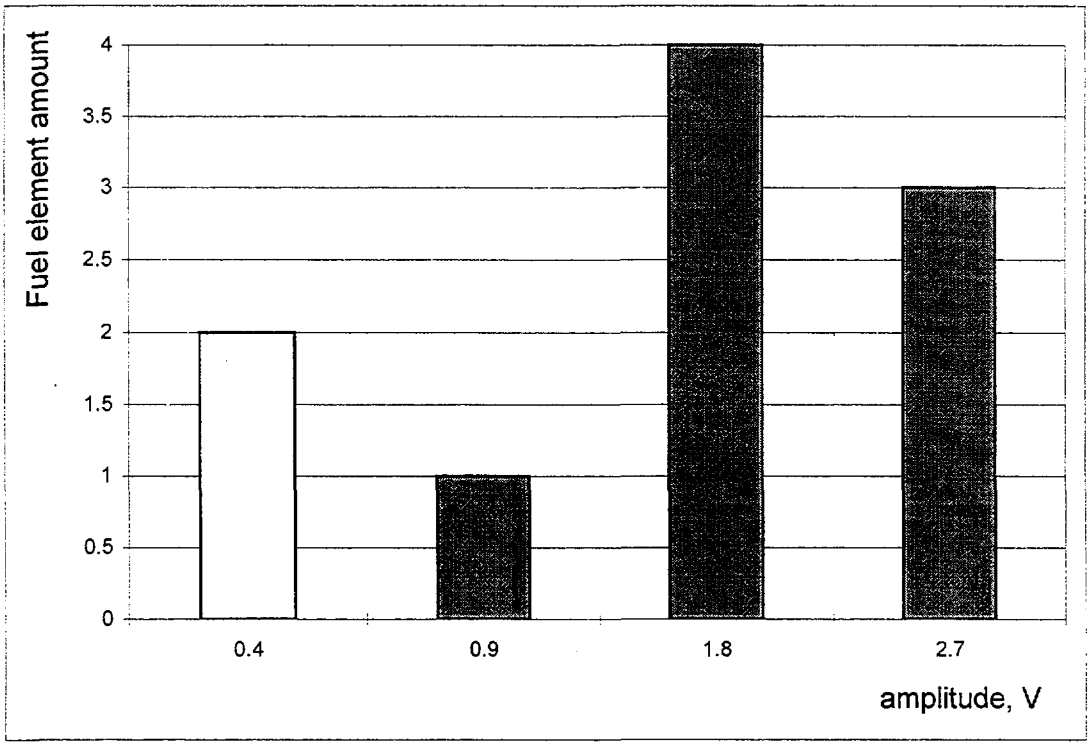
For the sound cladding a series of signals decreasing in signal amplitude (signals 3 in Fig. 6a) is observed which go one after another in equal intervals. These signals correspond to waves, which go around the cladding once, twice, etc.. For the leaky cladding these signals are not detected due to strong wave decay.

Thus, the detection of the leaky fuel elements can be carried out based not only on the amplitude of the signal of the first accepted wave (signal 2), but also on the presence of the sequence of signals 3 from waves, having gone round the cladding several times that raises reliability of correct identification of leaky fuel elements.

Figure 7 presents the example of distribution of signals for leaky and sound WWER-440 and WWER-1000 fuel elements at generation and detection of waves on the side of the top plug. The amplitude of signals for sound WWER-4400 fuel elements changes from 3.0 to 10.0 V, for leaky fuel elements the signal was lower than the noise level. For sound WWER-1000 fuel elements the amplitude changes from 1.0 up to 2.5 V, and for leaky fuel elements the signal is also lower than the noise level.



a



b

FIG. 7. Distribution of the signal amplitude for leaky and sound fuel elements for WWER-440 (a) and WWER-1000 (b) FAs.
▭ - leaky fuel elements, ▬ - sound fuel elements.

4. CONCEPT FOR CREATION OF THE EQUIPMENT FOR POOLSIDE INSPECTION AND REPAIR OF DISMOUNTABLE WWER-440 AND WWER-1000 FAs.

Taking into account the world experience for creation of stands for inspection, repair and reconstruction, and experience for creation and operation of the experimental stands the concept of stand creation is developed to inspect dismountable WWER-440 and WWER-1000 FAs.

The analysis of possible sets of stands and their methodical providing and hardware has shown that despite the distinction in designs of WWER-440 and WWER-1000 FAs in technological operations during inspection, in set of the methods, etc., which will no doubt affect the design of the stand for every listed type of FA, a significant unification of these stands is possible. Therefore, a modular principle is the basis of the concept. A set of the basic functional blocks is developed. Their combination allows to make a stand for particular program examination.

The set of the functional blocks consists of:

- FA inspection stand being a rod of the whole equipment complex. Its basis is the mechanism which allows to move measuring devices and equipment for technological operations.

- Inspection stand of the single fuel element which is installed nearby the FA inspection stand. Before installation of the stand into the spent fuel pool the measuring devices being necessary for the particular program examination are established.

- Measuring devices for examination of the fuel assembly and separate fuel elements. These devices are made as an independent ones which are easily installed on the inspection stands of FA and single fuel element.

- Technological equipment for dismounting and mounting of FA. It includes tools for taking off and installing of the FA shroud tube and head, tools for removal of fuel elements from the fuel assembly.

The stands should be carried out in such a way as to realize their transportation from block to block within the NPP as well as between NPPs.

According to the concept the sequence and nomenclature of the experimental and design work should be the following.

1. The FA inspection stand for methods of visual inspection, dimension measurement and detection of leaky fuel elements in the FA as the most frequently used facility at FA inspection in the spent fuel pools is necessary to create.

2. Then providing the stand with other FA inspection methods, take an opportunity to carry out non-destructive examination of fuel assembly (without its dismounting), similar to the examinations in hot cells.

3. Development and creation of equipment for mounting and dismounting of the FA and inspection stand of the single fuel element. It allows to carry out examination of the single fuel elements removed from the fuel assembly, and further to repair the leaky FAs.

The realization of the given concept allows to obtain a variety of stands for inspection, repair and reconstruction by means of a small set of basic functional blocks.

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