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EXPERIENCE AND PROBLEMS WITH IMPLEMENTATION OF DIAGNOSTIC SYSTEMS FOR VVER REACTOR PLANTS

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Justification and keeping of integrity and reliability of the equipment is one of the important task in the problem of NPP guaranteed safety. This task has been solving at all stages of NPP life cycle.

At the NPP design stage a complex of analytical and experimental investigations carries out for substantiation of equipment strength and durability. As a result, design requirements and limitations generate on operation conditions of NPP equipment and systems.

At the stage of comissioning extensive start-up tests and measurements carry out. Their task is to confirm that the design requirements and limitations are satisfied for the equipment of each concrete reactor plant. Such measurements are the tool of early equipment diagnosing as well, because they allow to reveal and eliminate possible non-design conditions before the beginning of commersial plant operation.

At the consequent commercial plants operation the equipment integrity confirms by periodic technical inspections which carries out at annual outages. Such inspections include, in main, control over equipment integrity by non-destructive methods.

In the last decade the equipment integrity monitoring during NPP operation was added to above mentioned kinds of monitoring reasoning from operation experience and appeared standard documents of authorities. Some specific plant equipment should be the object of the operation monitoring. First, it should be the equipment, the life time of which is less than plant age as a whole. Then, it should be an equipment on which are the most probable non-design conditions because of various reasons (NPP staff errors at equipment mounting during outages, changing of equipment fixing conditions during operation, substitution of some components of an equipment, etc). The effects of these and other similar factors can be rether serious for one cycle between outages, because of it the operation monitoring is necessary.

Main assignment of such operation monitoring realized through systems of operation diagnostics is to reveal non-design equipment states at on early stage of their ocurrence when I&C signals can not yet fix these states while non-destructive instrumentation can not yet be applied. Such systems allow to reduce equipment damage, to lower probability of incidents and, therefore, to ensure NPP safety. Besides diagnostic systems allow to estimate and predict a real ageing of the equipment so that to the beginning of the next outage to know "weak" equipment components first of all being subject to repair or substitution, i.e. to provide preventive maintenance. Solving this task the diagnostic systems represent themself as information support of non-destructive inspections, as the final confirmation of malfunctions and faults can be only obtained by instections.

The niche of diagnostic systems in the overall system of NPP reliability measures is shown in fig. 1 at the example of substantiation and keeping of equipment vibration strength.

Majority of diagnostic systems for operating VVER plants (fig. 2) is oriented to methods of noise and acoustic diagnostics, which are the most sensitive to early anomalies detection. At the same time it is obvious that equipment conditions diagnosis using such systems demands advanced techniques and algorithms of diagnosing, as such systems reveal abnormalies and malfunctions by indirect way on equipment response to technological noises, acoustic noises and impulses at appearance of anomalies, etc.

Therefore the development of methods of the analysis and interpretation of signals in diagnostic systems is an independent problem of diagnostics. The objective of this activity is to develop mathematical support of diagnostic systems as techniques and algorithms of diagnosis, diagnostic modes and setpoints.

For VVER plants the mathematical support of diagnostic systems is developed in some stages.

Before delivery of hardware at NPP's some minimum (base) diagnostic possibilities are provided as standard "portraits" of a response of the equipment at know effect as well as diagnostic indications of manifestation of abnormal conditions.

For leak monitoring system, such knowledge base is elaborated in test rigs conditions with simulation field parameters and with organization of inspected coolant leakages through artificially growed cracks as well as through untightness of flange connections. The examples of acoustic noises "portraits" at coolant leakage are presented in fig. 3.

Similary-artificial creation of abnormalies in test rigs conditions-knowledge bases are elaborated for control rod drives diagnostic system, and also system of loose parts detection.

For vibration monitoring system, base diagnostic possibilities are provided by means of a complex of analytical-experimental researches for definition of eigenfrequencies and modes of the equipment depending on its fixing conditions. As a result, there is possibility to identify the most characteristic peaks in the vibration spectra and estimate change of fixing conditions by the values of shiff of these peaks (fig. 3).

For the residual cyclic life time system, the analytical-experimental way provides interrelation between the most stressed components and indications of thermocouples, installed in characteristic points.

After mounting and adjustment of the hardware at NPP system adaptation is carried out for concrete unit condition. The objective is reached by special basic measurements, at which empirical dependences are defined between known entry effects and response of various systems sensors.

After these measurements operational documentation of diagnostic systems should be developed which should contain the list of achieved systems functionalities, the metrics for equipment normal conditions and diagnostic setpoints.

Experience of implantation of the first diagnostic systems at operating Russian VVER plants has shown necessity of defined organizational structure for operation and maintenance of the systems as well as for sequences of actions after diagnostic events.

As a result, the branch system of diagnosis is organized by now. Block diagram of it is represented in fig. 4. According to the scheme, the process of diagnosis and decision making is divided into two stages.

At the first stage this activity is carried out by NPP diagnostic staffs, which are organized at all Russian NPP with VVER by now. NPP diagnostic staff provides operation and maintenance of the hardware, carries out acquisition and express-analysis of the signals and makes preliminary conclusions at diagnostic events using operational documentation of the systems.

At the second stage the analysis of the information should be executed in branch Center of diagnostics with enlisting of various organizations experts. The enlisting of the experts of various profile (on strength and durability of the equipment, on process technology, etc) means qualitatively higher level of the analysis. Besides of that there is the possibility to carry out the analysis not only in time but also on an ensemble one-type reactor plants.

Except above mentioned functions the Center is also assigned for acquisition on diagnostic information from all NPP's, generalization of experience of diagnostic systems using, system operation support, training and checking of NPP diagnostic staff.

By now majority of Russian VVER reactor plants is equipped with systems of components of systems shown in fig. 2, therefore culture of operation raises, experience of their using is typed and in a number of cases abnormal conditions were revealed /1/.

In particular, at two units with VVER small leakages of the coolant were detected using of acoustic leak monitoring system.

Further, temperature monitoring of some characteristic plant components (injection nozzle of the pressuriser, feed water supply nozzles of SG) allows to eliminate non-stationary thermal loading which arose in transients because of NPP staff omissionss.

As the last and the most serious case of diagnostic events we shall consider results of vibration monitoring of reactor internals at unit 1 Khmelnitskiy NPP during comissioning /2/. Increased vibrations of the core barrel and adjoined components were revealed there during hot tests (fig. 5). It has required realization of the whole complex of measures, including:

confirmation of reliability of obtained experimental data;

additional analysis of vibration monitoring results for revealing of the reason of abnormal vibration conditions;

reactor disassembling and conducting of additional inspections and checks of core barrel fixing;

repair works on restoring of design conditions of core barrel fixing;

additional measurements of internal vibrations during start-up.

As a result, core barrel vibrations were lowered to the acceptable level.

However, it is necessary to mark, that some lacks occur during implantations of the first diagnostic systems at operating VVER's. So, monitoring scopes were determined not only by their impact on NPP safety but mainly by technical possibilities of suppliers. Further, the operational documentation on hardware did not fully meet to requirements for automized systems. Besides of that some of the systems were implanted without a due mathematical support.

It is obvious that development of normative base of diagnosing is necessary for elimination of marked lacks. So, concrete normative documents should be developed which should determine the order of diagnostic systems introduction as well as regulate conditions of their putting into industrial operation.

Application of I&C signals with their specialized processing and analysis is another direction of rising of diagnosis quality. On the one hand, it allows to support the indications of systems of noise diagnostics to provide entirety of the diagnosis. On the other hand, it allows to monitor NPP equipment and system at various operation conditions including transients with presence of malfunctions or emergency conditions.

This approach is realized at the moment at diagnostic system development for new VVER plants under design. According to this approach, the diagnostic system is developed as a complex frame, a lower layer of which are systems of noise diagnostics while operator support system is the upper layer. Applied I&C signals are conditionally joined in concept of process diagnostics. Depending on three possible states of the plant (normal, transient, emergency) I&C signals operation; discrete signals, which change plant mode operation; discrete signals resulting emergency means in operation.

The first group of I&C signals is used for early detection of anomalies. Some physical balance correlations (conversation of mass, temperature, energy) are made for these signals /3/. If imbalance occurs, temporary characteristics of signals are used as a image of malfunction (for example, temporary delays of one signal in relation to other, time of exceeding of diagnostic setpoints, etc). The above-mentioned systems of noise diagnostics supply the upper level of the diagnostic system with alarms on detected anomalies in standalone components or units of the equipment.

Besides of supporting of noise diagnostic systems, system of process diagnostics allows to monitor plant parameters, which are defined durability of the equipment, and transfer the lasts in the residual life time monitoring system.

Thus, the combining of noise diagnostic systems with I&C signals allows to describe all kinds and stage of malfunctions. And it is such complex system which allows to enhance and keep NPP safety.

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Stages of justification and keeping of vibrational strength of VVER reactor internals

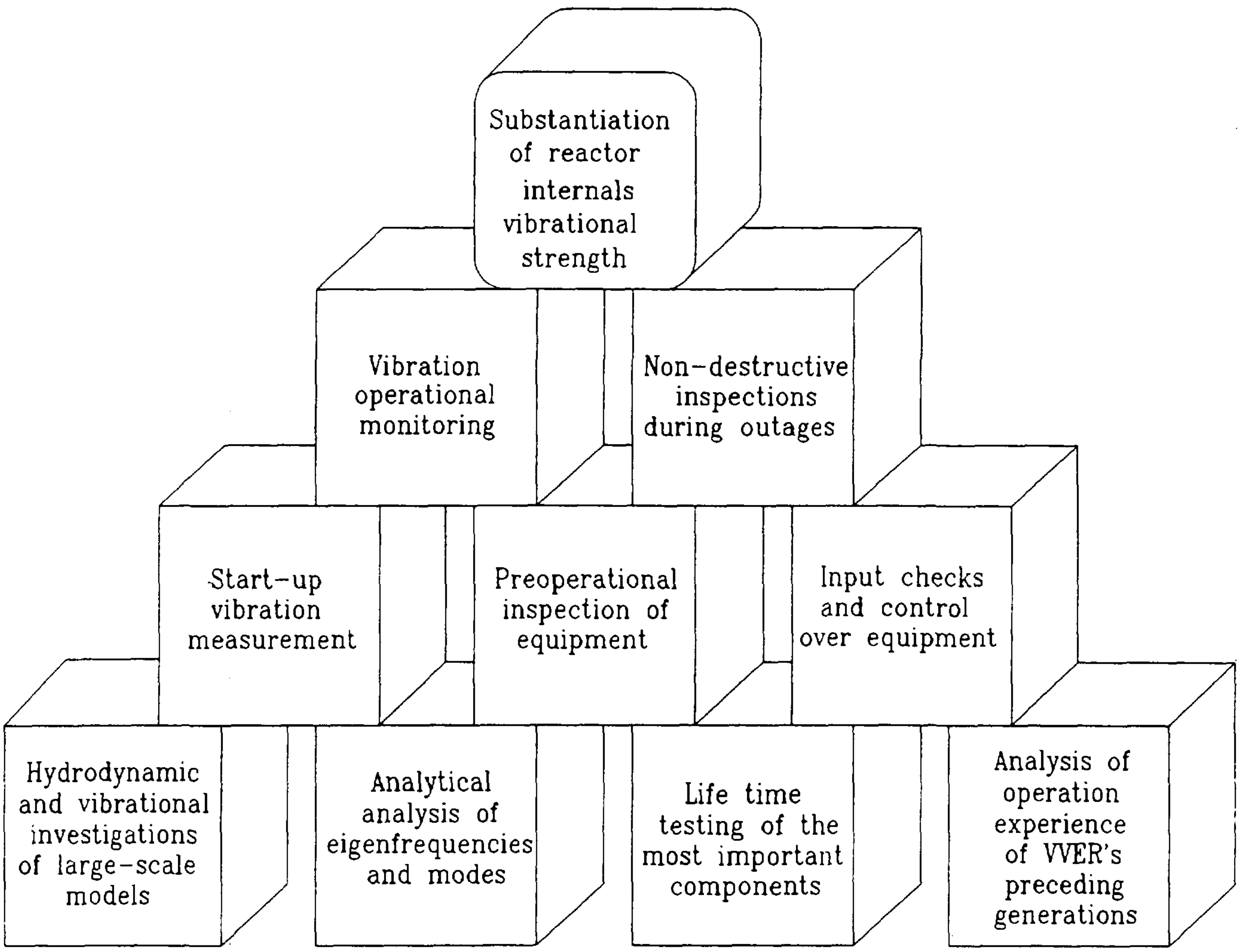
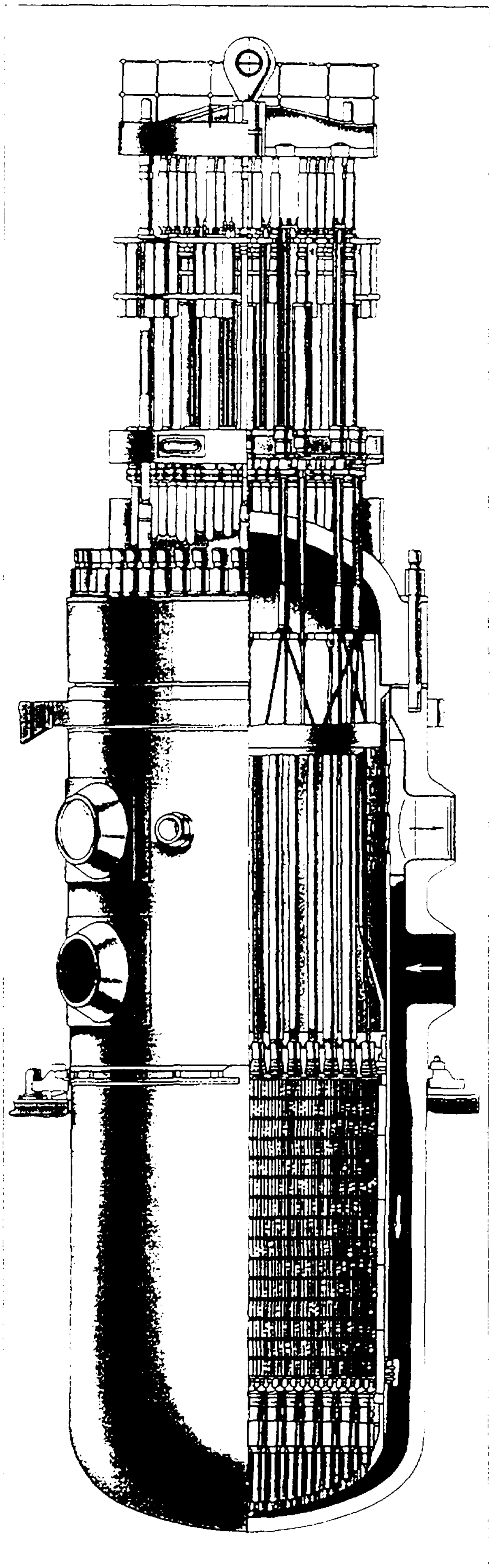


Fig. 1

VVER-1000 Reactor Monitoring and Diagnostic Systems



Leak Monitoring System

Vibration Monitoring System

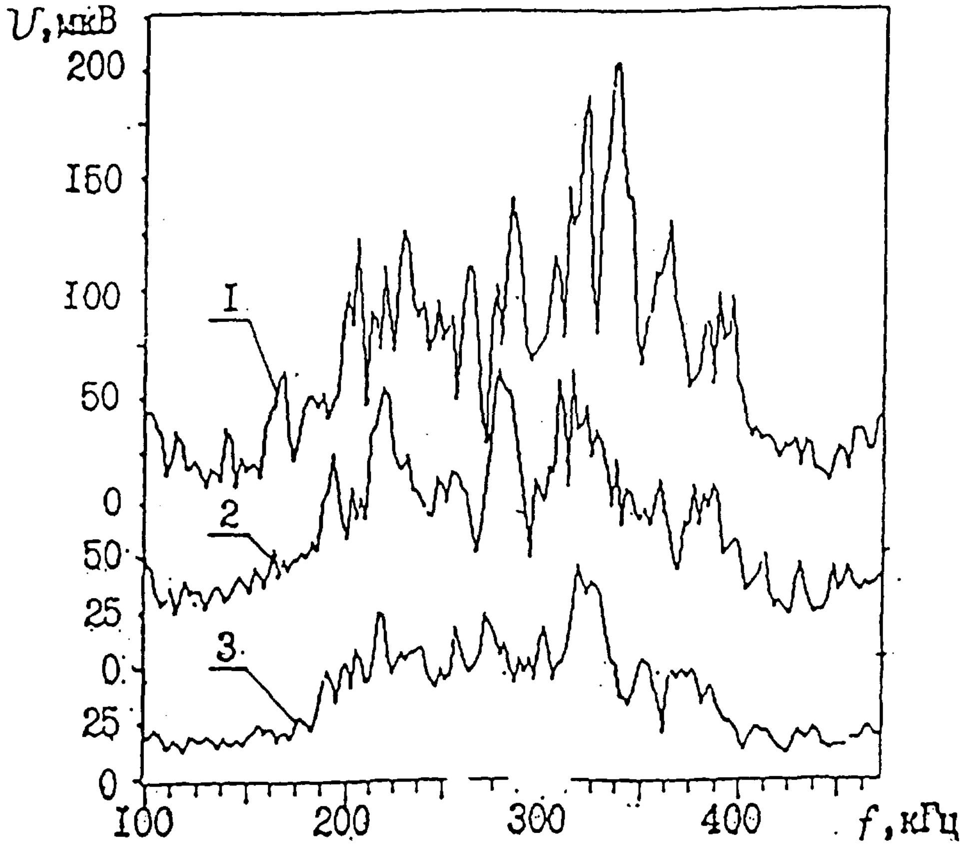
Control Rod Drive Monitoring System

Loose Parts Monitoring System

Residual Lifetime Monitoring System

Fig. 2.

Acoustic noise spectrums during coolant flow through cracks of different lengths at operation conditions (p=15,7 MPa, T=325⊕C)



1 - crack length 100 mm, Q=2 l/min
2 - crack length 70 mm, Q=1,4 l/min
3 - crack length 48 mm, Q=0,9 l/min

Vibration stresses spectrum at core barrel model

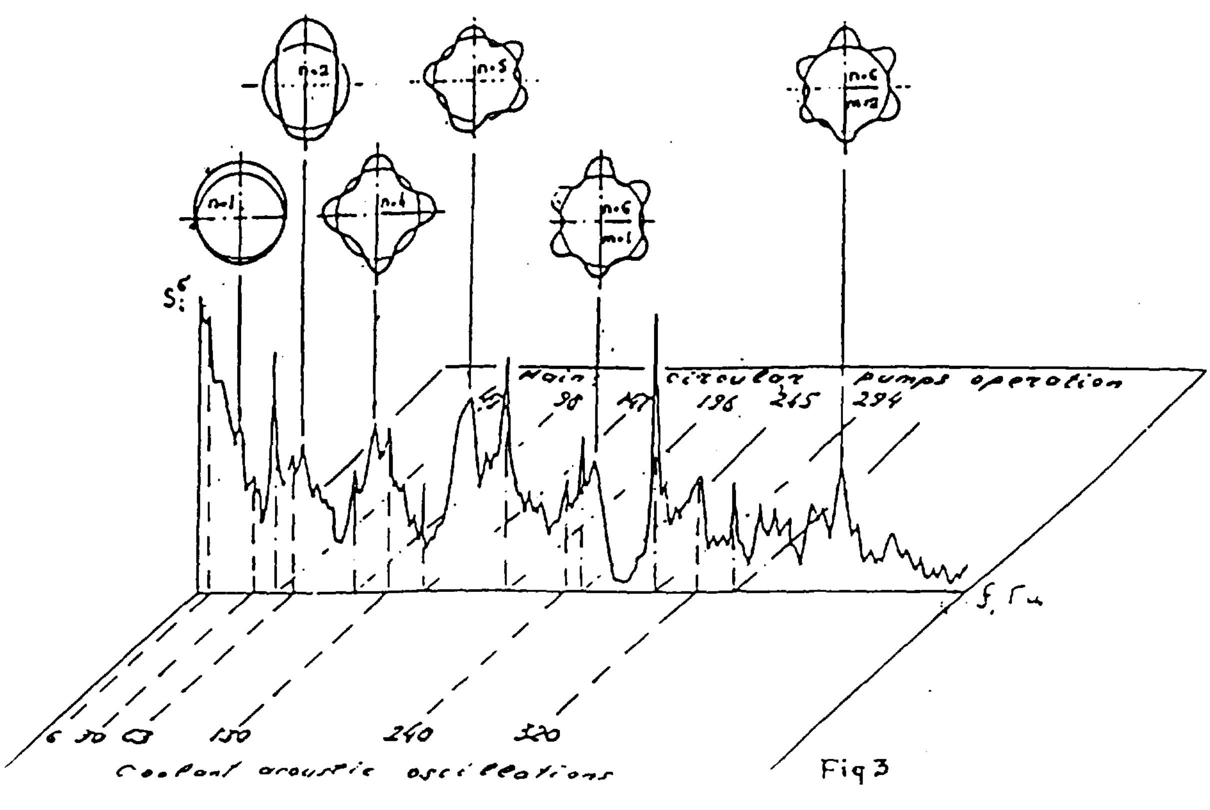


Fig 3

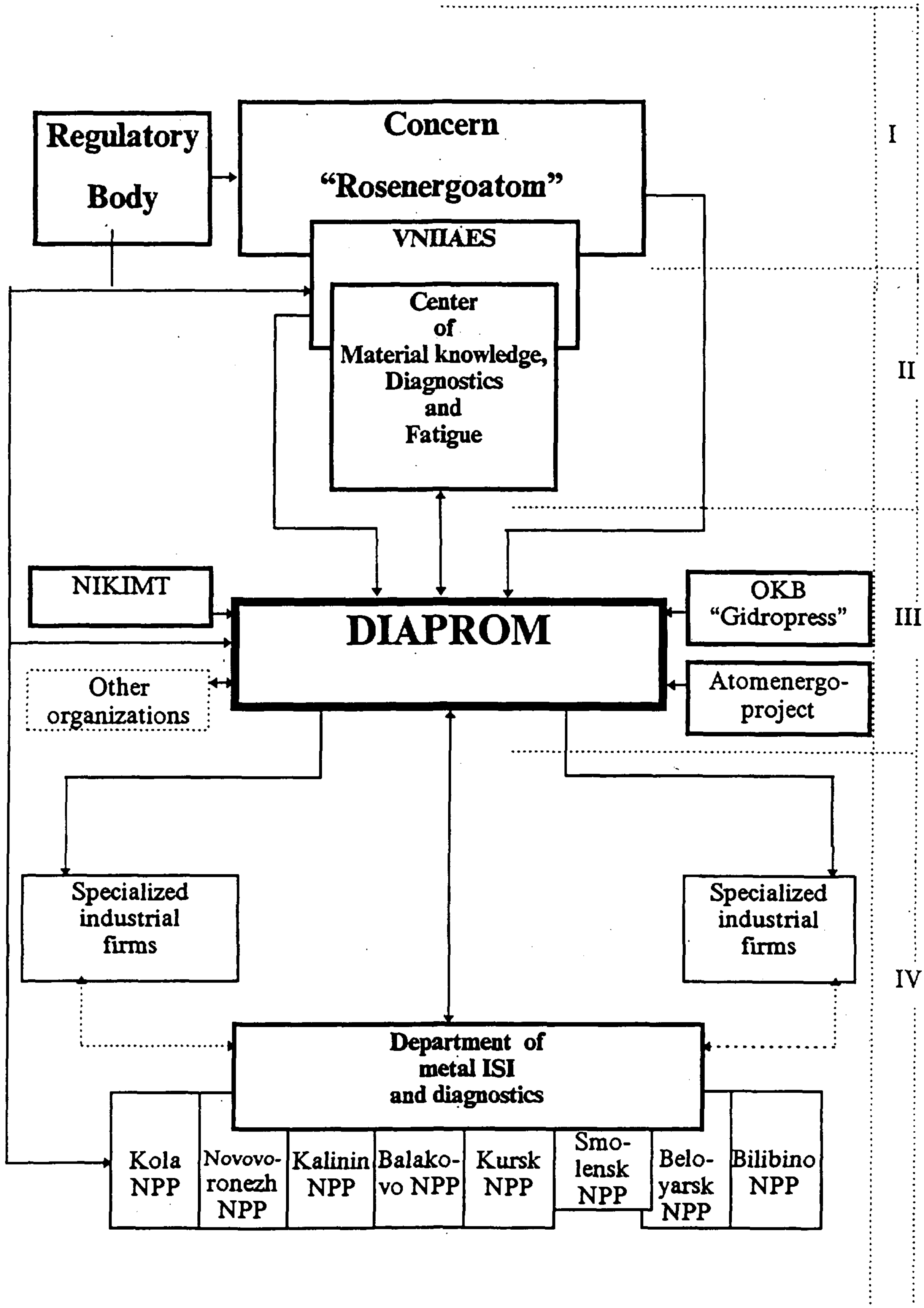
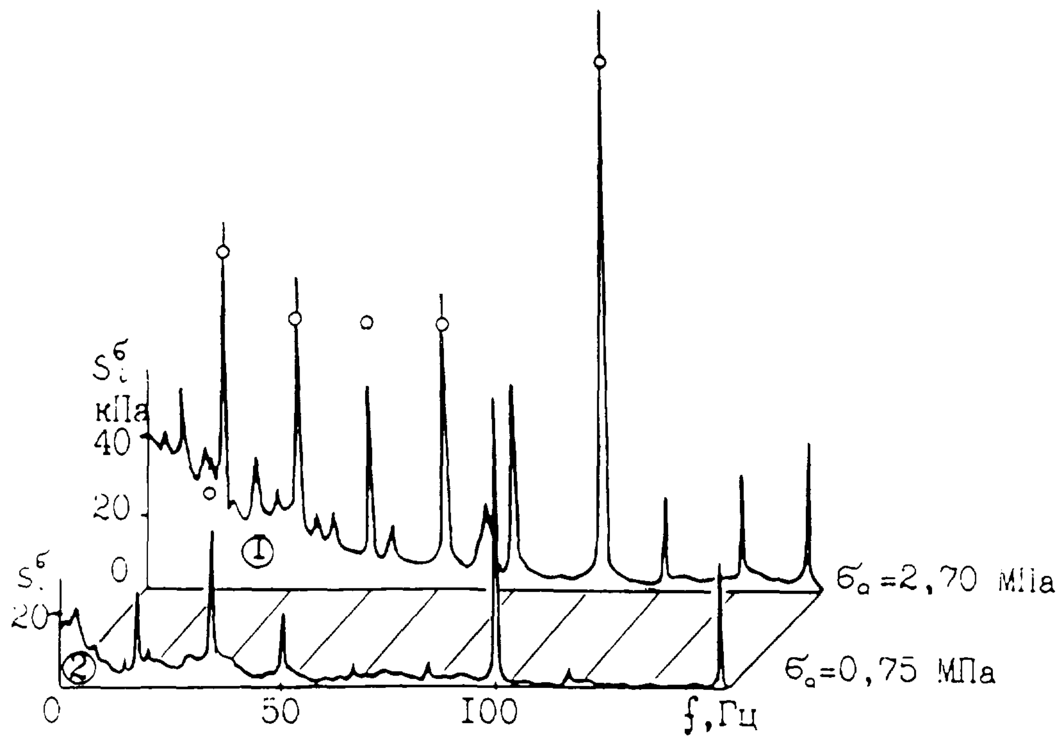


Fig.4 Structural diagramme of the industry's diagnostics system.

Vibration stresses spectrums at core barrel of khmelnitski-1 reactor



1 - measurements during hot tests
2 - measurements during start-up
o - project acceptable values

Fig.5