INFLUENCE OF NDT ON REDUCTION OF LOSSES CAUSED BY EMERGENCIES IN RUSSIA.

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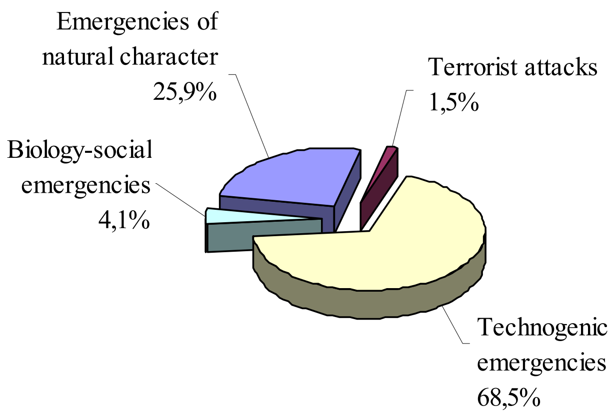
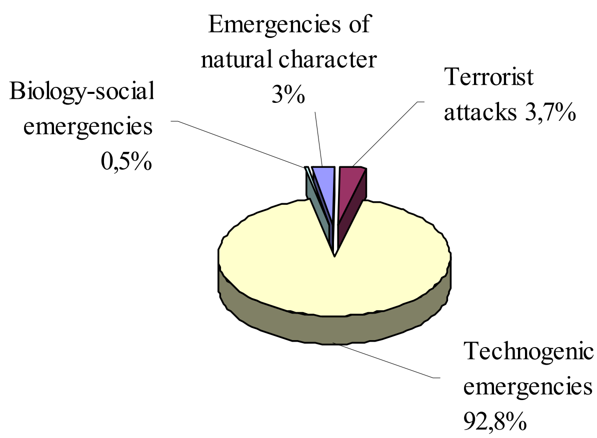
Abstract: The practice shows, that the basic reasons of occurrence of hazards and dangerous situations are technogenic accidents and emergencies. In current Russian conditions this can be explained by two basic circumstances: 1) - about 70% of Russian territory is located in low temperature climatic area; 2) - destruction of former USSR caused dramatic economic consequences: - assets ageing that are not accompanied with modernization; -and reduction of investments on NDT and technical diagnostics (TD). Such critical situation can be significantly improved and the risks of objects failures can be reduced on order if provided is the objective inspection with the help of NDT and TD.

Introduction: The relative hazard of various components of accidents in Russia can be demonstrated by the distributions presented in Fig. 1 & 2.
It is necessary to underline that the reliability of natural disasters forecasting in Russia is 70-80%. Presented data make it evident that main dangers are caused by the emergencies and accidents of technogenic nature.
The practice shows that this critical situation can be significantly improved and the risks of objects failure can be reduced on order if provided is the objective inspection with the help of NDT and TD. From the other side it is necessary to remember that of great importance and influence on final results is, so called, human factor.
That is why another very important point of the situation improving is qualification of specialists performing NDT. Training and examination of NDT specialists are of special attention in Russia. In this area efforts are made by several state institutions and Russian NDT Society (RSNTTD). In the paper the practical results of changing in regulating documents and norms relevant to NDT personnel certification will be given.
The various aspects of possibility of NDT use will be discussed as well.

Results: Any implementation of NDT is based on use of the system comprising three elements: examined object, selected NDT method and operator.
The accuracy of images estimation, completeness of recognition and detection time for different operators can vary with ratio 5:1.

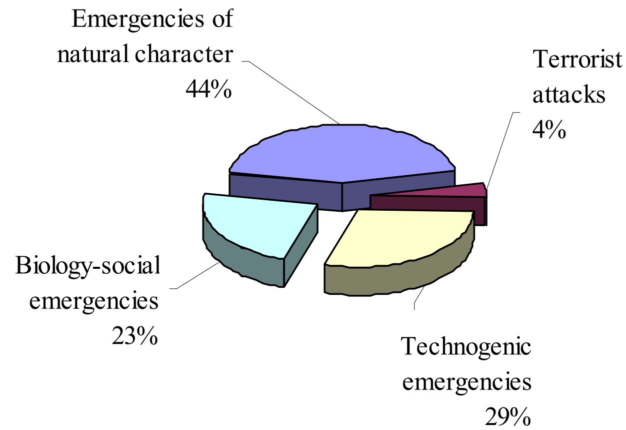


a) Distribution relative to the nature of emergencies

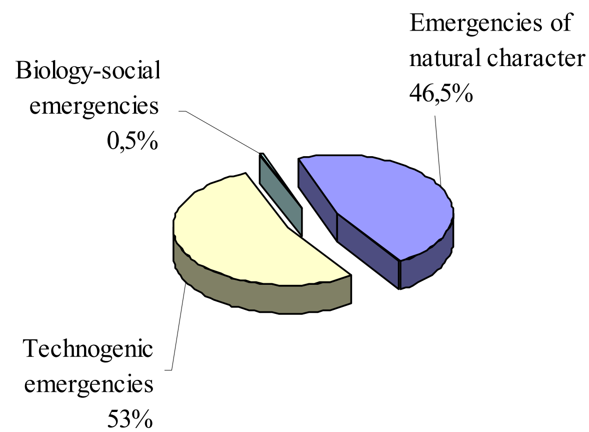


b) Number of dead cases in the result of emergencies of various natures

Fig. 1. Distribution of various types of emergencies that happened in Russia in year 2001



a) Injured persons



b) Declared losses

Fig. 2. Distribution of emergencies' consequences in Russia in year 2001

From the total amount of rails and other items breaks about 20% is due to defects missed by operator.
In case of X-ray TV testing the number of flaws that can be detected and further removal is reduces by the factor 170.
The probability of detection of cracks checked during "blind tests" was varying from 25 to 95%.
Only 10% of welded joints in which the flaws are detected with the help of manual UT should be repaired and in fact are potentially dangerous for structure, the rest 90% can be still in operation without any potential hazard.
With the help of eddy-current equipment it is possible to detect flaws with length 0.25 mm and more and with depth 0.125 mm.
The regulating documents should be revised in accordance with international and modern requirements.

Discussion: Let us revise in mode details three basic components of any NDT method.

The examined object. The objects that are subject to NDT examination should be in compliance with requirements of flaw detection technology (in other words, be suitable for examination procedures). When talking about possibility to use industrial radiography it is clear that tested structure in accordance with the most efficient exposure scheme should have free access to its examined part of both X-ray source and registration-transforming unit. At the same time, within the limits of working beam the outside elements of the structure should be absent as this can reduce the efficiency of the examination. For example, if the image of welded joint is shaded by image of projection of material thickness overfalls or by boundaries of the structure components, etc. it is difficult to detect undercut on the background images of other outside elements.

For acoustic testing it is required that the sounding trajectory should provide the minimal disturbing reflections, possibility to use the coupling liquid, surface roughness R_z and curvature radius not more than 400 and 3 mm correspondingly.

When using eddy-current testing method it is required to ensure a constancy of gap between tested object surface and exciting and receiving coils and to provide absence of any disturbing outside elements of examined structure.

Ideally any construction should provide possibility of examination procedure automation, i.e. automatic positioning of the sources generating exciting physical field into working position and registration of reflected signals after influence of the above field. This is of special importance when the goal is to achieve the efficient implementation of methods, schemes and NDT means, providing detection of flaws and defects (under defect is understood any deviation from set parameters) during production, operation and repair of industrial objects.

When discussing the requirements imposed on the objects under examination it is necessary to pay special attention to defects that can be detected in these objects. The defects detectable in metal items or semi finished metal products differ to the following attributes: sizes, places of location and origin nature. They may occur during melting or molding (these are blisters, pores, friable areas, inclusions, hot cracks, etc.), pressure treatment (internal and surface cracks, delaminations, etc.), thermal and chemical-thermal treatment (areas of overheat and burn, thermal cracks, etc.), mechanical processing (grind cracks), welding, soldering and gluing (incomplete fusion, cracks, poor connection) during storage and operation (corrosion damage, fatigue cracks, thermal wearing, creeping) etc. But all these defects have common feature – they cause changes of physical parameters of the material such as specific electrical conductivity, magnetic permeability, density, velocity of ultrasound propagation, coefficient of radiation attenuation, etc.

The defects that occur during operation differ from those occurring during fabrication. The first ones usually happen on the object surface and have a character of fatigue cracks or corrosion damages. The probable location of such defects can be predicted basing on the fatigue theory or on the analysis of destruction of previously examined samples.

If to talk about composite materials they may have flaws of several types: surface shock damage, surface thermal pores, internal bubbles, delaminations, etc.

When working out the probabilistic description of the flaw it is postulated the existence of a priory distribution of number of flaws in the object and their geometrical parameters (size, orientation, etc.). To describe the number of defects in the examined object rather often the Poisson distribution is used. Another good approach to approximation of defects distribution along the real size is gamma distribution. All these approaches help to estimate the possibility of application of this or that NDT method in advance.

Operator. Very important part of any examination procedure is human factor, as even if the NDT system is highly automated still operator is of great importance. The operator carries out interpretation of optical, ultrasonic, thermal, magnetic and other images of tested objects. He also makes decision in case of non-standard situations and estimates current conditions determined by several poorly correlated events. Total automation of NDT systems does not look realistic and hence the operator still will have leading role for quite a long time.

When performing flaw detection by means of introscopy methods the process of flaws detection comprises two phases (whixh determined more or less conventionally): detection and recognition. When talking about detection it is understood the selection of flaw image on some background and its classification in accordance with particular interest. Under recognition more accurate flaws' classification or grouping is understood. It is recommended to use model of flaw detection from the theory of random search. The general ideas of such an approach can be described as follows:

1. The probability of flaws detection (in case of various values of interferences density and speed of image motion on the indicating screen) can be described by the following formula:

$$P(t) = 1 - \exp(-\nu t) \qquad (1),$$

where ν - coefficient dependent, all other things being equal, on area and contrast; t - time.
2. Average time of flaw detection is proportional to the area of screen part where it can occur.
3. Average time of flaw detection does not depend on its outline shape and contrast sign.
4. The training of operator practically does not have any influence on the curve described by (1), it only causes increase of the parameter ν.

   Parameter **a** - the impact of signal generated by the flaw on the vision system of the operator rather accurately can be approximated by power function of the flaw size:

$$a = (r - r_{min})^{\nu} \qquad (2),$$

where r_{min} – minimal size of detected flaw; $\nu \geq 5$ and hence the probability of flaw detection within small time interval Δt is supposed to be equal to $\sigma a \Delta t$; $\nu = \sigma a$ and σ - the coefficient dependent on informative characteristics of NDT systems and training level of the operator.

In Fig. 3 the curves 1 & 2 present the typical probability curves of flaw detection in case of fixed examination time, and this curves present the function of flaw sizes. The curve 3 is determined by probability calculated with the help of equation (1) when $\nu = \sigma r^5$.

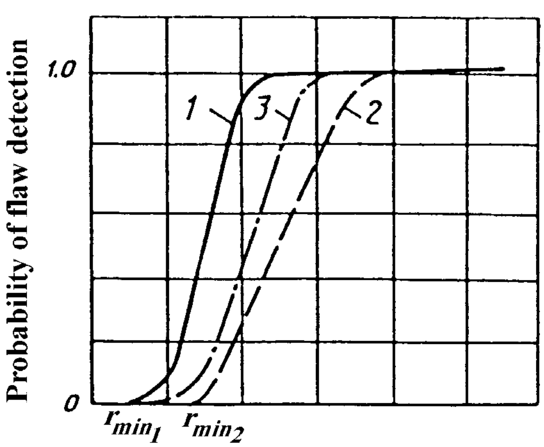


Fig. 3. Probability of flaws detection like a function of their sizes: curve 1 – experienced operator; curve 2 – non-trained operator; 3 – relationship described by equitation (1).

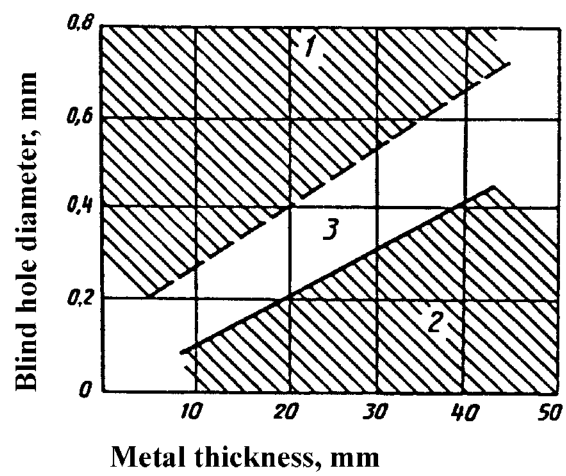


Fig. 4. The areas of 100% (1), zero (2) and (0 ≤ P ≤ 100%) (3) probability of detection of drilled blind holes in aluminum in case of radiographic testing method.

The analysis of curves 1&2 in Fig. 3 makes it possible to formulate the following conclusions:

1. Curves 1&2 confirms practically total reliability of detection of big size flaws and practically zero probability of small size flaws detection.
2. Cut-offs in the area of small flaws r_{min} are explained by limitation of operator's vision as well as by degradation of shadow images of flaw at different stages of its forming.
3. The curve 1 practically is displaced in parallel relative to the curve 2, but more sharp inclination of curve 1 is likelihood connected with better experience of trained operator, i.e. experienced operator with higher probability detects small and big flaws while inexperienced one more likely to miss small flaws (this fact is confirmed by various inclination of presented curves).
4. The curve 3 correctly reflects the trends of curves 1&2. On inclined part of the curve when size of the flaw doubled the probability of its detection changes from 0.1 to 0.9, i.e. by the factor 9.

Recognition (classification) of light images of flaws has several difficulties due to the fact that any information that should be extracted from the images is limited due to dependence on many things, for example, final portions of quantum, photons, electrons and other corpuscles, their step-type behavior, chaotic character of distribution in time and space and presence of ghost signals.

All researches have the same opinion that improvement of flaw detector' resolution and noise-to-signal ratio helps better to detect and classify the flaws. Also from some research works it is known that accuracy of images estimation, completeness of recognition and detection time for different operators can vary with ratio 5:1.

Below are given some examples of use of NDT equipment for inspection and diagnostics at railway transportation means in Russia. At the moment some 10.000 flaw detectors of various types are used. Yearly examined are more than 4.2 mln km of rail ways, 2.5 mln. rail welds, millions of items and elements of mobile units. Due to this activity more than 70 thousand failures of critical parts of rail ways and rolling stocks are avoided and predicted. Nevertheless, the reliability of the examination mostly is determined by experience and qualification of personnel performing these jobs. From the total amount of rails and other items breaks about 20% is due to defects missed by operator.

It is known that two things have positive influence on operator: continuous motivation of his abilities and creation of working environment that involves him/her into education process i.e. helps better to understand goals facing him/her. That is why it is so important all the time to have feedback between operator and the quality of obtained information. The person who is concentrated and goal oriented solves the detection tasks more efficiently than his/her antipode.

NDT methods.

It is necessary to mention that when making a decision about what NDT method or methods will be used for examination of this or that object its parameters are not always the most important ones. Rather often the decision is made on the basis of available equipment and experience of the operator. Further in the text four methods, i.e. radiographic, eddy-current, ultrasonic and vibration analysis are described and this can be explained by the fact that they are widely and mostly used in Russia and in many other countries.

Radiographic NDT methods. In the process of examination the flaw is registered as a local excess (increase), sometimes very small, of the quantum flow over the general radiation background in the specific direction. Maximal sensitivity of any radiographic system is determined by statistic fluctuations of the registered quantum number. In most ranges of electromagnetic spectra the number of registered photons is so great that it is seldom possible to achieve the maximal sensitivity as a number of different features occur to be more essential. But when talking about X-ray range, the energy of each quantum is high enough to provide required energy flow even with small number of quantum. In such a way the statistic fluctuations of general number of registered quantum combining the background photon radiation and valid signal are the most limiting factor of X-ray NDT method sensitivity.

In Fig. 4 the areas of 100% and zero probability of drilled blind holes detection are presented (the diameter of the hole is equal to its height) depending on the thickness of aluminum alloy of SAV-1 type in case of RT.

When performed is the X-ray television examination of tubes with L = 10 m and λ = 0.2 1/m (flaws number per unit of length), $\sigma a_0 = 1.2\ \text{min}^{-1}$, (the size of the flaw $\varepsilon \approx 1$ mm) and examination speed v = 2m/min the proportion of flaws after examination procedure providing their detection and further their removal reduces from $[1 - \exp(-\lambda L)] = 0.865$ to $\{1 - \exp[-\lambda L \bullet \exp(-\sigma a_0 t)]\} = 0.005$, i.e. by the factor 170.

Ultrasonic NDT method. UT is widely used for examination of metal products and items. The examination of high pressure vessels, when in operation, is not as easy as the access and conditions are difficult and time is limited. Interpretation of acoustic data and reliability of flaws detection have some difficulties as the reflected signal depends not only on the size of crack but on orientation and surface roughness as well. During "blind tests" the probability of detection of cracks split in four groups (small acceptable flaws, small unaccepted flaws, big unacceptable flaws and continuous ones) was varying from 25 to 95%. This can be explained by theoretical limitations imposed on flaws detection and resolution, external reasons relevant to calibration of instruments scales and operators qualification and internal factors (variations of the crack material parameters, etc.).

UT of welded joint of tubes from PVC with 90% reliability provides detection of so called cold butts and voids. For example, the echo-pulse signal amplitude is affected not only by the size of the crack but by its orientation; shape; homogeneity of parent material, etc. as well. The increase of measurement sensitivity reduces the probability of false acceptance of the item but at the same time increases the probability of false item rejection.

The modern method of multi frequency acoustic holography uses coherent echo-signal processing to obtain the image of tested item. On the output of the instrument using this new approach after mathematical processing the B, C and D scans are formed. The practical operation of such instrument at Russian Nuclear Power Plants made it evident that only 10% of welded joints in which the flaws are detected with the help of manual UT should be repaired and in fact are dangerous for structure, the rest 90% can be still in operation without any potential hazard.

Eddy-current NDT method. This method proved to be very successful in case of detection of surface and near surface cracks. It is sensitive to changes of mechanical properties and can be used for detection of cracks in holes. The method sensitivity strongly is dependent on quality of surface processing and its relief. In fact, eddy-current method is contactless though its sensitivity depends on the gap between the tested item and the measuring coil.

The typical probabilities of cracks detection are presented in the table.

Table 1. Experimental values of probability of cracks detection dependent on their size (13 μm opening)

Crack length, mm	Crack depth, mm	Detection probability
0.95	0.84	1
0.70	0.64	1
0.50	0.57	1
0.45	0.57	1
0.40	0.42	1
0.35	0.36	0.9
0.3	0.3	0.8
0.2	0.25	0.7
0.20	0.20	0.2

With the help of eddy-current flaw detectors it is possible to obtain very useful information about the quality of items of airspace industry. For example, to detect surface and undersurface flaws in the elements of gas-turbine engines very efficient is eddy-current equipment. With its help it is possible to detect flaws with length 0.25 mm and more and with depth 0.125 mm.

Vibration analysis. Diagnostics of equipment condition and evaluation of the level of danger based on vibration measurements – is one of the efficient ways of reliability improvement. Thus, use of vibration monitoring of the pump equipment at the number of chemical and refinery facilities made it possible practically to avoid non-authorized shut downs while the accidents caused by failure of the pumps till recently was about 40% of total amount of shut downs.

As it was mentioned before the experience and qualification level of operator is great, if not the most important, part of success of implementation of NDT methods and means. The qualification and competence of knowledge of the NDT specialists strongly depends on the systems of certification that provides verification of knowledge and qualification of NDT specialists.

Establishment of the scheme of NDT specialists' certification in Russia. Activity to establish three level scheme of NDT specialists' certification in Russia started in early 80th within the frames of work of sub-committee "Specialists qualification" of ISO TC 135. In December 1986, Scientific Committee "Non-destructive physical methods of testing" of USSR Academy of Science approved the first list of specialists of level III qualification for seven NDT methods. In this list, for example, 14 specialists from "MSIA "Spectrum" were included.

The activity within the field of NDT specialists' certification becomes increasingly intensive during 1992-1997. This can be explained by the following. Only within the territory of Russia, there are more than 160 thousand of potentially hazardous facilities, including 1500 nuclear power facilities and 3000 of chemical and biological ones. Naturally the basic area of NDT methods and means implementation is industry and especially potentially hazardous facilities and installations. Under term "the potentially hazardous facility" the various objects, structures and installations are meant. Within Russia there are several authorized by authorities' bodies supervising safety issues. Such specialized bodies exist within Ministry of Energy, Ministry of Nuclear Power, Ministry of railway roads, Marine Ministry, Airspace Ministry, etc. All of them have areas where specialists providing NDT services exist. The schemes of NDT personnel certification within the areas of supervising bodies' competence can vary. In such a way in Russia like in many other countries, there are several NDT personnel certification schemes, but most of them are harmonized with EN 473. The certification of specialists is carried out by special Independent Certification Centers. Totally in Russia there are some 25 such centers.

Former USSR and present Russia have wide, well-developed and comprehensive industry, due to dramatic economical changes in the country during last 10 years special importance gained issues of industrial safety. It is difficult to imagine one is able to provide safe operation of industrial installations and structures without highly qualified and skilful specialists able to implement in their work NDT. In July 1997 was approved and put in force the federal law "Industrial safety of hazardous production facilities". This law took into account the international experience. The law made an important impact on development of documents regulating industrial activity including those relevant to NDT implementation and qualification and certification of NDT specialists providing inspection services of products, systems, etc. In the same 1997 year the Intergovernmental Council for standardization, metrology and certification of C.I.S. accepted and approved the standard GOST 30489-97 that is equivalent translation of EN 473. Moreover, on November 25, 1997 GOSSTANDART of Russian Federation registered the Scheme for voluntary NDT personnel certification developed and implemented by Russian Society for NDT and Technical Diagnostics (RSNTTD).

It is well known that within different, existing in various countries, schemes of NDT personnel qualification and certification – different requirements are imposed on competence of the candidates. In Tab. 2 are presented general requirements used in system established by GGTN and similar to those existing within voluntary system described above.

Table 2. General requirements imposed on candidates' qualification

Level	Education, qualification & training	Professional skill	Competence area
I	Secondary education, at least 80 h of specialized courses	Operator	Performance of specific products tests in accordance with test procedures under supervision of level II & III personnel
II	Secondary or higher education, specialized courses based on program approved by ICB	Controller (Inspector)	Independent implementation of NDT and assessment of tested object quality, knowledge of NDT documents
III	Secondary or higher technical education	Technologist	Competence in all aspects of NDT activity (method) for which certificate is obtained

Perspectives of development of NDT specialists' certification system. In the nearest future Russia plans to join WTO and it means that country has to adjust its regulating system to remove administrative and technical barriers for free trade operations. Establishment of common market in Europe required development and introduction of harmonized rules of technical regulation, of minimization of state control.

The basic goal of technical regulation is to work out compulsory technical requirements imposed on products safety. The norms determine consumer properties and quality of the products are voluntary, i.e. the products' quality is controlled by market itself. Since 1987 more that 20 Directives prepared by EC were put in force, these documents were prepared and approved on the basis of new global approaches. At the same time some 2000 old style directives are still valid and implemented.

In the resolution of EC of 1985 the following principles of technical regulation are stipulated: - the requirements that determine product safety are stipulated at the legislation level; -technical specification of product that presents its consumer properties establish the basis of agreed standards; - implementation of agreed or other standards are voluntary; the manufacture has the right to implement any technical requirements that are not in contradiction with compulsory requirements; - the products manufactured in accordance with requirements of agreed standards have preference in comparison with other ones.

Russia has to change its regulating system in accordance with new approaches used all over the world, it means that the technical regulation should be changed and adjusted in accordance with listed above principles. The first step made by Russia is approval of new federal law of December 27, 2002 "On technical regulation". Due to this new law in the nearest seven years regulating documents, rules and norms should be revised in accordance with new approaches.

This law introduce such a term as "technical regulations (in Russian it sounds 'reglament' or standing order)". The law stipulates that some "technical standing order" should be approved at the level of Federal law and in some cases such a document can be introduced by the Government Decree. In technical standing order are formulated the compulsory requirements imposed on: - objects that are subject to technical regulation (this can be products, processes, production methods, operation and utilization); - types of assessment of compliance to compulsory requirements; - terminology; package; construction; - type of performance etc.

The most important thing is that this document covers not only the requirements towards products but towards processes and methods of production, operation and utilization.

The philosophy of the new law "On technical regulation" is as follows: 1)- The mandatory requirements are stipulated only in the documents named "Technical standing order" and the recommended ones – in standards; 2) - Technical standing orders and standards are based on

international and internationally recognized standards and norms; 3) - The opinion of all interested parties should be taken into account during development of the new set of regulating documents; 4) - Federal Bodies of executive authorities do not have any more power to establish mandatory requirements within the area of technical regulation.
In the new documents should be stipulated forms of compliance assessment and such an assessment can be both mandatory and voluntary. It means that Manufacture has the right to choose the most convenient option.
Special attention in the law is paid to the necessity to carry out any assessment or certification by Independent test or certification centers. From now for any Supervising Body or Institution it is forbidden to provide both the development of mandatory requirements and assessment of this requirement fulfillment. Still the responsibility to supervise the fulfillment and compliance to the requirements of newly developed documents will be responsibility of specially appointed by authorities supervising executive bodies.
All stated above means that in the nearest future in Russia the system of NDT personnel certification also should be adjusted in accordance with new requirements and approaches. For sure the experience of international institutions used by RSNTTD will make this transition period smoother.

Conclusions: One of the ways of efficient prevention of emergencies and accidents in general – introduction and wide use of NDT and technical diagnostics methods and means, but these methods and means should be used by highly professional and qualified personnel.
The role of NDT in the modern world is continuously increasing, it is clear that non-destructive testing and specialists providing services within the field of NDT play important part in safe operation even if such services have strong influence on the final costs. But in some cases, when technogenic disasters with transboundary effects happen, it is too late to talk about money, as not only money are lost but people lives and damage to environment with long term consequences. From the other side not only Russia but many other countries face the problem that due to lack of finances the old equipment can not be replaced by new one that is why more and more employers start to understand that NDT is of vital technical and economical importance.
The problems facing Russian NDT community: (a) - to increase the number of Independent Certification Bodies accredited by European or internationally recognized accreditation centers, i.e. to have more specialists with certificates recognized in other countries; (b) – be more active and efficient in the process of European and International harmonization, especially in issues connected with requirements towards examination questions and test specimens.