



Nanotechnologies for testing and diagnostics of materials, constructions and elements of engineering systems of buildings from them with fire retardant coatings.

Part 2

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ABSTRACT: Introduction. To determine the effectiveness of fire-retardant coatings (FRC), a system of methods for fire and high-temperature testing of fire-retardant materials and structures made of them is being used. However, there are no methods and means that could provide current effectiveness of fire protection, and existing methods cannot be applied to determine fire resistance of building structures with fire protection, they set only a group of the effectiveness of the flame retardants. Therefore, to assess the quality and durability of the FRC, in case they provide the parameters of thermal stability of the protected materials, structures and elements of the engineering systems of the objects, it was necessary to develop a quick method and a portable diagnostic complex of fire-retardant coatings (PDC FRC). **Methods, models and tools.** Based on a system analysis of the existing fire protection technologies for building materials from wood, metals, rubber and polymers, a rapid analysis methodology and PDC for thermo-electro-acoustic (TEA) sensing of FRCs using thermo-acoustic methods have been developed. That made it possible to determine thermal conductivity, the ultrasound speed and its absorption coefficient in the FRC, as well as to conduct a comparative analysis of the «FRC image» obtained on a BETA-analyzer with measured characteristics, based on which to calculate the time of its operability. **Results and discussion.** The PDC of FRC consists of a case with a laptop, with the immittance meter and a two-channel oscillographic attachment connected to the laptop, to the inputs of which a TEA-zonding unit is pressed, pressed to the FRC of the tested object (structure, material, cable), by thermal, electrical and acoustic signals from which the laptop software identifies the properties and stages of operational stability of the FRC. The PDC of the FRC and the proposed approach allowed us to synthesize a model of the Internet system of TEA - diagnosis of FRC and of the monitoring of the operational stability of the protected materials. The novelty of the study is protected by patents of the Russian Federation. **Conclusion.** The proposed approach and the PDC of the FRC made it possible to implement a quick analysis of the FRC at the facility and to synthesize a model of the Internet system of TEA-diagnostics of FRC, which can become the basis of the national supervision system for the given area.

KEYWORDS: fire retardant coatings, degree of fire resistance, materials and structures, quality of fire retardant coatings, durability of fire retardant coatings, thermo-electro-acoustic method, heat conductivity, thermal diffusivity, heat capacity, aging of fire retardant coatings, dangerous factors of fire.

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INTRODUCTION

To determine the effectiveness of fire-retardant coatings (FRC), a system of methods for fire and high-

temperature testing of fire-retardant materials and structures made of them is being used [1, 2]. However, there

are no methods and means that could provide current effectiveness of fire protection, and the existing assessment methodology divides the FRC into seven groups, depending on the time of heating up to 500°C of an I-section steel column of profile No. 20 or profile No. 20B1 with a height of 1700 mm, coated with FRC [3]:

- 1st group – at least 150 minutes;
- 2nd group – at least 120 minutes;
- 3rd group – at least 90 minutes;
- 4th group – at least 60 minutes;
- 5th group – at least 45 minutes;
- 6th group – at least 30 minutes;
- 7th group – at least 15 minutes.

Moreover, the methodology cannot be used to determine fire resistance limit of building structures with fire protection, it sets only the efficiency group of the flame retardants themselves. The same approach is applied for FRC used to protect wood, cables, etc. [2–5].

Thus, the latent form of assessing the effectiveness of the FRC is again evident: not by the thermal stability of the material being protected, but by the indirect characteristics of the FRC itself [6].

That is why, in order to assess the quality and durability of the applied FRC, in case they provide parameters of resistance to the impact of the protected materials, structures and elements of engineering systems of objects (buildings, structures), it was necessary to develop a quick method and portable diagnostic complex of fire retardant coatings (PDC FRC).

METHODS, MODELS AND TOOLS

Based on a system analysis of the existing fire protection technologies for building materials from wood, metals, rubber and polymers, a rapid analysis methodology and a portable diagnostic complex (PDC) for thermo-electro-acoustic (TEA) sounding of FRC using thermo-acoustic methods were developed, which allowed determine the thermal conductivity, ultrasound speed and its absorption coefficient in the FRC at the facility, and also conduct a comparative analysis of the «FRC-image», including its operational aging, obtained on a BETA-analyzer, with the measured characteristics at the facility during the test, by which to calculate its working time [6–10].

The developed method of thermo-electro-acoustic (TEA) sounding uses not only the method of acoustic emission (AE), but also the method of molecular acoustic analysis (MA), which allows you to determine the speed – with (T) and frequency – ω (T) of ultrasound in the FRC, then calculate the absorption coefficient α_c and check the value of the E – Young’s modulus obtained on the BETA-analyzer [9–11]:

$$E = \rho \cdot c^2, \text{ where } c(T) = (2l_b + d/2)/(\tau_r - \tau_n), \quad (1)$$

$$\alpha_c = \frac{\omega^2}{2\rho \cdot c^3} \left[\frac{4}{3} \eta + \varepsilon + \lambda \cdot \left(\frac{1}{C_V} - \frac{1}{C_P} \right) \right], \quad (2)$$

where l_b is the length of the acoustic waveguide, d is the diameter of the sample, τ_r is the time the first sensor excites the pulse from the reference generator, τ_n is the time the second sensor receives the pulse from the reference generator, ρ is the density of the sample, c is the speed of sound in the sample, ω is the circular frequency sound wave, η is the shear viscosity coefficient, ε is the bulk viscosity coefficient, λ is the heat conductivity coefficient, C_V is the heat capacity at a constant volume, C_P is the heat capacity at a constant pressure.

TEA sounding is carried out using a special board (Fig. 1), which contains three metal probes mounted on the plate from fluoroplast in a straight line at fixed distances, each of which has an acoustic sensor. The extreme sensors are connected to the individual inputs of the oscillographic set-top box through preamplifiers, registering acoustic signals, and the central one – to the output of its reference generator through a controlled electronic key, operating as an emitter of ultrasonic signals [7, 9].

On each of the three probes, one thermal sensor is installed, connected to the input of the emittance meter through a managed switch, measuring the temperature (by changing their resistances). Each of the three probes represents a pointed thermo-electro-acoustic molybdenum waveguide, connected to the input of the emittance meter via a controlled switch, for measuring the electrical and thermal parameters of the FRC between the probes, and to an oscillographic prefix for measuring acoustic signals [9].

When calibrating according to known parameters of the body wall of the PDCFRC of an aluminum alloy: density (ρ), heat capacity (C_p) and bulk modulus ($K = 1/\beta$), as well as calibrated distances between probes (l_u and l_k), special software (Fig. 2) controls the PDCFRC and determines the following parameters [9, 12]:

- mechanical – Young’s modulus ($E = \rho C^2$), shear modulus ($G = 3E/(9-E/K)$) and Poisson’s ratio ($\nu = E/2G - 1$);
- thermal – surface temperatures (T_c and T_k), thermal conductivity (λ) and thermal diffusivity ($a = \lambda/(\rho \cdot C_p)$);
- electrical – resistance (R), conductivity (G), impedance (Z), loss tangent ($\text{tg}\sigma$), dielectric (ε) and magnetic permeability (μ), solving the characteristic (surface according to Leontovich) impedance equation ($Z = (\mu/\varepsilon)^{1/2}$);
- acoustical – the intensities of the flow (quantity per unit time) of acoustic emission (AE) events dN_a/dt , their total amount of N_a , amplitude A and spectral composition of radiation $U(f)$, as well as sound speed (C).

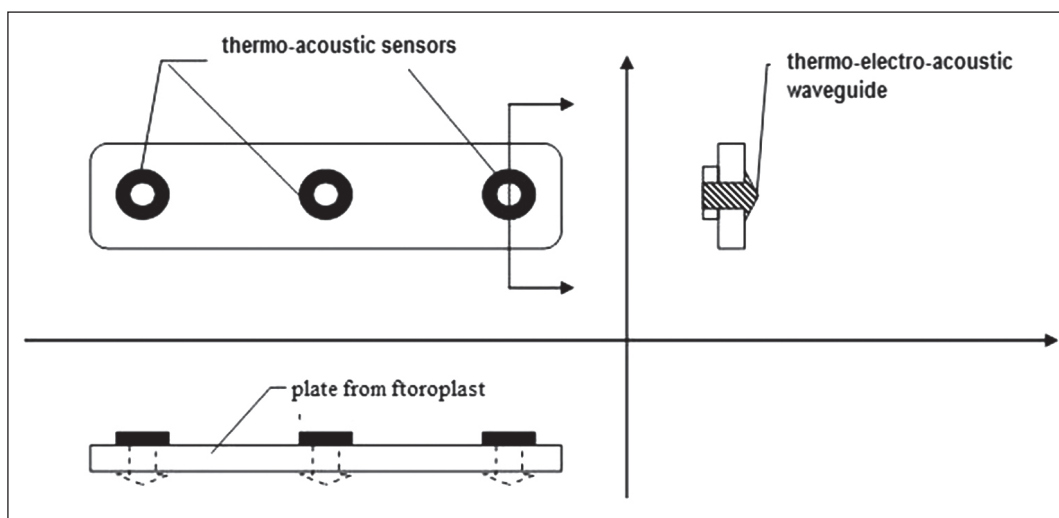


Fig. 1. TEA soundingboard

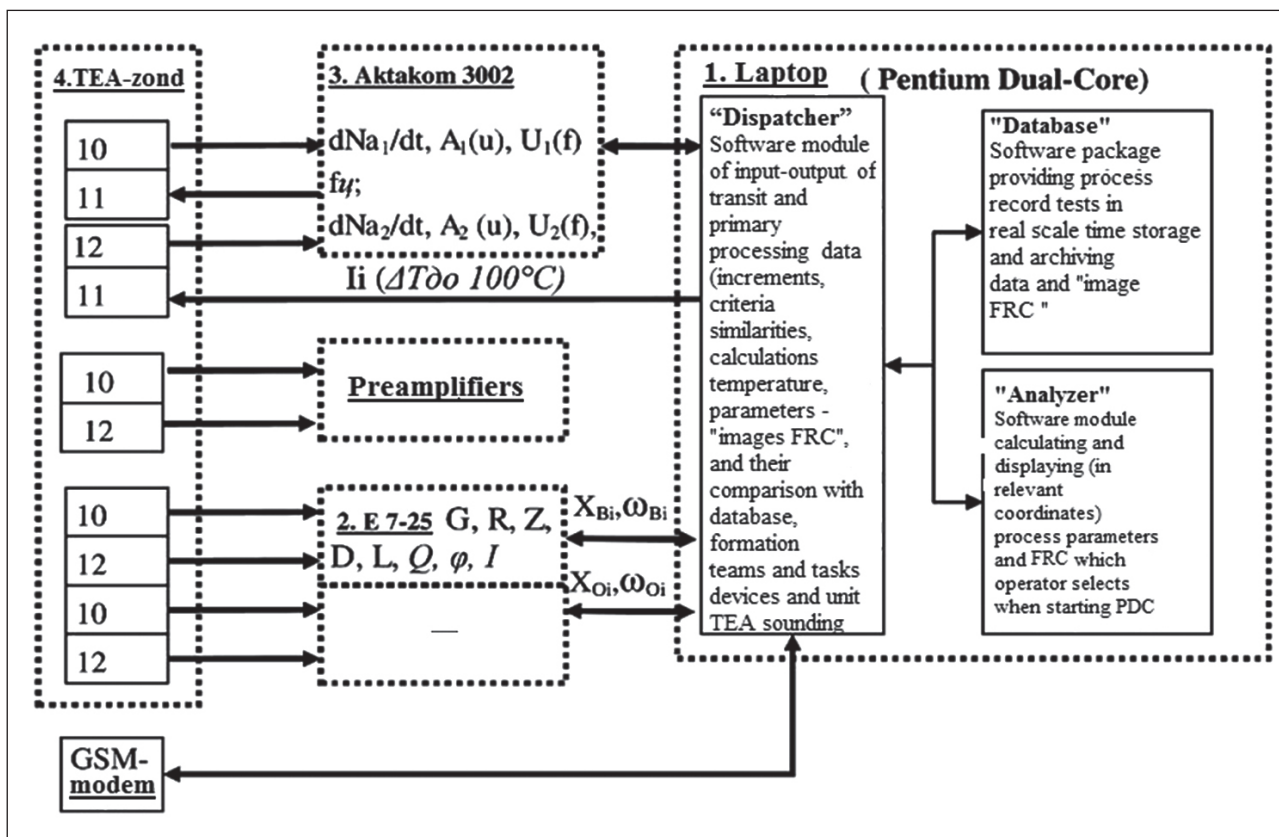


Fig. 2. Block diagram of special software

RESULTS AND DISCUSSION

During the calibration, all measuring channels are tuned to the parameters of the «case-shunt» made of aluminum alloy (Fig. 3), by calculating the corresponding

errors of the electric (Δe), temperature (Δt) and acoustic (Δa) measuring channels and their correction.

PDCFRC consists of a housing (1) with a laptop (2), with an imittance meter (3) and a two-channel oscillographic set-top box (4) connected to the laptop, the inputs of which are connected with the appropri-

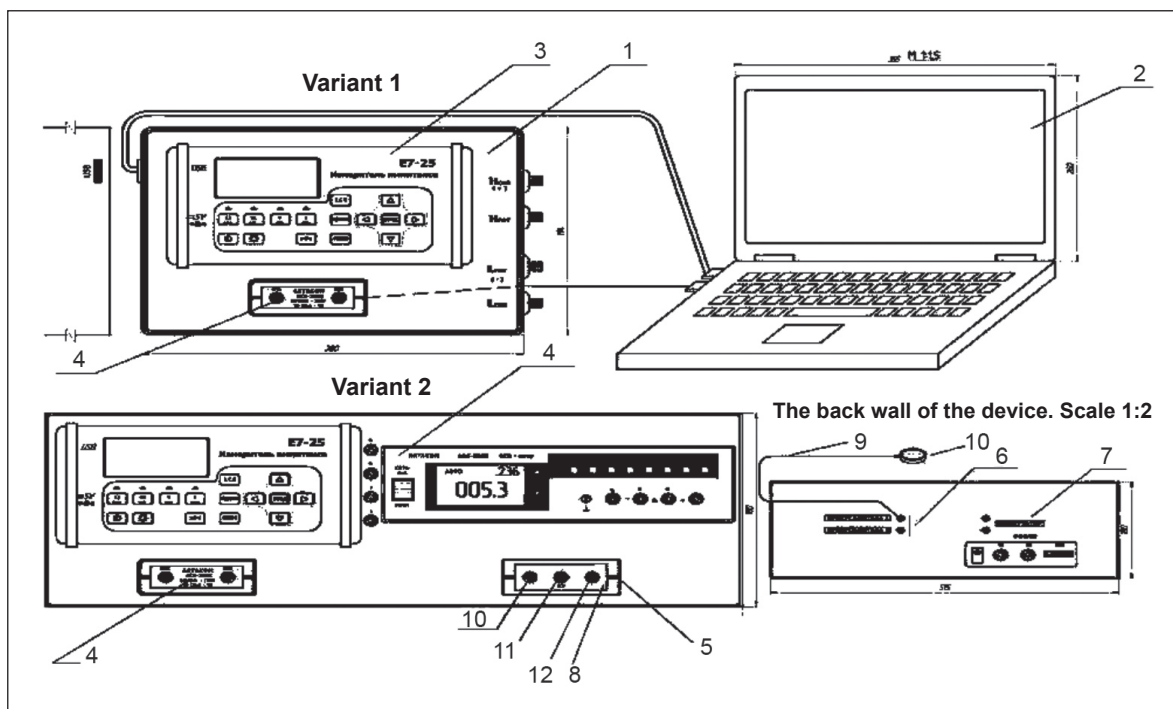


Fig. 3. General view of the PDCFRC with options for execution

ate cables to the thermo-electro-acoustic (TEA) sensing unit (5), pressed to the FRC of the tested object (structure, material, cable), by thermal, electrical and acoustic signals from which, the special software of the laptop identifies the properties and stages of operational stability of the FRC. In this case, the oscillographic set-top box is connected and powered by the USB port

of the laptop (Fig. 4), and the imittance meter is powered by the built-in battery and connected to another USB port. The TEA sensing unit is part of a portable complex, consists of two preamplifiers (6), a switch (7), a multi-core connecting cable (9) and a TEA probe board (8), on which a reference probe (10), a central measuring probe (11) are installed) and the extreme

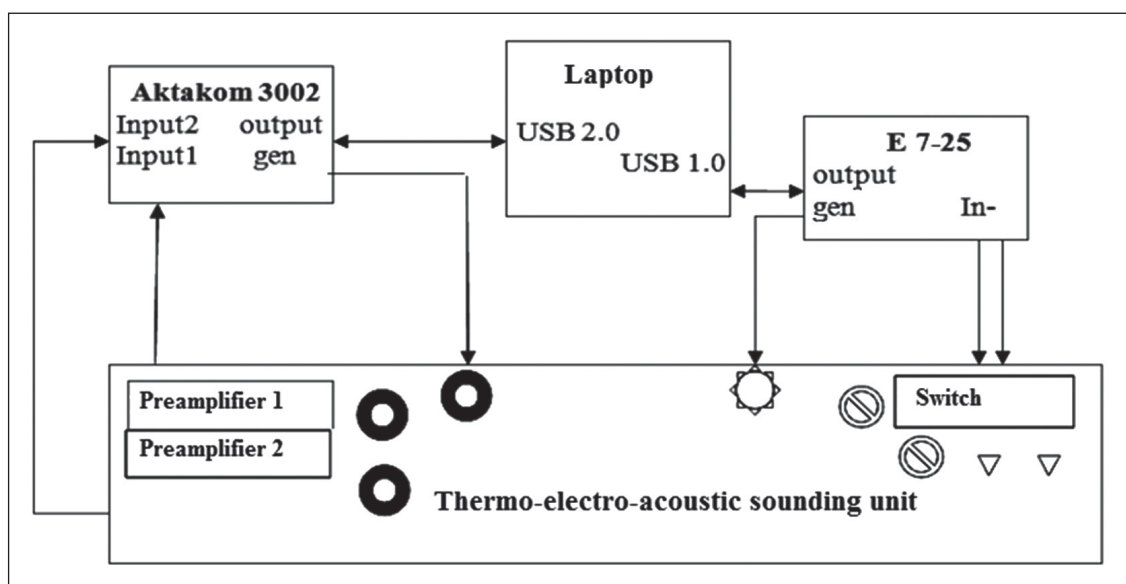


Fig. 4. Block diagram of a portable diagnostic complex

measuring probe (12). The reference probe contains an acoustic sensor emitting an ultrasonic pulse, a thermal sensor-heater of the molybdenum probe to a temperature of 100°C. The central and extreme measuring probes are the same and are pointed metal rods that act as thermo-electro-acoustic waveguide probes on which thermal and acoustic sensors are mounted. To measure the temperature and resistance of the FRC between the probes, an imittance meter with a switch is used, and sensors that record acoustic signals are connected to an oscillographic prefix [9, 12].

A laptop can be any two-processor computer with at least 4 GB of RAM and Windows 7 OS, the software (software) of which, in addition to the software module packages (SMP) of the imittance meter and two-channel oscillographic set-top box, includes special software (SSW), which synchronizes the operation of all these components of the PC and, processing the obtained TEA data, calculates the current parameters of the FRC, which identifies the stages of its operational stability and determines the effectiveness of protection [9, 12].

E7-25 with autonomous power supply was used as an emittance meter, and the oscillographic set-top box should be two-channel (for example, Aktakom 3002) with the function of a spectrum analyzer and powered by a laptop’s USB connector (Fig. 4).

PDCFRC is activated by turning on the laptop and the emittance meter with the choice of the «calibration» procedure from the «menu», after which the TEA-sensing unit is removed from the PC case and pressed to the object under test with the FRC (structure, cable, material), after which the mode starts «Diagnosis of FRC» using the same special software (Fig. 2). Moreover, to identify the state of the FRC, i.e. stages of its operational aging, in the PC database there should be an «FRC image», which is its life cycle vector function in the temperature range from minus 55°C to plus 65°C, obtained on a BETA analyzer, by which the stability stage is determined and calculates the update time of the FRC [12, 13].

PDCFRC and the proposed approach made it possible to systematically synthesize a model of the Internet system for thermo-electro-acoustic diagnostics of FRC and

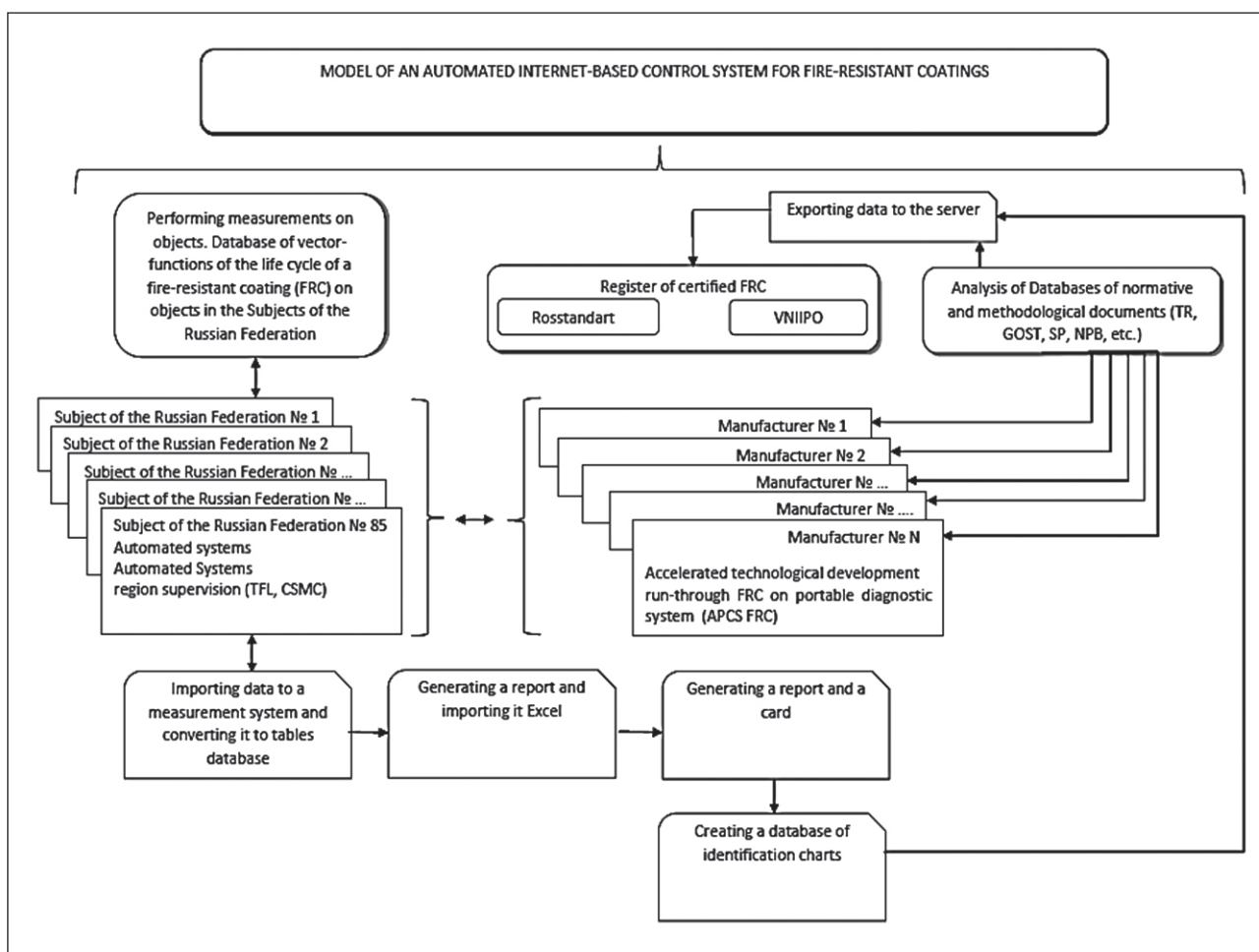


Fig. 5. General view of the information exchange scheme

operational stability of the protected materials (structures and elements of engineering systems), which can become the basis of the national surveillance system in this subject area [12, 14].

Such a national surveillance macro-system is an automated laboratory-operational Internet system (Fig. 5), consisting of 3 separate, but functionally connected systems – test, control and information [14].

Testing system – should consist of BETA analyzers with the proposed adaptation, which should be equipped with all regional forensic institutions Testing Fire Laboratories (TFL) EMERCOM of Russia and Centers for Standardization, Metrology and Certification (CSMC) of the Federal Agency for Technical Regulation and Metrology (Rosstandart) [10, 15, 16].

The control system consists of the PDCFRC, which with the help of TEA probes will allow to measure, process and carry out diagnostics by the specialists of these test divisions of the condition of the protected materials and the FRC in the conditions of operation at the facilities [8, 12, 14].

The information system (Fig. 5) will consist of servers and sites of Rosstandart and VNIPO EMERCOM of Russia, with a bank of TEA-data of FRC and protected materials filled by FMC and VNIPO (FSBI SEU FPS IPL) EMERCOM of Russia, as well as a database of the current TEA-diagnostics FRC on the objects filled in

«on-line» mode through the specified sites by bodies for certification of products, objects and bodies of supervision [14].

The solution of tasks in the information system can be carried out using the available Internet portals [12, 14]:

- FSBI VNIPO EMERCOM of Russia (<http://www.vniipo.ru>),
- Rosstandart (<http://www.gost.ru/wps/portal/>).

CONCLUSION

The proposed approach and PDCFRC implement a quick analysis of the FRC at the facility, complementing the known methods for determining fire retardant efficiency, which are reflected in the relevant regulatory documents [1, 3–5] and research [6–8], including thermal [17] and thermo-electro-acoustic analysis [18, 19], creating a «FRC image» for the subsequent identification of the stages of its «aging», and, therefore, for determining the actual time of its updating at any objects of supervision [12, 14, 15].

The proposed approach and PDCFRC allowed synthesizing a model of the Internet system of thermo-electro-acoustic diagnostics of FRC and operational stability of the protected materials (structures and elements of engineering systems), which can become the basis of the national surveillance system in this subject area [14].

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