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Survey of Soviet Scientific Research Projects in the Field of Fire Safety of Buildings and Structures

I. G. Romanenkov

Co-Chairman, U.S.-U.S.S.R. Panel on Fire Resistance
of Buildings and Structures

Moscow - 1979

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U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, *Secretary*

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Jordan J. Baruch, *Assistant Secretary for Productivity, Technology, and Innovation*

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

FOREWORD

This publication is a translation of a letter from Dr. I. G. Romanenkov of the Soviet Ministry of Construction to Dr. R. S. Levine of the National Bureau of Standards. Romanenkov and Levine are Co-Chairmen of the U.S.-U.S.S.R. Panel on the Fire Resistance of Buildings and Structures. This letter is in response to a part of a continuing Protocol (Agreement) to cooperate in this field. In turn, this Protocol is part of a wider U.S.-U.S.S.R. Agreement to cooperate in the field of "Housing and Other Construction". The responsible U.S. Government agency for the parent agreement is the Department of Housing and Urban Development (HUD). Mr. Lawrence P. Simons, Assistant Secretary for Housing and Federal Housing Commissioner, is U.S. Co-Chairman for the parent agreement.

The Office of International Affairs at HUD provided funds for the translation from the original Russian. The excellent translation was provided by Mr. William P. Keasbey of Transematics, Inc.

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SURVEY OF SOVIET SCIENTIFIC RESEARCH PROJECTS IN THE FIELD OF FIRE SAFETY OF BUILDINGS AND STRUCTURES

I. G. Romanenkov

Abstract

This publication is an annotated survey and bibliography by Soviet specialists of 1977-79 Soviet publications on Fire Safety of Buildings and Structures. Some 109 publications are referenced, divided into eight categories: Material tests, fire spread on surfaces and field tests, calculating fire endurance, mathematical modeling, fire spread to neighboring structures, automatic suppression and detection, protective coatings, and life safety in fires.

Key words: Fire; fire detection; fire endurance; fire protection; fire safety; fire suppression; fire tests; flame spread; mathematical fire modeling; protective coatings; Soviet fire research.

INTRODUCTION

In the Soviet Union a number of scientific research institutes of Gosstroy USSR, The State Committee for Civil Construction, the Ministry of Internal Affairs of the USSR, and also the scientific research, designing and educational institutes in the construction field of various ministries and agencies deal with the problem of "Fire Safety of Buildings and Structures".

The direction of the research of the various institutes on this problem is determined by Gosstroy USSR.

This survey contains brief information about the results of research on individual aspects of the problem.

1. TESTING MATERIALS FOR FLAMMABILITY, SMOKE GENERATION AND TOXICITY IN FIRES

The study of the fire technology characteristics of building materials is carried out at the Central Scientific Research Institute for Construction Elements named for Kucherenko (TsNIISK im Kucherenko), the Scientific Research Institute for Concrete and Reinforced Concrete (NIIZhB), the All-Union Scientific Research Institute for Fire Prevention (VNIIPO), the Moscow Engineering Construction Institute named for Kuybyshev (MISI im Kuybyshev) and other institutes. Questions of the theory of burning of substances are worked out at the Institute of Chemical Physics of the USSR Academy of Sciences. In studying the fire technology characteristics of materials serious attention is given to the expansion of the nomenclature of the indices used and to the elaboration of methods of testing for ignition, flammability, heat release, spread of flames, smoke formation, toxicity of the products of combustion, etc.

As a rule these methods are worked out on the basis of the recommendations of Technical Committee 92 of the International Organization for Standardization (ISO). In the framework of the cooperation of the member countries of the Council for Economic Mutual Assistance (CEMA)* two CEMA standards for methods of testing materials for flammability have also been developed. The work (1.1)[1] is devoted to an analysis of methods of fire testing building materials. Methodological questions of evaluating the fire danger of plastics are discussed in book (1.2).

In publication (1.3) a three stage model of the burning of a condensed substance is considered. The distribution in space and time of the temperature and concentrations of the products of burning depending on the size of the parameters entering into the system are found.

In work (1.4) a new theory of stationary convective burning based on a model of "double" porosity is proposed, which takes into account the effects involved in the internal pore structure of the systems being penetrated by gas. The speed of stationary convective burning and the boundary of the attainment of the stationary condition are calculated.

In article (1.5) the limiting conditions of the burning of polymers is considered. The relationships for the approximate calculation of the limiting concentration of oxygen and the limiting temperature are obtained. It is shown that high values of the limiting concentrations for carbonaceous fabrics and materials that form a carbonaceous carcass when burned are brought about by significant radiation heat losses. The experimental dependence of the limiting concentration of oxygen on the velocity of the oncoming stream is obtained for polymethylmetacrylate at various pressures. The nature of the experimental dependence correlates with the calculated values.

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*Also known as Comecon (translator's note).

[1]Figures in parentheses refer to references at the end of this publication.

The critical dimensions of burning (1.6) are determined as one of the limiting conditions of the burning of polymers. A number of variants for determining them are suggested. The possibility of burning of polymers is closely linked with heat losses from both the gaseous and condensed phases, and the dampening of combustion is determined by processes that occur at the forward edge of the gaseous flame, where chemical kinetics are substantial. The limiting dimensions of the combustion of thermally thin layers of polymers depending on the concentration and pressure of oxygen in the atmosphere are studied; the relationships between these parameters are established.

In work (1.7) the critical conditions (dimensions and overloads) of the combustion of thin layers of cellulose depending on the thickness of the sample, pressure and concentration of oxygen in the makeup of the gaseous mixture are considered. In the burning of thin layers of polymers the loss of stability of burning occurs because of the imbalance of heat intake and losses in the gaseous phase. From an analysis of dimensions at the limit of combustion a critical relationship is proposed that satisfactorily agrees with the experimental data. The influence of inertial overloads on the combustion of polymers is studied and it is demonstrated that a cessation of combustion may occur under their influence.

The combustion of cylindrical and flat samples of epoxy resins in mixtures of oxygen with argon or nitrogen is studied at linear flow velocities (1.8). The products of combustion are selected with the aid of a quartz microsonde and analyzed on a mass spectrometer. The presence in the flame of oxygen, carbon monoxide and dioxide, benzol, toluol, methane, propylene, ethylene, acetylene, formaldehyde, acetaldehyde and water is established. It is shown that near the surface of the burning sample the flame is so turbulent that the composition of the gaseous phase does not depend on the location of the point of selection.

In work (1.9) the regularities in the processes of combustion and pyrolysis of polymer building materials are described. Ways and means of lowering the flammability of polymer materials based on thermoplastics and reactive plastics and also of construction elements made with the use of polymers are discussed.

The effect of the orientation of fiber glass and its content is studied, taking into account the factor of scale on the ignitability of the oriented glass plastic made with epoxyaniline binder (1.10). The following factors were selected for study: the thickness of the tested samples, the orientation of the fiber glass to the front of the flame and the quantity of binder in the fiber glass. It is shown that in creating oriented material of reduced flammability the factor of scale in the intervals of variation studied cannot be considered a reserve for reducing flammability. Primary attention should be directed to the content of the burning part of the glass plastic and to the orientation of the fiber glass relative to the possible source of ignition.

In article (1.11) the flammability of various types of plastic foam for construction purposes is discussed. A comparative evaluation of the fire danger of polystyrene, polyurethane and phenolformaldehyde plastic foams is made. The ways to reduce the flammability of these materials are discussed.

The least studied stage of the process of the initiation of combustion of substances by short term external influences (a blow, friction, pinholes, a spark, a heated thin wire) is the stage of the spread of combustion beyond the boundaries of the flaming sources of the conflagration, which form in condensed substances under these influences. This stage is studied theoretically on the basis of the thermal approach and an approximate principle of the spread of combustion beyond the boundaries of the sources of conflagration is formulated (1.12).

The spread of a laminar diffusion flame on the surface of a gasifying burning material located in an oxidizing medium is considered (1.13). Primary attention is devoted to an analysis of the structure of the flame and to the influence of a chemical reaction on it: estimates of the dimensions of the areas of gas and burning material, the temperature of which is raised by the heat coming from the zone of chemical reaction; of the dimension of the area of the forward part of the flame, where chemical kinetics are of primary importance, etc., are made. The analytical dependence of the speed of spread of the flame on the speed of the chemical reaction, the properties of the oxidizing medium, the size and direction relative to the flame of the flow of the oxidant, the thickness of the layer of burning material and other parameters is obtained. It is established that there are three types of limits on the spread of a flame, which differ in their mechanisms: the thickness of the layer of burning material; heat losses; and the velocity of convective movement of the oxidant.

The influence of the thermophysical and thermochemical properties of polymers on the speed of spreading of a flame is studied (1.14). The behavior of a polymer in concentrations of oxygen over 35 percent can be characterized by the heat of burning and the coefficient of temperature conductivity. Several instances of the utilization of this relationship to estimate the speed of spreading of a flame on the surface of polymers and composition materials are analyzed.

A way to increase the accuracy of measurement of the indices of flammability of polymer materials is suggested. For this the air is exhausted from a chamber with the sample to be tested. Then the sample is heated to the temperature of thermal decomposition, maintaining the temperature of thermal decomposition, maintaining the temperature of the sample until the formation of a given concentration of volatile products of decomposition, which are mixed with air, bringing the pressure up to atmospheric, and the mixture obtained is heated to the temperature of testing and the temperature of self-ignition is registered (1.15).

In work (1.16) data are cited on the carbonization of various polyurethane foam plastics depending on the duration of the fire testing and the temperature of the materials.

Data on the smoke forming capacity of the tested materials make it possible to select the best of them by comparative analysis if the values for the indices of combustibility and spread of flame are equal and to forecast the degree of smokiness of rooms (1.17).

The satisfactory additivity of the thermal effect of a reaction of oxidation of various combinations of burning components of a mixture, which occurs on the elements of a battery thermocatalytic sensor is established (1.18).

The authors (1.19) studied the toxicity of the combustion products of four samples of soft polyurethane foam, synthesized from 2,4-tolylene diisocyanate. They found that all of the samples of polyurethane foam studies were on the same level with regard to the degree of toxicity. The basic volatile products determining the toxicity of polyurethane foam are hydrogen cyanide and carbon monoxide. The combined activity of the combustion products of polyurethane foam is characterized by the intensification of the effect.

2. FIRE RESISTANCE AND THE SPREAD OF FIRE IN CONSTRUCTION ELEMENTS (INCLUDING THOSE MADE OF WOOD AND OF POLYMER MATERIALS), FIELD FIRE TESTING AND METHODS OF DEFENSE

The methodological basis for conducting tests for the purpose of determining the fire resistance of components is the standard "Fire Prevention Standards for Construction Designing. Method for Testing Construction Elements for Fire Resistance" (CEMA Standard 1000-78).

At the present time the Central Scientific Research Institute for Construction Elements named for Kucherenko in the framework of cooperation with the member countries of the Council for Economic Mutual Assistance (CEMA) is working out a methodology for testing internal construction components (partitions, wall trim, columns, ceilings and beams inside a room) for the spread of fire. In the future it is planned to develop a method to test for the spread of fire in external components.

The Central Scientific Research Institute for Construction Elements named for Kucherenko, The Central Scientific Research and Design Experimental Institute of Industrial Buildings and Structures and the All-Union Scientific Research Institute for Fire Prevention of the Ministry of Internal Affairs of the USSR devote considerable attention in their work to seeking ways to increase the fire resistance of external protective components consisting of suspended panels produced industrially, and also of walls assembled from metal sheets, foam plastics and other effective insulators. This research is timely because of the possibility of expanding the use of such components in view of their high economic and utilization indices.

As is noted in work (2.1), metal facing sheets 0.8 to 1 mm thick, as a consequence of their high heat conductivity, heat up to temperatures of 270-300°C, which correspond to the beginning of intensive thermal decomposition and the ignition of many types of insulators, already within 2-3 minutes after exposure to fire. This creates the danger of the rapid development of a conflagration.

Construction components with various types of insulators and various types of designs for the junction of the panels with the steel and aluminum facings were subjected to tests. The results of this research have been published in part in the works (2.1-2.5). It was established that in testing components using foam plastics of the domestic brands PPU-3, PPU-308 M10, "Izolan", and also foam plastic of the "Sispur 4055" brand intense smoke emission was observed during the thermal decomposition and combustion of polyurethane and polystyrol foam plastics. The high speed of carbonization and melting of many foam plastics (data on the speed of carbonization of polyurethanes are furnished in work (2.5)) lead to the burning up of the foam plastic in the zone exposed to fire in the course of 6-9 minutes, after which the flame begins to penetrate through the junctions of the panels. The most intense burning of the foam plastics spreads along the junctions of the panels.

At the present time the search is continuing for new formulas for foam plastics and other insulators that have high fire resistance. The Vladimir Scientific Research Institute of Synthetic Resins of the Ministry of the Chemical Industry of the USSR is working on this problem. The Central Scientific Research Institute for Construction Elements named for Kucherenko together with a number of other interested organizations is conducting work on the modification of polyurethane and polystyrol foam plastics by means of the introduction of light mineral fillers--keramzit, porous glass, perlite and vermiculite. In several cases it has succeeded in achieving an increase in fire resistance and a decrease in combustibility of components (2.4). Attempts are being undertaken to create new types of construction insulators from mineral raw materials (2.6).

On the basis of the analysis of the experimental research on the fire resistance of the above-mentioned components recommendations were developed for increasing the fire safety of light facing elements. For example, in utilizing panels of the "sandwich" type in the construction of power sites, taking their special responsibility into account, it was recommended (2.2) that they be mounted higher than the service level of the basic technological equipment, that the area of the wall be divided horizontally and vertically by non-flammable diaphragms and that the walls be separated from the roofing material by horizontal fire prevention belts.

In using walls assembled from sheets it is recommended (2.3) that the size of the air gap between the individual layers of the component be kept to a minimum and that the volume of air spaces be broken up by means of the insertion of semi-rigid panels of glass wool not less than 750 mm wide.

In 1977 the Central Scientific Research Institute for Construction Elements named for Kucherenko together with the All-Union Scientific Research Institute for Fire Prevention conducted fire tests of models of metal coverings of the membrane type. Models of membranes made of steel designated St. 3 and of the aluminum alloy AMg-2p were tested (2.7,2.8). The tests showed that the destruction of the membranes made of steel did not occur even when they were heated to 900°C. Therefore, the limit of fire resistance of steel membranes must be designated in terms of reaching the limit of sagging. Membranes made of aluminum alloy were destroyed after exposure to fire for 5-6 minutes. Therefore, it was recommended that they be protected against fire, for example with the compound VPM-2.

The Central Scientific Research and Design Institute for Standard and Experimental Designing of Educational Buildings together with the All-Union Scientific Research Institute for Fire Prevention are involved in research on the fire resistance of multi-layered partitions assembled on a framework of wood, metal or asbestos cement with sheets of gypsum plasterboard. The results of these experiments showed that the use of sheets of gypsum plasterboard of higher quality (reinforced with fiber glass) makes it possible to reach a limit of fire resistance of up to two hours.

In connection with the expansion of the field of use of wooden components in contemporary construction the problem of their fire safety gains ever greater timeliness.

Fire testing of wooden construction components under a load is being conducted at the Central Scientific Research Institute for Construction Elements named for Kucherenko together with the All-Union Scientific Research Institute for Fire Prevention of the Ministry of Internal Affairs of the USSR.

In research on the fire resistance of wooden construction components questions of the combustibility of wood, the spread of flame and the effectiveness of fire protection compounds and coatings are considered.

The study of the spread of flame on unprotected wooden bearing elements (beams) was carried out on fragments of coatings, consisting of glued beams and covering panels with facings of asbestos cement and water resistant plywood.

The experiments showed that the temperature impulse from the burning of the plywood facing of the covering panels increases the speed of spread of the fire along the unprotected beams by two times.

In work (2.9) results are cited for fire testing of glued wooden beams produced by various plants. A significant influence of the quality of production on the bearing capacity of beams when exposed to fire is established. The nature of the destruction, depth and speed of carbonization of the wood, the distribution of temperature in the remaining section and the fire resistance of beams in a conflagration are revealed.

The tests showed that the destruction of the beams results from the splitting at the support, and a wide scattering is observed in the values of tangent pressures at the moment of destruction.

In publication (2.10) the results of a series of fire tests of wooden covering panels for sport equipment are announced. The framework of the panels consisted of longitudinal ribs with a cross-section of 210 x 75 mm, made of glued and whole wood. Between the ribs mineral wood insulation was placed. Steel bands fastened on the bottom prevented the mineral wool from falling out when the facing was destroyed by fire. Asbestos cement perlite sheets, wooden boards impregnated with a solution of antipyrene and gypsum plasterboard were used as facing for the panels. It was established that asbestos cement perlite sheets 10 mm thick protect the wooden frame from ignition for 30 minutes. The steel band lining holds the insulator in the prescribed position for 10-50 minutes, protecting the frame from ignition. It is also established that the burning of wood that has been subjected to deep impregnation with a solution of antipyrene ceases when the source of heat is removed. The influence of heat on the strength of the glued seam is noted.

The Scientific Research Institute for Concrete and Reinforced Concrete of Gosstroy USSR, together with other institutes, is studying the fire resistance of concrete and reinforced components, including the explosion-like destruction of concrete in a conflagration (1.11).* Measures to prevent this phenomenon are being developed (2.12).

3. METHODS FOR CALCULATING THE FIRE RESISTANCE OF CONSTRUCTION ELEMENTS

At the present time a great deal of attention is being devoted to the development of methods for calculating the limits of the fire resistance of construction elements. In work (3.1) the foundations of methods for calculating the fire resistance of reinforced concrete and metal components are outlined. The solution of the thermophysical problem involving the determination of the non-stationary temperature field taking into account the dependence of the thermophysical properties of materials on the temperature, was carried out on a computer according to an obvious finite difference system. In solving the problem of statics the bearing capacity of the components was determined, taking into account the change in the mechanical properties of materials when heated. For the purpose of simplification the concept of critical temperature was used; it was assumed that the mechanical properties of materials are unchanged at higher temperatures, but on reaching the critical temperature the materials lose their strength.

The Central Scientific Research Institute for Construction Materials named for Kucherenko is developing methods for calculating the limits of fire resistance of load-bearing wooden, metal and multi-layered bounding

*sic - the intended reference appears to be (2.11) (translator's note).

components. The Moscow Engineering Construction Institute named for V. V. Kuybyshev, the Voronezh Engineering Construction Institute and the Higher Engineering Fire Technology Institute are taking part in working out individual problems in this field. The Scientific Research Institute for Concrete and Reinforced Concrete is working out methods for calculating the limits for the fire resistance of reinforced concrete components. The Central Scientific Research Institute for Construction Elements named for Kucherenko together with the Scientific Research Institute for Concrete and Reinforced Concrete is developing basic principles for methods for calculation such as the choice and justification of loads acting on components during a fire and the choice and justification of estimated parameters of building materials used in calculations for fire resistance. These institutes jointly undertook the study of the possibility of utilizing the methods of the theory of reliability and economic probability methods as a basis for the requirements for fire resistance of building components.

The development of methods of calculating the fire resistance of components has been conducted keeping in mind the general methods adopted in the USSR for calculating the properties of building components, in particular the method of limit states, and also the need to unify as far as possible the methods for calculating the effects of fire on components with the methods for calculating the effects of stress that are established in the existing standardization documents on construction.

The development of methods of calculating the fire resistance of reinforced concrete components in 1977-78 was directed mainly toward the improvement of the methodology proposed earlier. The basic results of this work found their reflection in the textbook (3.2), which was published in 1978. Work on the study of the strength and deformation properties of various concretes when exposed to high temperatures (3.3,3.4) were also continued.

In book (3.5) data from field investigations of buildings after a fire are analyzed and, on the basis of these data, a methodology is proposed for determining the suitability for further utilization of reinforced concrete components that have been damaged in a fire. In one of the chapters of this book the author gives a brief survey of the methods for calculating the remaining strength of reinforced concrete components that have been unevenly heated along the cross-section. Introducing a corrective coefficient of heat inertia that takes into account the heating of distant layers of concrete after the cessation of exposure to fire, the author proposes taking into account the layer-by-layer change associated with temperature of both the strength of the concrete and its maximum deformation in calculating fire resistance.

At the present time practically all of the methods proposed for calculating the fire resistance of concrete and reinforced components utilized the hypothesis of the continuity of concrete. Often, however, during fires and fire tests pieces of concrete break off, laying bare the reinforcement and reducing the cross section of the component, which brings about a significant lowering of their limit of fire resistance. This type of destruction is called explosion-like or brittle destruction in domestic literature. Work on the study of this phenomenon is going on at the Scientific Research Institute for Concrete and Reinforced Concrete. A method of calculating the probability of brittle destruction of concrete in a fire has been proposed (3.6). In this method the coefficient of the intensity of stress of the first type is adopted as the indicator of the tensile strength of concrete. A formula is given that makes it possible to calculate the critical moisture content of concrete, the exceeding of which leads to brittle destruction. On the basis of this method recommendations for protecting concrete and reinforced concrete components from brittle destruction in fires have been compiled (3.7).

To calculate the heating of unprotected metal components to critical temperatures the assumption is made in work (3.8) that the temperature does not fall along the cross-section and that the coefficient of heat exchange is constant, which makes it possible to obtain a simple analytical solution. To take into account the dependence of the coefficient of heat exchange and the thermophysical properties of the metal on the temperature the authors propose carrying out the calculations in stages, taking into account the temperature already reached by the metal.

In many cases wooden bearing components compete successfully with other bearing components with regard to cost, durability in aggressive environments and a number of other indicators. Their use is hampered, however, by the flammability of wood. Therefore research on determining the limit of fire resistance of bearing wooden components is especially timely.

A methodology for calculating the limits of fire resistance of bearing wooden components, the basic principles of which are cited in the publications (3.9-3.11), has been worked out at the Central Scientific Research Institute for Construction Elements named for Kucherenko.

In the work (3.12) it is proposed to use the method of elementary balances to calculate the time of heating of bounding components made of noncombustible materials.

4. THE DEVELOPMENT OF A FIRE IN BUILDINGS AND ITS MATHEMATICAL MODELING

Research on the process of development of a fire in buildings involved the All-Union Scientific Research Institute of Fire Prevention and the All-Union Institute of Fire Technology of the Ministry of Internal Affairs of the USSR up to 1976, and work on the analysis and generalization of data on the development of fires has included the Central Scientific Research and Design Experimental Institute of Industrial Buildings and Structures, the Central Scientific Research and Design Institute for Standard and Experimental Housing Design, The Central Scientific Research and Design Institute for Standard and Experimental Designing of Educational Buildings, the Central Scientific Research and Design Institute for Standard and Experimental Designing of Auditoriums and Athletic Structures and also several educational institutes in the construction field since 1976. The tasks of these institutes include a deeper study and analysis of the process of development of a fire and the conditions affecting the characteristics of a fire, differentiated by types of building and structure, modeling the process and developing proposals for improving the fire safety standards in construction, in particular providing a basis for the requirements for fire resistance of buildings and structures.

A description of the process of development of fires in its most general form is given in the publications (4.1-4.4). The general differential equations describing the fire on the level of average thermodynamic parameters according to the size of the room are formulated and several questions of depicting and modeling fires are considered.

Average parameters and equations of a fire are cited in work (4.1). The development of a fire with constant values for the consumption of air and the speed of burning of combustible substances is considered. An analysis is conducted of the behavior of temperature and gas exchange in rooms with natural ventilation.

In work (4.2) the gas exchange of a room is considered in two approximations. The formulas of the first approximation, which describe the dependence of the consumption of incoming air and the consumption of departing gases on the parameters of the medium within the room, do not take into account the idiosyncracies of the distribution of temperatures in the gaseous medium. The formulas of the second approximation, which describe the gas exchange of the room, are obtained taking into account the temperature field in the gaseous medium.

The authors (4.3) discuss the question of the applicability of the methods of modeling in studying danger factors affecting a person in the conditions of a fire.

In work (4.4) the process of development of an idealized fire is studied, taking into account the spread of a flame according to a burning load for the purpose of discovering the basic factors that have a substantial effect on the speed and direction of the development of a fire. At the base of the proposed mathematical model are placed the geometric characteristics of a fire of a pile of wood; dependencies are proposed that make it possible to study the relationships between the geometric parameters of a fire. It is shown that the basic principles of the kinetics of a fire can be studied on small models and then transferred to nature. The algorithms that have been worked out for the mathematical model are carried out on the computer, which makes it possible to conduct numerical experiments and forecast the development of fires on actual objects.

Questions of the development of a fire in closed areas are considered in the articles (4.5) and (4.6). A non-stationary mathematical model for the development of a fire is proposed that includes equations of indissolubility, movement, energy and diffusion components (4.5). In solving the problem a diffusion model of the burning of a substance is used under the condition that in every point of the area under consideration the medium is in thermodynamic equilibrium and the position of the front of the flame is determined by the condition of absence in each of these points of fuel and oxidant simultaneously. Algorithms and a program for calculating the process of development of a fire with the use of a computer have been worked out. The data in work (4.6) are of an experimental nature. The dependence of the time of burning, temperature and pressure of the medium in the room, the mass speed of burning of the fuel and the composition of the gaseous medium on the volume of the room, the area and height of the source of burning is cited in this work. A series of experiments are conducted on three geometrically similar models of a room.

The development of a fire in premises with openings is studied in works (4.7-4.10). The authors of (4.7) cite data on the influence of the proportionate burning load for constant areas of burning and open space on the temperature distribution and heat flows in the component of a building during fires. Experiments were conducted with wood as a fuel in a room with the dimensions 6x6x6 meters and an openness of 21.4 percent. The results of the experiments made it possible to establish empirical links between the time of achieving the maximum value of the average integral proportionate heat flows on the components with the size of the proportionate burning load. Exponential expressions are cited that determine the change during the average integral heat flow and the average volume temperature that have been cited. This work points out the necessity when solving the problem of fire resistance of components in conditions of an actual fire of devoting special attention to the study of local characteristics of heat exchange on bounding surfaces. In article (4.8) the local characteristics of a fire and the influence on them of border conditions of the first and second order when there is an opening are discussed. The results of a computer experiment confirm the effectiveness of the model that has been worked out for obtaining qualitative and some quantitative characteristics of a fire in a room in which there are openings. In publication (4.9) a mathematical model of an advanced stage of a fire based on an equation of heat balance is considered. A number of generally accepted assumptions are made, which make it possible to use normalized values for the parameters of the fire. In this model an established pattern for an advanced stage of a fire is proposed in which the intensity of heat release in the confines of the room is determined by the mass consumption of the air flowing into the room, which is expressed mathematically through the parameters of ventilation as a characteristic of the geometry of the openings of the room. A program for calculating the dependence of the average internal temperature in the room on the time at an advanced stage of a fire is worked out. The author of (4.10) describes an experimental fire in a living room with an area of 20 square meters on a fragment of a tall building with a functioning system of protective ventilation against smoke. An empirical formula is obtained for calculating the pressures in the upper part of the room of the source of the fire depending on the average internal temperature in the room.

A method for calculating the temperature system of a fire by means of the optical characteristics of the medium is proposed in work (4.11). In this work it is shown that in the conditions of actual fires in buildings of large size and in smoky rooms the gaseous medium is not transparent and the optical characteristics of the medium exert a substantial influence on the process of heat irradiation toward the bounding components. The methodology proposed is based on an equation of heat balance for a fire in a room but differs from other known methods for calculating the temperature system of a fire in a room for an optically transparent medium by using a special criterial equation, on the basis of which the coefficient of heat radiation is calculated in conditions of complex heat exchange, taking into account the optical density of the gaseous medium. The comparison of the results of the calculations with the data from large scale experiments in a room with the dimensions 6x6x3 meters showed that the method proposed made it possible to obtain a satisfactory quantitative correspondence of the calculated temperature characteristics of a fire with the experimental data at an advanced stage of the fire. It was also shown that the calculations made for the optical transparency of the medium give results that are lower than the actual ones.

In articles (4.12) and (4.13) questions connected with the heat exchange of bounding components in the conditions of a fire are considered. The problem that has been posed is solved on the basis of the theory of the boundary layer. The approximate method of solving the problem of the boundary layer, which is linked with an analysis of the equations of the quantity of motion and energy in integral form, is studied. In calculating the radiant energy making up the heat flow in the equation one takes the approximation of the optically thick layer (diffusion approximation). As a result of the operations carried out the calculated relationships are obtained for determining the proportionate heat flows to the bounding components in complex heat exchange in conditions of natural convection in smoky rooms (optically dense medium) for a laminar boundary layer (4.12) and a turbulent boundary layer (4.13). The values for the proportionate heat flows obtained in accordance with the calculated relationships agree well with the experimental data.

5. THE SPREAD OF FIRE TO NEIGHBORING BUILDINGS AND STRUCTURES

Construction standards that regulate the fire safety distances between buildings have been worked out on the basis of the generalization of experience in designing and construction.

The articles (5.1) and (5.2) are on this subject. One of them is devoted to the basis for the fire safety distances arising from the assumptions about the spread of fire to neighboring buildings by means of the transfer of sparks (5.1). The distance between buildings is to be set no less than the distance that a spark can be carried while it is burning. On this basis the proposals for the setting of standards for the fire safety distances are worked out.

The publication (5.2) is devoted to a study of the basic data for setting the fire safety distances between gas wells and other sites located in their immediate vicinity. The results of polygon tests on the investigation of the geometric and thermal characteristics of the flame of compact and dispersed gas fountains are outlined. The conclusion is reached that the heat effect of the gas fountain on the diverse sites depends on the type of fountain, the rate of flow of the well and the velocity of the wind. The average values for the surface intensity of illumination (288,600 W per square meter) and the temperature of the flame (1,500°K) are determined with the degree of blackness of the flame set equal to unity. A graph of the dependence of the area of the flame on the rate of flow of the well and the diameter of the packing is furnished.

6. AUTOMATIC INSTALLATIONS FOR FIRE SUPPRESSION AND SIGNALING

Questions of the theory of systems of automatically extinguishing fires, the development of these systems and their implementation are dealt with by the organizations of the Ministry of Internal Affairs of the USSR, in particular the All-Union Scientific Research Institute for Fire Prevention and the Higher School of Engineering Fire Technology.

In connection with the introduction into mass construction of highly effective building components and also in connection with the general tendency that has been noted for the optimization of expenditures on the erection and utilization of construction sites, the increase in the effectiveness and reliability of automatic systems of extinguishing fires becomes especially significant.

The experience accumulated in the USSR on this question is analyzed in the monographs and textbooks (6.1-6.4).

In monograph (6.1) scientific studies and practical experience in devising and designing systems of fire protection are analyzed and treated systematically. The solutions of the most widespread problems in designing automatic systems of extinguishing fires and other technical systems of fire protection with the use of probabilistic mathematical models and data processing technology are outlined. An analysis is given of the operation of sprinkler installations and systems for supplying water for firefighting in stationary and non-stationary processes for the delivery and distribution of water.

In the book (6.2) the more specialized questions of ensuring the fire safety of enterprises of the chemical and petroleum processing industry are considered. A special place is set aside for the highly effective systems of automatic extinguishing of fires. The book also reflects the latest technical solutions and scientific achievements in the field of devising, designing and constructing automated systems for extinguishing fires at sites of the chemical and petroleum processing industry.

In the textbook for persons attending the Higher Engineering Fire Technology Institute of the Ministry of Internal Affairs of the USSR (6.3) general questions of automatic fire protection (APZ) of economic sites are discussed--the classification of automatic fire protection installations, general requirements for them, principles of designing and methods of functioning. The basic types of fire detectors are designated--heat, smoke, light, ultrasonic and photoelectric; the principles for choosing them to protect sites are outlined. A description is given of the telemechanical systems for fire alarms and the systems for removing smoke in multi-story buildings and the principles for designing them, and also the purpose, construction, principles of operation, field of utilization and methodology of designing and devising automatic fire extinguishers using water, foam, gas, steam and powder. The theoretical bases for the reliability of automatic firefighting equipment and the methodology for calculating the indices of reliability are considered and the results of statistical studies of the reliability of fire alarms and fire extinguishing installations are cited. Questions concerning the expertise displayed in designs for automatic firefighting equipment and the demands made by ergonomics and technical aesthetics on the fire alarm and extinguishing installations are outlined, and also the organization and content of their use. In conclusion a methodology is given for evaluating the economic effectiveness of the use of automatic fire protection and the prospects for the development of automatic firefighting equipment.

In item (6.4) from the reading list for persons taking courses at fire technology schools the same questions are surveyed in a more accessible form and, in addition, the principles for organizing supervision over the designing, assembly and use of automatic firefighting installations are considered.

In the survey article (6.5) the status and prospects for development of automatic firefighting installations are analyzed. It is shown that with the introduction of automatic fire defense at enterprises of the gas and petrochemical industry a significant economic effect can be obtained.

One of the areas considered promising by the author is research relative to increasing the fire extinguishing effectiveness of water and foam. Fire tests have shown that foams made of water and gas are capable of extinguishing the flame of liquefied hydrocarbon gases and polar liquids. Research on the utilization of polymer additives to water to reduce the hydraulic resistance in the pipe systems of stationary firefighting installations is considered very promising. The appropriateness of research directed toward the creation of new and the modernization of existing stationary gas firefighting installations, in particular using the isothermic storage of carbonic acid, is noted. Research on the influence of polymer additives to water on the reduction of hydraulic losses in pipes with technical roughness that was carried out at the All-Union Scientific Research Institute of Fire Prevention showed that the use of such additives in certain concentrations made it possible to reduce the metal contained in the sprinkler systems by 17 to 20 percent through decreasing the diameter of the pipes while at the same time increasing the effectiveness of their operation. At the present time this organization is preparing guidelines on hydraulic calculations for firefighting installations using water with polymer additives.

Questions of calculations concerning automatic firefighting systems of various kinds are dealt with in research, the results of which have been published in the articles (6.6-6.9).

Recently fast-acting automatic systems that include devices operating on the impulse principle have found use for local extinguishing. Powder and liquid components having inhibiting properties are used in them as fire extinguishing agents. In creating an installation operating with a liquid component, in particular with phenol, the need arises to determine the tactical and technical characteristics of the stream of the fire extinguishing mixture. In connection with the evaporation of freon in the delivery area a fundamentally new method for determining the characteristics of the mixtures has been worked out, based on the solution of a system of differential equations for the movement of a point of variable mass in a medium with resistance (6.6).

In the boundary conditions given the system of differential equations is handled easily on a computer, which makes it possible to determine such important parameters as the initial velocity of flow, the height of suspension of the operating device and the time of delivery of the fire extinguishing agent. Local fast-acting automatic fire extinguishing systems find use for the protection of certain technological processes where there is danger of fire. The fire extinguishing liquid in such systems is under pressure of compressed gas and is kept from flowing out by a lock-release device. In article (6.7) the solution of the problem of the time of flow of a liquid from a vessel under certain assumptions is considered. As a result of the joint solution of the equation expressing the relationship between the pressure and the volume and the equation of conservation of mass, a mathematical expression is obtained for the time of flow of the liquid and a graphic interpretation of the solution obtained is presented. One of the most important indices of the stationary systems of fire protection is their inertia. By inertia is meant the interval of time from the moment of discovery of the fire by the automatic sensor to the moment of the egress of water from the farthest sprinkler. A component part of the inertia is the interval of time during which the dry pipes are filling with water after the fire pump begins to operate.

In work (6.8) a dependency for determining the time for filling the pipes is obtained from the fundamental equations for the movement of a liquid in pipes. For the purpose of checking the correctness of the dependency experiments were conducted to determine the actual time for filling the pipes. The results of the experiment coincided quite satisfactorily with the calculations. The principles of analysis, the choice of the most rational methods and the development of systems of fire extinguishing with the use of fire suppressing powders are dealt with in research, the results of which are outlined in the publications (6.9-6.11). The basic types of pneumatic high pressure transport of powder are considered in them: the movement of the powder in a continuous stream; usual pneumatic transport of powder; movement of powder as an aerosol transport stream. For all of the types of transport of the mixture equations are proposed in determining the loss of pressure in an horizontal conduit. Pneumatic transport in a continuous stream has the best economic indices of the forms of movement of the mixture that were analyzed. The usual pneumatic transporter can be put in last place, since it is characterized by a low concentration of the mixture and large proportional losses of pressure. For this reason pneumatic transport in a continuous stream serves as the principle of operation of manual powder fire extinguishers and aerosol transport is used in equipment designed to be mounted on a self-propelled chassis.

The publications (6.12-6.15) are also dedicated to the solution of practical problems of creating and improving equipment and systems for automatically extinguishing fires. As a result of investigations of the process of extinguishing a fire the functional dependence of the intensity of delivery of the fire extinguishing agent on the time of extinguishing are obtained in work (6.12). On the basis of these data it was possible to select the optimal consumption characteristics of the system of fire protection and determine the design of the spray fittings, the flame cutting devices and the means of supplying the system with water. A two-speed method of delivering water is recommended. In the initial period during 8-15 seconds the fire extinguishing agent is delivered at an optimal intensity for extinguishing the fire. When the time indicated has elapsed the further flow is automatically shifted to a lower level to localize the burning, if the fire for some reason or other has not been extinguished.

In article (6.13) the special features of fire safety of sites like museums are considered, especially large rooms and exhibition halls with an enfilade layout that are also connected with one another vertically. In small rooms (workshops, storage places for collections and libraries) it is considered possible to use heat and smoke detectors to discover fires. In large rooms photoelectric, photoradiation or flame detectors are used. The use of carbonic acid and freon (khladon) is recommended for extinguishing fires that arise: in small rooms in installations for protecting the whole room, and in large rooms in installations for local extinguishing of fires. Numerical values for the standardized indices of reliability of automatic firefighting equipment for sites like museums are proposed--the risk of not carrying out an assignment, the coefficient of readiness and the probability of failure-free operation at the moment of carrying out the assignment. Values for the rated indicators of reliability of the basic types of firefighting and alarm installations are also cited.

In the publications (6.14 and 6.15) the deficiencies of the designs for systems of protection against smoke and water supply for fighting fires in buildings with many stories are discussed. An analysis is also given of the basic shortcomings in the utilization of these systems and the system of organizing their technical service in the cities of Moscow and Leningrad is described. Plans for coordinating the engineering equipment of buildings, including the equipment of the fire protection systems, are considered and proposals for improving these plans are outlined.

The results of experimental research on the force of tightening of the threaded joints of the caps of the gas and aerosol automatic firefighting equipment are listed in the articles. Optimal values are proposed for the tightening which preclude the damaging of the threaded joints and reduce the leakage of the fire extinguishing agent from the bottles. Special attention is paid to questions of raising and optimizing the reliability of automatic fire extinguishing systems. Terminological aspects of the problem of the reliability of automatic firefighting equipment are discussed in the article (6.18). The articles (6.19 and 6.20) are devoted to the optimization of reliability and the raising of the effectiveness of automatic fire extinguishing equipment and systems. In the work (6.19) an analysis is given of the basic factors affecting the optimal reliability of automatic firefighting equipment (probability of the occurrence of fires, probability of the failure of the automatic firefighting equipment, the economic loss from fires if the automatic firefighting equipment fails and if it does not fail) and a methodology is provided for determining the optimal values for the indices of reliability of the automatic firefighting equipment. The authors of article (6.20) evaluate the reliability of fire extinguishing systems according to indicators, the choice of which depends on the manner of using these systems. Thus for unsupervised systems the discovery of failures and the restoration of their operating capacity take place in most instances in the period of regular servicing. The basic indicator of reliability in this case is the probability of failure-free operation in the period between service checks. In systems in which the operating capacity is verified automatically failures are discovered practically immediately, after which the process of repair begins. An analysis of the economic model of functioning shows that in this case the basic indicator of reliability is the coefficient of readiness. Statistical data on the functioning of 332 systems are listed, and also the qualitative and quantitative evaluation of the indicators of reliability. These data show that the introduction of devices for verifying the operating capacity of fire extinguishing systems makes it possible to increase the values of the indicators of reliability substantially and to obtain an economic effect.

Research on the reliability of sprinkler installations is covered in the works (6.21 and 6.22). The results of experimental studies on the water output of water sprinkling installations with a service life of 5-10 years are surveyed in (6.21). In this work the changes in the parameters of water output are specified--consumption, rate of change in it and the time when massive failures set in. Recommendations are worked out with the aim of preventing failures of the sprinkler installations as a consequence of such a parametric failure as a reduction in water output.

In publication (6.22) consideration is given to an economic-mathematical model of the functioning of sprinkler installations under the conditions of non-stationary operation with random water consumption. On the basis of a graphic analytical method the special features of the operation are analyzed and the indicators of efficiency and reliability of sprinkler installations are found. The basic elements in the analysis are hydraulic characteristics of the water feeder, the hydraulic resistance of the distribution system, the number of sprinklers required to be operating simultaneously during a fire, the probability that the needed water will be available and the costs incurred--capital investment, operating costs and the direct and indirect losses from fires. The proposed model makes it possible to determine the optimal number of sprinklers operating at the same time from the condition of holding costs incurred to a minimum. The results of studying the causes of spurious actuation of automatic fire prevention systems and an analysis of this phenomenon from the standpoint of the theory of reliability are outlined in articles (6.23 and 6.24).

In article (6.23) there is a discussion of the reasons for and ways to prevent the false actuation of elements and assemblies of automatic fire prevention equipment, which occurs as a result of deficiencies that occur at the stage of production of the items, the designing and installation of the equipment and during operation.

Article (6.24) contains the results of statistical processing of the number of failures of the type "spurious actuation" in the functioning assemblies and instruments of the automatic fire extinguishing systems.

7. FIRE PROTECTION COATINGS

The increase in the limits of the fire resistance of metal components and the decrease in the flammability of wooden components can be accomplished through the use of fire protection coatings. The highest levels of fire resistance of metal components are observed when they are protected with coatings. The Central Scientific Research Institute for Construction Elements named for Kucherenko (7.1) developed and introduced the phosphate fire protection coating OFP-MM. Tests that were conducted on columns protected with the compound OFP-MM in various thicknesses showed that the limits of their fire resistance could be increased up to three hours. The components of the covering include liquid glass, asbestos, perlite sand and a hardening agent. The covering can be applied by spraying with the use of special equipment.

The properties of a number of coatings made from asbestos, perlite, vermiculite with gypsum used as a binder, liquid glass with the addition of sodium fluorosilicate and portland cement (7.2 and 7.3) are studied. The volumetric mass of the coatings studied ranged from 300 to 870 kilograms per cubic meter and depended on the combination of filler and binder. The steel columns with fire protection coatings from 50 to 76 millimeters thick were tested for heating when exposed to the temperature conditions of a standard fire while subject to a central load. The limit of fire resistance was determined by the loss of bearing capacity. The highest limit of the fire resistance of metal components was observed when they were protected by coatings that included quick-hardening cement.

One of the promising means of protecting metal components is the expansible coating. The coating designated VPM-2, which was developed by the All-Union Scientific Research Institute for Fire Prevention, is a thick paste, which is mixed with water and applied to the surface of the components in a thin layer (7.4). The advantage of the coating VPM-2 in comparison with other well known fire protective expansible coatings lies in its higher fire protection and heat insulating capacity. It ensures the increase in the limit of fire resistance of metal components up to one hour. In addition, it is non-toxic and is available for widespread production and use in view of the characteristics of the ingredients included in its composition and their specific relationships.

Organic salts are used as a binder in the composition of the coating, making it possible to preserve for a long time the fusibility and elasticity of the coating, which are necessary for the formation of a foamy layer in the event of a fire; the gas-forming substances are added to the composition in a proportion that ensures the highest expansive properties of the coating under the condition of an even thickness of the carbon layer that is formed; the heat resistant fillers, which have a higher temperature of decomposition in comparison with the other components of the mixture, make it possible to obtain a solid, fine-celled carbon layer having excellent thermal insulating properties; the fiber filler is distributed evenly in the foam layer and forms a framework, increasing its stability and resistance to burning. The capital expenditures for organizing the production of the fire protection expansible coating are insignificant. This coating can also be used to protect wood and aluminum components. Wooden components treated in this way are regarded as fire-resistant.

Research on expansible fire protection coatings made of vermiculite was conducted by the Ural Scientific Research and Design Institute for Building Materials (7.5). The composition of the coating included vermiculite in various modifications, fiber glass, urea-formaldehyde resin, zinc oxide, asbestos, dicyandiamide and sodium fluorosilicate. The volumetric mass ranges from 1,300 to 800 kilograms per cubic meter. The coating ensures the increase in the limit of fire resistance of metal components up to one hour.

The use of materials in panels for fire protection of construction components has a number of advantages over their application in the form of coatings and paints. Perlitephosphorgel panels (PFG) ensure a limit of fire resistance of steel components of 2.5 hours at a thickness of 50 mm (7.6). The composition of the material includes perlite, fiber glass, orthophosphoric acid and waterproofing additives. The technological process of production consists of dosage, mixing the components, pressing, rolling the semi-dry masses and subjecting the articles to heat treatment. The volumetric mass of PFG is 200-300 kilograms per cubic meter, the heat conductivity 0.07 kilocalories per meter per hour per degree, the limit of flexural strength 4 kilograms force per square centimeter. The panels are produced by the Mytishchi combine "Stroyperlite" on five assembly lines.

Panels faced with asbestos perlite cement are widely used in construction. It seems promising to use them as a fire protection facing for metal components (7.7). For the purpose of studying the fire protection capability of asbestos perlite cement panels a series of fire tests of sample panels measuring 500 x 500 x 12 mm fastened to the surface of steel plates with a special compound was conducted at the All-Union Scientific Research Institute for Fire Prevention of the Ministry of Internal Affairs of the USSR. The time required for the steel sheets to heat up to a temperature of 500°C was taken as the criterion for evaluating the fire resisting capacity of the panels. The tests showed that asbestos perlite cement panels have a high fire resisting capacity. Thus the limits of fire resistance of the protected steel sheets 3.0, 8.0 and 25.0 mm thick were 0.83, 1.3 and 2.5 hours respectively.

Taking the experimental data on the heating of asbestos perlite cement panels as a basis values were calculated for the coefficients of their thermal conductivity and heat capacity by the method of successive approximations.

Polymer materials, which are widely used in construction as heat insulators, have the substantial shortcoming of high combustibility and capacity for spreading the burning in a fire. The All-Union Scientific Research Institute for Fire Prevention together with the Central Scientific Research Institute for Designing Steel Components conducted studies of the behavior of foam polyurethanes of various brands when exposed to direct fire under the conditions of a standard fire and with the use of fire protection coatings. The samples tested consisted of steel sheets measuring 1 x 1 meters with a layer of polyurethane foam 50-60 mm thick sprayed on one side, on which, in turn, a fire protection coating was applied (7.8).

On the basis of the experimental data the speed of carbonization of the polyurethane foam is evaluated. The lowest figure--about 1 mm per minute--is noted for the "Izolan-2" brand of polyurethane foam. For PPU-316M it was 2-3 mm per minute, PPU-308M--5-6 mm per minute and PPU-17N--6-7 mm per minute. It is noted that all of the polyurethane foams tested with the exception of PPU-308M carbonized without the appearance of a flame and that further carbonization was not observed when the source of heat was removed.

The method of protecting the elements of metal components from fire by filling their hollow spaces with a cooling liquid has the following shortcomings: the presence of an air space inside the element and the low limit of fire resistance of the protected components. To increase the limit of fire resistance it is proposed to add to the hollow spaces of the elements a covering of cooling granules as thermal insulating shields. This method can be used for the protection of the hollow rods of the metal frameworks of buildings and other structures. It is appropriate to use it when the increase in the limit of fire resistance of several individual rods sharply increases the reliability of the whole framework (7.9).

The fire resistance of coverings of the membrane type was determined on two models in a fire chamber, the temperature in which was raised in accordance with the standard program (7.10). The experiments showed that the limit of fire resistance for the models of steel membrane coverings was 0.75 and 0.54 hours, from which the conclusion was drawn that similar components could be used without fire protection coating. An experimental dependence was determined for the limit of fire resistance of aluminum membranes on the consumption of fire protection coating, on the basis of which a formula was proposed for calculating the limit of their fire resistance.

Experience in treating wood to protect against fires is analyzed at the Irkutsk Polytechnical Institute (7.11). The technology of impregnating wood with protective compounds made of phenolformaldehyde, furan, organosilicate and carbamide polymers is described and the properties of the impregnated wood are discussed. The principles and the technological procedures for reducing the combustibility of wood are outlined.

8. SAVING THE LIVES OF PEOPLE IN BUILDING FIRES

Several organizations (the All-Union Scientific Research Institute for Fire Prevention and the Higher Engineering Fire Technology Institute of the Ministry of Internal Affairs of the USSR, the Moscow Engineering Construction Institute named for V. V. Kuybyshev, etc.) are involved in research and development of measures to save the lives of people during fires in buildings.

The All-Union Scientific Research Institute for Fire Prevention devotes considerable attention to developing systems for the anti-smoke ventilation of buildings. The Higher Engineering Fire Technology Institute studies the initial stage of a fire in buildings used for various purposes and, after analyzing the change in the level of the danger factors of a fire, establishes the time allowed for evacuation. The Moscow Engineering Construction Institute named for V. V. Kuybyshev is studying the space planning for evacuation routes and working out proposals for standardizing and methods for calculating the time for the evacuation of people from buildings in the event of a fire.

The results of work done in recent years in studying the initial stage of a fire and determining the allowable time for evacuation is reflected in the publications (8.1-8.7).

In article (8.1) a methodology is outlined for calculating the allowable time for evacuating buildings with a corridor system from the standpoint of smokiness and heat of the air along the evacuation routes. The essence of the methodology is that the volume of the combustion products entering the corridors from the rooms at specified time intervals is determined according to known formulas of the theory of aeration, then the time it takes for the corridor to fill with smoke and for the air to be heated to dangerous temperatures is determined, after which the evacuation of people along the corridors becomes impossible.

In publication (8.2) a formula is proposed for calculating the time available for evacuating people from a room from the standpoint of the appearance of dangerous concentrations of toxic combustion products. This formula links the time available for evacuation with the permissible level of concentration of toxic combustion products through the parameters of the volume of the room and the air circulation, the characteristics of burning substances and the size of the burning surface.

In article (8.3) consideration is given to one of the possible methodological approaches to the choice of the level of safety of buildings that is required. The approach is based on a comparison of the conditions and parameters of the development of a fire with the magnitude of its consequences. In this process it is proposed to use a complex criterion to evaluate the danger factors of a fire, taking into account the duration of their effect on the human organism.

Through special studies (8.4 and 8.5) of the composition of the combustion products of textile materials and an analysis of statistical data it has been established that in modern textile enterprises the majority of fatalities in fires are caused by poisoning. This is explained by the fact that concentrations of hydrogen cyanide and hydrogen chloride that are dangerous for human life are formed at high values of the coefficient of abundance of air, which may constitute a real danger for human life even in the initial stage of development of a fire in a closed area.

Through experiments (8.6) conducted at a fragment of a worsted plant the possibility was demonstrated of using a system of mechanical ventilation to remove smoke in fires at enterprises of a similar type. It is emphasized that the removal of the smoke increases the degree of protection of people from the effect of dangerous factors of a fire. At the same time it is shown on the basis of special experiments (8.7) that when liquids burn the decisive factor for determining the time available for evacuation is the increase in the temperature of the environment; the dangerous concentrations of carbon monoxide and dioxide appear later than the dangerous temperature.

On the basis of the foregoing theoretical and experimental work the All-Union Scientific Research Institute for Fire Prevention worked out plans for the anti-smoke ventilation of multi-story buildings (8.8 and 8.9). It is proposed to use the head of air in the stairwell-elevator shaft together with the removal of smoke from the corridor between the apartments. In this operation it is anticipated that the fresh air will come into the corridor between the apartments through the open door in a quantity that will compensate for the exhaust draft. The increase in the volume of smoke drawn out and the inflow of air make it possible to keep the smoke completely out of the corridor between the apartments if there is sufficient pressure and ensures within certain limits sufficient visibility for evacuation in the lower part of the corridor--if the windows in the area where the fire is blazing are closed. It is shown that if the anti-smoke ventilation is properly set up a zone more than 1.2 meters high in the lower part of the corridor is formed in which a person can be without special protective gear. The development of these plans was preceded by an analysis of the parameters of the ventilating devices for protection against smoke (8.10) and a study of the hydraulic resistance of stairwells in multi-story buildings (8.11) on models and in actual buildings. In recent years a large number of experimental studies and tests of systems of anti-smoke ventilation were also carried out in field conditions.

Article (8.12) gives the results of tests from a study of anti-smoke ventilation that was brought about by the creation of surplus pressure in the stairwells and elevator shafts and the removal of the smoke from the apartments through the ventilation ducts of the kitchens. It is shown that closing the apartment doors tightly ensures normal conditions in the corridor for 0.5 hour if there is a head of air. It is shown that if the windows are closed and the doors are open in the apartment where the fire is located the system being studied does not guarantee normal conditions for evacuation.

In publications (8.13 and 8.14) materials are listed on field, including fire, tests of ventilation systems for the anti-smoke ventilation of multi-story buildings proposed by the All-Union Scientific Research Institute for Fire Prevention ensure the absence of smoke from the stairwell and creates a zone free of smoke in the lower part of the corridor without protective gear, while the system of anti-smoke ventilation based on the method of dilution does not guarantee the safety of people in buildings during a fire. Deficiencies in the system as it has been carried out in actual buildings are also noted. The spread of smoke in the building is facilitated by the absence of the necessary sealing of the joints of the bounding components, the air ducts of the ventilation and the places where the utility lines are put through the walls and floors. The poor seals on the valves for smoke removal lead to an increase in the consumption of gases in the smoke removal shaft, in connection with which it is necessary to use a fan of greater capacity and pressure. Therefore, in calculating the pressure of air in the elevator shaft one must take into account the filtration of air not only through the cracks in the elevator doors but also through the ventilation openings of the machine section, the assembly openings in the walls and in the bottom of the elevator shaft. Analogous deficiencies are noted in the investigation of the system of anti-smoke ventilation of a 14-story building. In article (8.15) concrete recommendations are given for removing these deficiencies, and it is noted that is designing buildings with a system of anti-smoke ventilation that provides for the delivery of air in the elevator shafts it is necessary to take into account the position of the elevator cabins in the shafts. The elevator cabin located in the intermediate position blocks the shaft, as a result of which the hydraulic resistance increases sharply and the surplus pressure in the shaft below the elevator cabin is reduced.

In the Moscow Engineering Construction Institute named for V. V. Kuybyshev studies have been conducted in recent years on regularities in the movement of streams of people and the demands made on evacuation routes have been analyzed. On the basis of these data the possibility of various means of evacuating multi-story and very tall apartment buildings and other public buildings has been evaluated. The studies that have been carried out have enabled the Moscow Engineering Construction Institute named for V. V. Kuybyshev to prepare a new draft version of the section of the fire prevention designing standards for the evacuation of people from buildings and rooms during a fire.

In recent studies the Moscow Engineering Construction Institute named for V. V. Kuybyshev has turned its attention to the possibility of using elevators for the evacuation of persons located in a building and transporting firemen to the upper floors of the burning building (8.16).

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This publication is an annotated survey and bibliography by Soviet specialists of 1977-79 Soviet publications on Fire Safety of Buildings and Structures. Some 109 publications are referenced, divided into eight categories: Material tests, fire spread on surfaces and field tests, calculating fire endurance, mathematical modeling, fire spread to neighboring structures, automatic suppression and detection, protective coatings, and life safety in fires.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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