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NUCLEAR EXPERIMENTAL TECHNIQUE

A Computerized Monitoring and Control System for the Gas-Mixture Preparation Complex for Experiments on Muon-Catalyzed Fusion

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Abstract—A computerized system for monitoring and controlling the gas-mixture preparation complex of the TRITON installation is described. The installation is designed for experimental investigations of muon-catalyzed fusion in triple mixtures of hydrogen isotopes H/D/T over wide ranges of temperature and pressure. The system is used to control the entire complex of gas-mixture preparation, the target parameters, and the gas-mixture composition, as well as to carry out radiation monitoring. Good performance characteristics, the high reliability of the system, and the possibility of its rapid adaptation to new tasks have been demonstrated in physics experiments.

INTRODUCTION

The TRITON facility was developed by the All-Russia Research Institute of Experimental Physics (VNIIEF, Sarov) in collaboration with the Joint Institute for Nuclear Research (JINR, Dubna) for systematic investigations of muon-catalyzed fusion in triple mixtures of hydrogen isotopes H/D/T at temperatures of 20–800 K, pressures of up to 160 MPa, and activities of tritium in the free state of up to 10 kCi. The facility consists of a gas-mixture preparation complex (GMPC) [1], a cryogenic system [2], a detection system for nuclear-reaction products [3], and replaceable targets that are structural components of the GMPC: a liquid-tritium target [4], a high-pressure tritium target [5], a high-pressure deuterium target [6], and a number of others.

The structure of the GMPC consists of ten units and systems connected to each other as shown in Fig. 1: (1) a sealed box containing the basic functional units of the GMPC, which are used to prepare a mixture of given composition and purity and to deliver it to the target; (2) a vacuum panel allowing the evacuation of gas from the working pipelines, the recycling of most of the tritium-containing gas mixture, and the molecular analysis of the gas mixture; (3) a receiver, intended for collecting the "tails" of the gas-mixture from backing-pump discharges; (4) a device for eliminating traces of tritium and its compounds from gas mixtures enclosed in sealed reservoirs (boxes, receivers, etc.); (5) a discharge early-warning system, intended to prevent discharges into the atmosphere of gas mixtures with above-normal tritium content; (6) a set of pumps used to evacuate gas pipelines, hermetically sealed reservoirs, receivers, etc.; (7) a gas station for supplying the GMPC with diffusion-purified protium and deuterium, filling hermetically sealed reservoirs with inert gases, and conveying the carrier gas to the radiochromatograph; (8) a radiation-monitoring system that allows both the states of the GMPC and the ambient radioactivity in the working area to be monitored; (9) a control console for controlling the GMPC and high-pressure target; and (10) a computerized system that monitors the states of the GMPC components and high-pressure target and automatically records all data on the experiment.

Initially, the GMPC and targets were controlled from the control console. The console was used to measure temperatures and pressures, control the backing pumps, measure the vacuum, and regulate the temperatures of the sources and filters.

The analog process variables were controlled using autonomous instruments; all control operations were performed manually and required the close attention of the operator.

The computerized monitoring system overlapped the control functions of the control console and performed a number of other tasks: It monitored the states of the valves of the complex, the temperatures and pressures in the modules of the complex, the gas-mixture composition, and the target parameters; it also allowed the data on the experiment to be recorded and mathematically processed.

The monitoring system was developed on the basis of the CAMAC-standard modular hardware (analog multiplexers, analog-to-digital converters (ADCs), and input registers) and equipment with the IEEE-488 inter-

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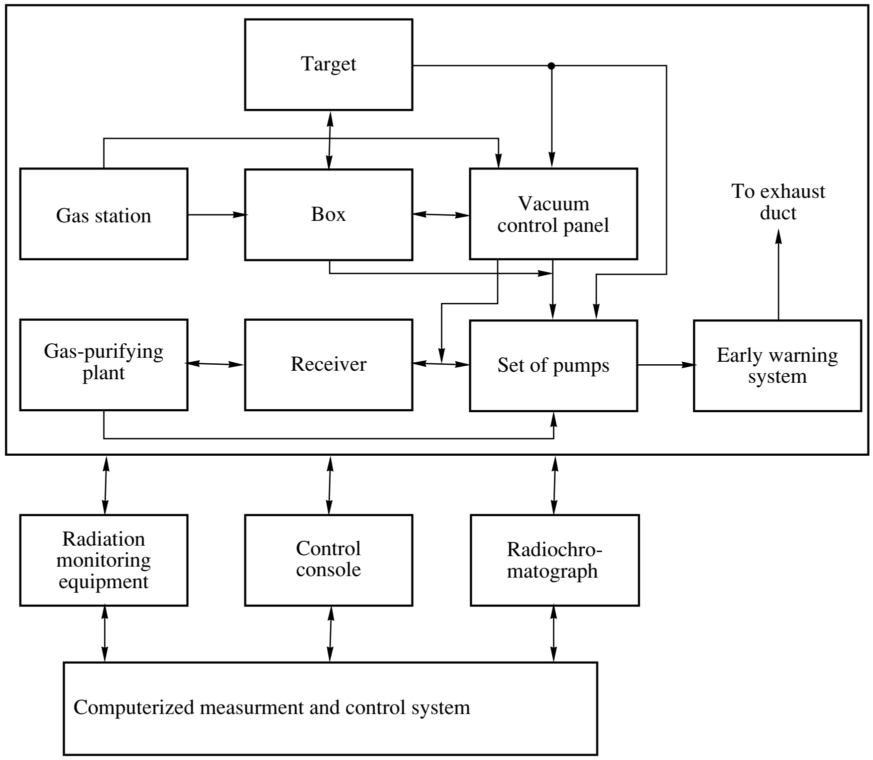

Fig. 1. Schematic diagram of the GMPC [1].

face (electrometric voltmeters). This configuration of the computerized monitoring system was used from 1996 to 1998.

In 1999, a step-by-step modernization of the system was carried out. A refined monitoring and control system (MCS) was built from state-of-the-art equipment, and almost all control console functions, aside from control of the pumps, were delegated to it.

Below, we describe the current state of the computerized MCS.

1. STRUCTURE AND COMPOSITION OF THE SYSTEM

The monitoring and control system includes the subsystems (1) for monitoring and control of the GMPC components, (2) radiation monitoring, (3) target (ТМВД [5], ДМВД [6], and ЖТМ [4]) control, and (4) monitoring the molecular composition of the gas mixture [7].

When preparing and performing an experiment, account must be taken of the following features of the MCS subsystems:

(1) The subsystems for gas-mixture preparation and radiation monitoring are in continuous use from the start of preparation for an experiment until the end of the experiment.

(2) The target subsystem is used at the stage of target preparation, as the target is being filled, and during its operation.

(3) The subsystem for monitoring molecular composition is used periodically to analyze gas-mixture samples.

(4) It is often necessary to use all of these subsystems simultaneously.

Taking into account the necessity of following numerous process variables and physical parameters and operating all of the GMPC subsystems simultaneously, the MCS has been structurally divided into three subsystems for ease of handling. Each subsystem is based on its own personal computer. The computers of the subsystems communicate with each other by the Ethernet network.

The first subsystem allows GMPC operation and radiation monitoring, the second is intended to operate the target, and the third monitors the molecular composition of the gas mixture.

The monitoring and control subsystems form distributed nets of intelligent modules connected to the control computer through RS-232 and RS-485 interfaces.

The analog/digital monitoring and control are carried out with I-7000 ICP DAS modules. Modules of this type are compatible in their performance characteristics with the products of other manufacturers (ADAM, NUDAM, and 6B series of Analog Devices) and, in

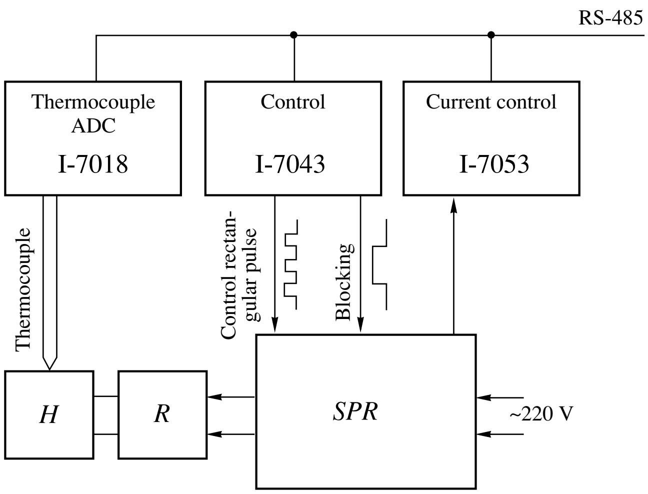

Fig. 2. Block diagram of the heating-control circuit: (*SPR*) semiconductor power regulator; (*R*) heater-blocking relay; (*H*) heater; (I-7018) multichannel analog-input module; (I-7043) multichannel digital-output module; and (I-7053) multichannel digital-input module.

addition, have a number of advantages that ensure the reliability and safety of the computerized system. Among these advantages are:

(1) a hardware watchdog timer, which automatically resets the module in the event of its hanging up;

(2) a software watchdog timer, which monitors the states of the control computer and, in the event of its hanging up or a break in communications, drives all of the module outputs to their preset (safe) states;

(3) the possibility of the "hot" (i.e., without a shutdown of the system) replacement of any module.

The vacuum is monitored with sensors from Balzers Instruments. They are connected to TPG controllers equipped with an RS-232 interface. Microprocessor controllers *RMC* with an RS-485 interface are used to monitor the radiation environment. The states of the valves and valve plates are checked with a DIO-144 digital-input/output ISA adapter.

During experiments, the monitoring and control equipment is affected by the electromagnetic interference that appears when switching the backing pumps, electromagnetic valves, heaters, etc., on or off, and during their operation. Hence, while developing the MCS, special emphasis was placed on ensuring the interference immunity of the measuring channels and control circuits, as well as on the conductive isolation of the input and output circuits.

The software for the measuring and GMPC-control system is based on the CRW-DAQ package, a powerful multiple-windows medium for the development of measuring, controlling, and data-processing systems. The program-package kernel CRW_RUN.EXE is started in the DOS operating system or in a DOS session under Windows 95/98 in all of the three MCS computers. A running program is defined for each computer by the loadable configuration file, which is similar to the *.ini* file of the Windows operating system.

2. THE GMPC AND RADIATION-MONITORING SUBSYSTEM

The complex for gas-mixture preparation [1] is used to prepare a mixture of given composition and purity and to convey it to the target, to evacuate the gas-supply pipelines, to recover a larger portion of the tritium-containing gas mixture, and to purify gas mixtures from traces of tritium and its compounds.

2.1. Control of the Heaters

The gas sources in the GMPC are generators based on hydrides of metals [8]. Diffusion palladium filters eliminate contaminants from the gas mixtures [9]. When operating the generators and filters, it is necessary to control the temperature of their heating, to monitor and stabilize the temperature, to monitor breaking of contactsin the load circuits, to deenergize the heaters if the temperature or pressure exceeds the predetermined value, and to disable the heaters under certain valve conditions.

A multichannel firmware subsystem has been developed to control the heating. In designing it, special emphasis was placed on its reliability and safety in the event of an emergency. Under no circumstances must the subsystem allow an object to be overheated above a critical level; in a number of cases, it must disable the heater if the pressure, radiation level, or other parameters exceed the predetermined value. A block diagram of a heating-control channel is shown in Fig. 2.

The heating temperature is determined with a thermocouple, and the thermal emf ε is measured accurate to 0.05% with an I-7018 multichannel-analog-input module. The thermal emf is converted into a temperature using the spline description of the standard tabulated function $\varepsilon(T)$ for this thermocouple type. The software of the subsystem permits the use of any type of standard thermocouples (chromel–alumel, chromel-copel, copper-constantan, tungsten–rhenium, etc.).

Semiconductor power regulators driven by an external logic signal have been developed to control the heating. The maximum output power of the regulator reaches 1 kW, and the regulation is performed by the pulse-width modulation method with a period of 2–5 s. The heated objects are rather massive; therefore, the oscillations caused by turning the power on and off are integrated and will not manifest themselves in the temperature of the object. The power regulators are computer-controlled via I-7043 multichannel digital-output modules, and the temperature is stabilized with an accuracy of ±2°C.

The power regulator comprises a load-current sensor, whose output signal is detected with an I-7053 digital-input module. A blocking relay controlled through

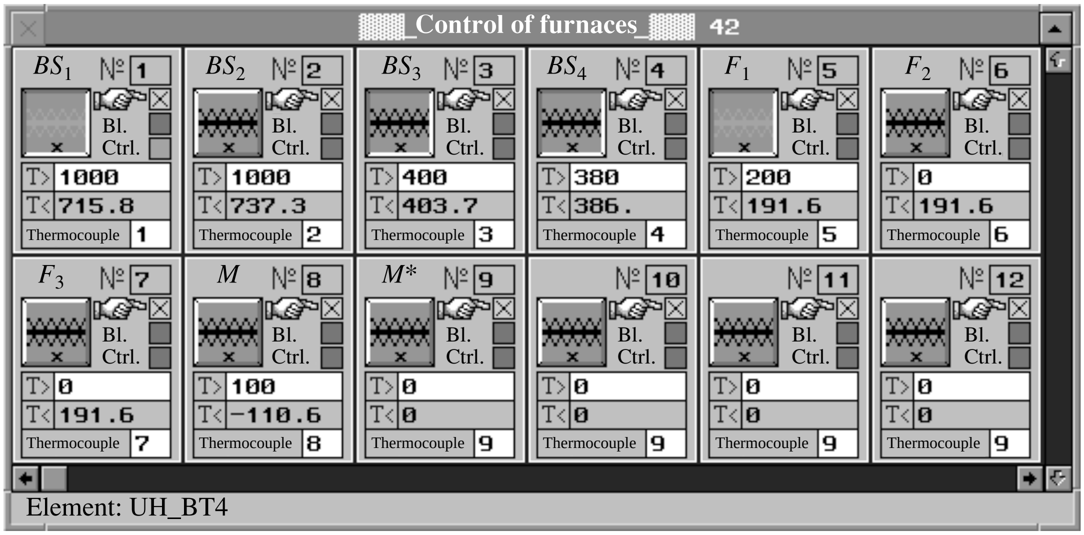

Fig. 3. Control panel for GMPC heaters.

I-7043 multichannel digital-output modules is included in the system to avoid uncontrollable power transfer to the heater, which is caused, e.g., by a short circuit in the output element of the regulator.

The I-7000 modules ensure the reliability of and level of protection for the subsystem. If computer control is lost, they automatically turn the power regulator off and enable the relay-type blocking.

The subsystem for GMPC monitoring and control contains seven regulating channels of this type for the generators BS_1–BS_4 and filters F_1–F_3. Heating is controlled using the active mnemonic panel shown in Fig. 3. The software of the channel makes it possible to measure, set, and stabilize the heating temperature, as well as to specify the temperature and pressure conditions for blocking the heaters.

2.2. Monitoring of the Analog and Digital Parameters of the Complex

Four ПМТ-4М thermal vacuum gauges and two IKR261 and TPR260 (Balzers) vacuum gauges are used to monitor the vacuum in the GMPC units. The ПМТ-4М tubes are connected to the electronic unit, which provides adjustment and control of the tube current. The output voltage of the ПМТ-4М thermal converters is measured with an I-7018 multichannel analog-input module, and the pressure is computed from the calibration data presented in the tube documentation.

The Balzers vacuum gauges are connected through a six-channel TPG-256 controller. The control of the controller and the digital-data acquisition are carried out via the RS-232 port.

High pressures are measured with strain gauges, low pressures (up to 10–20 atm) with САПФИР transducers. The strain gauges are operated from a stabilized power source with an output voltage of +12 V. The strain-gauge and САПФИР output signals are recorded by the I-7018 analog-input modules. The polynomial representations for individual calibrations of each transducer are used to convert the measured voltages into a pressure.

The states of the valves *V* and electromagnetic valves *EV* of the apparatus are monitored (via 110 position pickups with two pickups for each valve or valve plate) with the DIO-144 digital-input/output adapter plugged to the ISA bus of the control computer. The pickup signals arrive at the digital inputs of the adapter through a switching unit, which converts them into TTL levels. The states of four water-pressure sensors are monitored with an I-7053 multichannel digital-input module. The software of the automated system displays the states of the valves, valve plates, and water-pressure sensors.

2.3. Structure of the GMPC and Radiation-Monitoring Subsystem

The subsystem for GMPC control and radiation monitoring is based on the control computer *PC* (Fig. 4).

An intelligent addressable interface converter based on a PC-compatible I-7188 microprocessor controller with four serial input/output ports is used to connect the computer to devices with different interfaces and transmission speeds (I-7000 modules, a PTG-256 controller, and controllers *RMC* for radiation monitors). Communication with the control PC is carried out through the COM4 port (RS-232).

An addressless TPG-256 controller is connected to the COM1 port of the I-7188 module and, from the point of view of the control computer, has a virtual home address. The I-7000 modules are connected to the COM2 port (RS-485, a data rate of 115200 baud). Two-

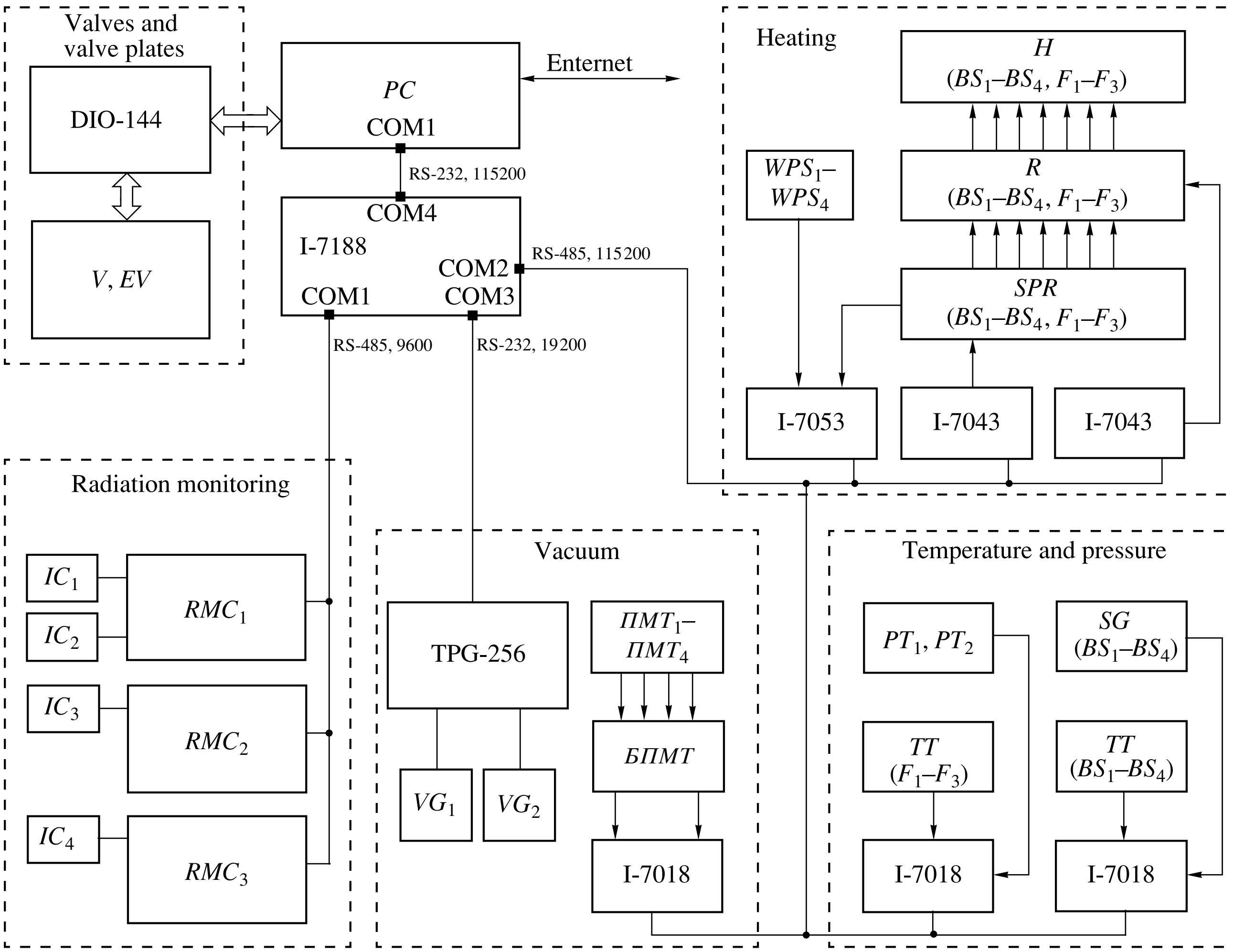

Fig. 4. Schematic diagram of the GMPC and radiation-monitoring subsystem: (*PC*) subsystem control computer; (DIO-144) 144-channel digital-input/output ISA adapter; (*V*, *EV*) controlled valves and electromagnetic valves; (*RMC*) controllers for radiation monitors; (*IC*) ionization chambers; (TPG-256) six-channel controller for Balzers vacuum gauges; (*VG*) vacuum gauges (Balzers); (*PT*) САПФИР-22-Ex-M pressure transducers; (*ПМТ*) *ПМТ*-4 tubes; (*БПМТ*) connector for *ПМТ*; (*TT*) thermocouple transducers; (*SPR*) semiconductor power regulator; (*R*) blocking relay; (*SG*) strain gauges; (*H*) heaters; (*WPS*) water-pressure sensors; (I-7188) PC-compatible microprocessor controller; (I-7018) eight-channel analog-input module; (I-7043) 16-channel digital-output module; and (I-7053) 16-channel digital-input module.

channel measuring units for ambient radioactivity monitoring are connected through the COM3 port (RS-485, a data rate of 9600 baud).

2.4. Radiation Monitoring

While designing the gas-supply complex, special attention was given to radiation safety when working with tritium. Safety is ensured both as a result of incorporating the principles of physical protection in the design of the gas system and by the subsystem monitoring of the tritium activity.

Initially, the tritium concentration in the gas pipelines and in the air of the working area was measured with РГБ-06 industrial radiometers. A radiometer of this type consists of a БДГБ-02П detector (a flow-type or diffusion ionization chamber of volume 1 or 10 l with a БПН-16П voltage changer) and a УИ-117П test set, which is used to read the data and control the detector.

Since the design of the РГБ-06 radiometers makes it impossible to include them in computerized monitoring and control systems, an РГБ-06МА automated multichannel tritium radiometer was developed when the system was being modernized. It is compatible with unified БДГБ-02П detectors and provides a means for their integration into control systems. Each radiometer is composed of a microprocessor-based radiation-monitor controller *RMC*, which may be connected to two industrial БДГБ-02П detectors. The radiation-monitor controller is used:

(1) to control the operating modes of the detector (measurement, monitoring, and interlock);

(2) to measure the tritium concentration in light of the background activity;

(3) to provide dual-threshold analysis of the radiation environment in each channel and to control two standard БСР-19П external warning-signal devices;

(4) to communicate with the control computer in accordance with the RS-485 standard.

The РГБ-06МА radiometer has passed all tests for the approval of measuring devices (and was awarded certificate RU.C.38.046.A no. 11019 on November 1, 2001). When used with ionization chambers with volumes 1 and 10 l, it allows the tritium volume activity to be measured over ranges of 5×10^5 to 5×10^{10} Bq and 5×10^4 to 5×10^9 Bq, respectively. The limit on admissible basic measurement error for tritium volume activity is ±25%; for calibration and testing with γ-rays of ^{60}Co, the limit is ±20%.

The radiometer can operate both in the off-line mode and as a component of a computerized multichannel radiation-monitoring system. In the off-line mode, the instrument measures the volume activity and gives warning of any threshold crossing. When used as components of a multichannel system, the radiation environment monitors are united in a local network by a two-wire communication line made to RS-485 standard, which ensures the reliable communication of the control PC with local stations under conditions of industrial noise within a distance of up to 250 m.

When it was modernized, the monitoring and control system of the complex was supplemented by three *RMC* units with four ionization chambers (ICs) to monitor the tritium concentration at the following points: the gas-purification plant, the pump assembly, the early warning system, and the site of the automated control system's control computers.

2.5. Software for the GMPC and Radiation-Monitoring Subsystem

The software for the GMPC monitoring and control subsystem supports the monitoring of the analog (vacuum, temperature, and pressure) and discrete (states of the valves, valve plates, and water-pressure sensors) parameters of the complex.

The controllable analog parameters are displayed in text and graphic forms in the real-time mode. The graphic windows for the display of analog data offer wide possibilities for the viewing and processing of dynamic curves (a selection of curves for viewing, scaling, filtering, etc.). The software permits the continuous recording of controlled parameters on the hard disk of the PC.

Active mnemonic panels are used to display the states of the GMPC units and control the setup. The basic mnemonic panel corresponds to the gas system of the setup; a fragment of it is shown in Fig. 5.

The software of the radiation-monitoring subsystem

(1) provides control of the radiation monitors (the selection of operating modes and adjustment of the upper and lower thresholds for indicating the ambient radiation conditions);

(2) continuously monitors the radiation environment and saves the results on the hard disk of the PC;

(3) displays the ambient radiation conditions in graphic form;

(4) provides the personnel with an audible warning in the event of an emergency (an excess of the predetermined levels of the volume activity).

3. TARGET-CONTROL SUBSYSTEM

Any study of muon catalysis in H/D/T mixtures requires that experiments should be conducted over a wide temperature range (from cryogenic temperatures to 1600 K) and at pressures as high as 160 MPa. Different targets are used for this purpose: a liquid tritium target, a high-pressure tritium target, and a high-pressure deuterium target. The target-control subsystem allows operation with all types of targets. This subsystem is responsible for:

(1) monitoring the vacuum;

(2) measuring high temperatures at two points with thermocouple sensors;

(3) measuring high pressure with a strain gauge;

(4) measuring low pressure with an САПФИР transducer;

(5) measuring low temperatures at two points with thermodiode sensors;

(6) controlling a heater with up to 1-kW power;

(7) controlling a low-power heater used at low temperatures;

(8) temperature stabilization in the working volume of the target.

The target-control subsystem is based on a PC (Fig. 6).

The vacuum is monitored with a Balzers transducer connected to the PC through a TPG-252 two-channel controller. High pressure is measured with a strain gauge, to which a constant voltage of +12 V is applied. Low pressure is measured with an САПФИР transducer. The outputs of the strain gauges and the САПФИР sensors are recorded with I-7018 analog-input modules. The polynomial representations of individual calibrations for each transducer are used to convert the measured voltages into pressure values.

The control circuit described above is used for the high-power heater H_1. It comprises a thermocouple transducer (TT_1 or TT_2), a semiconductor power regulator *SPR*, and a blocking relay *BR*. The thermocouple signals are recorded by a multichannel I-7018 analog-input module. The regulator SPR_1, the relay-type blocking, and the current are controlled from a multichannel I-7050 digital-input/output module.

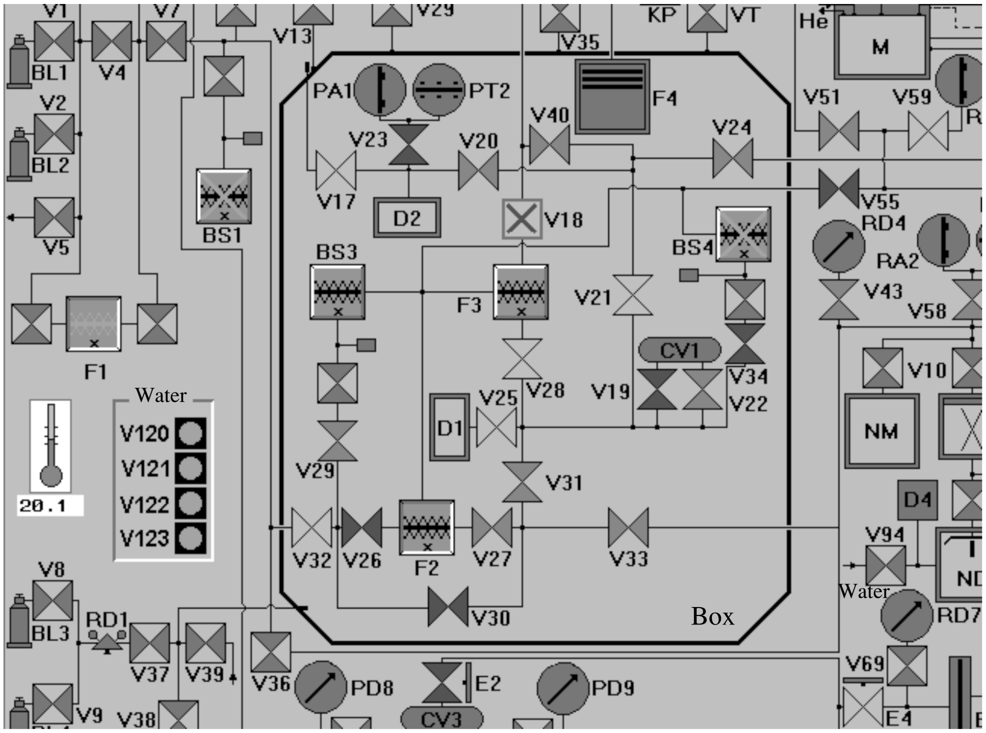

Fig. 5. Graphic interface of the GMPC subsystem.

The temperature in the working volume of the target is controlled by the heater H_2. Stringent requirements are specified for temperature stability and the accuracy of temperature measurements. The circuit allows connection of the heater H_2 to the output of the power amplifier *PA* (a dc amplifier) or to the output of the power regulator through a step-down transformer.

Heating regulation using the power amplifier is conventionally done at cryogenic temperatures. The power amplifier is rated at an output power of ~40 W (with an output voltage of 20 V at a peak current of ~2 A). The control voltage is applied to its input from a 16-bit I-7021 analog output module.

Two silicon thermodiode sensors measure temperatures of from 2 to 330 K with an accuracy of ±0.1 K for the range 2–100 K and 1% at >100 K. The thermodiodes are connected through current stabilizers (with a current of 10 μA ± 0.05%); the output thermodiode voltages are measured with a multichannel I-7018 analog-input module. The temperatures are computed using a spline description of the manufacturer's temperature specifications for a silicon thermodiode (a standard specification is given in Fig. 7). This apparatus and the software of the subsystem help to stabilize the temperature with a relative accuracy of ±0.05 K.

To obtain higher power at the heater H_2, one has to switch over to a standard heating-control circuit with the power regulator SPR_2 operating off a 220-V ac line. The switchover is software-controlled using an I-7060 relay-output module. By selecting the step-down ratio of the transformer, it is possible to vary the maximum power of the heater over a wide range.

The software of the target subsystem is used to set and stabilize the heating temperature in the working volume of the target, as well as to measure the vacuum, temperatures, and pressures.

The temperature curves of target cooling and stabilization, and the pressure curves measured during the endurance tests of the high-pressure tritium target in February 2002, are presented in Figs. 8 and 9, respectively.

4. MONITORING MOLECULAR COMPOSITION

The molecular composition of a gas mixture is monitored by a heat-conductivity detector and a small-sized ionization chamber with a volume of 5 cm^3. Isotopes are separated with a 3-m-long chromatographic column operated at the temperature of liquid-nitrogen. Neon is used as a carrier gas.

In the initial version of the monitoring system, the output signal of the heat-conductivity detector was digitized by a CAMAC ADC. The ionization-chamber current was measured with B7Э-42 and B7-57/1 industrial electrometric voltmeters connected to the PC through an IEEE-488 interface. Experience in using electrometric voltmeters to measure a rapidly changing (by a factor of 10^2–10^3 with a rise time of 30 s) current shows that some data may be lost over an interval of 10–15 s. Moreover, gaps exist between the different ranges of

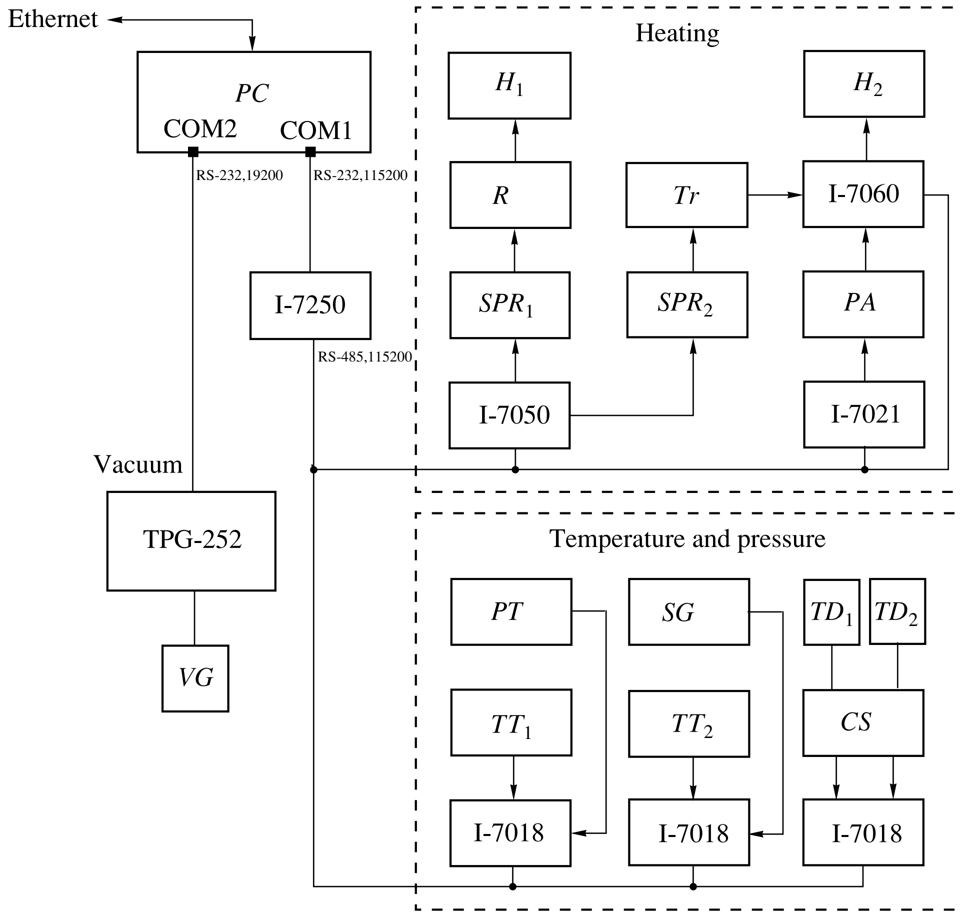

Fig. 6. Block diagram of target control: (H_1) high-power heater (~1 kW); (H_2) low-power heater (~300 W); (*SPR*) semiconductor power regulator; (*R*) blocking relay for heater H_1; (*PA*) power amplifier for heater H_2; (*Tr*) transformer; (*TT*) thermocouple transducer; (*TD*) thermodiode; (*SG*) strain gauges; (*PT*) САПФИР pressure transducer; (*VG*) vacuum gauges (Balzers); (*CS*) current stabilizers for thermodiodes; (I-7520) RS-232/RS-485 interface converter; (I-7018) eight-channel analog-input module; (I-7060) multichannel relay-output module; (I-7021) 16-channel analog-input module; (I-7050) multichannel digital-input/output module; and (TPG-252) two-channel controller for Balzers vacuum gauges.

these voltmeters. For these reasons, the subsystem for monitoring molecular composition has been completely refined and equipped with modern electronics.

The subsystem for monitoring molecular composition is PC-based (Fig. 10). The output signal of the heat-conductivity detector is digitized by an I-7011 analog-input module (a measurement range of ±50 mV) with a frequency of 10 s^{-1} and an accuracy of 0.05%.

A linear electrometric amplifier (ЭМУ-2) with band switching has been developed to measure the current in the ionization chamber. The amplifier is designed to amplify currents of 10^{-13} to 10^{-5} A. Its output voltages range from –5 to +5 V. The amplifier has short-circuit protection at the output. While developing the amplifier, much attention was given to shielding and noise suppression.

The switching between four bands is controlled from the PC through an I-7050 digital-output module, while the output signal of the amplifier is digitized by an I-7012 analog-input module (with a measurement range of ±5 V). All the modules in the subsystem are connected to the control PC via a two-wire line through an I-7520 RS-232/RS-485 interface converter. The rate of data communication is 115 200 baud.

The noise level in the most sensitive amplifier band is $\sim 2 \times 10^{-14}$ A. A representative curve of current measurements in the flow-type ionization chamber with the absence of radioactive contaminants in the gas is shown in Fig. 11. The noise signal is symmetric about the zero line, thus providing powerful noise suppression through the use of mathematical methods. This plot also presents an experimental curve smoothed by a Fourier filter with a 1-s time slot. It is evident that the noise level decreases down to 3×10^{-15} A.

The software of the subsystem for analyzing the molecular composition of gas mixtures controls the data acquisition, processes the spectra measured with the heat-conductivity detector and the ionization chamber, and computes the molecular composition of the mix-

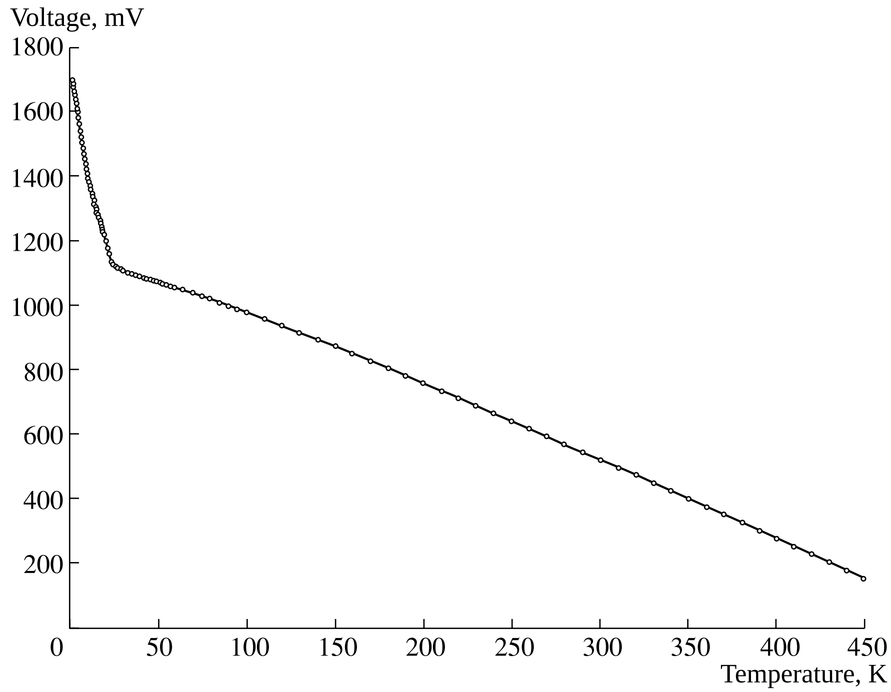

Fig. 7. Standard temperature characteristics of a thermodiode (a D 200 19 707 LEYBOLD silicon diode).

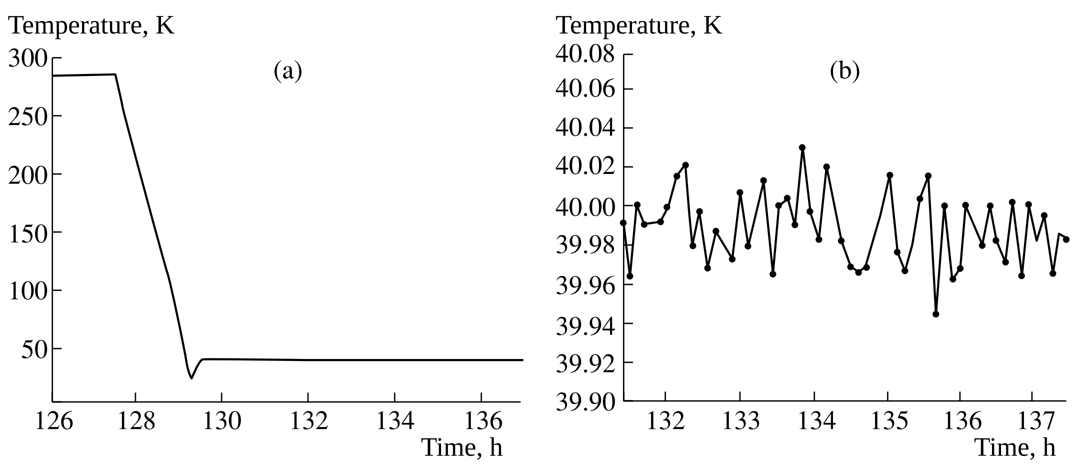

Fig. 8. Cooling and target-temperature stabilization.

ture. Standard responses of the heat-conductivity detector and the ionization chamber are shown in Fig. 12.

CONCLUSIONS

The TRITON facility was designed in 1996 by VNIIEF (Sarov) in collaboration with JINR (Dubna) for systematic investigations of muon-catalyzed fusion. Since 1997, physical experiments have been regularly conducted on the facility. It contains a complex for gas-mixture preparation with replaceable targets that is equipped with a computerized monitoring and control system.

While preparing for the experiments of 1999, the computerized system was substantially refined. It now performs almost all the functions of the previous system: monitoring and control of the complex for gas-mixture preparation, monitoring and control of target characteristics, analysis of the gas-mixture composition, and monitoring radiation.

The modernized monitoring and control system is composed of state-of-the-art instruments, making it possible to significantly improve accuracy and reliabil-

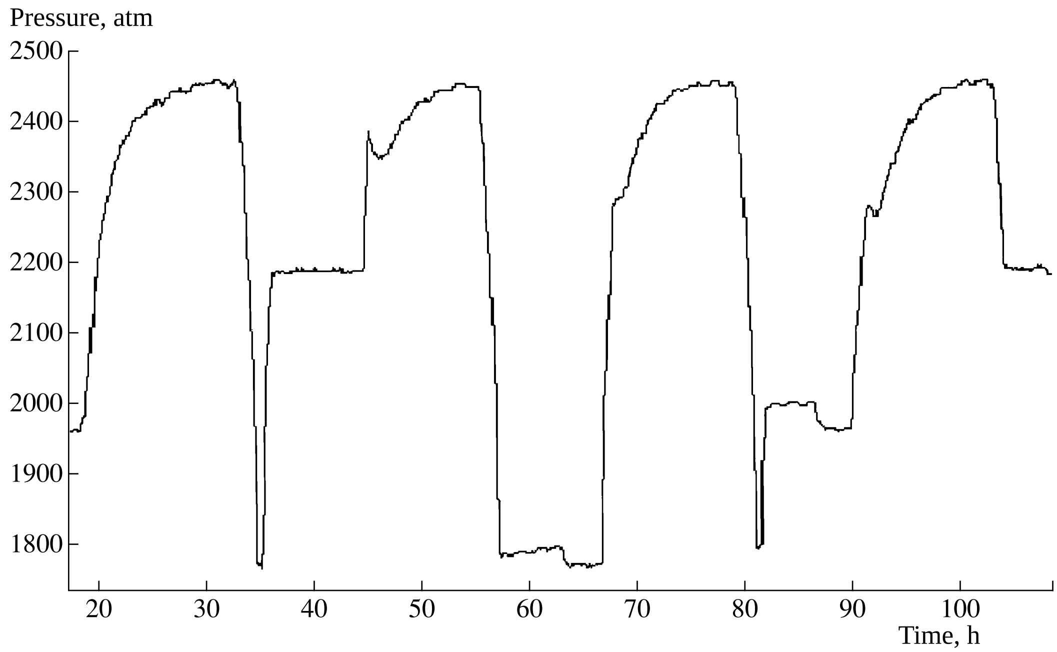

Fig. 9. Measurement of target pressure.

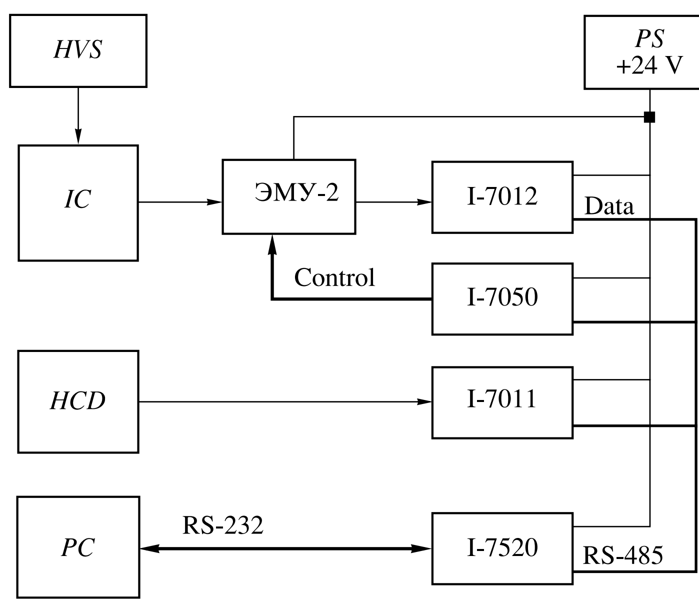

Fig. 10. Block diagram of molecular composition monitor: (*PC*) personal computer; (*HVS*) high-voltage supply; (*IC*) flow-type ionization chamber; (ЭМУ-2) electrometric amplifier with band switching; (*PS*) power source (+24 V); (*HCD*) heat-conductivity detector; (I-7011) analog-input module; (I-7520) RS-232/RS-485 interface converter.

ity in measuring physical parameters and process variables.

Numerous physics experiments carried out on the TRITON facility have demonstrated the high performance characteristics and the high degree of reliability of both the hardware and software of the monitoring and control system.

The approach that was adopted to MCS design (a distributed network of intelligent modules and the CRW-DAQ software package currently in use) allows it to adapt easily to alterations in the CPGM apparatus and targets that might be required when preparing for new experiments: the changing of sensor types, the incorporation of new sensors, the addition of new sources with heaters, etc.

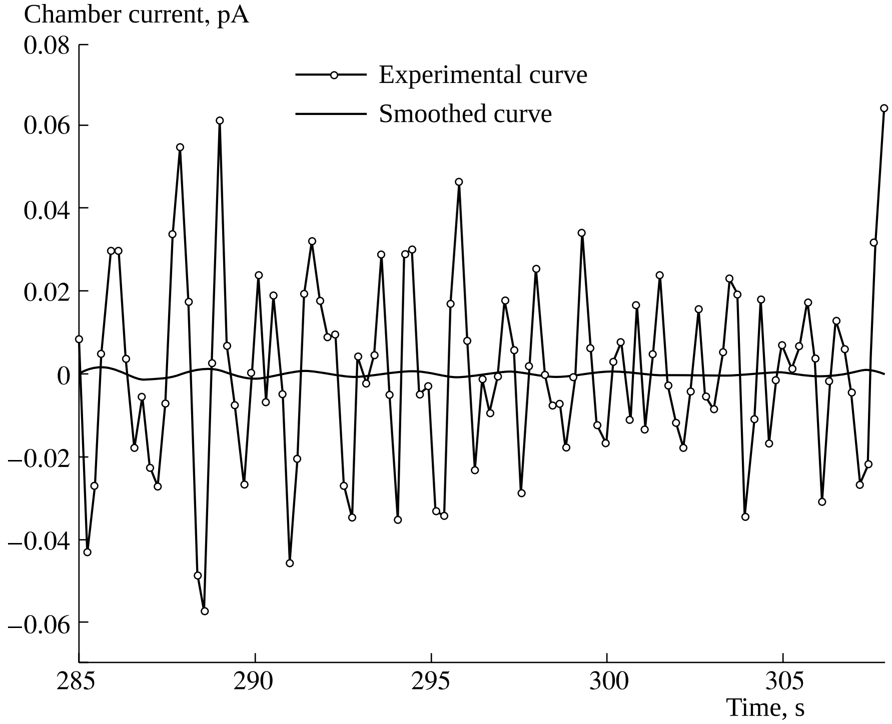

Fig. 11. Noise characteristics of measuring channel with an electrometric amplifier.

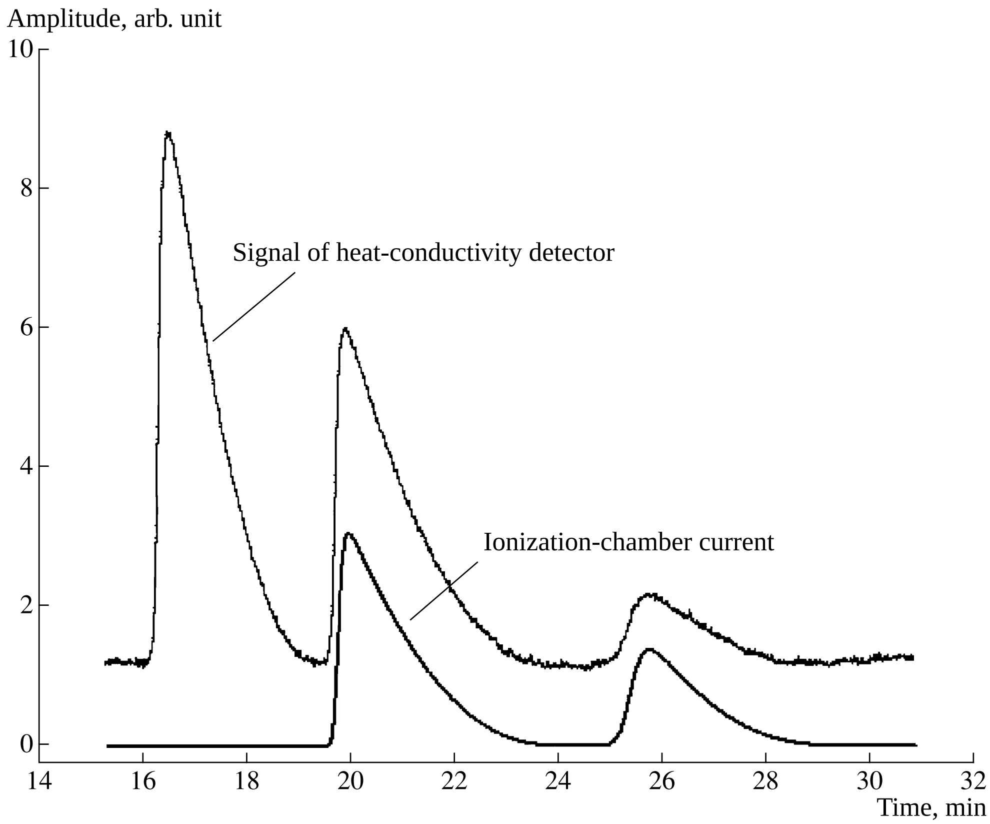

Fig. 12. Response curves used to analyze molecular composition.

The experience gained in developing and operating the complex's MCA has been successfully used in the automation of other facilities based on tritium technologies: a universal test facility for investigating the accumulation of tritium and its penetration through metals and construction materials [10], and a tritium target designed for the study of exotic neutron-rich nuclei [11].

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