

RESEARCH COMPLEX LINAC-300 UPGRADE PROJECT AND THE LINES OF NUCLEAR RESEARCH

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The paper describes the problems of upgrading the research complex LINAC-300 and the program of physical studies expected to be performed at it. The acceleration complex LINAC-300 includes three electron beam ejection channels, the beam translation system and the spectrometer SP-95. Some special features of already upgraded systems of the complex LINAC-300 are considered in detail, as well as the plan of activities for its further modernization is given together with the expected electron beam characteristics. Special attention is paid to the program of physical investigations that are underway or expected to be performed at the experimental complex.

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1. INTRODUCTION

At the present time, a quick progress of accelerator technology in the world and the conduction of numerous investigations in the field of basic and applied nuclear physics, and also, in the field of radiation technologies, call for a cardinal modernization of a number of systems at the LINAC-300 complex. This is necessary for both to improve the characteristics of the beam formed and to upgrade the existing instrumentation of the experimental facilities. The modernization is necessary for performing experiments in the areas of nuclear and applied physics, in particular, for irradiation of various process materials. The LINAC-300 complex has three electron beam ejection channels (to eject the beams of energies 30, 60 and 160 to 200 MeV), the beam translation system for the 160-200 MeV beam ejection channel, and the spectrometer SP-95.

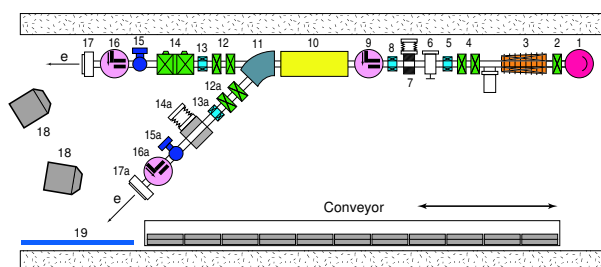


Fig.1. Layout of the 30 MeV beam ejection channel: 1 gun; 2 metal-sheathed lens; 3 section "I"; 4 quadrupole lenses; 5 corrector; 6 automatically operated valve; 7 collimator; 8 corrector; 9 faraday cup No 2; 10 section "1C"; 11 deflecting magnet; 12, 12a quadrupole lenses; 13, 13a correctors; 14 lens; 14a collimator; 15,15a transit-time pickups; 16 faraday cup No 7; 17 faraday cup No 6; 18 18a video camera; 19 ionization detector

2. THE 30 MeV BEAM EJECTION CHANNEL

The main components of the 30 MeV beam ejection channel are presented in Fig.1. The main characteristics of the electron beam extracted from the mentioned channel are presented in Table 1. As it is obvious from Table 1, some characteristics of the ejected electron beam (emittance, energy spectrum width) are inconsistent with the requirements imposed by current investigations in the field of nuclear and applied physics.

Table 1. The main beam characteristics in the 30 MeV beam ejection channel

Energy, MeV	up to 35.0
Pulse length, μs	2
Direct average output current, μA	100
Deflected beam average current, μA	85
Energy spectrum width, %	5...12
Emittance (steady-state conditions), mm·mrad	1

2.1. Research program

The following investigations are planned to be performed at the 30 MeV beam ejection channel:

- 1) Investigation of near-threshold photofission of ^{238}U (6...6.5 MeV).
- 2) Investigation of excited states of nuclei by means of (γ, n) and (γ, p) reactions.
- 3) Characterization of delayed neutrons from nuclear fission reactions.
- 4) At the direct output of the 30 MeV electron beam, to complete the test bench with the equipment system and measurement instrumentation for conducting fundamental and applied investigations on the physics of particle flux interaction with periodic media, substance, and applied studies necessary for nuclear engineering and for the development of radiation technologies.
- 5) Activation analysis of bulky samples (10...400 kg) for the content of fissile materials and ^{238}U .
- 6) Investigation of radiation defects in spinel materials.

2.2. Scheme of work on upgrading the 30 MeV beam ejection channel

In order to realize the above-given program, it is necessary to fulfil the following range of works at the 30 MeV beam ejection channel:

1. To perform modelling of self-consistent particle dynamics in the injector part, in the accelerating section and during the passage through the magnetic components.
2. To determine the main parameters of the beam versus the RF power supply parameters.
3. Relying on the calculations made, to choose the optimum configuration of the accelerator, the type of the injector-buncher with the required parameters; to order its manufacture and to install it in the accelerator.
4. To upgrade the HF power supply system (to energize additionally the injector-buncher); the control system (to install current and beam position sensors, to provide computer-assisted analysis of information on the main characteristics of the beam, to install automatic control of the main locking devices of the accelerator, to develop the automatic system for controlling the energy spread of the electron beam formed); to improve the existing thermostating system

3. THE 60 MeV BEAM EJECTION CHANNEL

3.1. The main characteristics of the 60 MeV beam ejection channel

By the present time, a substantial scope of work has been done to upgrade the 60 MeV beam ejection channel. The main components of the 60 MeV beam ejection channel are schematically presented in Fig.2.

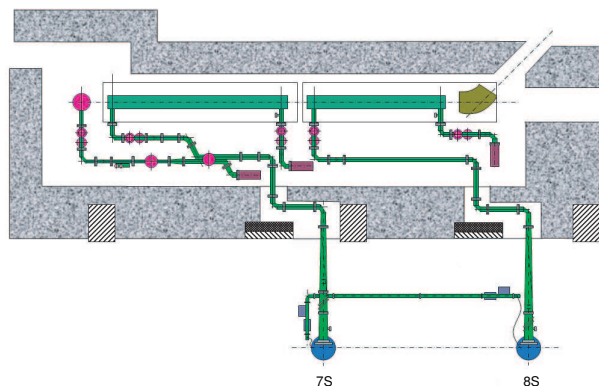


Fig.2. Schematic of the 60 MeV beam ejection channel

As it is known, the injector of the 60 MeV beam ejection channel will be operated in two substantially different modes: 1) weak-current (pulsed current ≈ 90 mA), short-pulse (pulse length ≈ 100 ns) conditions for the storage ring "Nestor"; 2) moderate-current (pulsed current ≈ 200 mA), long-pulse (pulse length $\approx 2 \mu\text{s}$) conditions for the direct output (200 MeV beam ejection channel) to the experimental SP-95 facility and the streamer chamber. The main beam characteristics in the 60 MeV beam ejection channel (operation for the "Nestor" storage ring) are presented in Table 2.

Table 2. The main beam characteristics in the 60 MeV beam ejection channel

Energy, MeV	up to 100.0
Pulse length, ns	100
Pulsed current, mA	90
Energy spectrum width (steady-state conditions), %	0.75
Emittance (steady-state conditions), mm·mrad	0.07

3.2. Design features of the main 60 MeV beam ejection channel systems

3.2.1. A compact electron injector

Structurally, the injector (Fig.3) consists of the following units: a diode electron gun, a bunching system, a coaxial power input, a waveguide-to-coaxial adapter, a short solenoid, a current sensor and an axially symmetric magnetic lens. In the gun, a spherical impregnated oxide cathode, 5 mm in diameter, is used [1]. The buncher is made from oxygen-free copper by the "disk-ring" technology, i.e., each cavity consists of a cylindrical ring and two disks with holes made in them to let the beam pass. The internal surfaces of cavities are diamond tooled. The rings and the disks are connected between themselves by hard brazing in a vacuum furnace.

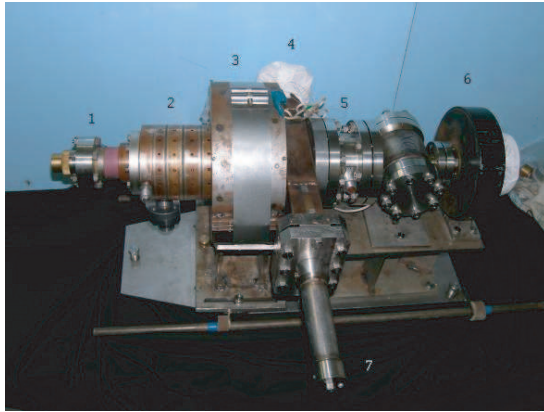
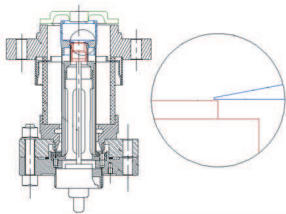


Fig.3. Ready-assembled injector: 1 - electron gun cathode unit; 2 - buncher; 3 - solenoid; 4 - RF input waveguide; 5 - beam current sensor; 6 - magnetic lens; 7 - short-circuit piston motion mechanism

At the periphery of cavities 16 channels are made for the coolant passage. The first cavity comprises a calibrated induction probe to control the field amplitude. Owing to a rather high field intensity on the axis of the fifth cavity the beam particles get a transverse impulse, which leads to a beam center shift. Because of the energy straggling of particles, the beam position correction by magnetic components causes deterioration of the transverse emittance. One of the methods to eliminate this phenomenon is to use a coaxial input of the microwave power into the system. The scheme and the main characteristics of the electron source are presented in Fig.4.



Electron energy	25 keV
Current beam	240 mA
Crossover radius of beam	2.2 mm
Distance up to a crossover	23 mm
Emitans, $\epsilon_{rms\ xy}$	$3.2 \pi \cdot \text{mm} \cdot \text{mrad}$

Fig.4. Source of an electron

Figure 5 shows the scheme and the main characteristics of the buncher-collimator. It can be seen from Fig.5 that in the resonance system of the buncher the field on the axis exponentially increases from the point of electron injection till the point of electron escape from the system due to a special choice of cavity dimensions.

3.2.2. Electron source modulator

Figure 6 is a basic diagram showing the principle of operation of the electron source modulator.

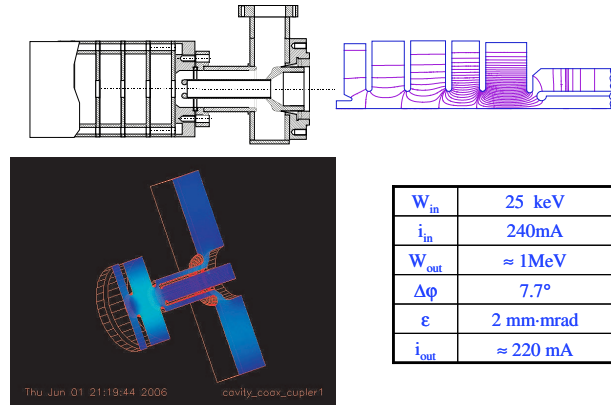


Fig.5. Buncher, collimator. Electron energy - 25 keV; Beam current - 240 mA; Beam radius in the crossover - 2.2 mm; Distance to the crossover - 23 mm; Normalized emittance $\epsilon \approx 3.2\pi \cdot \text{mm} \cdot \text{mrad}$

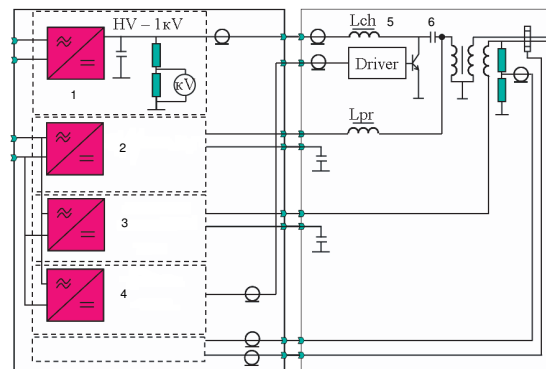


Fig.6. The Modulator of Electron Source: 1-high-voltage unit; 2-demagnetization unit; 3-heating current control; 4-generator unit; 5-charging inductance unit; 6-capacitor

As it can be seen from the diagram, the electron source modulator consists of the following main units:

1. high-voltage unit;
2. demagnetization unit;
3. heating current control;
4. generator unit;
5. charging inductance unit;
6. capacitor.

An essential difference of the given diagram from a standard circuit consists in the use of the partial discharge capacitor. Here, the role of thermionic relay belongs to a control transistor. The discharge capacitor from the high-voltage unit is charged via L_{charge} up to 2 kV. During voltage pulse generation at the source, a control signal of necessary time duration is fed from the generator unit via a driver to open the transistor and to realize the discharge of the pulse-forming capacity. At the necessary moment, the control signal stops, the capacity ends discharging and the pulse formation ceases. The advantage of this circuit is the absence of the thermionic relay, which is uncontrolled and leads to the forming line depletion. The present circuit can provide voltage pulses of any duration for the source.

3.2.3. Accelerating sections

Figure 7 shows the main frequency and temperature characteristics of the sections employed at the 60 MeV electron beam ejection channel.

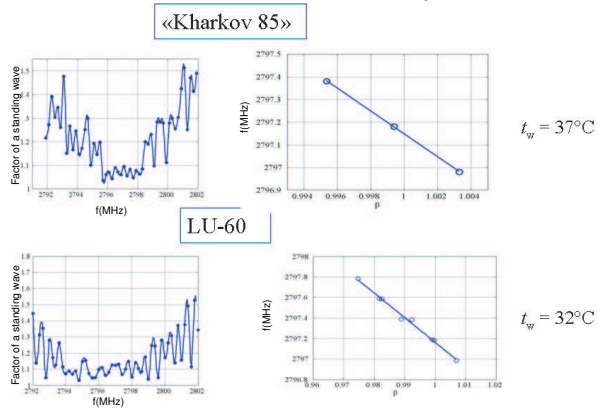


Fig.7. The Accelerated sections

3.2.4. The control system

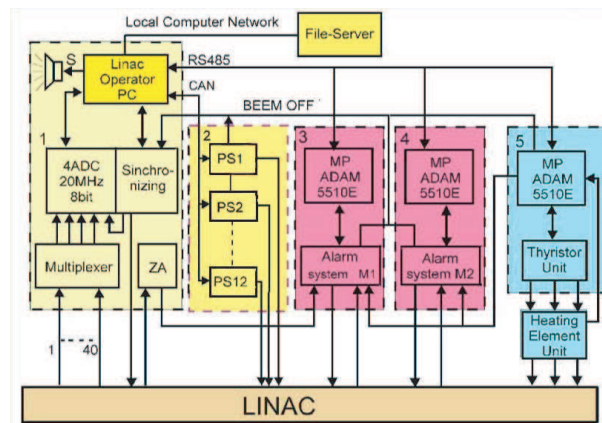


Fig.8. Functional diagram of the control system of the 60 MeV beam ejection channel. 1 - control center post in the linac control room, synchronizer, PC, zone lock unit (ZA), 4-channel ADC with a multiplexer; 2 - post of magnet component power sources (PS); 3, 4 - modulator and klystron universal locking system; 5 - thermostating system electronics bay

The control system [2] has the following main functions:

- automated (on operator's command) control of accelerator switching-on and off, and also control of the accelerator system parameters;
- measurement of electron beam parameters;
- beam hazard protection of the personnel (zone locks);
- indication of system parameters and the electron beam.

The main subsystems are:

- synchronizing system;
- beam parameter control system;
- magnet power system;
- thermostating system;
- zone lock system;

- remote control system (RF, klystron pulse amplifier)
- blocking and signaling system of modulators and klystron pulse amplifiers.

The functional diagram of the control system of the 60 MeV beam ejection channel is presented in Fig.8. It can be seen from the diagram that the main systems of the accelerator are controlled by means of a personal computer (Linac operator's PC) and programmable controllers ADAM. The system also comprises computer-controlled power sources Marathon CAN-100. The information about the basis parameters of the beam is displayed on the PC screen.

3.2.5. Magnetic-component power system

The magnetic-component DC power sources [2] (henceforth PS) have been developed in two modifications: "Marathon CAN-100/1" (voltage from -100V to +100V, current up to 1A) and "Marathon CAN-30/4" (voltage from -30 to +30V, current up to 4 A). Structurally, the PS were manufactured in two variants: 1) two-channel in a standard 19" case, 3U in height, and 2) single-channel in a metal case. CAN 2.0A and 2.0V, RS232 are the interfaces for the PS control. The PS are intended for constructing the CAN-interface network-controlled system of distributed electric power supply. They are depicted in Fig.9. Figure 10 shows the diagrammatic layout of thermocouple elements on the 60 MeV beam ejection channel.



Fig.9. Magnetic-component power system

3.2.6. The thermostating system

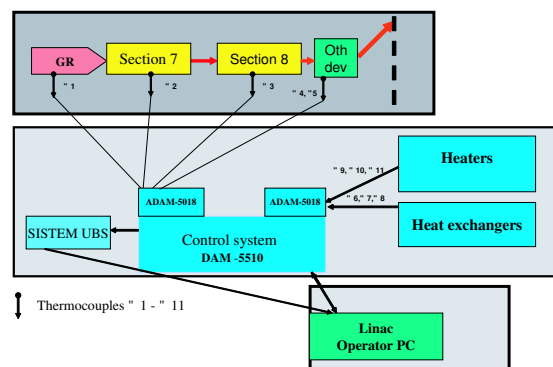


Fig.10. Scheme of temperature sensors (thermocouples) arrangement on the accelerator LU-60M equipment

The figure shows the thermocouple installation sites, and also the scheme of thermostating system control by means of the programmable controllers ADAM. Figure 11 illustrates the temperature conditions of the thermostating system operation.

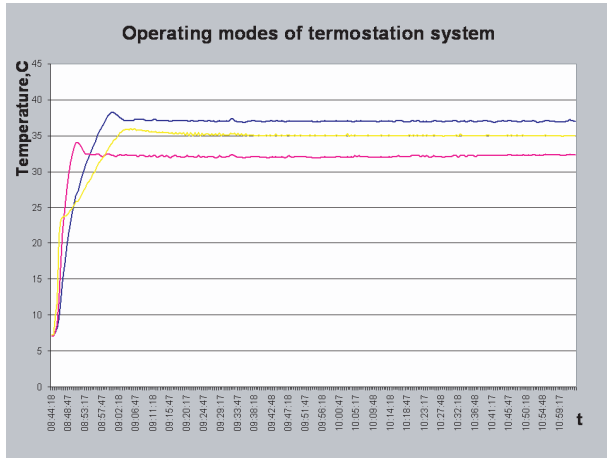


Fig.11. Temperature conditions of the thermostating system operation (without recirculated water)

It can be seen from Fig. 11 that the thermostating system is brought into operation within 20 minutes and it maintains the temperature stability of individual units at a 1% level. Figure 12 shows the photometering data for the trace on the glass from the beam that has passed without magnetic elements.

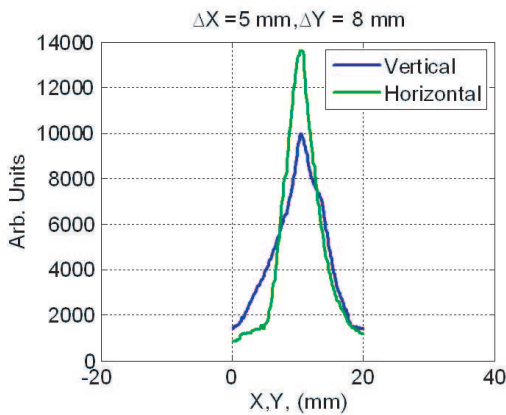


Fig.12. Photometering data for the trace on the glass

It is obvious from the figure that the picture width at half-blackout is no more than 10 mm. We have presented above some design features of the main systems of the 60 MeV beam ejection channel. During arrangement of the given systems some defects were revealed, which are now being eliminated. Besides, considering that the mentioned channel will be operated in two regimes (short- and long-pulse conditions), the injector-buncher as well as the electron source modulators and accelerating sections must be substantially improved. This is connected with the fact that for the operation of the accelerator with

the "Nestor" facility it is the pulse front width is the basic characteristic, because it determines the transient period of a short pulse. For the operation of the accelerator with the experimental facility SP-95 (spectrometer) and the streamer chamber it is the stability of the flat top of the voltage pulse that is of most importance.

4. THE 160...200 MeV BEAM EJECTION CHANNEL

4.1. The main components of the 160...200 MeV beam ejection channel

It should be noted that nowadays in the world there are no electron accelerators of energies between 100 and 200 MeV, whereas in this energy range there are a wide variety of problems, which are currently central for nuclear physics. Therefore, it appears of importance for us to work at forming an electron beam of energy up to 200 MeV and an average current of no less than $1 \mu\text{A}$, directed to the direct output, the experimental facility SP-95 and the streamer chamber. In this connection, two additional sections must be installed for the 60 MeV beam ejection channel; its general layout together with the beam translation system is presented in Fig.13.

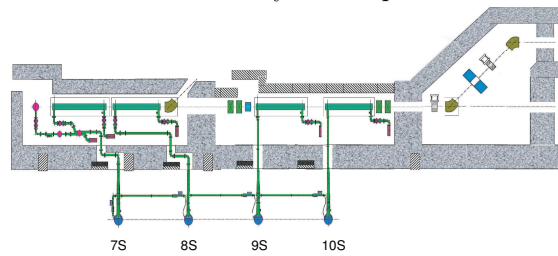


Fig.13. Layout of the 60 MeV beam ejection channel

The phase and energy characteristics of the beam formed in this case are given in Fig. 14. It can be seen from the last figure that here the energy spread of the beam also should not exceed 1 %.

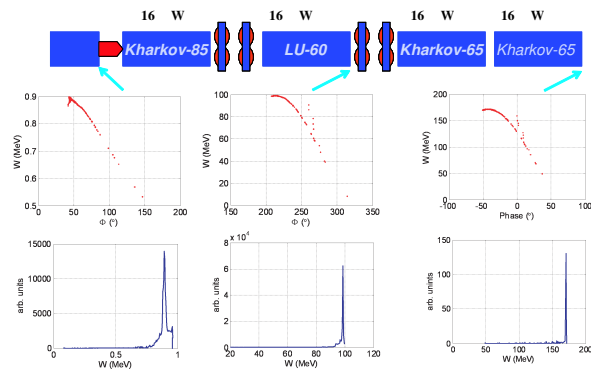


Fig.14. Phase and energy characteristics of the beam formed at 60 and 160...200 MeV ejection channels

The expected beam characteristics at the 160...200 MeV ejection channel are given in Table 3.

Table 3. *The expected beam characteristics at the 160...200 MeV ejection channel*

Energy, MeV	Up to 200.0
Pulse length, ns	1500
Pulsed current, mA	200
Energy spectrum width (steady-state conditions), %	1
Emittance (steady-state conditions), mm·mrad	0.1

4.2. Work plan for upgrading the 160...200 MeV beam ejection channel

The upgrading of the 160...200 MeV beam ejection channel calls for the following works to be done:

1. to perform repairs and all-round setting-up of modulator equipment for sections 9 and 10;
2. to install accelerating sections 9 and 10, to make their vertical and horizontal alignments with respect to accelerating sections 7 and 8, and also to align the beam translation system.
3. to arrange the vacuum system of sections 9 and 10;
4. to arrange the RF power supply of sections 9 and 10;
5. to arrange the thermostating system of sections 9 and 10;
6. to upgrade the control system of the 60 MeV beam ejection system of the with due regard for the necessity of controlling the operation of sections 9 and 10;
7. to restore the radiation shielding.

4.3. Basic research at the direct output of the 160...200 MeV beam ejection channel

1. Characterization of the radiation of axially channeled particles in the crystal at energies between 100 and 160 MeV and elucidation of the conditions, at which this mechanism of radiation is determinant as the beam passes through the crystal.
2. Investigation of the process of coherent radiation under conditions of real particle dynamics in the crystal.
3. Studies into coherent radiation characteristics at the conditions of dynamic chaos occurrence during particle motion in the periodic field of crystal atomic chains.
4. Feasibility analysis of producing monochromatic and polarized radiation in the energy range $E_\gamma \sim 100...160$ MeV.
5. Studies on the processes of interaction between the particle fluxes of energies up to 160 MeV and various materials.

5. THE BEAM TRANSLATION SYSTEM

5.1. The main components of the beam translation system and the spectrometer SP-95

Below we specify the main components of both the beam translation system and the experimental setup SP-95. As of today, the units that require great efforts for their upgrading are marked by italicizing, and the units that must be replaced are shown by underlining>.

The main components of the beam translation system

1. Bending magnets BM-1 and BM-2 with a field stabilization system;
2. electron line with a vacuum valve;
3. high-vacuum pump;
4. hole/slit collimators;
5. monochromators.

The main components of the experimental setup SP-95

- I. Electron line from the bending magnet BM-2 to the spectrometer SP-95:
 1. the electron line itself with a vacuum valve;
 2. vacuum facilities including fore pumps (3), a high-vacuum pump (1) and vacuum-measuring devices;
 3. beam steering system consisting of a corrector and two quadrupole lenses;
 4. beam energy compression system;
 5. secondary-emission monitor (SEM);
 6. Faraday cup (FC);
 7. current integrator of the SEM and FC.
- II. Spectrometer SP-95:
 1. scattering chamber;
 2. target facilities; a) for solid-state targets +four- and twelve-cell devices; b) for gas targets - GT-1 and GT-2;
 3. spectrometer's magnet with its proper vacuum chamber and cooling system;
 4. magnetic field stabilization and measurement system;
 5. magnet swing frame;
 6. radiation shielding of the electron counter;
 7. TV cameras for monitoring the beam position on the target and the bending angle of the magnet.
- III. Multichannel electron counter:
 1. electron counter head;
 2. high-stability photomultiplier (PM) power supplies of voltage up to 3 kV;
 3. electron lines of pulses from the electron detector PM, including coincidence circuits.
- IV. Computer for control and analysis of measurement data.
- V. Facility control panel.
- VI. Beam translation system and SP-95 control cabinets.
- VII. Cabling system: power, signal and control cables.

5.2. The basic research program for SP-95

1. Investigation of giant resonances in light nuclei as well as transverse and longitudinal response functions of nuclei at momentum transfers $q=0.5...1.1 \text{ fm}^{-1}$.

2. Investigation of isovector and isoscalar giant resonances.

3. Experimentation to determine the contribution of meson exchange currents to the zero moment of the longitudinal response function.

4. Studies on the extrapolation of response functions to the region of high-energy transfers (as indicated in the literature, this is the problem, the absence of the solution to which makes impossible the experimental verification of the majority of sum rules calculations).

5. Obtaining of data necessary for determining the exchange part of the Coulomb energy of atomic nuclei.

6. CONCLUSION

Thus, here we have outlined technical peculiarities of a number of main systems of the research accelerat-

ing complex LUE-300. Work plans have been developed for upgrading the beam ejection channels, the beam translation system and the spectrometer SP-95. The projected lines of research on radiation technologies, basic and applied nuclear physics appear topical for the nearest decade and the years ahead.

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ПРОЕКТ РЕКОНСТРУКЦИИ ИССЛЕДОВАТЕЛЬСКОГО КОМПЛЕКСА ЛУЭ-300 И НАПРАВЛЕНИЯ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

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Работа посвящена вопросам реконструкции исследовательского комплекса ЛУЭ-300 и программе планируемых на нем физических исследований. В ускорительном комплексе ЛУЭ-300 имеется в наличии три канала вывода электронного пучка, система параллельного переноса и спектрометр СП-95. В работе подробно описаны особенности модернизированных систем комплекса ЛУЭ-300, а также приведен план работ по его дальнейшей реконструкции и ожидаемые характеристики электронного пучка. Отдельное внимание уделяется программе физических исследований, проводимых и планируемых на экспериментальном комплексе.

ПРОЕКТ РЕКОНСТРУКЦІЇ ДОСЛІДНИЦЬКОГО КОМПЛЕКСУ ЛПЕ-300 ТА НАПРЯМОК ЯДЕРНИХ ДОСЛІДЖЕНЬ

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Работа посвящена вопросам реконструкции исследовательского комплекса ЛПЕ-300 та програмі фізичних досліджень які на ньому плануються. У прискорювальному комплексі ЛПЕ-300 є в наявності три канали виводу електронного пучка, система паралельного переносу та спектрометр СП-95. В роботі докладно описано особливості модернізованих систем комплексу ЛПЕ-300, а також наведено план робіт що до його подальшої реконструкції та характеристики електронного пучка що очікуються. Окрема увага наділяється програмі фізичних досліджень, які проводяться та які планується проводити на експериментальному комплексі.