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# A RAND NOTE

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INDICATIONS OF A SOVIET PARTICLE-BEAM WEAPON PROGRAM III. THE TIMING OF PAVLOVSKIY'S ACCELERATOR DEVELOPMENT (U)

Simon Kassel

August 1981

N-1739-ARPA

Prepared For

The Defense Advanced Research Projects Agency

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(U) The likelihood of a Soviet military program to develop charged-particle-beam weapons and the probable history of such a program are investigated on the basis of evidence in Soviet open-source technical publications. Individual notes examine three aspects of pulsed-power development: atmospheric propagation of high-current electron beams; repetitive pulsed-power switch technology; and probable history of Soviet accelerator developments. (EFP)

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## (U) PREFACE

(U) This Rand note was prepared in the course of a continuing study, sponsored by the Defense Advanced Research Projects Agency, of Soviet research and development of high-current, high-energy charged-particle beams and their scientific and technological applications.

[redacted] The note is the third in a series investigating, on the basis of evidence in Soviet open-source technical publications, the possible existence of a Soviet military program to develop charged-particle beam weapons and the probable history of such a program. This note examines the indications that A. I. Pavlovskiy has built a new, third generation of charged-particle accelerators. Pavlovskiy is known as the developer of the radial-line accelerator, a concept of military significance. Earlier notes in the series examine Soviet work on the propagation of high-current electron beams in air* and switch development.**

(U) The note, prepared for the Director's Office, DARPA, may also be of interest to pulsed-power specialists engaged in accelerator development and planning.

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*(U) Simon Kassel, *Indications of a Soviet Particle-Beam Weapon Program: I. High-Current Electron-Beam Propagation in Air* (U), The Rand Corporation, N-1737-ARPA, August 1981 (Secret).

**(U) Simon Kassel, *Indications of a Soviet Particle-Beam Weapon Program: II. Pulsed-Power Closing Switches* (U), The Rand Corporation, N-1738-ARPA, August 1981 (Secret).

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(U) SUMMARY

(S) A detailed study of A. I. Pavlovskiy's R&D activities during the past two decades, based on open-source publications, indicates that in 197[illegible] he probably built a high-current charged-particle accelerator capable of resolving the atmospheric beam propagation problem. This accelerator would be a third-generation machine, a successor to the LIU-10 accelerator. The pace of the Soviet program needed to produce such an accelerator by the mid-1970s is estimated to be similar to that of the current U.S. program at the Lawrence Livermore National Laboratory.

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CONTENTS

## (U) I. INTRODUCTION

(U) In assessing the present status of a possible Soviet particle-beam weapon (PBW) program, an essential step is to determine the timing of key Soviet R&D events that may be pertinent to such a program. Particularly important are the installation and activation dates of major particle accelerators and the milestones marking the progress of the various research projects. Soviet published technical literature contains ample material with which to structure R&D events in the time dimension. The continuity of successive research reports reflecting the evolution of theoretical concepts and experimental results provides the basis of the sequential structure. Dates of submission of papers to the editor and of publication, dates of cited Soviet and foreign papers, dates of conferences involving research disclosures, dates of filing and publication of patents, and dates of events mentioned in the text of research reports provide the necessary fixed points for the basic time sequence.

(/) An important question that arises here is whether, in view of the special sensitivity of events that may bear on PBW, the Soviets would elect to tamper with the dates of such events. The simplest way to conceal an advanced state of the art is to delay publication. The announced dates of activation of experimental facilities can be set later than the actual dates and made to conform to the delayed publication. It would be of interest to determine whether such artificial time shifts are likely in the case of substantial flows of interrelated documents and continuously evolving research activity. While the need to conceal the tempo of their development might tempt the Soviets to practice artificial dating, the network of mutually corroborating events and the evolutionary nature of the R&D process may well destroy the consistency required for such practice.

(/) This note traces the development between 1966 and 1980 of A. I. Pavlovskiy's work in an area pertinent to PBW and estimates the likelihood of the Soviets having tampered with the dating of key events. Pavlovskiy developed charged-particle accelerators with a broad range

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of military applications. An earlier Rand report[*] provides the groundwork for the present analysis, which extends the coverage of Pavlovskiy's publications through 1980.

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[*] (U) See Simon Kassel, *Development and Potential of Radial-Line Accelerators* (U), The Rand Corporation, R-2112-ARPA, March 1977 (Confidential).

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## (U) II. THE TIMING OF LIUB-2 AND LIU-10 ACCELERATORS

([redacted]) Pavlovskiy's publications reflect a long-term accelerator development that began in the 1950s with air-core betatrons, continued with toroidal inductor linear accelerators of the LIUB type, and reached an advanced state of the art in the LIU-10 radial-line accelerator. If the advanced parameters of the LIU-10 machine imply a significant military capability, whether as a radiography tool or a PBW test bed, it would be desirable to determine when such a capability became available to the Soviets. The establishment of such a benchmark would then make it easier to infer the level of achievement reached by the Soviets in high-performance accelerators and in the solution of beam behavior problems.

(U) The following analysis is based on the assumption that the LIUB and LIU-10 accelerators represent successive stages of accelerator development, i.e., that the latter evolved from the former. The simplest indication of this evolution is the progression of the operating parameters: from 2 MeV, 2 kA for the initial LIUB-2 machine; through 0.4 MeV, 25 kA for its later version; to 3.5 MeV, 50 kA for the LIU-10. Other indications derive from the evolution of the concept of air-core toroidal cavity inductors and, of course, from the comparison of time periods involved. If this assumption is correct, the timing of the LIU-10 development depends to some extent on the history of LIUB-2.

### (U) THE LIUB-2 ACCELERATOR PROJECT

(U) Several key dates mark the development of the LIUB-2 accelerator. The earliest is July 27, 1966, the filing date of the basic patent (author's priority certificate) describing beam transport in a magnetic field within the LIUB-2 accelerator [1].* The LIUB-2 was put into operation about a year later, sometime in 1967 [2]; however, nothing was published on it until 1970. If the LIUB-2 was initially

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*(U) This is the only patent among several filed by Pavlovskiy for air-core accelerators that is cited in the Soviet literature as pertaining directly to the LIUB-2 [2,16].

classified, some sort of preliminary downgrading must have taken place in April 1970. After that date, the above patent and a number of theoretical and experimental reports on the LIUB-2 were published, but without mentioning the accelerator by name [1,3-7]. The final declassification was reflected in an early 1974 paper [2], which disclosed the LIUB-2 designation, provided the installation date, and tied the patent and the several previous reports to this machine.

The classification hypothesis in regard to the LIUB-2 is supported by several additional interesting details. The publication of the 1966 LIUB-2 patent was delayed 4 years and 2 months, while other Soviet patents in the same category filed in 1966 were delayed 18 months on average and over 80 percent were delayed from 8 months to 2 years (see Fig. 1). For example, another Pavlovskiy patent for a linear induction accelerator concept, filed on the same day as the LIUB-2 patent, was published 16 months later [8]. Fourteen months after filing, the number of the LIUB-2 patent appeared in the Patent Bulletin with the notation "not for publication" in place of the usual abstract [9].* The long delay, together with the notation appearing at the normally expected publication time, strongly suggest that the LIUB-2 patent had been classified. The same procedure was later applied to the LIU-10 patent.

In addition to patents directly (although retrospectively) ascribed to particular accelerator systems, Pavlovskiy filed several unclassified patents for variants of his accelerator concept [8,10-12]. These patents were all published within approximately 1.5 years of filing, regardless of the assumed classification of LIUB-2 materials.

Thus, for the LIUB-2 accelerator, 1 year elapsed between patent filing and installation; about 3 years between installation and publication of the first papers reporting a current of 2 kA at 2 MeV; and 7 years between installations and publication of the final paper disclosing both the LIUB-2 project and the achievement of 25-kA beam output by a varianc of the machine. Figure 2 shows this time sequence in a graphic form.

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*Such a notation is frequent in the Soviet Patent Bulletin practice and does not necessarily imply classification.

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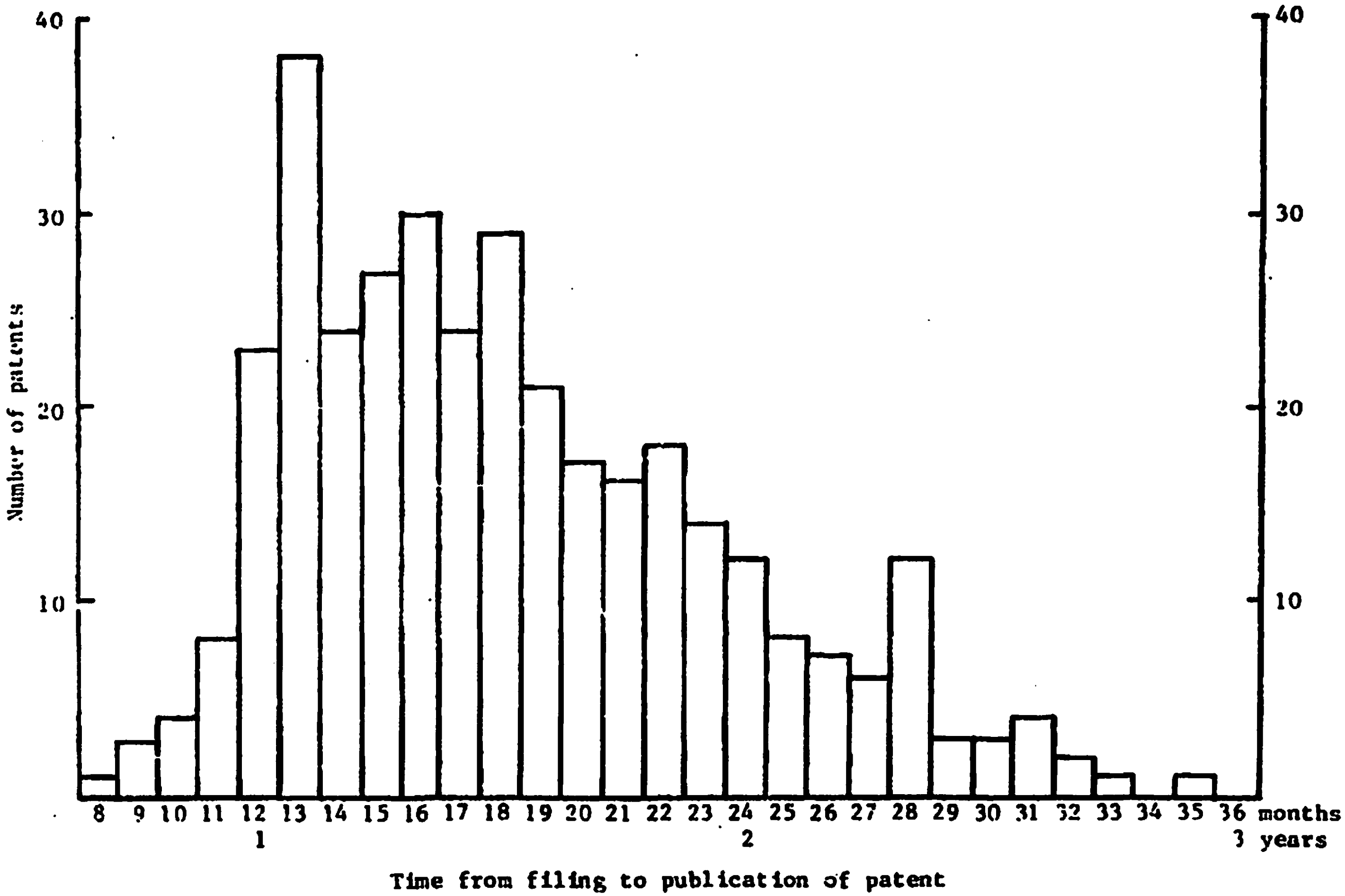


Fig. 1--Delay in publication of Soviet patents (authors' certificates) in Category 21g (category of Pavlovskiy's accelerators), filed in 1966 (SOURCE: *Otkrytiya, izobreteniya, promyshlennyye obraztsy, tovarnyye znaki. Ofitsial'nyy byulleten'*, Nos. 1-24, 1967, and 1-36, 1968)



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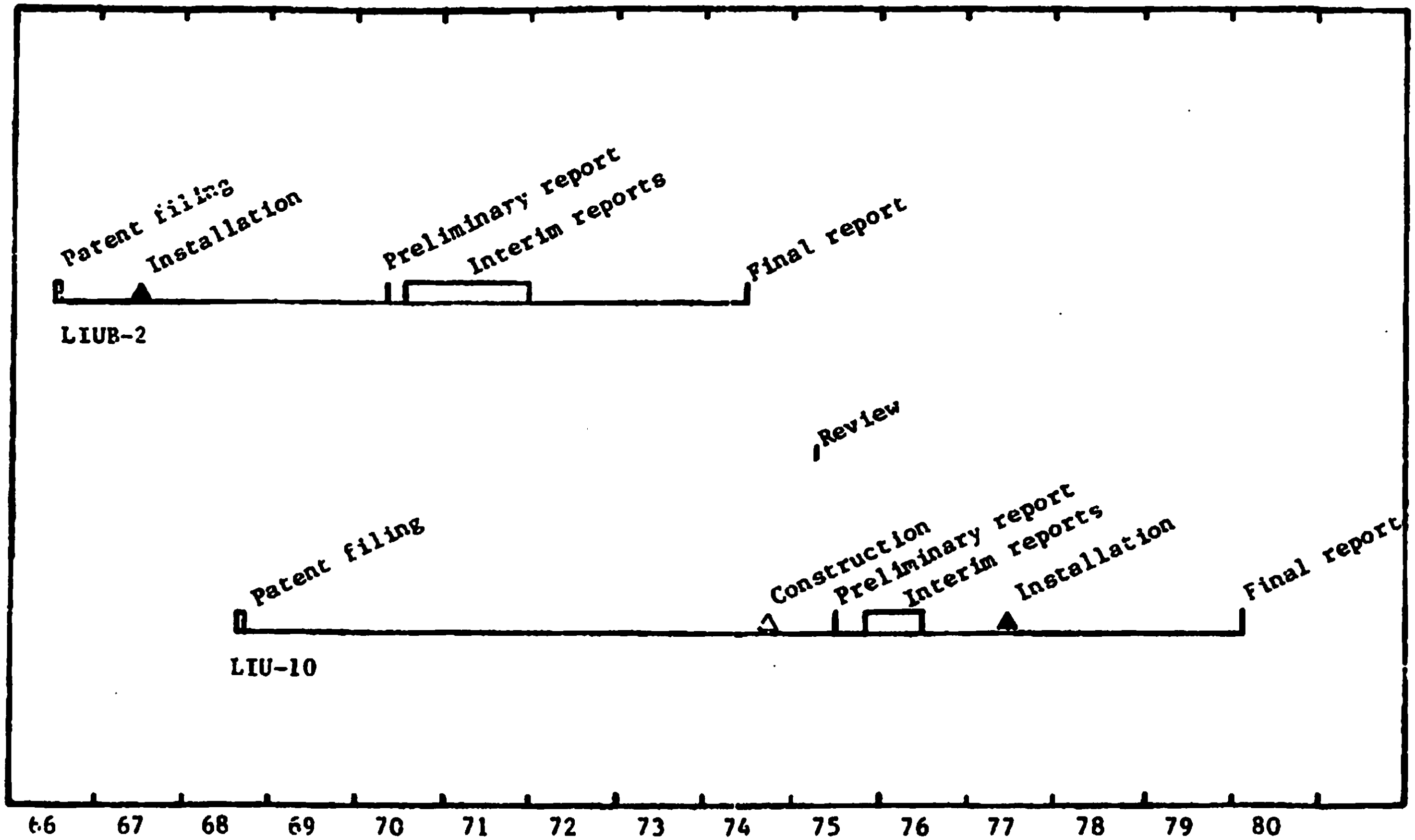


Fig. 2--Flow chart for development of Pavlovskiy's linear induction accelerators

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([redacted]) It is probable that the LIUB-2 project started well before the patent was filed. This assumption is based on the fact that only a year elapsed between the time the patent was filed and the LIUB-2 was put into operation, and a year seems too short a time for the design, construction, and installation of the accelerator. The important question, however, is whether the LIUB-2 machine was actually installed earlier than reported. The fairly long wait of 7 years before the Soviets disclosed the existence of the project argues against such a hypothesis. Furthermore, if the LIUB-2 were installed much earlier than the filing date of the patent, it would imply a carefully planned artificial program of gradual disclosure, including patent classification and declassification, projected over 10 years in advance, a highly unlikely procedure. Therefore, it is assumed that the time schedule of Fig. 2, derived from the available publications, and the installation date of 1967 reflect actual events. The 25-kA current was probably achieved in early 1972. The classification was probably downgraded in early 1970 because the next project involving radial-line accelerators and the LIU-10 had begun. We assume here that a new generation of technology renders the preceding generation relatively obsolete and thus less sensitive to disclosure.

(U) THE LIU-10 ACCELERATOR PROJECT

(U) As in the case of the LIUB-2, the LIU-10 project began with a basic patent [13], filed in August 1968; the patent, whose number was recorded in May 1970 as "not for publication," was finally published in November 1971. The patent specified a linear induction accelerator consisting of toroidal inductors with distributed parameters and a ring switch producing rectangular accelerating voltage pulses to ensure monochromatic particle energy. According to the patent disclosure, the proposed accelerator system was suitable for the generation of single pulses or a series of pulses of charged particles with a beam current of $>10^4$ A and a low repetition frequency ($\approx 0.1$ Hz). Pavlovskiy stated that this patent represented a new type of linear induction accelerator based on radial lines and intended to produce high-current charged-particle beams

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of tens and hundreds of MeV [14]. The term *radial lines* and the goal of $10^8$ eV appeared for the first time.

The similarity of the LIUB-2 project also extends to the report publication pattern, consisting of a preliminary [14] and a final [15] report.* The preliminary report, submitted to the editor in November 1974 and published in June 1975, announced that a radial-line accelerator had achieved an intermediate range of parameters (100 to 150 kA at 1 MeV) and that a larger (unnamed) machine was under construction. The final report, submitted to the editor in October 1979 and published in February 1980, disclosed the LIU-10 designation and installation date of 1977 and tied the patent and the preliminary report to the LIU-10 machine.

The timing of these events, however, was quite different from that of the LIUB-2 development. As shown in Fig. 2 (above), the interval between the filing date of the patent and the reported installation of the LIU-10 accelerator was over 9 years. The preliminary report was published about 2 years before the installation and the final report over 2.5 years after the LIU-10 was put into operation. Besides the long interval between the filing of the LIU-10 patent and the installation of the accelerator, the most significant departure from the LIUB-2 pattern was that Pavlovskiy reported the installation of LIU-10 as having occurred after the publication of the preliminary report.

In comparing the LIUB-2 and LIU-10 development patterns, as derived from Pavlovskiy's publications, one finds that the completion of the LIUB-2 cycle was followed shortly by the publication of a review paper [16] summarizing the LIUB-2 parameters and concept and outlining the possibilities of the LIU-10 project. The review paper was, in turn, followed within a few months by the preliminary paper of the LIU-10 project. The interval between the publication of preliminary and final reports was 4 years in both cycles, reflecting a remarkable consistency in Pavlovskiy's publication practices.

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*The term *final report* is used here only to show similarity to the LIUB-2 publications; it does not preclude possible future publications by Pavlovskiy on this subject.

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([redacted]) The LIU-10 accelerator is a more complex machine than the LIUB-2 or the 25-kA variant, requiring a longer time for construction, installation, and experimental work. However, the reported interval of 10 years between the installation dates of the LIUB-2 and LIU-10 accelerators seems excessive, in view of the fact that the respective patents were filed only 2 years apart. On the other hand, the publication interval, as noted above, was the same—4 years—for each project. These facts lead to the hypothesis that both 4-year publication periods were devoted mainly to the processing and presentation of material obtained at some earlier time, and that the LIU-10 had been installed earlier than Pavlovskiy had reported. If his work is indeed as consistent as it appears from Fig. 2 (above), the LIU-10 accelerator should have been installed after the filing of the patent and before the submission of the preliminary report. If the LIU-10 had been installed in, say, 1970 instead of 1977, some key facts about Pavlovskiy's projects could be more easily reconciled. Specifically, a 1970 installation date would:

1. Give Pavlovskiy 5 years for experimental work before publication, in contrast to the 3 years available to the LIUB-2 project and the 2 years available to the LIU-10 project if the 1977 installation date were valid.
2. Coincide with the hypothetical declassification of LIUB-2 materials and provide a rationale for such action.
3. Render more credible Pavlovskiy's statement about the accumulated experience of 5,000 to 10,000 shots sustained by the LIU-10 machine.
4. Allow twice as long an interval between patent filing and installation for the LIU-10 as for the LIUB-2, reflecting the greater complexity of the LIU-10.
5. Conform to the LIUB-2 development pattern.

([redacted]) The discrepancy of 7 years between the hypothesized and reported installation dates of the LIU-10 accelerator may be resolved by

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considering that an accelerator is regarded as "under construction" (as stated in Pavlovskiy's LIU-10 preliminary report) until a formal acceptance procedure has been completed. In this case, the final report, stating that the LIU-10 had been put into operation in 1977, can be interpreted as referring to the formal acceptance date.

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## (U) III. THE THIRD GENERATION

([redacted]) On the basis of the hypothetical installation date of 1970 for the LIU-10 accelerator, it is possible to extrapolate the known pattern of LIUB-2 and LIU-10 development to the next generation of Pavlovskiy accelerators. The third-generation accelerator would be more complex and powerful than the LIU-10 and would probably require more time than the two preceding systems. It is assumed that the additional time for the third-generation accelerator can be estimated by doubling the intervals between (1) the LIUB-2 and LIU-10 patent filing dates and (2) the patent filing and installation of each accelerator. Two years elapsed between the filing of patents for the LIUB-2 and LIU-10 accelerators. Therefore, the third-generation accelerator patent is assumed to have been filed 4 years after the LIU-10 patent filing date, i.e., in 1972. The interval between patent filing and installation was 1 year for the LIUB-2 and 2 years (hypothetical) for the LIU-10, and is thus assumed to have been 4 years for the third-generation accelerator--leading to an estimated installation date of 1976. Figure 3 shows the progression of Pavlovskiy's accelerators up to the hypothetical third generation.

([redacted]) The 1976 installation date is close enough to the LIU-10 preliminary report publication date to conform to the pattern of the preceding generations. It could be argued that the publications on the LIU-10 accelerator were released because the next generation machine was installed, just as it was assumed that the hypothetical installation of the LIU-10 provided the rationale for releasing the publications on the LIUB-2.

(U) The above assumptions and hypotheses are speculative. They are driven by a superficial logic of characteristic time spans apparent in the development cycles of the first two generations of Pavlovskiy's accelerators, and by a sense of imbalance inherent in the reported timing: the overly long period between the two documented generations of accelerators (10 years from the installation of LIUB-2 to that

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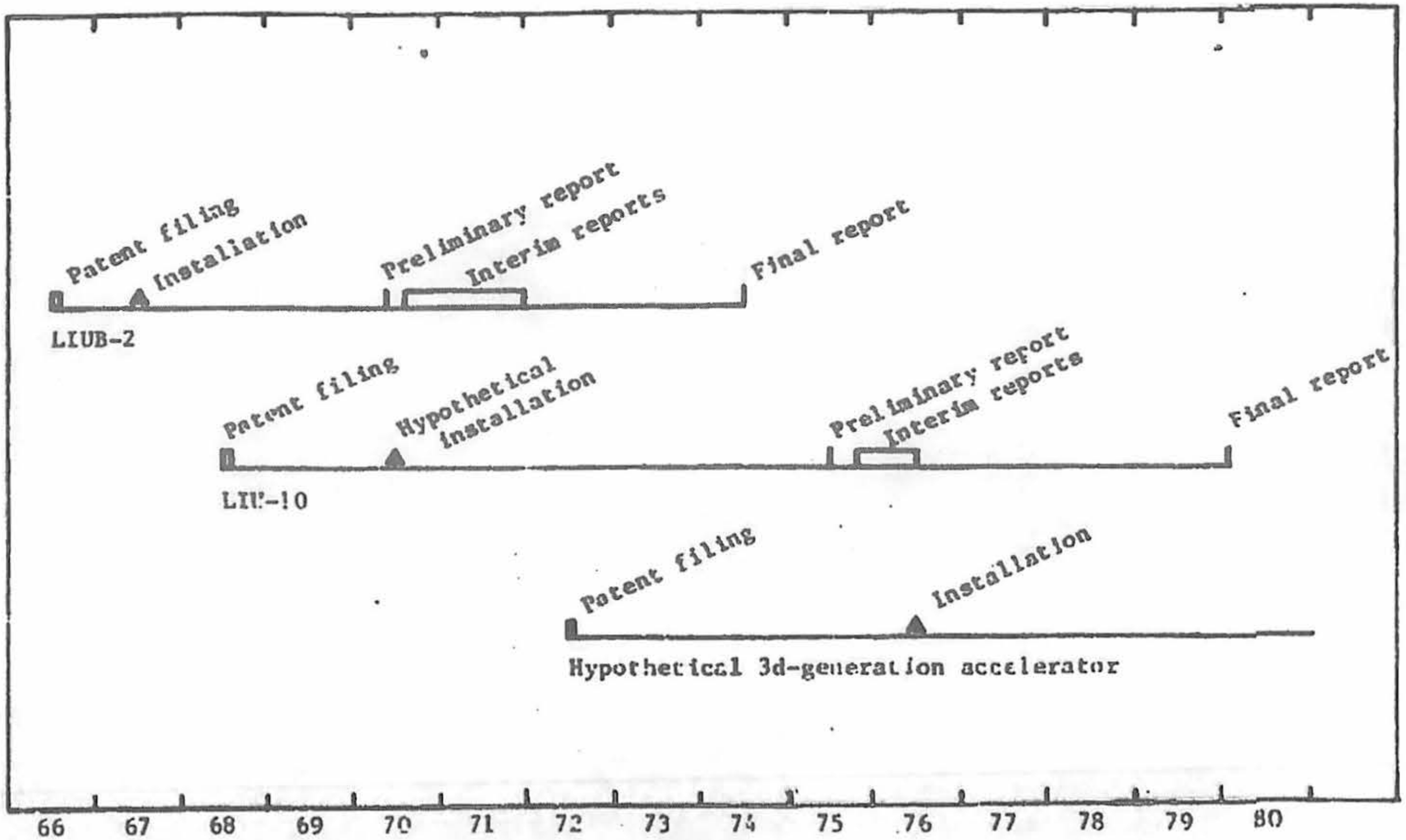


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(U) Fig. 3--Hypothetical extrapolation of Pavlovskiy's accelerator development

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of LIU-10), and the overly brief period of 2 years between the reported installation of LIU-10 and the final report.

([redacted]) If these hypotheses are correct, it would mean that in the mid-1970s the Soviets had an accelerator capability far surpassing anything that the United States has available today. Scaling up from the 2 MeV of the LIUB-2, through the 13.5 MeV of the LIU-10, the third-generation accelerator should have enough beam energy to address the question of atmospheric propagation directly, by experiment. The installation of the third-generation accelerator in 1976 would thus amount to a significant milestone in the Soviet high-current accelerator program.

(U) So far, we have discussed the central portion of Pavlovskiy's activities: the development of air-core linear induction accelerators. We now turn to examine how these activities fit within a broader perspective of Pavlovskiy's work.

## IV. THE TIMING OF COLLATERAL RESEARCH ACTIVITIES

Pavlovskiy's publications reflect a broad range of R&D projects with varying degrees of relevance to his development of high-current accelerators. Some of these projects involve the study of physical phenomena, such as radiography, relevant to the development of nuclear weapons. Others are in the category of basic or applied research with less obvious applications. The following published research projects not involving accelerators have been associated with Pavlovskiy during the past 15 years:

1. Development of high-energy lasers.
2. Study of the Faraday effect in megagauss fields.
3. Study of gas discharges forced by a magnetic field to interact with insulators.
4. Study of neutron and X-ray emission from plasma focus.
5. Production and study of a discharge channel in air.
6. Generation of high magnetic fields.
7. Dynamic compression of crystals by magnetic fields.

The first three projects were initially performed by known institutes and were later joined by Pavlovskiy and members of his group. The last four projects appear to be internal to Pavlovskiy's organization. As the following discussion will show, the timing of the collateral projects and their organizational relationships may have an important bearing on our understanding of the overall thrust of Pavlovskiy's activities. Equally significant may be the circumstances of installation and use of the following three distinct types of energy storage facilities available to Pavlovskiy:

1. A 500-kV Marx generator.
2. A series of explosive magneto-cumulative generators (MCG).
3. Two high-energy capacitor banks for 1.35 and 2.7 MJ, designated MKB-1 and MKB-2, respectively.

Each of these facilities was attended by its own team of designers and experimentalists, and each had a role in several of the accelerator development and collateral projects.

The Marx generator was designed and operated by the same team that developed Pavlovskiy's accelerator. Early in 1971, the Marx generator was described as intended for the LIUB-2 accelerator [4]. The MCGs were used to drive variants of Pavlovskiy's betatron [17], and the MK-2 type C-160 MCG was reported to be delivering 1 MJ to a LIUB accelerator [18].

Pavlovskiy's magnato-cumulative generators, first suggested in 1951 by A. D. Sakharov, were realized for the first time in the Soviet Union in 1952 [19-21]. Remarkably fast progress was made in the early years: the MK-2 was built within a year of the initial proposal. and in 1953 it delivered 100 MA [20,21]. According to Sakharov, the MCG development cycle lasted from 1952 to 1956. It is not clear whether Pavlovskiy was involved in the development. R. Z. Lyudayev, a member of the team that built the first Soviet MCG, was later identified with Pavlovskiy's MCG team.

According to Pavlovskiy, these early devices were not practical. Subsequently, extensive research, reported on after 1965 by Pavlovskiy's team, was dedicated to improving the MCGs, shortening the current rise time, and increasing the efficiency of conversion from chemical to electromagnetic energy and energy gain. Despite the high level of effort that he devoted to MCGs, Pavlovskiy considered them temporary substitutes in exploratory research for which large capital expenditures for extensive facilities were not readily available [22].

The MKB-1 capacitor bank was installed in 1965 and the MKB-2 in 1968, according to a report published in 1974. This report, without mentioning any application to accelerators, stated that the capacitor banks were intended for the study of fast processes [23]. They were used, however, to provide the initial field in some MCGs [24].

The use of the above energy storage facilities, which in the 1960s involved the LIUB-2 accelerator, appears to have changed in the 1970s, and between 1973 and 1975, all three were used in collateral projects.

The Marx generator found aplication in laser development. The laser work had begun in the 1960s at the Physics Institute of the

Byelorussiar Academy of Sciences in Minsk, initially under B. I. Stepanov and A. N. Rubinov [25]. Between 1970 and 1974, the Minsk Institute issued a steady flow of papers by Rubinov. L. V. Sukhanov, and others on rhodamine lasers and their effect on various materials [26-31]. These papers are closely interlinked by author, subject, and a network of citations. When Pavlovskiy became associated with this group, he made the Marx generator available to it.

Since 1975, a series of reports have been published jointly by Pavlovskiy and Sukhanov on the investigation of several laser types, including an Nd glass laser with a coaxial flash lamp which yielded 660 J in a 250-μs pulse [32] and a $CO_2$ laser pumped by an electron beam [33]. The Marx generator was reported in connection with an electric discharge $CO_2$ laser [34]. This paper had no Minsk coauthors, possibly because the Minsk researchers did not have direct access to Pavlovskiy's facility. In 1979, again in a joint effort, Pavlovskiy investigated the effort of a rhodamine 6G laser on aluminum, exposing the metal to a beam intensity of 5 to 60 $MW/cm^2$ [35].

The MCG facility began the study of electro-optical phenomena in high magnetic fields about 1974 and the compression of quartz by high magnetic fields in 1978. As in the case of the laser project, the electro-optical studies began much earlier outside Pavlovskiy's organization.

In 1959, G. S. Krinchik of the Moscow State University was the first to introduce the concept of magnetic susceptibility of a magnetic crystal at optical frequencies to explain the Faraday effect in ferrite garnets [36]. V. V. Druzhinin of the Moscow Engineering Physics Institute has worked on the energy-level structure of paramagnetics since at least 1965 [37]. In a paper submitted to the editor in 1972 and published in 1974 [38] Druzhinin noted Sakharov's MCG paper [19] and expressed interest in the study of polarization plane rotation in various media in strong magnetic fields. Shortly afterward, Pavlovskiy, Krinchik, and Druzhinin coauthored several papers on the Faraday effect, using MCGs to produce the magnetic field [39-41]. Since that time, Pavlovskiy and Druzhinin have jointly reported experiments using increasingly strong magnetic fields [42-45]. At the same time, Krinchik and Druzhinin have continued to publish separately and without Pavlovskiy the results of their work not involving megagauss fields [46-51].

The MKB capacitor bank facility reported between December 1973 and July 1975 on the study of electric discharge channels in air [52], generation of strong magnetic fields [53], and plasma focus experiments [54,55]. These studies appear to be wholly internal to the Pavlovskiy organization, consist of one or two papers each, and do not cite earlier papers by their authors in the areas involved. The MKB-1 capacitor bank was used in all experiments.

The pattern evident in the use of the three energy storage facilities suggests the following hypothesis: The establishment of all three facilities in the mid-1960s coincided with the start of work on the LIUB accelerators.* From that time until the early 1970s these facilities were used for the LIUB accelerators and possibly for Pavlovskiy's betatrons. Since 1973, just after the final report on the LIUB-2 machine, the energy storage facilities were switched to collateral projects. They do not appear to have been used in connection with the LIU-10 accelerator.

Figure 4 shows the three energy storage facilities and the projects in which these facilities have been used. The cluster of the collateral projects appears on the right side of the chart.

*The installation date of the Marx generator is not known; however, since it was intended for the LIUB accelerators, we can assume that it goes back at least as far as the LIUBs.

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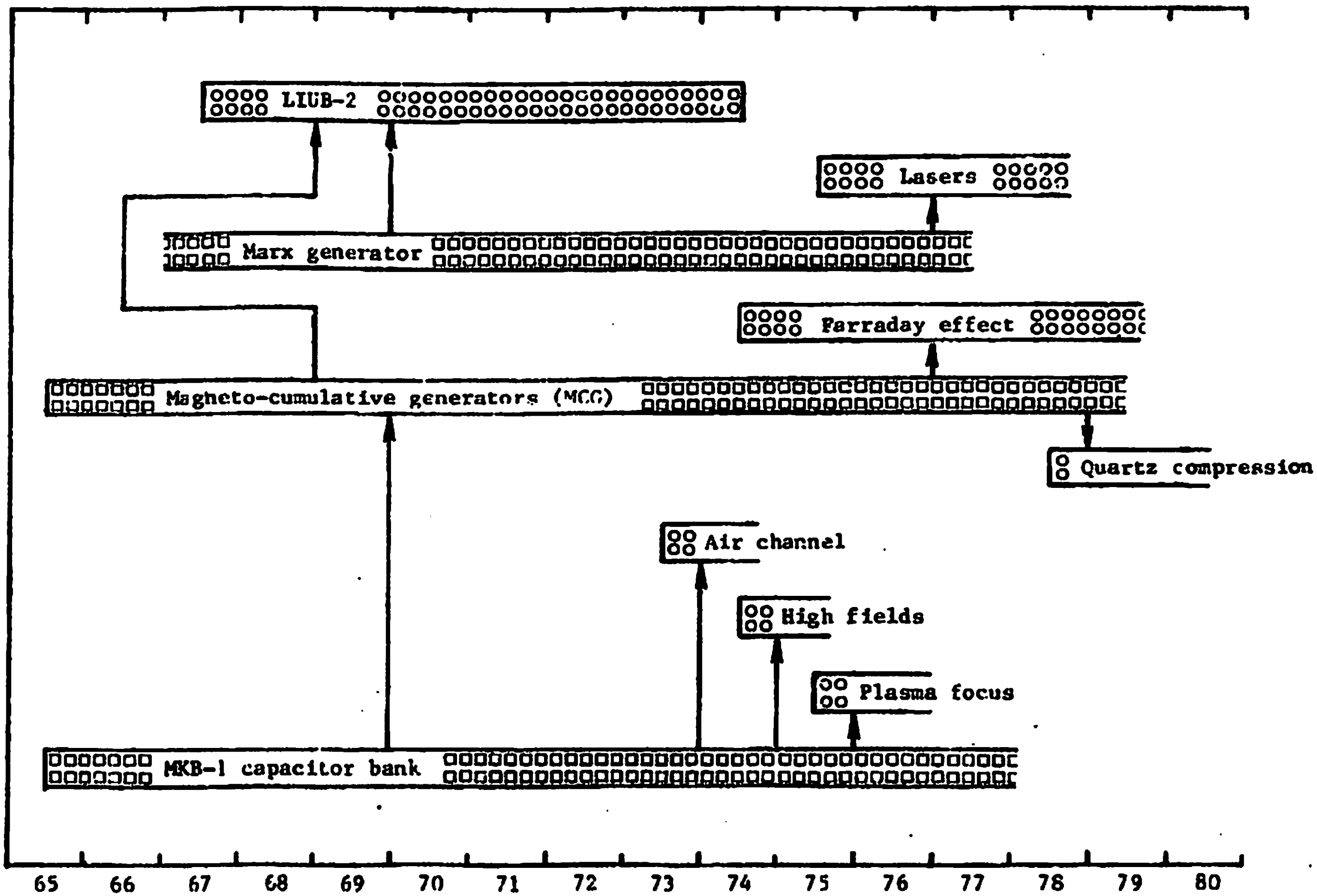


Fig. 4--Pavlovskiy's energy storage facilities (square shading) and their applications (circle shading)



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## V. CONCLUSIONS

If the above hypothesis about the shift of the energy storage facilities to collateral projects is to have any validity, the starting dates of these projects in Pavlovskiy's organization must be known with an accuracy of 1 to 2 years. In the case of the two largest projects, those involving lasers and the Faraday effect, such dates can be established through the history of this work prior to Pavlovskiy's entry. In both cases, before Pavlovskiy participated, there is an unbroken continuity of reports published by the initiating institutes: the Minsk Institute of Physics for the laser project and the Moscow State University and Moscow Engineering Physics Institute for the Faraday effect project. In both cases, after joining the projects, Pavlovskiy relied on their earlier work, citing their results in his publications. It is neither likely, nor reasonable to assume, that he and his associates worked on these projects long before the publication of his first reports in these areas.

The two major projects thus provide a circumstantial, but nevertheless positive, indication of the starting dates of Pavlovskiy's involvement. They also represent sufficient evidence of the shift of the energy storage facilities to collateral activities, since they involve the two facilities that were previously directly associated with accelerator development. The third facility, the MKB capacitor banks, was not intended, at least according to published reports, to be used for the accelerators. The timing of its first use in the collateral projects cannot be established positively; it can merely be said that none of the reports from these projects shows any citation history and all appear to be recently commenced work.

If the above evidence is valid, the energy storage facilities were shifted to collateral activities between 1973 and 1975. Between 1965 and 1973, these facilities were used in accelerator development and perhaps also in other, unpublished applications.

Declassified [redacted]



(U) The history of the energy storage facilities can now be compared with the history of the LIUB-2 and LIU-10 accelerators discussed in the early sections.

([redacted]) Figure 5 shows that the timing of the shift in the use of the energy storage facilities coincides precisely with the timing of the LIUB-2 final report, the review of past work and future possibilities, and the preliminary report on the LIU-10. The shift also coincides with the hypothetical period of construction of the extrapolated third-generation accelerator. These coincidences provide strong evidence that a major, significant transition must have occurred in Pavlovskiy's accelerator program at that time.

([redacted]) One interpretation of this transition is that after the LIU-10, Pavlovskiy phased down or abandoned further development of accelerators. However, the scale of Pavlovskiy's enterprise and the tempo of his work render this possibility very unlikely. His effort was particularly intense in the case of the last reported accelerator, the LIU-10, used in up to 10,000 shots. Even if we allow 5 years of operation from the hypothetical installation date, rather than the 2 years reported by Pavlovskiy, the accumulated total of shots represents an impressive operating rate. It is more probable, therefore, that Pavlovskiy continued to develop accelerators and produced the third-generation machine.

([redacted]) No evidence connects any of the three energy storage facilities to the LIU-10 accelerator. The LIU-10 may possibly have its own, specially built energy storage system. The shift of the three known facilities to collateral research may indicate that a totally new and unique energy storage system has been acquired in the third-generation accelerator, releasing the older facilities and some of their personnel from work related to accelerators.

([redacted]) In the light of this conclusion, the 1973-1975 period marked the completion of all work on the LIUB-2, the completion of experimental work and publication of the preliminary report on the LIU-10, the shift of the old energy storage facilities to collateral work, and the construction of the third-generation accelerator. This turning point in Pavlovskiy's accelerator development was signaled by the review

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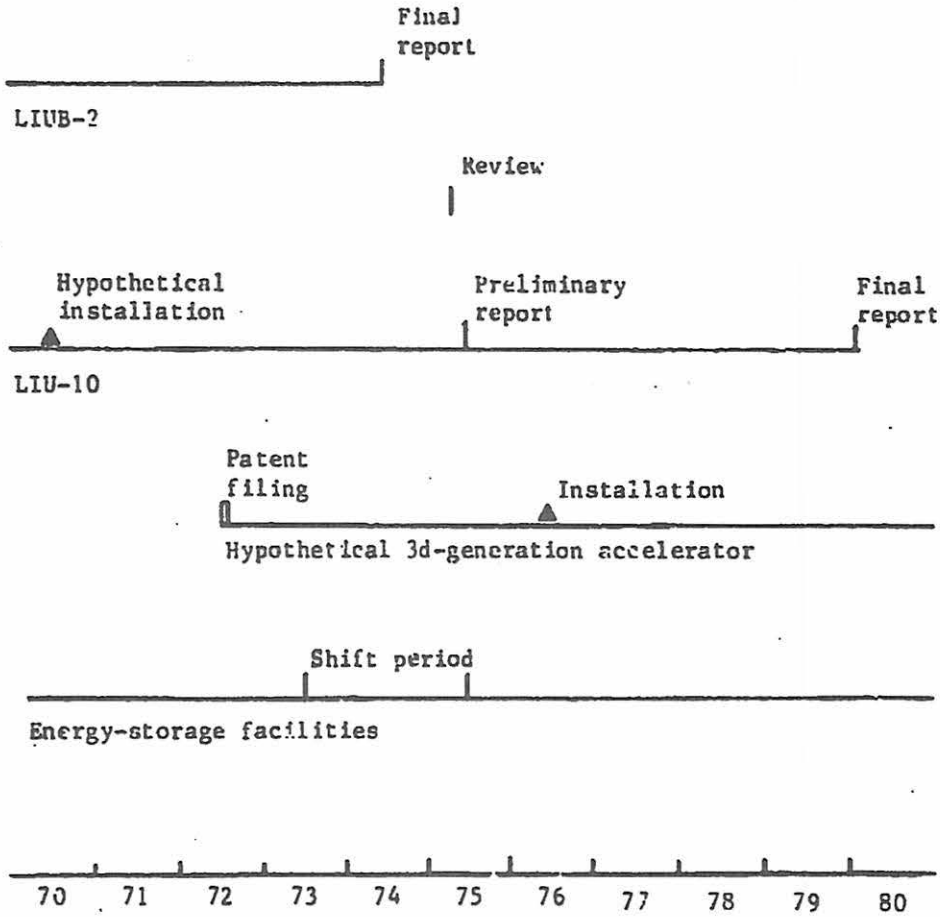


[redacted]

(U) Fig. 5--Hypothetical flow chart of Pavlovskiy's research activities

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[redacted]

published during that period [16]. The launching of the new, hypothetical accelerator system might have rendered the older LIUB-2 and LIU-10 less sensitive to publication and provided an opportunity for reviewing past work and hinting at future plans. These hints were, of course, vague, merely indicating the desirability of continuing the development of accelerators with distributed parameters and the expectation of megajoule machines.

([redacted]) The third-generation accelerator may or may not be a megajoule machine. However, the progression of Pavlovskiy's accelerator generations indicates that the third generation would at least equal the parameters of the future Advanced Test Accelerator (ATA) of Livermore. The rate of progress required to achieve this state of the art need not have been greater than that of the Livermore program. The interval between the installation date of the LIUB-2 and the hypothetical installation date of the LIU-10 (the first and second generations) is the same 3 years projected between Livermore's FTA and ATA. This study postulates another 6 years between the LIU-10 and the third-generation accelerator, implying a fairly moderate pacing of the Soviet program.

([redacted]) If these hypotheses are correct, we may conclude that in 1976 the Soviets had a charged-particle accelerator capable of a direct experimental assault on the problem of atmospheric beam propagation.

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*See list of reference abbreviations, p. 27.

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AE--*Atomnaya energiya*
Byul. OIPTZ--*Otkrytiya, izobreteniya, promyshlennyye obraztsy, tovarnyye znaki. Ofitsial'nyy byulleten'*
DAN SSSR--*Doklady akademii nauk SSSR*
FMM--*Fizika metallov i metallovedeniye*
FP--*Fizika plazmy*
FTT--*Fizika tverdogo tela*
KE--*Kvantovaya elektronika*
OS--*Optika i spektroskopiya*
PTE--*Pribory i tekhnika eksperimenta*
UFN--*Uspekhi fizicheskikh nauk*
ZhETF--*Zhurnal eksperimental'noy i teoreticheskoy fiziki*
ZhETF Pis'ma--*Pis'ma v Zhurnal eksperimental'noy i teoreticheskoy fiziki*
ZhTF--*Zhurnal teoreticheskoy fiziki*
ZhPS--*Zhurnal prikladnoy spektroskopii*