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# SOVIET LASER-FUSION RESEARCH ORGANIZATIONS: A PRELIMINARY OUTLINE

Simon Kassel, Nikita Wells
Cathleen Campbell and Maureen Coté

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## PREFACE

This working note was prepared within the framework of the Rand project entitled "A Study of Soviet Laser Fusion" for the Fusion Energy and Physical Research Division, U.S. Department of Energy. It describes Soviet research organizations engaged in areas pertinent to laser fusion, using as source materials regular Soviet serials published from 1969 to late 1978.

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## KEY TO INSTITUTES

| | |
|---|---|
| FIAN | Lebedev Physics Institute, Academy of Sciences |
| IAE SOAN | Institute of Automation and Electrometry, Siberian Department, Academy of Sciences |
| IAM | Institute of Applied Mathematics |
| IHT | Institute of High Temperatures |
| INP SOAN | Institute of Nuclear Physics, Siberian Department, Academy of Sciences |
| IPE | Institute of the Physics of the Earth |
| ISR | Institute for Space Research |
| Kurchatov | Kurchatov Institute of Atomic Energy |
| LITP | Landau Institute of Theoretical Physics |
| MEPI | Moscow Engineering Physics Institute |
| NPRI | Nuclear Physics Research Institute, Moscow State University |
| PTI Ukr AN | Physico-Technical Institute, Ukrainian Academy of Sciences |
| Yefremov | Yefremov Institute of Electrophysical Equipment |

# I. INTRODUCTION

The present report constitutes the first stage of the Soviet Laser Fusion project intended to develop a comprehensive picture of Soviet laser fusion research in its organizational and substantive aspects. The aim of the first stage has been the collection of organizational data on Soviet research in this area and the initial identification of specific research teams, leadership structure, institutions and objectives, and their changes in time.

Knowledge of the organizational structure of Soviet laser research is a necessary prerequisite in the study of Soviet results: it supplies a context for Soviet published materials and makes it possible to interpret in a meaningful way the idiosyncratic features of Soviet approach, methodology, and planning.

Soviet publications on laser fusion research do not provide detailed tables of organization. Therefore, comprehensive organizational information can be obtained only by careful compilation of a large flow of routine publications in the pertinent research area. The bulk of such publications consists of the regular serials covering technical reports and surveys of past research results. These sources were used as the main input to the first-stage implementation of the project. The picture of the Soviet research organization obtained in the course of this effort is preliminary and incomplete. It is a basic outline of the active Soviet research units and their relationships, to be further refined and filled in during subsequent stages of the project.

While the regular serials, or technical journals, are important in providing the necessary basic organizational framework, they frequently fail to supply up-to-date information on new or planned research. In the area of laser fusion, for example, Soviet regular serials have little, if any, information on the newest technical facilities being built, such as the Del'fin laser system. Such data on the new systems as are available, are usually provided in the Soviet irregular publications represented by institute proceedings, preprints, etc.

Consequently, the present report does not comment on the new facilities, and refers to specific systems and experiments only to the extent to which they are available in the regular serials. The present report is also limited in its coverage of the substantive aspect of Soviet research, i.e., Soviet theoretical and experimental work, techniques, and results. Since the main objective of this report is the organizational picture of Soviet laser fusion research, the substantive aspect is included only to define the operational profile of the organizational units.

The regular serials used for this report were Soviet technical journals pertinent to laser fusion and published during the period from 1969 to the present. Approximately 1,000 research reports and surveys published in these journals were analyzed, and over 470 were selected for use in this report. The selection process started with papers directly and explicitly associated with the Soviet laser fusion effort. As the outlines of the principal teams involved in the effort emerged, other relevant papers of the participating authors were included. The coverage was also extended to a significant body of supporting material pertinent to laser fusion theory and experimentation.

The study consists of three sections and an appendix. The section entitled "Preliminary Results" provides an overview of the network of teams, institutes, and subject areas of research, discusses the relationships within the teams and groups of teams, and presents statistical data concerning the authors, papers, and subject areas for the years included in this report. The discussion of the results obtained so far is followed by a section entitled "Plans for Further Work" outlining the steps beyond the first stage, necessary to complete the organizational picture of Soviet laser fusion research.

The section entitled "Soviet Research Institutes and Teams" provides a series of individual team outlines arranged in institutional groups. Each team outline consists of a brief definition of the subject area of activity of the team, followed by personnel listing and statistical data for the team. The personnel listing identifies the leadership of the team, the main body of participating authors, and, whenever possible, the non-author participants in the team's activity, such as supervisors, technicians, and reviewers. The category of reviewers of technical reports generated by the team is important in that it reveals inter-team and inter-institutional relationships. Statistical data provide an annual breakdown of active authors and papers published by the team. A brief analysis of the main papers, achievements, and apparent objectives completes the team outline.

The Appendix lists all Soviet personnel identified in this study in alphabetical order and in a breakdown by function. Each entry in the listing includes the time period of active participation, institutional affiliation, and team designation.

## II. PRELIMINARY RESULTS

The first-stage analysis of open-source regular serials reporting on Soviet laser fusion reveals 26 specialized author-teams pursuing their research projects either during the entire 1969-1978 period covered in this report, or at least during a significant portion of that period. The projects fall within 12 subject areas, arbitrarily designated for the purpose of this report.

The specialized teams are arranged into institutional groups; the largest are the two groups of teams of the Lebedev Physics Institute. The first, designated as Group I, is under the leadership of N. G. Basov and consists of six distinct teams. The second, or Group II, headed by A. M. Prokhorov, also consists of six teams. Next, there are two groups of two teams each, one of the Kurchatov Institute of Atomic Energy, and the other of the Yefremov Institute of Electrophysical Equipment. Finally, there is a group of three teams, each headed by V. Ye. Zakharov, and each affiliated with a different institute. The remaining teams do not form groups and are allocated one to an institute. The teams appear to be highly specialized; none deal in more than one of the 12 subject areas, although several teams may fall within the same subject area.

### A. SUBJECT AREAS OF RESEARCH

The set of 12 subject areas has been identified on the basis of the technical content of the entire body of research reports analyzed for this report. The subject breakdown is in part based on the distinction between those research activities that are directly involved in laser-fusion research, and those that may be also oriented toward other applications, or provide indirect support to laser-fusion theory and experiments. Thus, the theory of parametric instabilities in plasma, the subject of a major portion of Soviet open-source materials published in the laser-fusion area, is being developed explicitly for laser-fusion targets by some teams, and on a more general level, as a phenomenon of electromagnetic wave-plasma interaction, by other teams.

A second basic criterion of the subject breakdown is derived from the apparent extreme specialization of the Soviet research teams. The dynamics of the laser-fusion target heated by the beam seems divided by Soviet researchers into several distinct aspects: processes occurring in the target-derived plasma corona involving the beam absorption and reflection problems, processes involving thermonuclear burn, and compression processes occurring during the implosion of the target. Each aspect is emphasized by a different team or set of teams.

The following is a brief description of the 12 subject areas; the first three correspond to the three aspects of the laser target heating process. The names of the subject areas have been designed for the purpose of this report.

1. Target plasma dynamics. This is the largest of all subject areas in terms of the number of active authors, published papers, the number of teams, and the prestige of participating researchers. The area includes all processes known to occur in the heated target but focuses on the early stages of the heating process. The dominant theme is the energy transfer mechanism based on the Langmuir turbulence theory. The research involves various types of parametric instabilities and their effect on electromagnetic energy absorption in plasma, the energy balance of laser plasma, and the development of the so-called soliton model to describe Langmuir turbulence.

2. Target fusion dynamics. A single team appears to be active in this area dealing with the later stages of target implosion. The team is involved in a more speculative research than that of other teams, and considers future research objectives, including the design of commercial fusion reactors. It is also the team that has published the well-known papers on the large high-aspect-ratio shell targets of high mass and low density expected to yield energy gains of 1,000. A main topic is the consideration of neutron yields.

3. Target compression theory. A single team has been investigating the Rayleigh-Taylor instability applied to shell targets.

4. Plasma dynamics. While similar to the first subject area above, the plasma dynamics area includes research on plasma-beam heating without explicit application to laser fusion. The specific topics are numerical simulation of parametric instabilities, turbulence of isothermal plasma, anomalous absorption, hydrodynamic plasma models, and self-focusing in nonlinear media.

5. Solid-derived plasma. This may be an area most remote from direct application to laser fusion.* Significant topics are optical breakdown near the surface of solid targets, theory of vaporization of metals, absorption of laser light in breakdown plasma, radiative and detonation waves in plasma formed on solid surfaces by laser beams, and analysis of the recoil pressure exerted on solid target surfaces by shock waves generated by laser beams. Mass-spectroscopic studies of laser plasma derived from metals and other solids are made to establish the kinetics of plasma expansion. An explicitly stated application is a multicharged ion source for accelerator injectors.

6. High magnetic field laser interaction. Threshold magnetic field intensities are investigated by a single team to determine their effect on the expansion of laser spark plasma. The area topics also include the investigation of the possibility of increasing plasma beam absorption by strong magnetic field.

7. High energy short pulses. Work in this area carried on by several teams includes picosecond pulse generation and shaping of picosecond pulses for laser fusion experiments, development of passive shutters based on synthetic dyes for picosecond lasers, and investigation of plasma heating effects by picosecond laser pulses.

8. X-ray Spectroscopy. This subject area involves the development of methods of x-ray spectroscopy for laser-plasma parameter measurements in explicit support of laser-fusion research, and other applications.

9. Kilojoule $CO_2$ Lasers. The development of high-power $CO_2$ lasers extends in this area to electro-ionization laser types, investigation of window materials, thermal self-focusing and breakdown in crystals, and detectors of nanosecond laser pulses.

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*There are, however, several phenomena directly pertinent to laser fusion research, such as effects near spatial pinholes in laser amplifier systems.

10. Neodymium Rod Lasers. Research in this area consisted of the development of multi-stage kilojoule neodymium lasers with rod-shaped active elements, designed explicitly for laser-fusion experiments. The work included experiments with irradiating heavy targets. A separate research effort was aimed at the study of glass damage by high-energy Nd glass laser beams.

11. Neodymium Disc Lasers. The investigation of large-aperture disc lasers for multi-stage systems is being performed in this area in explicit applications to laser-fusion research.

12. Chemical Lasers. The development of high-energy high-efficiency chemical lasers has laser fusion as an explicit application. Chemical lasers of the HF type are proposed as the heating agents for high aspect ratio targets 1 cm in diameter.

The distribution of research teams and institutes among the above subject areas is shown in Table 1. The participation of a team in a given subject area is indicated in the table by the name of a leading member of the team. The breakdown of authors affiliated with research institutes into individual teams is approximate and based on co-author linkages and subject of research. Team numbers are arbitrary and are assigned to identify the teams.

## B. THE RESEARCH ORGANIZATIONS AND THEIR RELATIONSHIPS

While the Soviet sources seldom provide information on the structure and personnel of the research teams, or identify such teams as distinct units of their research organization, a compilation of a large number of research papers issued over an extended period of time clearly reveals cohesive groups of co-authors pursuing specific research projects. These groups, called teams in this report, vary considerably in size and in the duration of their activity. Their basic structure, however, is generally the same. Each team has a nucleus of leading authors whose names appear throughout most of the period of the team's activity and who are responsible for most of the papers published by the team. Around the nucleus there is a number of authors whose publication frequency is relatively low. If an institute has several teams pursuing related projects, the peripheral authors may move from one team to another, while the leading authors as a rule are fixed within the team.

Table 1

RESEARCH TEAM DISTRIBUTION BY SUBJECT AREA

| Institutes and Teams \ Subject Areas | Target Plasma Dynamics | Target Fusion Dynamics | Target Compression Theory | Plasma Dynamics | Solid-Derived Plasma | High B-Field Laser Interactions | High Energy Short Pulses | X-Ray Spectroscopy | Kilojoule $CO_2$ Lasers | Nd Rod Lasers | Nd Disc Lasers | Chemical Lasers |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FIAN | | | | | | | | | | | | |
| Group I, Basov | | | | | | | | | | | | |
| Team 1 | Silin | | | | | | | | | | | |
| Team 2 | | Gamaliy | | | | | | | | | | |
| Team 3 | | | | | | | | Boyko | | | | |
| Team 4 | | | | | | | Kryukov | | | | | |
| Team 5 | | | | | | | | | | | | Orayevskiy |
| Team 6 | | | | | | | | | Danilychev | | | |
| Group II, Prokhorov | | | | | | | | | | | | |
| Team 1 | | | | | | | | | Kuz'min | | | |
| Team 2 | | | | | Barchukov | | | | | | | |
| Team 3 | | | | | | | Malyshev | | | | | |
| Team 4 | | | | | | | Krasyuk | | | | | |
| Team 5 | | | | | Batanov | | | | | | | |
| Team 6 | | | | | | Kaytmazov | | | | | | |
| Landau ITP | | | Anisimov | | | | | | | | | |
| Kurchatov IAE | | | | | | | | | | | | |
| Team 1 | Rudakov | | | | | | | | | | | |
| Team 2 | Velikhov | | | | | | | | | | | |
| Yefremov IEPE | | | | | | | | | | | | |
| Team 1 | | | | | | | | | | Starikov | | |
| Team 2 | | | | | | | | | | | Mak | |
| V. Ye. Zakharov | | | | | | | | | | | | |
| IAE SOAN | | | | Musher | | | | | | | | |
| INP SOAN | | | | Rubenchik | | | | | | | | |
| IAM | | | | Degtyarev | | | | | | | | |
| PTI UkrAN | | | | Yerokhin | | | | | | | | |
| MEPI | | | | | Bykovskiy | | | | | | | |
| IHT | Alterkop | | | | | | | | | | | |
| IPE | | | | | Nemchinov | | | | | | | |
| ISR | Galeyev | | | | | | | | | | | |
| NPRI | | | | | | | | | | Fedorov | | |

The average mobility of scientific workers in the area of laser fusion research is quite low. This in conjunction with the leading and peripheral author structure suggests that a broad research area is at the outset broken down into a number of specialized research projects. Each such project is then assigned to an individual scientist who remains responsible for it for a fairly long period of time, in most cases ranging from five years to beyond the ten year period covered in this report. The scientist responsible for the project assembles a team of specialists, some of whom divide their time among several projects.

The set of institutes and groups identified in Table 1 also displays a structure whose basic outline is shown in Figure 1.

The major part of Soviet laser-fusion research, as it appears in the Soviet open-source technical journals, is performed by the Lebedev Physics Institute in Moscow. Of the two groups of teams engaged in this work at the Institute, Basov's group appears to be much more focused on laser fusion. Prokhorov's group tends to divide its efforts among several different subject areas in addition to laser fusion. While related to the issues of laser-fusion research, these areas are more general in scope and are oriented towards such objectives as laser-induced gas breakdown, and melting and vaporization of metals by high-power lasers.

Figure 1 shows a pattern of linkages among the main institutional blocks of researchers active in this area. These are essentially collaborative relationships revealed either by explicit statements of the research report authors, by the joint authorship of papers by members of different institutes, or by the network of reviewers of the research papers. The latter is an important aspect of Soviet research practice whereby major reports are reviewed before publication by leading experts from the same general subject area. The reviewers are generally from the same institute as the authors, but may also be drawn from a collaborating institute.

The pattern of linkages indicates that each group of the Lebedev Institute has its own set of collaborating institutes, except the Kurchatov Institute of Atomic Energy which works with both groups. Figure 1 shows only a partial set of the major institutes; a

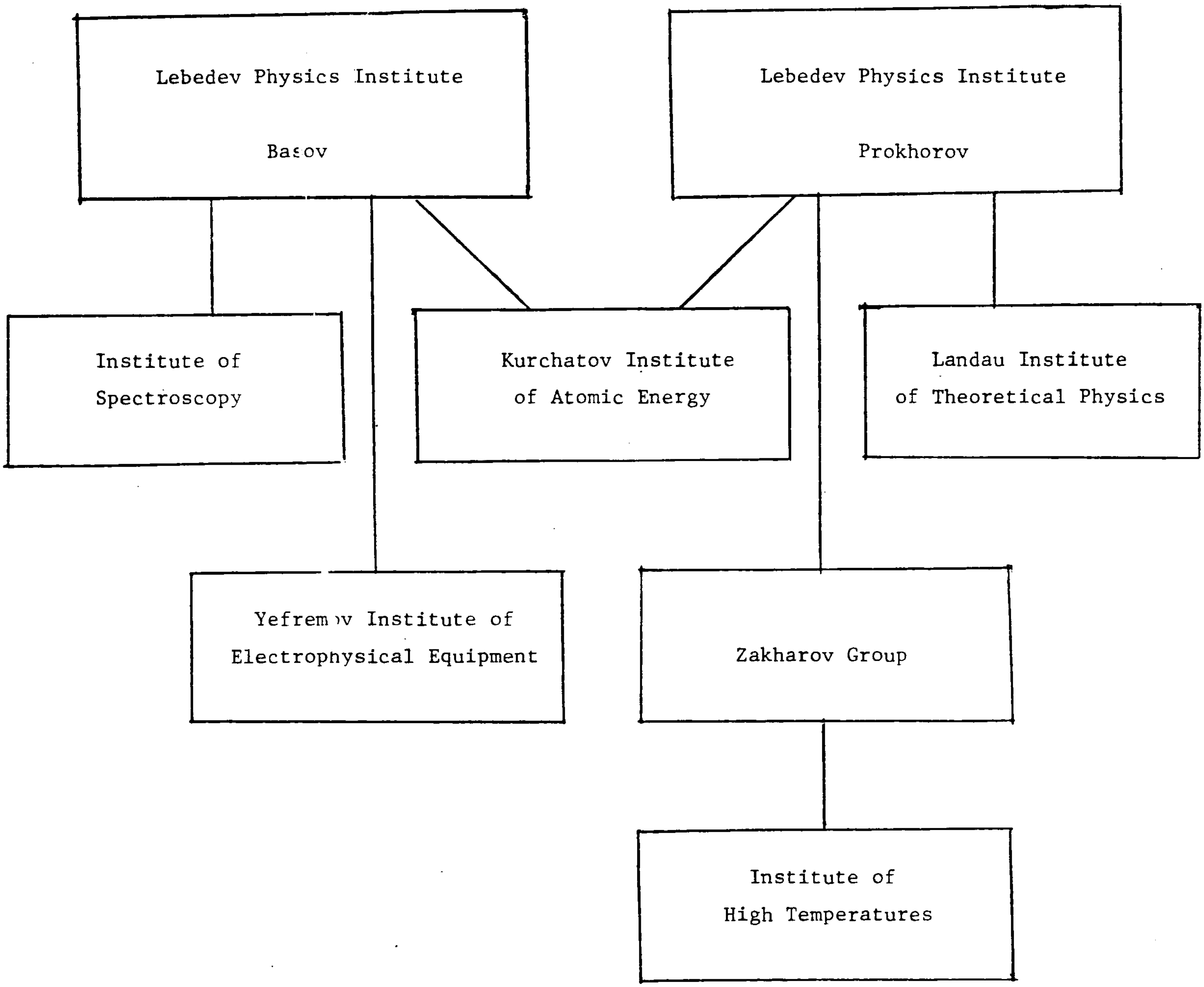


Fig. 1--Institutes participating in Soviet laser fusion research

number of other institutes may also participate in this network, and some of these may be also linked to both groups. For example, there are indications that the Institute of Applied Mathematics provides computer simulation support to Basov and Prokhorov,

It is of interest that the pattern of linkages reveals no direct cooperation between Basov's and Prokhorov's groups. In view of the proximity of research areas and objectives of the two groups, their apparent isolation from one another is puzzling.

## C. STATISTICS OF SOVIET RESEARCH

The material obtained from Soviet regular serials for the purpose of this report yields some statistical data on the paper and author distribution over time and by subject area. Statistics on the publication frequency of scientific papers do not provide a reliable indication of annual changes in the research effort level. They are significant because they indicate overall trends and allow comparisons to be made of the different teams' efforts. A more meaningful indication of effort levels is obtained from the distribution of authors of scientific papers, since the number of authors approximately reflects the level of professional staffing of a research team or institute.

To determine the number of authors in a given organizational unit, an author was included for every year of a period starting one year before the year of that author's earliest paper and ending one year after that author's last paper, affiliated with the unit. This method provides a conservative estimate of an author's membership in a unit and assumes that he did not leave the unit temporarily between successive publications. Furthermore, the method avoids the misleading variations in the authors' number due to uneven publications of their papers.

Figure 2 and Table 2 show the distribution of authors and papers for all research teams and all subject areas in Soviet laser-fusion research. The data on authors show a rapid acceleration of the research effort in the three years between 1971 and 1974. The effort leveled off between 1974 and 1976 and shows a definite decline after 1976. The data for 1978 are included on the graph for orientation purposes only, since the count for that year is incomplete by approximately 20 percent.

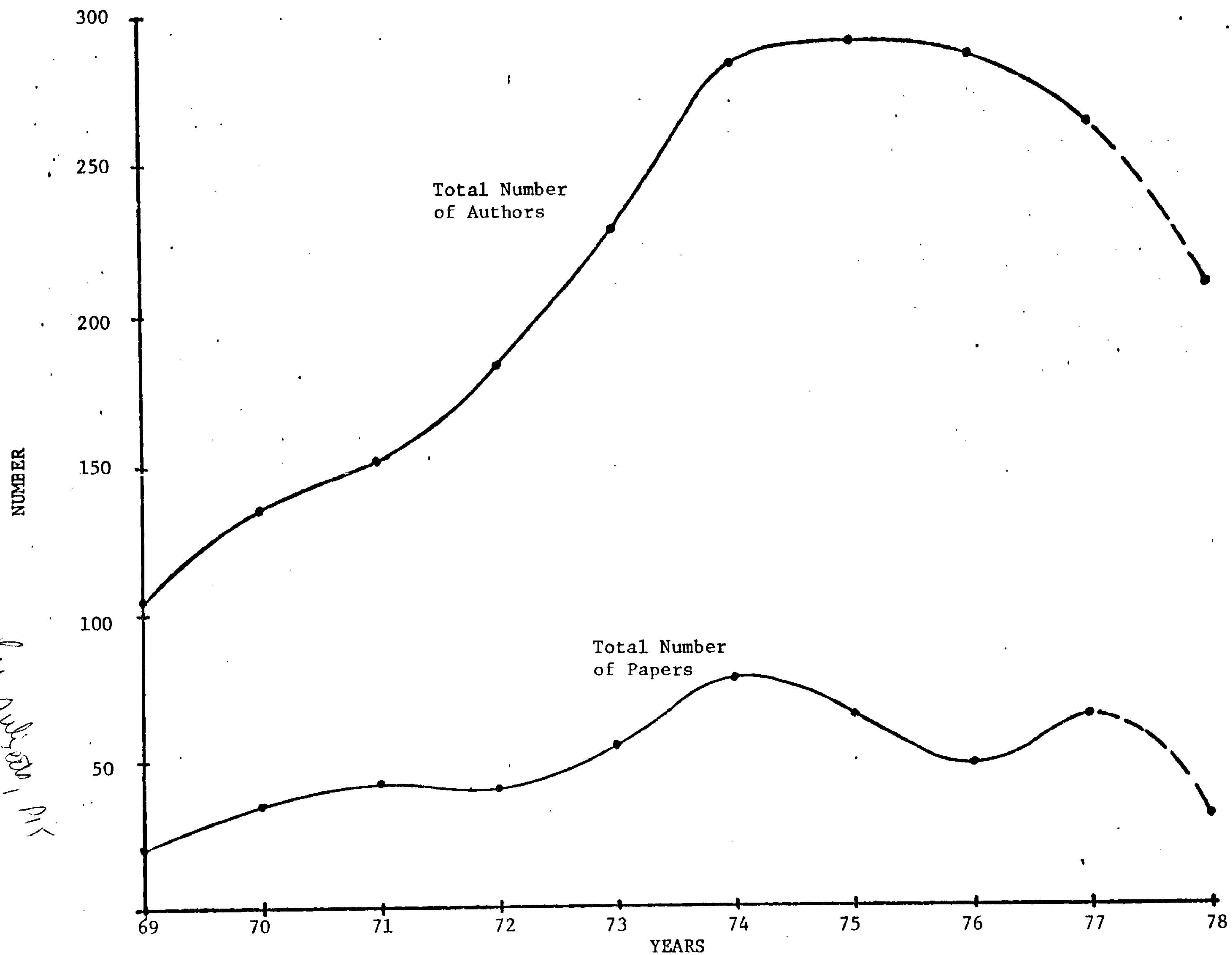


Fig. 2--Annual distribution of authors and published papers.

Table 2. Annual Distribution of Authors and Published Papers

| <u>YEARS</u> | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|
| <u>AUTHORS</u> | 103 | 136 | 151 | 183 | 228 | 283 | 290 | 286 | 263 | 209 |
| <u>PAPERS</u> | 20 | 35 | 42 | 41 | 56 | 78 | 64 | 48 | 66 | 30 |

The statistical data assume a greater significance when used to compare the effort levels in terms of the number of authors among the different subject areas. Table 3 and Figures 3 and 4 illustrate the effort level differences in the subject areas.

Table 3 gives numerical data for the annual distribution of authors among all subject areas and for all years considered in this report. These data were used to plot graphs illustrating the variation in the number of authors for each subject area during the period in question (Fig. 3).

It is instructive to consider the individual subject areas in two periods of time: the early period prior to 1974, and the post-acceleration period after 1974. In the early period, several areas showed a fairly level effort with little or no acceleration. These are:

Target compression theory,
Plasma dynamics,
High B-field laser interactions,
Chemical lasers,
Neodymium rod lasers.

The above areas share the characteristic that, for the most part, they lead to various applications besides controlled fusion. The remaining areas are more fusion specific and exhibit a marked increase of effort.

In the period after 1974, the distinction between the declining and rising areas can be made sharper and more significant by considering the relative, rather than the absolute, number of authors and thus compensating for the drop in the absolute number during recent years. Figure 4 shows the percentages of the total number of authors contributing to each subject area in two years, 1975 and 1977. Table 4 lists the subject areas according to the relative changes in author number.

Table 3. Annual Distribution of Authors by Subject Area

| Subject | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|
| Target Plasma Dynamics | 19 | 26 | 33 | 47 | 63 | 74 | 74 | 64 | 56 | 43 |
| Target Fusion Dynamics | 4 | 4 | 13 | 13 | 15 | 19 | 23 | 31 | 30 | 21 |
| Target Compression Theory | 2 | 2 | 2 | 1 | 2 | 5 | 5 | 6 | 6 | 6 |
| Plasma Dynamics | 11 | 19 | 19 | 19 | 18 | 19 | 15 | 13 | 6 | 6 |
| Solid-Derived Plasma | 30 | 34 | 29 | 30 | 41 | 41 | 41 | 27 | 26 | 21 |
| High B-Field Laser Interactions | 4 | 7 | 7 | 7 | 7 | 7 | 5 | 3 | 3 | 3 |
| High Energy Short Pulses | 16 | 19 | 24 | 30 | 35 | 37 | 32 | 30 | 28 | 26 |
| X-Ray Spectroscopy | 0 | 0 | 2 | 10 | 10 | 18 | 24 | 32 | 25 | 15 |
| Kilojoule $CO_2$ Lasers | 3 | 8 | 8 | 14 | 17 | 36 | 35 | 51 | 50 | 43 |
| Neodymium Rod Lasers | 9 | 12 | 9 | 12 | 13 | 12 | 14 | 5 | 5 | 5 |
| Neodymium Disc Lasers | 0 | 0 | 0 | 0 | 0 | 5 | 10 | 16 | 14 | 9 |
| Chemical Lasers | 5 | 5 | 5 | 0 | 7 | 10 | 12 | 8 | 14 | 11 |

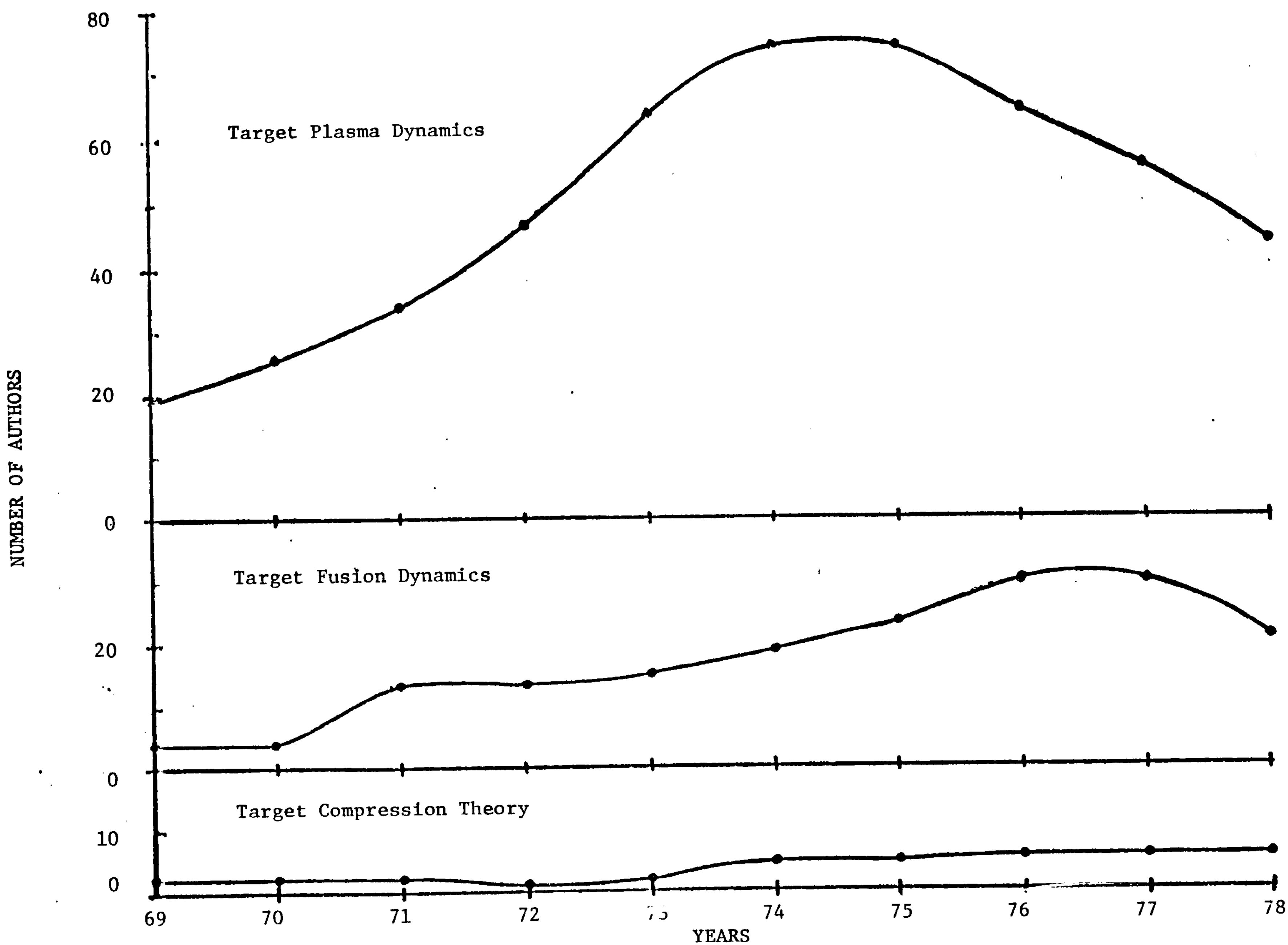


Fig. 3--Annual variation in author number by subject area.

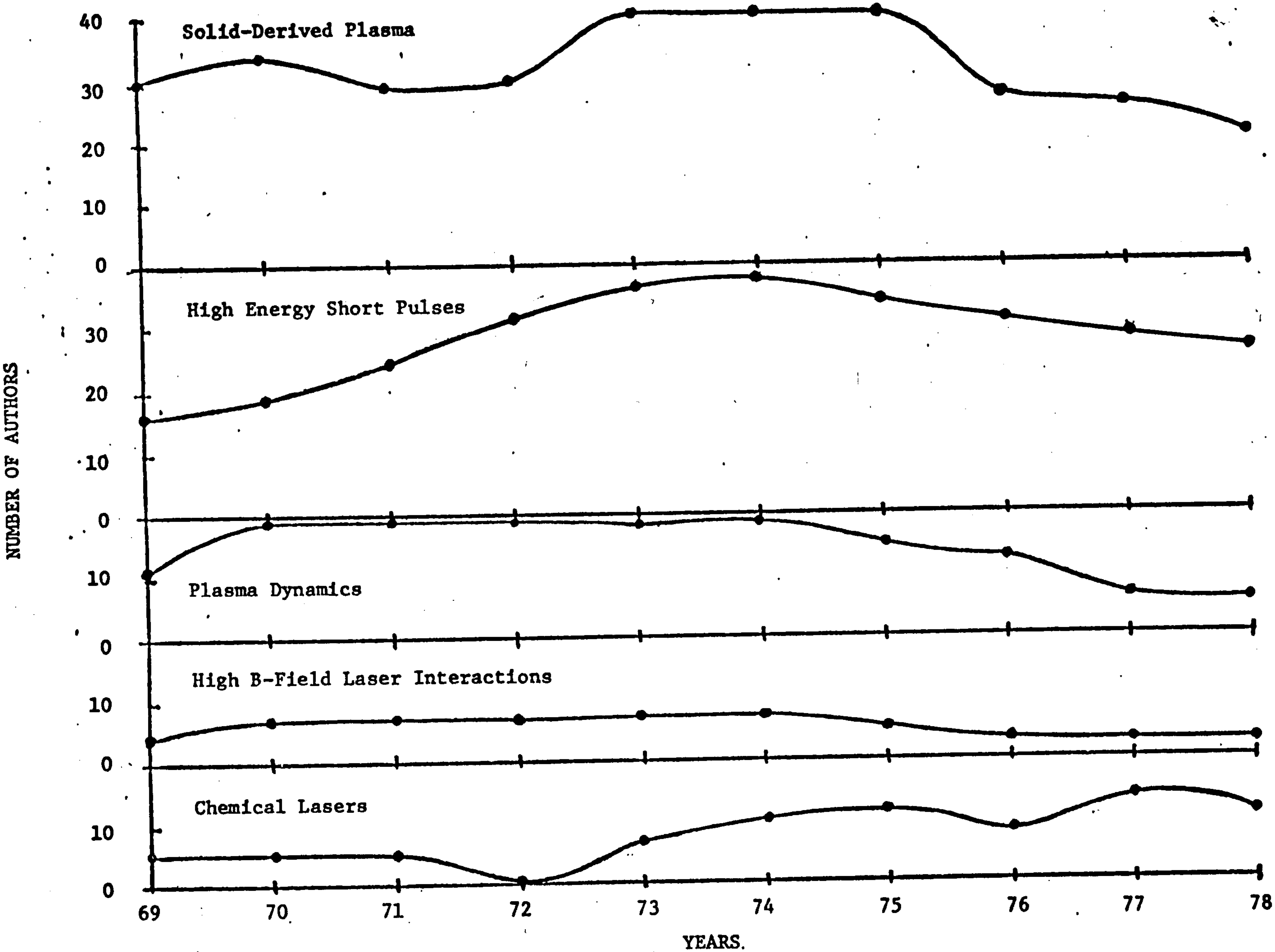


Fig. 3 (cont.)--Annual variation in author number by subject area.

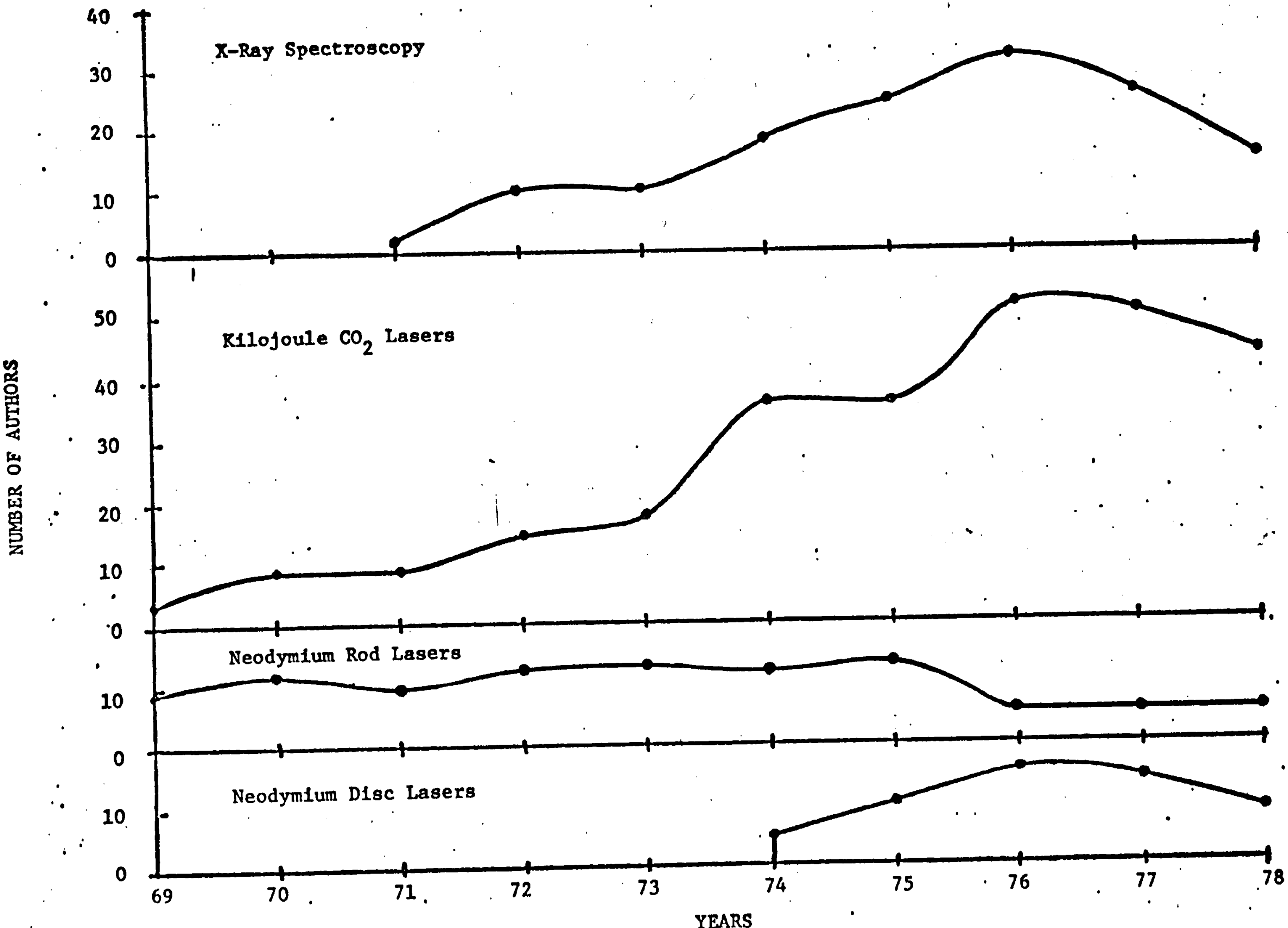


Fig. 3 (cont.)--Annual variation in author number by subject area.

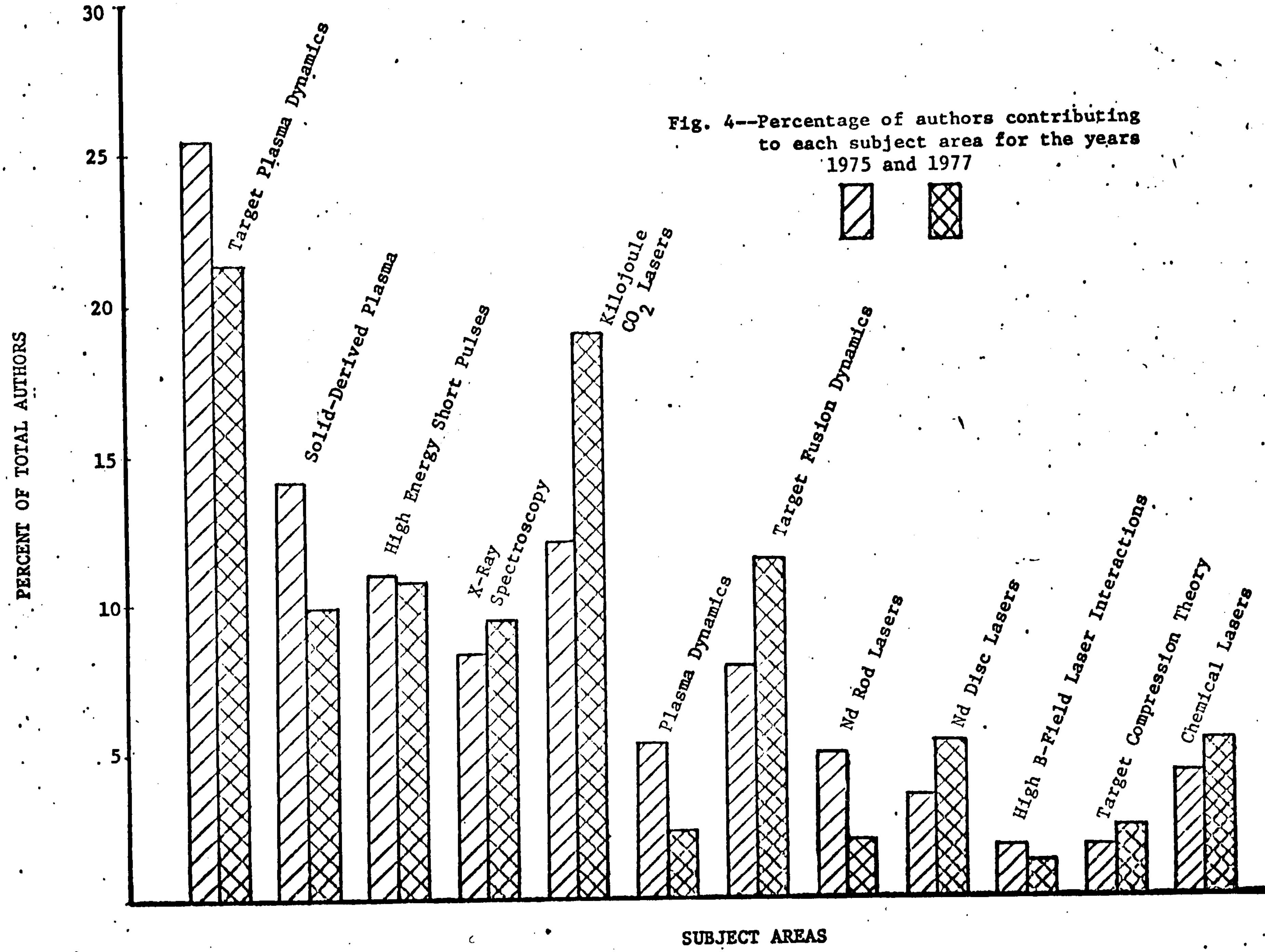


Fig. 4--Percentage of authors contributing to each subject area for the years 1975 and 1977

Table 4. Subject Areas Arranged by Changes in Relative Effort Level Between 1975 and 1977

Area of unchanged relative effort

High energy short pulses

Area of decreased relative effort

Target plasma dynamics

Solid-derived plasma

Plasma dynamics

Neodymium rod lasers

High-B field laser interaction

Areas of increased relative effort

Target compression theory

X-ray spectroscopy

Target fusion dynamics

Kilojoule $CO_2$ lasers

Neodymium disc lasers

Chemical lasers

## D. CONCLUSIONS

The statistical material derived from open-source regular serials reporting on Soviet laser fusion research indicates that the following trends have been taking place during the period from 1969 to the present: during the early part of the period, ending about 1974, the overall rise in the number of active authors can be attributed to a rapid intensification of fusion-specific research effort. The subsequent period, from 1974 to the present, was marked by a steady movement towards a more advanced stage of laser fusion research, indicating a degree of overall progress across the entire spectrum of Soviet research activities in this area. Thus, the largest effort remained in the theoretical study of the energy balance on the corona region of laser-fusion targets, specifically focusing on the problem of parametric instabilities affecting plasma in that region. However, the magnitude of that effort, relative to the other subject areas, has been decreasing steadily since 1974. On the other hand, studies involving advanced aspects of target heating, such as the target compression phenomena and thermonuclear burn effects, have been increasing. This was accompanied by more emphasis on the analysis of glass damage, diagnostics, and advanced experimentation. The increase in X-ray spectroscopy and high-energy $CO_2$ laser work illustrates this emphasis. Of similar nature is the change evident in the area of neodymium laser developments. The work on rod systems has been replaced by studies of disc systems, again indicating a movement toward more advanced fusion specific studies.

A further indication of such a trend is the increasing work on chemical lasers as promising candidates for laser fusion; they are considered specifically for experiments with the high aspect ratio, larger diameter fusion targets proposed by Soviet researchers. However, the appearance of orderly overall progress in Soviet laser fusion research, obtained from our analysis of Soviet research organizations, is not supported by evidence of significant technical achievements one would expect from such programs. Neither is it clear how the Soviet progress compares with the corresponding U.S. effort. The Soviet research appears to be considerably behind the U.S. in some major areas. For example, disc lasers are more advanced in the U.S. than in the Soviet Union. Similarly, the U.S. appears to be making faster progress in its experimental laser fusion system.

The Soviet research effort in the laser fusion area appears to have leveled off between 1974 and 1976 and to be declining in the last two years. A part of this decline, measured in terms of active authors and published papers, could perhaps be attributed to the increasing role of advanced experimentation and hardware development, which generally tends to decrease publication frequency. However, it could also be due to the absence of sufficient significant technical achievements and to the competition from alternative approaches to inertial fusion research, such as the electron and ion beam fusion.

A further insight into the dynamics of Soviet research in this area could be obtained from a systematic evaluation of the overall Soviet progress in terms of technical parameters and from a comparative analysis of U.S. and Soviet methods and results which should be the subjects of subsequent studies.

## III. PLANS FOR FURTHER WORK

The conclusions about Soviet laser-fusion research based on source materials published in the regular serials cannot be considered as definitive without the support of other sources, such as preprints, institutional proceedings, and the material emanating from personal meetings between U.S. and Soviet scientists. The virtue of the regular serials resides in the large-scale, systematic nature of these publications, which provides the opportunity to develop the basic outline of the organizational structure of Soviet laser-fusion research. This is the reason for choosing this material as the input for the first stage of the study of the Soviet activity. However, because of the limitations of Soviet regular serials, the organizational picture developed so far is incomplete and some aspects of it may be incorrect. This survey has been intended merely as a starting point for the process of completing and verifying the network of organizational relationships representing the Soviet research establishment in this area.

This process should expand the coverage to (1) other teams, not identified before, and (2) other types of sources, such as irregular serials, preprints, etc. (an all-source basis). The refining and validation of the developed organizational structure should focus on the new Soviet laser-fusion installations and experimental techniques and facilities. The results of this process would then serve as a foundation for the subsequent analysis of the rationale of Soviet research choices and of the particular directions the Soviet laser-fusion research would be expected to take in the future.

## IV. SOVIET RESEARCH INSTITUTES AND TEAMS

The detailed treatment of the individual research institutes, groups, and teams active in areas pertinent to laser fusion is intended to provide information on the personnel and subject of activity of these organizational units, and their development over time. Each organizational unit, or team, is described in the following terms:

1. Definition of research area
2. Membership
3. Publication statistics
4. Brief account of work done.

The account of team members lists primarily the authors of research reports published in Soviet regular serials with the addition of some non-authors provided in the text of these reports. A subset of leading authors and research heads is identified and listed separately from the set of authors of each team or institute. Other categories in the list include reviewers, supervisory personnel, and specialists. These categories may include authors as well as non-authors and are not included in the statistics. The name of each person listed is accompanied by the years marking the interval that person was in evidence in the source materials. The years shown designate a period beginning one year ealier and ending one year later than the date of the first and last pertinent publication of that person, respectively.

## Lebedev Physics Institute, Moscow

### Group I. N. G. Basov, Head

Group I appears to consist of major teams pursuing specific research projects, and several smaller teams represented by a limited number of papers. The research activity of Group I is centered in the Laboratory of Quantum Radiophysics. The following is a partial list of the leading personnel of the Laboratory:

Head
N. G. Basov
Section Heads
O. N. Krokhin
S. V. Sklizkov
Group Leaders
P. G. Kryukov
V. B. Rozanov
A. S. Shikanov
Senior Scientific Associates
Yu. A. Afanas'yev
S. A. Fedotov
The leadership of Group I also includes Ye. S. Gamaliy, Group Leader of the Neutron Physics Laboratory

A total of 274 papers published under 230 authors' names during the period from 1969 to 1978 was analyzed. The following is the annual breakdown of active authors and published papers of Group I:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 31 | 42 | 65 | 85 | 116 | 139 | 147 | 148 | 133 | 101 |
| PAPERS | 7 | 9 | 18 | 25 | 36 | 52 | 39 | 36 | 38 | 14 |

The following sections provide personnel data and brief activity analyses for the four teams of Group I:

## Team 1. Target Plasma Dynamics

The team of authors dealing with the subject of plasma dynamics resulting from the laser beam-target interaction is the largest distinct unit of the research activities headed by Basov, Krokhin, and Sklizkov. It is also possibly the oldest continuing team of Basov's fusion research group; a number of members of the team have been publishing materials in this area since the mid-sixties.

The team readily breaks down into two sections, theoreticians and experimentalists. The published papers also reveal the names of non-author specialists in computer programming and target preparation, and technicians. The theoretical and experimental sections have a similar vertical structure. Each has a clearly, if not explicitly, apparent head and a set of leading authors which constitutes the nucleus of each section. The nucleus authors and the section head write exclusively for the team and their frequency of publication is much higher than that of the other authors of the team. Many of the latter also participate in the activities of other teams.

The head of the theoretical section is V. P. Silin. He also appears to exert considerable influence on the work of the experimental section. The apparent head of the experimental section is A. S. Shikanov, whose official title is group leader of the Quantum Radiophysics Laboratory. Although his professional title is Junior Scientific Associate, Shikanov's membership in the nucleus of leading authors and his position as group leader make his section leadership logical. However, Silin is most probably the senior professional of Team 1 as a whole.

The reviewers of Team 1 are drawn partly from Team 1, partly from Team 3, and partly from other departments of the Lebedev Institute.

### Team 1 Membership List

Supervisory Personnel

N. Ye. Andreyev 1968-1976

A. Yu. Kiriy 1968-1978

O. N. Krokhin 1968-1978

A. S. Shikanov 1970-1978

V. P. Silin 1968-1978

G. V. Sklizkov 1968-1978

Theoretical Section Authors

Head

V. P. Silin 1968-1978

Leading Authors

N. Ye. Andreyev 1968-1978

V. Yu. Bychenkov 1971-1978

V. V. Pustovalov 1969-1978

A. N. Starodub 1972-1978

V. T. Tikhonchuk 1971-1978

Authors

V. V. Aleksandrov 1973-1977

I. S. Baykov 1972-1974

A. A. Chernikov 1976-1978

L. M. Degtyarev 1973-1976

V. I. Domrin 1975-1977

V. S. Fetisov 1976-1978

N. V. Filippov 1970-1978

L. M. Gorbunov 1971-1978

G. A. Gusev 1973-1978

N. I. Ionkin 1974-1976

Yu. S. Kas'yanov 1977-1978

A. Yu. Kiriy 1968-1978

V. V. Korobkin 1977-1978

V. F. Kovalev 1974-1976

L. V. Krupnova 1977-1978

S. B. Litvin 1975-1977

F. A. Nikolayev 1973-1975

A. N. Polyanichev 1976-1978

R. R. Ramazashvili 1976-1978

A. B. Romanov 1971-1976

M. A. Savchenko 1974-1976

A. P. Shevel'ko 1977-1978

I. I. Sobel'man 1973-1975

G. L. Stenchikov 1973-1978

A. V. Vinogradov 1968-1975

Experimental Section Authors

Head

A. S. Shikanov 1970-1978

Leading Authors

O. N. Krokhin 1969-1978

A. A. Rupasov 1971-1978

G. V. Sklizkov 1969-1978

Yu. A. Zakharenkov 1972-1978

Authors

Ye. V. Aglitskiy 1969-1975

A. V. Antonov 1973-1975

A. I. Avrov 1975-1978

V. A. Boyko 1968-1975

L. Ye. Chernyshev 1976-1978

Yu. A. Drozhbin 1969-1974

A. N. Fedorov 1970-1972

S. I. Fedotov 1968-1976

V. A. Gribkov 1968-1976

A. I. Isakov 1973-1975

Yu. S. Ivanov 1971-1973

N. V. Kalachev 1973-1975

M. V. Kazarnovskiy 1973-1975

A. A. Kologrivov 1972-1978

N. A. Konoplev 1972-1974

V. I. Mikerov 1973-1975

Yu. A. Mikhaylov 1973-1977

N. V. Morachevskiy 1968-1970

V. Ya. Nikulin 1969-1976

L. L. Pasechnik 1974-1976

V. V. Ryukkert 1971-1973

U. I. Safronova 1972-1974

O. G. Semenov 1974-1976

V. F. Semenyuk 1974-1976

M. R. Shpol'skiy 1974-1976

S. A. Startsev 1973-1975

M. A. Sultanov 1972-1974

V. P, Tsapenko 1971-1974

M. Yu. Tsvetkov 1976-1978

L. A. Vaynshteyn 1972-1974

V. A. Yakovlev 1969-1971

A. A. Yerokhin 1976-1978

Ye. A. Yukov 1972-1975

S. M. Zakharov 1968-1974

N. N. Zorev 1970-1978

Computer Specialists

N. E. Andreyev 1968-1976

L. M. Anosovoy 1972-1974

A. T. Matachun 1973-1975

V. V. Zvezdov 1973-1975

Technicians

B. N. Duvanov 1968-1970

O. V. Guseva 1971-1973

V. A. Kovalenko 1973-1975

Yu. S. Leonov 1975-1977

F. I. Matveyeva 1975-1977

Yu. A. Merkul'yev 1975-1977

V. V. Prizhimov 1974-1976

Ye. R. Rychkova 1975-1977

Target Preparation

Yu. S. Leonov 1975-1977

F. I. Matveyeva 1975-1977

Yu. A. Merkul'yev 1975-1977

Ye. R. Rychkova 1975-1977

Yu. A. Zakharenkov 1972-1978

Other

V. M. Groznov 1973-1975

N. V. Novikov 1973-1975

Reviewers

Yu. V. Afanas'yev 1968-1976

S. I. Fedotov 1968-1976

Ye. G. Gamaliy 1973-1978

M. V. Kazarnovskiy 1973-1975

Ye. Ye. Lovetskiy 1976-1978

V. V. Pustovalov 1969-1978

M. S. Rabinovich 1976-1978

R. R. Ramazashvili 1977-1978

V. P. Silin 1968-1978

B. M. Stepanov 1974-1976

V. T. Tikhonchuk 1971-1978

A. V. Vinogradov 1968-1975

G. S. Voronov 1976-1978

A total of 158 papers published under 72 authors' names during the period from 1969 to 1978 was analyzed. The following is the annual breakdown of active authors and published papers for Team 1:

Authors

| YEAR | EXPERIMENTAL | THEORETICAL | TOTAL |
|---|---|---|---|
| 1969 | 9 | 5 | 14 |
| 1970 | 13 | 6 | 19 |
| 1971 | 16 | 10 | 26 |
| 1972 | 21 | 12 | 33 |
| 1973 | 27 | 18 | 45 |
| 1974 | 28 | 21 | 49 |
| 1975 | 22 | 24 | 46 |
| 1976 | 17 | 22 | 39 |
| 1977 | 12 | 21 | 33 |
| 1978 | 11 | 18 | 29 |

Papers

| YEAR | EXPERIMENTAL | THEORETICAL | TOTAL |
|---|---|---|---|
| 1969 | 3 | 2 | 5 |
| 1970 | 3 | 3 | 6 |
| 1971 | 9 | 4 | 13 |
| 1972 | 5 | 8 | 13 |
| 1973 | 11 | 15 | 26 |

| YEAR | EXPERIMENTAL | THEORETICAL | TOTAL |
|---|---|---|---|
| 1974 | 11 | 20 | 31 |
| 1975 | 6 | 11 | 17 |
| 1976 | 6 | 12 | 18 |
| 1977 | 8 | 14 | 22 |
| 1978 | 2 | 5 | 7 |
| | 64 | 94 | 158 |

The theoretical investigation of plasma dynamics during laser beam-target interaction remained throughout the reported period under the leadership of V. P. Silin, the chief theoretician of this team. The nucleus of Silin's theoretical section consists of V. V. Pustovalov, A. N. Starodub, V. T. Tikhonchuk, N. Ye. Andreyev, and V. Yu. Bychenkov. As the work progressed, starting with the mid-seventies, Silin and the members of the nucleus of his section engaged in the work of interpreting experimental results in the light of his theory, and co-authored a series of papers with the experimentalists of the team. Silin has also been responsible for initiating and suggesting experimental projects performed by the experimentalists. Purely theoretical papers were prepared, not only by the members of the nucleus, but also by a number of other members of the theoretical section, each of whom, however, had a relatively low frequency of publication.

Silin's primary subject of research throughout the reported period has been the parametric instability theory applied to the beam-plasma interaction. As described in a 1969 paper [1] on microwave beams, a strong electromagnetic field generates a unique parametric instability effect in plasma, due to the oscillation of electrons relative to ions. The applicable theory of parametric resonance in plasma is nonlinear in nature and, according to Silin, cannot be treated in a linear approximation. The phenomenon of anomalous absorption is a consequence of this nonlinearity. Silin's early task was to provide a detailed model of plasma turbulence due to the parametric instability [339]. The section generated a series of papers on parametric instability of plasma in rf electric and constant magnetic fields [2,3], the possibility of increasing light absorption by inhomogeneous laser plasma [4], the dynamics of nonlinear absorption of intense electromagnetic radiation by a moving plasma [5], and parametric instability in nonlinear media subject to interaction with strong electro-magnetic waves [6].

Papers on the generation of coherent harmonics of the incident laser frequency from supercritical density plasma began in 1972 [7], and continued with experimental [8] and theoretical investigations [9,10]. The generation of harmonics in a moving plasma was studied theoretically in 1978 [11]. The parametric instabilities in laser plasma and the consideration of particular instabilities, such as the two-plasma decay, followed the early research [12-23]. Plasma decay was investigated in detail in [24-27]. The emergence of fast ions and fast electrons in parametrically unstable plasma was the subject of more recent research [28,29,30]. Stimulated Raman and Brillouin scattering effects were considered as instabilities capable of enhancing the anomalous heating of plasma [31,32]. The dependence of stimulated Raman scattering upon the electromagnetic wave propagation in a rarefied inhomogeneous plasma was reported in 1976 [33,34]. The spectral composition of the scattered radiation was reported in 1977 [35]. In 1978, materials were published on the decrease of the electromagnetic wave intensity due to stimulated Mandelshtam-Brillouin scattering in a disintegrating inhomogeneous plasma [36,37]. Here it was demonstrated that the stimulated scattering is strongly dependent upon the gas dynamics of the plasma corona and decreases with an increase in the plasma dispersion velocity and a decrease in the degree of inhomogeneity.

A combined experimental and theoretical section investigated the phenomenon of the "opacity region" observed in hot plasma by interferometry and attributed this effect to the non-local parametric turbulence extending over the entire corona [38].

Recent interpretation [39] of experimental results confirmed Silin's conclusions about the role of parametric instabilities in the energy balance of laser plasma. Experimental and theoretical data were found in good agreement at the beam intensity level of $10^{14}$ W/cm$^2$

in relation to the beam reflection coefficient and its decrease due to the parametric absorption mechanism. According to Silin, the parametric transformation of the transverse pump wave into Langmuir and ion-acoustic oscillations is an effective mechanism of anomalous plasma heating [40]. An expression was found for the heating rate of a turbulent plasma in the case of intense parametric coupling of the pump waves [41]. Consideration of temperature inhomogeneity of the plasma indicates that the parametric decay represents an absolute instability which, in contrast to the convective instability generally postulated for this case, enhances heating of the plasma. The detailed theory of absolute parametric instabilities is given in [42,43].

On the experimental side, early research focused on the measurement of the gas-dynamic parameters of laser plasma derived from solid targets. A low-power 800 J laser was used with an intensity of $10^8$ W/cm$^2$ [44]. In another series of early experiments, a 30 J laser with an intensity of $10^{12}$ W/cm$^2$ was used to generate hot plasma for studies of time behavior of temperature based on soft x-ray emission [45]. Early papers (1969-1972) also reported on neutron yield from a laser-derived $CD_2$ plasma (80 J laser) [46] and x-ray source for laser plasma diagnostics [47]. Anomalous absorption was observed with an Nd laser at the $10^{12}$ W/cm$^2$ intensity level [48]. In 1972, a nine-beam Nd laser system was reported [49], later designated as the "Kal'mar" (Octopus). The system had an adjustable pulse length from 2 to 16 nsec, and output energy from 600 to 1300 J, with an average beam intensity on target up to $10^{16}$ W/cm$^2$.

The Kal'mar system was used in 1974 to study DT neutron generation by heating targets in the spherical irradiation mode [50]. A year later it was reported in connection with the spatial density variation in the corona of Al targets [51], and the determination of the electron temperature of laser plasma near critical density [52]. In both cases a 200 J beam was used. The Kal'mar was reported also in 1976 experiments with the 3/2 $\omega_o$ harmonic generation in glass microspheres (120 J) [8], plasma corona studies in flat targets (250 J) at the intensity level of $10^{15}$ W/cm$^2$ [53], and the compression of hollow microspheres (150 J) at $10^{13}$ W/cm$^2$ [54]. The 1977 publications report the Kal'mar in observation of fast ions in laser plasma [55], heating of spherical targets at 150 J, $10^{14}$ W/cm$^2$ for the continuing investigation of the 3/2 $\omega_o$ harmonic [56] and interferometric studies of laser plasma corona at 250 J, 3 x $10^{14}$ W/cm$^2$ [57].

Compression of deuterium-filled $SiO_2$ hollow microspheres was performed towards the end of 1977 using the 9 beams of the Kal'mar facility. In these experiments [58] the laser pulse was approximately 1 nanosecond with an energy of 100 joules and intensity level of $10^{14}$ W/cm$^2$. The maximum output of 5 x $10^6$ neutrons was obtained for a target diameter of 140 microns. A one thousand-fold compression was observed with the aid of pinhole cameras. In 1978, a Q-switched neodymium-doped YAG laser was reported to be used in the Kal'mar facility [59].

The experimental work of the team also included dense laser plasma diagnostics using Mg and Al ions [60], schlieren photography of ruby laser beams at 5 x $10^{-10}$ sec exposure [61], studies of anomalous absorption using $10^{13}$ W/cm$^2$ Nd laser beam with aluminum and polyethylene targets [62], studies of the direction of reflected and x-ray radiation in laser plasma [63], nonspherical cumulative laser plasma flares [64], and high speed diagnostics of ionizing shock waves in a laser beam [65].

Team 2. Target Fusion Dynamics

Team 2 deals with the overall aspects of laser fusion target stability in all stages of the compression process including the stage of thermonuclear burn. It is also responsible for the analysis of the optimal target design and the future requirements of fusion reactors.

The personnel of the team include a nucleus of four leading authors, each of whom has a relatively high publication rate and publishes exclusively within the subject area boundaries defined for this team. Of these four leading authors, two are officially reported group leaders: Ye. G. Gamaliy is a group leader of the Neutron Physics Laboratory, while V. B. Rozanov is a group leader of the Quantum Radiophysics Laboratory. Both have the title of Senior Scientific Associate of the Lebedev Physics Institute.

The consideration of neutron yields and related problems, constituting a major theme of the team's activity, may have been responsible for the participation of the Neutron Physics Laboratory and Gamaliy's involvement in this work.

The remaining authors of this team have a lower publication rate and some have been participating in the work of other groups. The team also includes a number of non-authors identified in its report as computer specialists, technicians, and experimentalists.

Team 2 Membership List

Group Leaders

Ye. G. Gamaliy 1973-1977

V. B. Rozanov 1971-1978

Supervisory Personnel

A. A. Bunatyan 1973-1975

L. P. Feoktistov 1973-1975

Ye. G. Gamaliy 1973-1977

O. N. Krokhin 1968-1978

T. I. Kuznetsov 1973-1975

V. A. Murashkina 1973-1975

V. Ye. Neuvazhayev 1973-1978

L. I. Shibarshov 1973-1975

G. V. Sklizkov 1971-1978

Leading Authors

Yu. V. Afanas'yev 1968-1978

Ye. G. Gamaliy 1973-1978

O. N. Krokhin 1968-1978

V. B. Rozanov 1971-1978

Authors

Ye. M. Belenov 1968-1973

N. N. Bokov 1976-1978

A. A. Bunatyan 1976-1978

L. M. Degtyarev 1975-1977

N. N. Demchenko 1976-1978

A. P. Favorskiy 1975-1977

S. I. Fedotov 1971-1977

V. D. Frolov 1976-1978

A. V. Gulin 1975-1977

S. Yu. Gus'kov 1973-1978

A. A. Isakov 1974-1976

Yu. S. Ivanov 1971-1973

E. P. Kurdyumov 1973-1978

I. G. Lebo 1977-1978

Ye. I. Levanov 1971-1977

V. A. Lykov 1976-1978

Yu. A. Merkul'yev 1974-1976

Yu. A. Mikhaylov 1972-1978

V. Ye. Neuvazhayev 1976-1978

A. I. Nikitenko 1974-1976

I. A. Poluektov 1967-1973

Yu. P. Popov 1974-1977

E. R. Rychkova 1974-1976

A. A. Samarskiy 1971-1978

A. S. Shikanov 1977-1978

N. M. Sobolevskiy 1974-1976

A. P. Strotseva 1976-1978

A. N. Tikhonov 1974-1977

N. N. Tyurina 1975-1977

P. P. Volosevich 1971-1978

Yu. A. Zakharenkov 1977-1978

N. V. Zmitrenko 1976-1978

Computer Specialists

Ye. V. Kurasanov 1976-1978

A. Pasyukova 1973-1975

T. Shtaleva 1973-1975

Technician

R. N. Traktirnikov 1974-1976

Experimentalists

L. I. Ivanova 1971-1973

V. G. Larionova 1971-1973

Other

V. M. Groznov 1971-1973

N. V. Novikov 1971-1973

A. A. Yerokhin 1971-1973

N. N. Zorev 1971-1973

Reviewers

T. I. Kuznetsov 1973-1975

G. Ye. Shatalov 1974-1976

A total of 31 papers published under 39 authors' names during the period from 1969 to 1978 was analyzed. The following is the annual breakdown of active authors and papers published by Team 2:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 4 | 4 | 13 | 13 | 15 | 19 | 23 | 31 | 30 | 21 |
| PAPERS | 1 | 1 | 1 | 5 | 0 | 4 | 8 | 6 | 3 | 2 |

A well-known effort of this team has been the consideration of inhomogeneous spherical targets required for energy gains of 1000 using megajoule lasers [68]. The authors attributed their concepts of large target mass ($10^{-3}$ - $10^{-2}$ g) and relatively low density ($10^{2}$ g/cm$^{3}$), as well as high aspect shells, to experience gained in past Soviet high-temperature hydrodynamics research. Further work along this line indicated that the TN reaction from those targets should result in a pressure of $10^{14}$ atm, neutron density of $10^{24}$ cm$^{-3}$, superhigh ion ($\gtrsim$ MeV) and electron ($\gtrsim$ 100 keV) temperatures, and a neutron emission intensity of ~ $10^{30}$ n/sec [69]. Stability of high-gain target shells was considered for the compression stage when the denser peripheral layers are being retarded by the hot target core. It was concluded that for megajoule lasers, adequate stability could be expected if the initial variation of shell thickness, density, or mass, did not exceed 1% [70].

Earlier calculations were made to investigate the heating process and the compression of spherical targets when irradiated with an intense laser pulse. According to the calculations, from 20 to 30% of the mass of the target of the condensed mixture of deuterium and tritium can be compressed a thousandfold and heated to a temperature of 10 keV by a 10 kJ laser pulse [71].

The Institute of Applied Mathematics provided support in the two-dimensional calculation of the stability of glass spheres [47].

The asymmetry of irradiation and the thickness variation of the target shell were investigated in their effect upon the degree of compression and target shape as a function of amplitude and wavelength of the laser radiation [72]. The target considered was a glass shell 150 microns in diameter with a wall thickness of 3 microns filled with DT gas to a density of $10^{-3}$ gm/cm$^{3}$. The laser pulse had a Gaussian form with an energy of 1 kJ and pulse width of 1 nsec. Under the laser irradiation, 77 percent of the mass of the glass envelope was assumed to be evaporated. The remaining material of the envelope was accelerated to a velocity of approximately 300 km/sec. The heating of the gas under compression led to a noticeable evaporation of the envelope from the gas side (up to 6.5% of the total mass of the glass) which in turn increased the final compression of the gas.

The following conclusions were reached: 1) Microshell laser targets are less sensitive to irradiation asymmetry than they are to the fabrication inaccuracy. For the type of targets considered, the microshell target is less sensitive to the laser irradiation asymmetry than the homogeneous spherical targets. 2) For the wavelengths considered, the basic increase in perturbations is linear with time and occurs during the implosion process. The growth rate of the perturbations is proportional to the irradiation amplitude or the inhomogeneity of the target shell and does not depend on the number of harmonics. 3) The evaporation from the inner side of the microshell presents a stabilizing effect on the development of perturbations of the gas-glass boundary during the deceleration stage of the implosion process [72].

The team had considered the energy transfer in hot laser plasma by α-particles from a DT reaction, first for the case of homogeneous plasma [73], and later deriving α-particle distribution functions for inhomogeneous plasma [30]. It has been demonstrated [74] that the initiation of thermonuclear burn in a DT plasma, taking into account electron heat transfer and local α-particle absorption, can be accompanied by localized burning in certain areas for finite periods of time. Values for the starting temperature perturbations are presented which lead to resonance exitation burning. Hydrodynamic equations of laser plasma were derived taking into account the kinetics of TN reaction products [75]. The results of these analyses were applied in an attempt to sketch out the rough parameters of an economically competitive laser thermonuclear reactor [76]. The values of pressure, temperature, vaporized wall mass, energy deposited in the lithium blanket, etc., resulting from target microexplosions were given without going into specific engineering solutions. The Institute of Applied Mathematics provided the target behavior data obtained by the Monte Carlo method.

The activity of the team further includes proposals for the measurements of neutrons from DT reactions as a test for the presence of superdense target core and the possibility of measuring the superdense state of laser plasma from the yield of DT neutrons [77]. The limits of possible spherical heating of laser plasma were analyzed, taking into account the realizable laser parameters [78]. Methods of target preparation were presented. Specifically, a method of preparing and mounting solid hydrogen and deuterium spheres was suggested and tested, as well as a method of preparing small, hollow, thin-walled polymer spheres [79]. Recently, the group analyzed the absorption and reflection of laser radiation by expanding hot plasma. The analysis comprises Maxwell equations for the laser field and gas-dynamics equations, taking electron thermal conductivity into account. Numerical solutions are given for a plane layer of plasma and a range of laser intensities and pulselengths [80].

In 1978, the team used the Kal'mar facility to measure the compression time of sperical shell targets when irradiated by laser beams [81]. The experimental and theoretical agreement of the compression time as a function of both target and pulse parameters, at laser intensities of less than $10^{14}$ W/cm$^2$, demonstrated that the condition of the corona and the shell compression dynamics can be considered using the hydrodynamic model with the thermal conductivity being close to classical.

Theoretical work in 1978 [82] investigated the generation of magnetic fields in a spherical laser target caused by the appearance of thermoelectrical currents in the region between the thermal wave front and the target surface at which point the hydrodynamic velocity is equal to the local velocity of sound. Noncolinear temperature and density gradients were found to arise as a result of small pertubations and the development of Rayleigh-Taylor instabilities. For the case of glass shell targets irradiated by a 100 joule laser beam these magnetic fields are of the order of $10^6$ gauss and are capable of magnetizing the plasma. Outside the target the field drops rapidly decreasing to one gauss at a distance of 1 mm. The generation of magnetic fields can be associated with a number of mechanisms: 1) resonance absorption of plane polarized light and light pressure anisotropy, 2) magneto-thermal instability and 3) thermo-e.m.f. in an inhomogeneous plasma.

Team 3. X-Ray Spectroscopy

The team developing methods of x-ray spectroscopy to measure laser plasma parameters provides support to Basov's laser fusion research activity. The team has been engaged in this role since 1973. It consists entirely of experimentalists and is composed of a nucleus of their leading authors assisted by 29 other authors who publish infrequently. The work of the team is closely supervised by S. L. Mandel'shtam, Director of the Institute of Spectroscopy, and L. A. Vaynshteyn, Corresponding Member of the Academy of Sciences, USSR, General Physics and Astronomy Division. The reviewers of the reports generated by this team are drawn from groups dealing with beam-target plasma dynamics and stability, compression, burn conditions, and target design.

Team 3 Membership List

Supervisory Personnel

O. N. Krokhin 1972-1976
S. L. Mandel'shtam 1973-1978
G. V. Sklizkov 1972-1977
L. A. Vaynshteyn 1970-1978

Leading Authors

V. A. Boyko 1972-1978
A. Ya. Fayenov 1972-1978
S. A. Pikuz 1972-1978

Authors

Ye. V. Aglitskiy 1972-1978
V. I. Bayanov 1975-1977
V. K. Chevokin 1976-1978
V. A. Chirkov 1974-1977
A. Yu. Chugunov 1974-1976
S. I. Fedotov 1975-1977
S. S. Gulidov 1975-1977
T. A. Kalinkina 1974-1976
Yu. S. Kas'yanov 1976-1978
I. A. Konoplev 1972-1975
V. V. Korneyev 1976-1978
A. A. Mak 1975-1977
Yu. A. Mikhaylov 1975-1977
A. N. Oshurkova 1974-1976
G. V. Peregudov 1974-1976
Ye. N. Ragozin 1974-1976
U. I. Safronova 1970-1978
M. Ya. Shchelev 1976-1978
A. P. Shevel'ko 1976-1978
M. R. Shpol'skiy 1974-1976

I. I. Sobel'man 1973-1977
A. D. Starikov 1975-1977
A. N. Urnov 1976-1978
V. M. Uvarova 1973-1976
L. A. Vaynshteyn 1970-1978
S. M. Zakharov 1972-1975
I. A. Zhitnik 1976-1978

Computer Specialist

N. A. Konoplev 1972-1975

Reviewers

Yu. V. Afanas'yev 1973-1976
V. A. Boyko 1973-1978
A. Ya. Fayenov 1972-1978
E. G. Gamaliy 1974-1976
Yu. S. Kas'yanov 1976-1978
S. L. Mandel'shtam 1973-1978
M. A. Mazing 1976-1978
S. A. Pikuz 1972-1978
V. V. Pustovalov 1974-1976
V. B. Rozanov 1973-1976
A. N. Ryabtsev 1974-1976
I. Yu. Skobolev 1973-1975
I. I. Sobel'man 1973-1977
V. T. Tikhonchuk 1974-1976
L. A. Vaynshteyn 1970-1978
A. V. Vinogradov 1972-1977
E. A. Yukov 1973-1977

A total of 23 papers published under 34 authors' names during the period from 1971 to 1978 was analyzed. The following is the annual breakdown of active authors and published papers by Team 3:

| YEARS | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|
| AUTHORS | 2 | 10 | 10 | 18 | 24 | 32 | 25 | 15 |
| PAPERS | 1 | 1 | 3 | 5 | 6 | 3 | 4 | 0 |

The primary purpose of the experimental research activity of Team 3 has been the diagnostics of hot dense plasmas obtained in the course of laser fusion research. However, the authors also mention astrophysical research and the development of x-ray and UV lasers as possible beneficiaries of this work [84]. The work with multicharged heavy ions observed in laser plasmas has been noted as of interest to the synthesis of transuranic elements (2 - 114 and 126). Since 1974, the team has been producing dense plasmas by the cumulation method consisting of directing an 80 J laser beam, with intensity of $5 \times 10^{14}$ W/cm$^2$, into a conical hole on the surface of a solid target [85]. The focus of the work has been the measurement of x-ray spectra of hydrogen- and helium-like multi-charged ions performed to determine the temperature, density, and size of various regions of plasma derived by laser beam from massive targets of deuterized polyethylene with various admixtures [86,87,84,88,89]. Measurements of plasma densities as high as $10^{23}$ were made in [90]. The electron temperature profile in plasma was studied along the radial distance of 0.1 - 0.8 mm, with a maximum temperature of 0.8 keV, using massive targets of Mg, Al, $SiO_2$, Sc, Ti, V, and pressed powder [91]. The authors established a correlation between the maximum reflection and maximum intensity of hard x-rays (21 keV), as well as the maximum charge number of ions [92]. In 1976, a newly developed crystal spectrograph [93] was used to record the x-ray spectrum of laser-derived Mg plasma with a spatial resolution of 25 μ in a single laser flash [94]. Most recently, the authors of the group published tables of wave-lengths and probabilities of transitions from autoionization levels of multicharged helium-like ions [95].

The transient electron temperature of a laser-derived carbon plasma was measured in [96] by using an electro-optical camera with a scintillator located at the camera entrance. This method was found to be promising in the investigation of laser plasma in the x-ray region.

## Team 4. Ultrashort Laser Pulses

The team, consisting primarily of experimentalists, deals with the problems of subnanosecond pulse generation by neodymium glass lasers required for laser fusion experiments. The main problems considered throughout the period covered in this report are self-focusing and similar effects producing damage to the active medium, achievement of the required pulse shapes, and synchronization accuracy of the laser oscillator within the system. The nucleus of the team has been active at least since 1969, i.e., before the development of the Kal'mar system. At that time, the leading authors of the team worked together with the developers of the Kal'mar system (S. I. Fedotov and A. S. Shikanov, in addition to Basov, Krokhin, and Sklizkov). Since then, however, the team has been publishing its results separately. There is no evidence at this time that members of the team work together with the developers of systems advanced beyond the Kal'mar.

The team works closely with the Institute of Spectroscopy in Moscow. A number of team members (Yu. A. Matveyets, S. V. Chekalin, P. G. Kryukov, and A. N. Zherikhin) publish under the byline of the Institute of Spectroscopy [98,99]. The latter institute also contributed to Basov's laser fusion activity in the form of reviews of some of the results by S. L. Mandel'shtam, Director of the Institute of Spectroscopy.

### Team 4 Membership List

Group Leader

P. G. Kryukov 1968–1976

Supervisory Personnel

O. N. Krokhin 1971–1973
G. V. Sklizkov 1969–1973
Ye. K. Zavoyskiy 1972–1974
B. Ya. Zel'dovich 1973–1975

Leading Authors

S. V. Chekalin 1968–1976
P. G. Kryukov 1968–1976
Yu. A. Matveyets 1968–1976
Yu. V. Senatskiy 1970–1978

Authors

N. B. Baranova 1972-1975
V. N. Belyayev 1975-1977
M. M. Butslov 1972-1974
N. Ye. Bykovskiy 1973-1978
R. V. Chikin 1972-1974
S. A. Churilova 1971-1975
S. D. Fanchenko 1972-1976
A. I. Fedosimov 1971-1975
S. I. Fedotov 1969-1973
Ye. M. Gordeyev 1974-1976
V. A. Gribkov 1969-1971
Ye. V. Kurgamova 1973-1975
V. S. Letokhov 1968-1970
V. I. Panteleyev 1973-1975
N. V. Pletnev 1976-1978
A. V. Sharkov 1974-1976
O. B. Shatberashvili 1971-1975
V. A. Shcheglov 1972-1974
A. S. Shikanov 1969-1973
Ye. A. Smirnova 1972-1974
B. V. Sobelev 1975-1977
B. M. Stepanov 1972-1976
Ye. L. Tyurin 1972-1974
A. M. Vakulenko 1973-1975
V. T. Yurov 1973-1975
S. D. Zakharov 1971-1973
A. R. Zaritskiy 1971-1973
A. N. Zherikhin 1973-1975

Technicians

B. I. Belov 1971-1973
I. M. Divil'kovskiy 1971-1973
V. M. Groznov 1971-1973
G. Ya. Kolodnom 1976-1978
D. V. Kovalevskiy 1971-1973
B. V. Kruglov 1971-1973

Experimentalists

D. F. Bonchovskiy 1973-1975
V. A. Frolov 1972-1974
A. I. Kovrigin 1971-1973
Yu. M. Popov 1971-1973
I. S. Rez 1971-1973
M. F. Stel'makh 1971-1973
D. B. Vorontsov 1972-1974

Reviewers

S. I. Fedotov 1969-1973
B. Ye. Kinber 1973-1975
P. G. Kryukov 1968-1976

T. I. Kuznetsov 1973-1975
V. B. Rozanov 1971-1973
I. I. Sobel'man 1973-1975
S. M. Zakharov 1968-1978
Ye. K. Zavoyskiy 1972-1974
B. Ya. Zel'dovich 1973-1975

A total of 21 papers published under 35 authors' names during the period from 1969 to 1977 was analyzed. The following is the annual breakdown of active authors and published papers for Team 4:

| YEARS | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 8 | 9 | 14 | 21 | 28 | 24 | 22 | 12 | 5 | 3 |
| PAPERS | 1 | 1 | 1 | 4 | 3 | 8 | 1 | 1 | 1 | 0 |

Early research focused on the concept of a stable two-component medium, consisting of the amplifying material and a nonlinear fast-relaxation absorber, as a basis for an ultrashort-pulse laser amplifier [100]. The objective was to obtain a pulse train with a total energy of 10 J and a single-pulse energy of 1 J. This was followed by a series of experiments and theoretical analyses of nonlinear interactions at high energy density, such as the self-focusing effect. One of the concepts advanced to minimize the destructive nonlinear effects was the conical array of amplifier rods operating with a spherically divergent beams, rather than with parallel beams [101]. A model of a high-power Nd laser system employing diverging beams in funnel-like structures was theoretically analyzed as a means of eliminating glass damage due to self-focusing [102]. However, experimental results indicated that the amplification of diverging beams, while supressing the self-focusing effect, produces spectrum broadening and scattering of the beam [103].

In 1973, Yu. V. Senatskiy, one of the leading authors, proposed a means of eliminating self-focusing using penetrating radiation to form absorbing layers in soft apertures and on lateral surfaces of the active elements [104]. Self-focusing was considered as the brightness limiter in ultrashort-pulse Nd and YAG lasers. For intensities below 3-5 GW/cm$^2$ the main mechanism limiting the amplified power was whole-beam self-focusing which strongly affected beam divergence. Above 3-5 GW/cm$^2$

small-scale self-focusing caused divergence that increased with gain. Whole-beam self-focusing could be eliminated by corrective optics [99]. Several theoretical papers evaluated the possible methods of eliminating the effects of diffraction and self-focusing on high-power laser amplifiers [105,106].

A series of experiments was aimed at the detailed investigation of the nature of ultrashort pulse generation. The hypothesis of a fluctuating mechanism of ultrashort-pulse formation was proposed and verified with a ruby laser having a large number of axial modes and a slow nonlinear absorber performing the Q-switching and mode-locking functions [107]. In 1973, the authors reported on a direct observation of the picosecond structure of mode-locked Nd lasers. A repetitive fine structure with a period of 1-2 psec was observed [108]. An analytic treatment of the observed time-dependent time structure of ultrashort laser pulses was published a year later [109]. At the same time, the formation of laser pulses optimized for the requirements of laser fusion research (short risetime, high contrast) was studied experimentally. The method used in this work was based on electro-optical shutters cutting out short pulses. Another method combined 9 laser beams into a single beam of square cross-section capable of being focused on laser-fusion targets [110]. Other experimental approaches employed an amplifier with a nonlinear bleachable absorber as a stable two-component medium for pulse shortening and increasing contrast [111], and retardation of the process of regenerative spectral narrowing in the generation of single ultrashort laser pulses [112].

The team has also studied plasma heating as a function of laser frequency. In experiments reported in 1972, a Nd laser beam operating at the fundamental (1.06 μ) and second harmonic (0.53 μ) frequencies (KDP crystal) were used to measure plasma absorption. The laser intensity was $10^{14}$ W/cm$^2$. Over 50% of the laser output energy was converted into the second harmonic, whose output was 10 J. At 0.53 μ plasma absorption was found higher by a factor of 3 than that observed at 1.06 μ [113,114].

The team has reported on the design and construction of several instruments. In 1970, a Kerr cell was built as a fast Q-switch for 0.1-1 nsec pulses [115]. In 1974, the team reported a fast DKDP crystal shutter [116], and a recent paper described the test results of a 0.1-1 nsec Nd laser with a repetitive Q-switch just reported in 1975. The Q-switch was a quarter-wave Pockels cell with a DKDP crystal and provided a 1 nsec accuracy of system synchronization [117].

The team has also been studying the design of UV and x-ray lasers using laser plasma as the action medium. The x-ray spectra of multi-charged ions generated by heating plasma with 5 J, 250 nsec laser pulses, were used to determine plasma electron temperature and density [111].

The team does not appear to have been directly involved in the design and construction of the major laser systems such as the Kal'mar [49] or of its successors.

Team 5. Chemical Lasers

The development of chemical lasers represents an important part of the work of Basov's research group. While the team engaged in this development work, headed by A. N. Orayevskiy, is pursing chemical laser concepts aimed at various applications, it appears that a major objective is the use of chemical lasers in pellet fusion research. It is of interest to note that the team regards the fusion application of its chemical laser system in terms of the large, high aspect ratio targets considered by Team 2 of Basov's group. The main thrust of the chemical laser team is the theoretical and experimental evaluation of the total and chemical efficiency of chemical lasers initiated by high-current electron beams and by photolysis. Multi-stage systems consisting of a driving oscillator and amplifiers are being developed.

Team 5 Membership List

Leading Authors

A. S. Bashkin 1974-1978

A. N. Orayevskiy 1973-1978

V. I. Igoshin 1974-1978

Authors

B. L. Borovich 1973-1975

V. I. Galochkin 1969-1971

L. Ye. Golubev 1977-1978

P. G. Grigor'yev 1973-1977

A. F. Konoshenko 1977-1978

Yu. I. Kozlev 1977-1978

L. V. Kulakov 1969-1971

Ye. P. Markin 1973-1975

V. S. Masterov 1974-1976

V. Yu. Nikitin 1973-1978

A. K. Piskunov 1977-1978

O. Ye. Porodinkov 1975-1977

A. B. Skvortsov 1975-1977

V. N. Tomashov 1977-1978

V. N. Troshagin 1977-1978

N. N. Yuryshev 1977-1978

S. I. Zavorotnyy 1973-1975

V. S. Zuyev 1973-1975

Reviewers

A. S. Bash 1974-1976

N. G. Basov 1974-1976

V. I. Igoshin 1975-1977

O. A. Tumanov 1975-1977

Experimentalists

Yu. V. Gurov 1975-1977

L. D. Mikheyev 1975-1977

V. A. Samorodov 1975-1977

A. A. Shchirokov 1975-1977

A. B. Skvortsov 1975-1977

Technicians

A. V. Mezenov 1975-1977

N. V. Ponomarev 1975-1977

A total of 16 papers published under 21 authors' names during the period from 1969 to 1978 was analyzed. The following is the annual breakdown of authors and papers published by Team 5:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 5 | 5 | 5 | 0 | 7 | 10 | 12 | 8 | 14 | 11 |
| PAPERS | 0 | 1 | 0 | 0 | 0 | 1 | 5 | 5 | 1 | 3 |

While the work of this team on the development of chemical lasers has been performed since the early seventies, the proposal to use HF lasers in pellet fusion research was made in 1975 [118,119]. The proposal was based on the team's findings that the chemical laser reaction initiated by an electron beam with current density of $10^3$ A/cm$^2$ has a duration of the order of tens of nsec. In particular, the proposal was to develop HF lasers for those laser-driven pellet fusion experiments that postulate energy gain of 1000 from the compression of hollow target spheres 1 cm in diameter with a fuel mass of

$10^{-3}$ - $10^{-2}$ g down to a density of $10^2$ g/cm$^3$, and that do not impose high requirements on the pulse shape [120].

The team analyzed the operation of HF lasers at a low initial temperature of the active medium and determined the conditions for separating in time the stage of optical initiation from the stage of the explosive reaction. It was assumed that a drop in the temperature of the active medium will produce a period of induction, when the chemical process is slowed down so that a high concentration of active centers can take place. The subsequent heating of the mixture would lead to a sharp acceleration of the reaction and hence to a short laser pulse. Numerical analysis yielded the following requirements:

$F_2:H_2$ = 3:1,
total pressure - 1/3 atm,
initial temperature - 100 K,
initiating pulse length - $\leq$ 4 µsec,
active center concentration - $10^{18}$ cm$^{-3}$.

The resulting laser pulse would then deliver an energy of 0.761 J/cm$^3$ with a pulselength of 60 nsec. The chemical efficiency would be 16%, and the overall efficiency, 400%. Increasing the initial temperature to 150 K shortens the induction period to 1 µsec which then makes it possible to reach an efficiency of 1160% [120].

The above concept was the result of experimental and developmental work of the team. The necessary light source with the required light flux of $10^{24}$ photons/cm$^2$.sec was reported two years earlier. With a brightness temperature of 50,000 K, the source was considered an effective means of initiating chemical lasers [121].

The numerical analysis for this concept was based on a simple model of an $F_2$-$H_2$ laser developed specially for the fusion proposal. The model takes into account such parameters as the energy yield, laser pulselength, and laser efficiencies considering both amplifier and oscillator modes. The model provided an estimate of the energy yield for a wide range of initial parameters and a basis for the selection of optimal operating conditions in the laser amplifier mode. The chemical efficiency of the laser was found to depend strongly upon the length of the initiating pulse, reaching 30 percent for the pulse shortened to 100 nsec and a high concentration of $F_2$ [122]. The analytic method supporting the model was developed in [123,124] which computed stimulation emission in multi-level molecular systems.

Parallel with its work on the short-pulse HF laser, the team has been performing systematic theoretical and experimental studies of the efficiency of chemical lasers. Early research was focused on the $D_2$+$F_2$+$CO_2$+He mixture. The pulsed chemical laser developed on this basis with optical initiation and operating at atmospheric pressure was regarded as the first of its type to have an energy output of 0.02 J/cm$^3$ delivered in 10 μsec. The highest pulse energy obtained was 10 J and the average power per pulse exceeded $10^6$ W [125].

It was found that the chemical efficiency of such lasers decreases with decreasing rotational quantum number, and can be improved by employing transitions with higher rotational energy [126].

The DF-$CO_2$ laser was developed as a two-stage oscillator-amplifier system. It reached an amplifier energy output of 150 J/ℓ.atm at the wavelength of 10.6 μ, for a power density of the oscillator output of over 150 KW/cm$^2$ [127].

The team also investigated the HF laser with electron-beam initiation, whose main benefit is a high efficiency [128]. The properties of the HF medium were not well understood, however, and particular attention of the team was directed toward the parameters of the driving oscillator signal (power density) that are required for an effective delivery of the amplifier energy.

One experimental system used two IFP-20,000 flash lamps for the initiation of the oscillator stage, and a 200 keV, 0.2 kA, 30 nsec electron beam pulse for the initiation of the amplifier. The oscillator delivered 1.5 J in 4 μsec. The saturating power of the system was 200-500 W/cm$^2$. The ratio of the energy delivered by the amplifier to that delivered by the oscillator was 73 percent, considered capable of improvement. However, for this ratio, the amplifier efficiency was considerable, reaching 400 percent [129].

The authors of the team considered that, according to the above results, high efficiency could be obtained only with weak initiation and at low energy yields. They refer also to U.S. results indicating the same point. For example, J. A. Mangano obtained an overall efficiency of 875 percent with an energy yield of 51 J/ℓ and chemical efficiency of 2.8 percent. On the other hand, high energy yields at very high initiation levels were obtained at only moderate efficiencies.

The most recent work of the team was aimed at two objectives:

1. Increasing the energy yield of chemical lasers while retaining high efficiency, and

2. Increasing the efficiency of electron beam utilization, i.e., the ratio of output energy of the laser to the total energy of the electron beam.

In the experiments dedicated to this purpose, the electron beam parameters were 250 kV, 1.4 kA, and 35 nsec. The results showed that for a mixture of $H_2:F_2:O_2:He = 30:75:6:25$, and a pressure of 722 mmHg, the energy yield was 91 J/ℓ. The overall efficiency was 936 percent and the chemical efficiency was 4.7 percent. The laser pulselength was 1.0 μsec with a very steep front. The electron beam energy delivered to the laser was 4 J, so that the utilization efficiency of the electron beam was 250 percent [130].

Team 6. Electro-ionization lasers

The team pursued its activity throughout the seventies, primarily aimed at the development of high-energy lasers based on $CO_2$ and, to a lesser extent, CO. A range of different applications of such lasers has been investigated, with laser-driven fusion having a significant place. The nature of the electro-ionization laser involved the team with high-current electron accelerators. Some of this work was extended to the development of excimer lasers.

Team 6 Electro-ionization Lasers

Group Leader

V. A. Danilychev 1970-1978

Leading Authors

O. M. Kerimov 1970-1978

A. F. Suchkov 1970-1978

Authors

E. M. Belenov 1970-1975

V. A. Boyko 1974-1978

I. A. Berezhnoy 1974-1978

A. N. Brunin 1974-1978

A. Yu. Chugunov 1974-1978

A. G. Degtyarev 1975-1977

V. A. Dolgikh 1973-1977

B. N. Duvanov 1976-1978

V. V. Ignat'yev 1974-1978

A. A. Ionin 1972-1978

T. G. Ivanova 1976-1978

V. S. Kazakevich 1976-1978

M. N. Khasenov 1975-1977

D. D. Khodkevich 1976-1978

I. V. Kholin 1974-1978

L. Ye. Kholodenkov 1976-1978

A. D. Klementov 1976-1978

I. B. Kovsh 1970-1978

A. N. Lobanov 1973-1978

A. I. Milanich 1976-1978

A. S. Podsosonnyy 1972-1974

N. L. Poletayev 1976-1978

S. I. Sagitov 1974-1976

V. A. Sobolev 1972-1978

B. M. Urin 1973-1977

V. D. Zvorykin 1974-1978

Reviewers

A. Ya. Fayenov 1976-1978

V. A. Kovalenko 1976-1978

A. N. Lobanov 1976-1978

I. V. Nemchinov 1975-1977

S. A. Pikuz 1976-1978

N. N. Ragul'skiy 1976-1978

B. M. Urin 1976-1978

B. Ya. Zel'dovich 1976-1978

Technicians

G. I. Pantaleyev 1972-1978

S. I. Sagitov 1972-1974

I. A. Timoshin 1972-1974

V. K. Yeroshev 1972-1974

A total of 25 papers published under 29 authors' names during the period from 1970 to 1978 was analyzed. The following is the annual breakdown of authors and papers published by Team 6:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 0 | 5 | 5 | 8 | 11 | 19 | 20 | 26 | 26 | 22 |
| PAPERS | 0 | 0 | 2 | 2 | 4 | 3 | 2 | 3 | 7 | 2 |

The diagnostics of laser radiation reflected from plasma include the magnitude of the reflection coefficient, its dependence on the shape, energy, and focusing of the laser beam, directional distribution of the reflected radiation, and its spectral composition. All are important to experiments in heating laser fusion plasma.

The work of the team was based on a simple system of an electro-ionization $CO_2$ laser producing $10^{10}$ W pulses, in which a solid target was used as one of the mirrors. This configuration was first suggested by Basov in 1975 [131]. The plasma mirror laser favors the generation of nanosecond spikes [132]. Detailed analysis of this laser has been performed for 100 nsec pulses with energy up to 250 J and for nsec pulse trains with a power of up to 20 GW. The plasma mirror laser was found to have a high degree of stability [133]. The structure of the generated pulses is determined by the nonlinear properties of the plasma mirror with a temperature of several million degrees. The energy of the laser emission is effectively absorbed by plasma. For the power of $10^{10}$ W and laser light flux density on the target of $10^{11}$-$10^{12}$ W/cm$^2$, the electron temperature and density in the plasma mirror were 200 eV and $10^{19}$ cm$^{-3}$ respectively. It was concluded that the obtained parameters could be further improved. For example, the energy and power of the laser beam could be increased by increasing the volume of the laser cell. The density of the heating flux could be increased by using aspheric optics. The simplicity, high efficiency, and high power of this laser system render it suitable for laser fusion research [134].

The efficiency of the plasma mirror laser was 6-10 percent. The plasma-generating targets were 12 mm spheres of various materials. The laser cell was 10 x 10 x 100 cm$^3$. The authors concluded that the electro-ionization laser with a plasma mirror affords the opportunity to increase the output energy. The absence of complex optics makes it possible to increase the aperture and consequently the output energy without disturbing generation. The pulse repetition frequency could be increased to 10-100 Hz by flowing the active gas and automatic position adjustment of the target.

In the experiments, for a total laser pulse energy of 190 J, 140 J were delivered by the nsec spikes. The highest energy of a spike was 40 J for 1.8 nsec [135].

A large part of the team's activity has been the development of electro-ionization lasers pursued with the aid of G. A. Mesyats of the Institute of Atmospheric Optics in Tomsk who produced the necessary cathodes [135].

The work on electro-ionization lasers involve experimental studies of the $CO_2$+$N_2$+He laser [136,137], the high-output high-efficiency $CO_2$+$N_2$+He laser [138], and the CO laser which reached an output energy of 100 J and total efficiency of 30 percent [139,140].

Basov's first high-pressure electro-ionization $CO_2$ laser was operated in 1971 using a cold-cathode electron gun [144,142]. Subsequently, these lasers were investigated at pressures up to 60 atm [143,144,145]. These early lasers employed small volume cells of about 40 $cm^3$ and their output did not exceed a few joules [146]. In 1973, the team reported a 10 liter laser with an output of 200 J and efficiency of 10 percent [147]. An area of utilization of the electro-ionization $CO_2$ lasers was the study of laser-induced breakdown of compressed gas. The optical strength of compressed gas was important in determining the limits of infrared lasers operating at pressures of hundreds of atm [148,141].

More recent work by the team with the electro-ionization $CO_2$ laser involved air breakdown near a metal target irradiated by a $10^9$ W beam. The large area of the optical breakdown, reaching 27 $cm^2$, and the short laser pulse of 120 nsec produce an effect of a strong plane explosion. The recoil impulse may be quite high under these conditions [149].

These studies also showed for the first time supersonic radiation absorption waves at 10.6 $\mu$. The high absorption coefficient of the $CO_2$ laser made it possible to realize radiative propagation at power densities of (3-4) x $10^7$ W/$cm^2$ which is two orders lower than the power density required for the 1.06 $\mu$ radiation [150].

The team has also published papers on its work with excimer lasers pumped by high-current electron beams [151,152,153,154].

Miscellaneous Activities

In addition to the specific projects pursued by the main groups over relatively long periods of time, there is a number of projects of shorter duration, generally performed by smaller teams, that are part of Basov's laser fusion research activity. The limited size and time period of these projects, as perceived so far, do not warrant their treatment alongside the four main groups described above. Instead, they are presented here individually with a brief description of the subject of activity.

1. Target fabrication

Authors

A. N. Markov 1976-1978

A. B. Fradkov 1976-1978

V. D. Chernetskiy 1976-1978

According to these authors [478] a component of the Lebedev Physics Institute, called the "Cryogenic Department," has developed and tested a cryostat to study the interaction of laser beams with a fixed hydrogen and deuterium target. The cryostat has been designed without a mechanical shutter that normally protects the vacuum region during the target freezing stage. The new device produced cylindrical targets with diameters from 0.3 to 4.5 mm. The targets remained in a vacuum of $2 \times 10^{-5}$ mmHg over 30 min.

2. Plasma focus and Z-pinch

Authors

N. V. Filippov 1971-1974

T. I. Filippova 1971-1974

V. A. Gribkov 1971-1974

V. M. Korzhavin 1971-1974

During the sixties and early seventies, the Lebedev Institute had carried on a project called "Plasma Focus" as part of Basov's fusion effort. The most recent publications of the Lebedev Institute generated by this project are dated 1973 and the project, together with some personnel (V. M. Korzhavin), may have been transferred to the Kurchatov Institute of Atomic Energy after 1973 [479].

In 1972, the Lebedev Institute published the results of high-speed interferometry of the final stage of the plasma focus discharge [419]. In 1973, the same method was used to slow the formation of high-power electron beams subject to hose instability [408]. Finally, a high-power neutron source based on a Z-pinch was described [443].

3. Inductive electron accelerator for laser plasma diagnostics

Authors

V. K. Lugovskiy 1975-1977

F. A. Nikolayev 1975-1977

G. V. Sklizkov 1975-1977

A high-energy electron induction accelerator has been proposed as a tool for the diagnostics of laser fusion targets in the compression stage [383]. The accelerator would deliver a 20 MeV, 10 kA electron beam pulse. The design is based on the aircore betatron concept of A. I. Pavlovskiy (with whom Sklizkov worked up to 1965), modified to make better use of the magnetic field by suitably shaping the crossed fields and placing the electron source at the axis of the accelerating system.

4. Transport of electromagnetic radiation in plasma

Authors

A. I. Plis 1970-1978

V. P. Pimenov 1975-1977

V. A. Shcheglov 1970-1978

Ye. L. Tyurin 1970-1972

S. D. Zakharov 1970-1977

The propagation of monochromatic radiation through plasma has been studied by this group since 1971 [454]. Recent papers report on research performed in collaboration with A. I. Plis of the Moscow Power Institute. The work is aimed at an exact analytical solution for the case when absorption occurs in collisions of electrons with ions and neutral particles [453, 446].

## Lebedev Physics Institute, Moscow

### Group II A. M. Prokhorov, Head

Group II appears to consist of six distinct teams pursuing specific research projects, under the general guidance of Prokhorov and P. P. Pashinin playing the role of Prokhorov's deputy. The research activity of this group is less specific to laser fusion than that of Basov's group, and the group is less explicit about its research goals. While its work deals with short-pulse laser design and laser interaction with plasma and solids, the significance and objectives of the research may transcend, and in some cases, bypass the purposes of laser fusion research. In addition to the six teams within the Lebedev Physics Institute, Prokhorov's group is directly supported by a team of the Landau Institute of Theoretical Physics, Moscow, under S. I. Anisimov (presented separately below).

A total of 65 papers published under 90 authors' names during the period from 1969 to 1978 was analyzed. The following is the annual breakdown of active authors and published papers for Group II:

| YEARS | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 22 | 27 | 26 | 32 | 36 | 53 | 49 | 61 | 63 | 57 |
| PAPERS | 2 | 9 | 7 | 4 | 6 | 8 | 7 | 4 | 11 | 7 |

## Team 1. Development of Kilojoule $CO_2$ Lasers

During the period of 1969 to 1978 this team developed a $CO_2$ laser, the final design of which produced 7.5 kilojoules of beam energy in a 1 microsecond pulse. This result was claimed to be the best and most energetic output at the time of publication. The electron accelerator used to ionize the laser was developed by Mesyats and Koval'chuk of the Institute of Atmospheric Optics in Tomsk.

### Team 1 Membership List

Leading Authors

G. P. Kuz'min 1969-1978

N. V. Karlov 1969-1978

Ye. K. Karlova 1969-1978

Authors

S. P. Bugayev 1974-1976

Yu. I. Bychkov 1974-1978

T. I. Darvoyd 1974-1976

N. P. Datskevich 1976-1978

I. V. Kochetov 1976-1978

Yu. B. Konev 1976-1978

N. N. Kononov 1976-1978

B. M. Koval'chuk 1974-1978

I. O. Kovalev 1972-1974

I. K. Krasyuk 1977-1978

Yu. A. Kurbatov 1974-1977

B. A. Kuritsyn 1976-1978

Yu. S. Kuzminov 1976-1978

I. S. Lisitskiy 1974-1976

V. I. Manylov 1975-1977

G. A. Mesyats 1974-1978

S. M. Nikiforov 1976-1978

V. M. Orlovsky 1974-1978

V. V. Osiko 1976-1978

V. V. Osipov 1976-1978

P. P. Pashinin 1977-1978

R. P. Petrov 1972-1974

V. G. Pevgov 1976-1978

A. M. Rybalov 1974-1977

Ye. V. Sisakyan 1974-1976

T. B. Volyak 1977-1978

V. V. Voronov 1976-1978

D. Yu. Zaroslov 1972-1974

A total of 9 papers published under 31 authors' names during the period from 1969 to 1978 was analyzed. The following is the annual breakdown of active authors and published papers for Team 1:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 3 | 3 | 3 | 6 | 6 | 17 | 15 | 25 | 24 | 21 |
| PAPERS | 0 | 1 | 0 | 0 | 1 | 0 | 2 | 1 | 3 | 1 |

The primary effort of this team was to develop a high intensity $CO_2$ laser optimizing the energy output in the laser pulse. Initial developments of the laser were made in 1973 [155] with a spiral electrode configuration and operating at atmospheric pressure. In 1975 [156] a laser with an output energy of 500 joules was made with an operating efficiency of 33% (laser beam energy to electrical energy spent on the discharge). Later, in 1976 [157] a $CO_2$ laser, pre-ionized by a 120 kV, 3.6 kA electron beam, was developed and reached an output energy of 5 kilojoules. This laser operated at atmospheric pressure and had an active volume of 270 liters (30 x 30 x 300 $cm^3$). The exit window used a TCl-TBr crystal with a diameter of 230 mm. The main problem in the further increase of the laser energy was found in the lack of suitable optical elements allowing one to extract energy from the whole volume of the laser. In 1977 [158] the laser was modified using a $BaF_2$ exit window, 450 mm in diameter, in conjunction with an unstable resonator with metal mirrors. This allowed the laser output energy to reach 7.5 kilojoules in a 1 microsecond pulse and was claimed to be the best result obtained at the time of publication.

The shortening of the pulse length of an atmospheric pressure $CO_2$ laser, investigated in 1978, was accompanied by inter-cavity breakdown with burnthrough of thin metallic films. Pulses of 10 nanosecond duration at half maximum have been obtained with 3 to 4 nanosecond pulse fronts [159]. The effect of pressure and composition of the working medium upon the laser energy characteristics was studied in [160]. It was demonstrated that with large enough input energy the active medium became superradiant. The threshold of input energy required to bring the active medium to superradiance was determined as a function of gas pressure.

Concurrently, the team was involved in the investigation of the optical, thermal, and mechanical properties of window materials [161]. The threshold of surface and volume damage was determined for samples under either pulsed or continuous $CO_2$ laser radiation. Other experiments performed by the team [162] included thermal self-focusing and breakdown in crystals of NaCl, KBr and CsI under $CO_2$ laser radiation. The performance and use of BSN crystals as low-inertia pyroelectric detectors for high intensity nanosecond pulsed $CO_2$ lasers were analyzed in [163].

Team 2. Solid-Derived Laser Plasma

During the period from 1972 to 1978, this team investigated the irradiation of solid targets by a transverse discharge $CO_2$ gas laser beam. The optical breakdown near the surface of the target and the pressure impulse exerted upon the target were studied in detail.

Team 2 Membership List

Leading Authors

A. I. Barchukov 1972-1978

F. V. Bunkin 1972-1978

V. I. Konov 1972-1978

Authors

V. P. Ageyev 1976-1978

M. I. Arzuov 1976-1978

N. I. Chapliyev 1975-1978

M. E. Karasev 1976-1978

N. N. Kononov 1975-1977

V. V. Kostin 1976-1978

G. P. Kuz'min 1975-1977

A. A. Lyubin 1973-1975

G. A. Mesyats 1975-1977

S. M. Metev 1976-1978

A. S. Silenok 1976-1978

A total of 10 papers published under 14 authors' names during the period from 1972 to 1978 was analyzed. The following is the annual breakdown of active authors and published papers for Team 2:

| YEARS | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|
| AUTHORS | 4 | 5 | 6 | 10 | 15 | 13 | 10 |
| PAPERS | 0 | 1 | 1 | 2 | 1 | 4 | 1 |

All the papers presented by this research team investigated the irradiation of solid targets with a beam from a transverse discharge $CO_2$ gas laser. The research concentrated on the optical breakdown and the formation of a plasma near the surface of the target while under irradiation by the laser beam. The laser energy output in these studies was varied from 0.3 to 10 joules, the pulse length from 0.25 to 15 microseconds, while the beam divergence was approximately $10^{-2}$ radians (at the 1/2 power level). Some of the papers [164,165,166, 167] dealt with the measurement of the pressure pulse that was exerted upon the target during the breakdown of the gas in front of the target.

The first experiments were performed irradiating solid targets (Al, Cu, Mg, NaCl, etc.) with $CO_2$ laser light and observing, near the surface of the targets, that the optical breakdown threshold in air is considerably lower than had previously been observed. According to the new data, the optical breakdown appeared with light intensities from 5 to 10 x $10^6$ W/cm$^2$ as compared to $10^8$ W/cm$^2$ in previous studies. The breakdown plasma was found to almost completely absorb the laser light and to shield the surfaces of the target. At breakdown, a shock wave was formed which created a recoil impulse acting upon the target. These recoil impulses were measured experimentally and interpreted on the basis of the point explosion theory. The mechanism of the initiation of the gas breakdown, however, was not determined by these investigations [164].

Further experiments were made, resulting in more detailed studies of the processes of formation and the dynamics of the plasma that appears near the target due to the optical breakdown of air and other gases. The optical breakdown in air was studied as a function of target material, air pressure, and laser spot size on target [167,168,169]. Other experiments were carried out in air and argon under pressures ranging from 0.1 to 7 atmospheres [170], in atmospheric nitrogen [171], and in xenon from $10^{-3}$ to 1 atmosphere [172]. The targets used encompassed a number of different materials having various optical and thermal properties.

A two-faceted picture was observed in the development of the breakdown in air and argon at various pressures. When the laser beam intensity was below a certain critical value, a condition was found wherein the plasma did not separate from the target and developed into "laser plasmatron" condition. However, when the beam intensity was above the critical value, the "light detonation" condition was reached and the plasma separated from the target. In this case, the ionization front traveled, with a speed faster than sound, towards the laser.

The experimental data showed that the optically polished targets, such as the plates of $BaF_2$ and NaCl which are transparent to the $CO_2$ laser beam, as well as copper and aluminum mirror surfaces, did not break down up to 7 x $10^7$ W/cm$^2$ [170]. On the unpolished targets, the breakdown occurred in the interval (5 - 10) x $10^6$ W/cm$^2$ as seen in [164]. These findings demonstrated that the low breakdown threshold effect is caused by the evaporation from the targets of a dielectric substance, which is strongly absorbing at the wavelength of $\lambda = 10.6\ \mu$. On the optically polished target surfaces this layer is thin and can be gotten rid of by either a preliminary cleaning of the surface or by the initial laser pulses.

A theoretical explanation was presented in [170] on the low threshold gas breakdown phenomenon near the target which was not explained previously in [164]. The existence of this low threshold breakdown near solid targets can be the cause of the destruction of optical surfaces and the factor limiting the power output from $CO_2$ lasers.

Theoretical results were also obtained on the temperature and pressure in the region of one-dimensional gas flow near the target. The evaporation of solid targets under laser irradiation and gas dynamics of the formed plasma were also studied.

Experiments were later carried out [165] in order to determine the mechanical pressure exerted upon solid targets by the optical breakdown of gases in front of the target surfaces irradiated in air and other gases by beam pulses from $CO_2$ lasers. The optimum pulse length was determined in order to obtain a maximum value of the specific pressure impulse. This pressure impulse is of primary interest in the formation of laser jet propulsion as described in [173,174]. The dependence of pressure was studied as a function of the geometrical parameters of the plasma, the size and intensity of the irradiation spot, the size and shape of the target, and the type and pressure of the surrounding gas. The results were interpreted on the basis of the point explosion theory, taking into account the atmospheric counter-pressure.

Flat, hemispherical, and coneshaped targets were used in the experiments and were mounted on a ballistic pendulum measuring apparatus. The magnitude of mechanical impulse, which was exerted upon the target as a result of the interaction of the breakdown plasma formed near the target surface, was determined by the horizontal deflection of the pendulum. The areas of the targets were 1.5 to 2 $cm^2$, while the areas of the irradiating beam on target were 0.07 to 0.6 $cm^2$ depending upon the laser used.

The initial experiments were made in air and vacuum using three TEA $CO_2$ lasers with different pulse lengths and beam energy outputs up to 10 joules. The value of the specific pressure impulse was found to be double for the semispherical target as compared to the flat target [165]. The later experiments [166] were carried out in air, helium, and xenon in the pressure range of 0.01 to 1.0 atmosphere with laser beam energy up to 15 joules in a pulse length of approximately 2 to 5 microseconds. The light intensity was varied from $5 \times 10^6$ to $5 \times 10^8$ $W/cm^2$ and was always insufficient to obtain gas or air breakdown by itself, i.e., without the presence of the target. The pressure impulse was found to have a value of 2 to 3 dyne-seconds per joule at the low pressures and independent of the type of gas used, which substantiates the importance of the evaporation mechanism present in this pressure range. However, at the larger pressure ranges (greater than 10 mmHg), the pressure impulse is strongly dependent upon pressure and type of gas, reaching a maximum of 7 dyne-seconds per joule for xenon at atmospheric pressure.

The latest experiments performed by this team compared repetitive, continuous, and single $CO_2$ laser beam pulses in the heating of metal targets in air and nitrogen [175,171]. The results demonstrated that there was essentially no difference between the breakdown plasma formed by the single pulses or the repetitive pulses up to 30 Hz. The effect of the gas breakdown in front of the target and oxidizing reactions on the surface of the target upon the effective target absorptivity was investigated as a function of target temperature.

## Team 3. Ultrashort Laser Pulses

### Development of Passive Shutters

The team has been active throughout the seventies investigating the properties of synthetic dyes in passive shutters for the production of picosecond pulses in neodymium lasers. The head of the team appears to be V. I. Malyshev. A smaller sub-team headed by A. V. Masalov has been investigating the energy spectrum of picosecond pulses. Malyshev's team has recently been cooperating with the Institute of Organic Chemistry, Ukrainian Academy of Sciences, in developing fast shutters.

### Team 3 Membership List

Head

V. I. Malyshev 1969-1978

Leading Authors

V. A. Babenko 1970-1978
A. A. Sychev 1969-1978

Authors

M. A. Al'perovich 1974-1976
V. I. Avdeyeva 1974-1976
V. D. Kovin 1973-1975
M. A. Kudinova 1976-1978
I. I. Levkoyev 1974-1976
M. Ya. Shchelev 1976-1978
A. N. Shibanov 1974-1976
A. I. Tolmachev 1976-1978

Sub-team leading Author

A. V. Masalov 1969-1976

Sub-team Author

A. I. Milanich 1974-1976

A total of 10 papers published under 13 authors' names during the period from 1969 to 1978 was analyzed. The following is the annual breakdown of active authors and published papers for Team 3:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 3 | 4 | 4 | 3 | 4 | 10 | 10 | 9 | 7 | 7 |
| PAPERS | 0 | 2 | 2 | 0 | 0 | 1 | 3 | 1 | 1 | 0 |

The early papers dealt with the measurement of the finite relaxation time of the bleached state as the basic property of passive shutters employing synthetic dyes [176,177]. A series of papers published in the mid-seventies investigated the role of these shutters in producing single ultrashort pulses in neodymium lasers [178, 179] and the use of superradiance of synthetic dyes as a means of shortening the relaxation time [180]. A specific subject of this investigation was the transmission coefficient of the passive shutters as a function of power density of neodymium lasers [181].

A paper published in 1977 reported on the development, for the first time, of a passive shutter with a relaxation time of 1.5 psec. The shutter was claimed to ensure stable generation of neodymium laser pulses 2 psec long [182].

The sub-team of A. V. Masalov performed experimental studies of the spectral statistics of the emission of a single-pulse neodymium laser [183,184,185].

## Team 4. Ultrashort Laser Pulses, Plasma Heating Effects, and Initiation of Thermonuclear Reaction

In the early 1970s this team was involved in research on the principal mechanisms of optical breakdown in gas at picosecond pulse lengths and the role of stimulated Compton scattering in plasma heating by picosecond laser pulses. After a lapse in publishing in the mid-seventies the team showed a strong effort in 1977 and 1978 with an addition of many new authors. The most recent effort of this team was exerted in demonstrating the initiation of a thermonuclear reaction by bombarding a conical target filled with deuterium with a neodymium glass laser pulse of 25 nanoseconds duration with an intensity of approximately $10^{11}$ W/cm$^2$. A maximum neutron yield of $5 \times 10^4$ neutrons per pulse was obtained. The team was headed by I. K. Krasyuk and received some guidance from F. V. Bunkin. The work appears to have been closely supervised by Prokhorov and Pashinin. S. I. Anisimov of the Landau Institute of Theoretical Physics, Moscow, joined the team's effort in 1977 on the thermonuclear reaction experiment along with other new authors.

### Team 4 Membership List

Head

I. K. Krasyuk 1968-1978

Leading Authors

F. V. Bunkin 1969-1978

P. P. Pashinin 1968-1978

Authors

S. I. Anisimov 1977-1978

A. S. Goncharov 1976-1978

M. F. Ivanov 1977-1978

F. V. Kalinin 1977-1978

Yu. S. Kas'yanov 1976-1978

A. Ye. Kazakov 1969-1972

V. V. Korobkin 1977-1978

O. V. Koslov 1976-1978

A. A. Malyutin 1976-1978

V. M. Marchenko 1970-1972

S. L. Motylev 1977-1978

M. F. Pastukhov 1976-1978

L. N. Shchur 1977-1978

V. I. Vovchenko 1976-1978

Experimental Assistance

A. S. Grigorovich 1977-1978

N. V. Klyukvin 1976-1978

A. P. Lyubin 1976-1978

A. P. Shevel'ko 1976-1978

V. I. Vovchenko 1968-1972

M. V. Yevteyev 1968-1972

Reviewers

F. V. Bunkin 1969-1972

M. V. Fedorov 1970-1972

V. V. Korobkin 1970-1972

V. N. Lugovoy 1970-1978

A. A. Malyutin 1970-1972

A total of 14 papers published under 17 authors' names during the period from 1969 to 1978 was analyzed. The following is the annual breakdown of active authors and published papers for Team 4:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 5 | 6 | 6 | 6 | 3 | 3 | 0 | 9 | 16 | 16 |
| PAPERS | 1 | 3 | 2 | 1 | 1 | 0 | 0 | 0 | 2 | 4 |

Experimental and theoretical investigations have been performed in the irradiation of gases with picosecond pulses from ruby lasers. In the early papers, experiments were performed on the optical breakdown in nitrogen [186], argon, and helium [187] under the action of picosecond light pulses from a ruby laser at a wavelength of 0.69 $\mu$. The dependence of the breakdown threshold intensities was measured as a function of gas pressure in the region from 2 to $10^4$ mmHg. A strong dependence of the breakdown threshold upon pressure was observed to exist at the high pressure range for all three of the gases investigated. However, it exhibited a weak dependence in the rest of the pressure range, below 5000 and 6000 mmHg for argon and helium respectively, and below 360 for nitrogen. In this region, multi-photon ionization was found to be the mechanism responsible for the breakdown.

Further investigations were made [188] in order to clarify the mechanism involved in the formation of the breakdown in argon and nitrogen under the action of picosecond pulsed laser radiation at a wavelength of 0.35 μ using the second harmonic of the ruby laser [188]. Comparison of the data of [186] and [187] with [188] demonstrated that by doubling the irradiating frequency, the breakdown threshold in argon decreased by almost a factor of 20, and in nitrogen by a factor of 300. This result was regarded as a confirmation of the hypothesis that multi-photon ionization, rather than electron tunneling, is the principal breakdown mechanism.

Additional experiments were made [189] on the breakdown in air, nitrogen and argon under atmospheric pressure by picosecond laser pulses at a wavelength of 0.69 μ. The structure of the laser spark and the dynamics of the formation of breakdown spots were investigated using a fast, high-sensitivity, electro-optical camera. The mechanism of self-focusing of a laser beam in a gas was found to play an important part in the development of breakdown at optical frequencies and it was determined that its effect should be taken into account when estimates of breakdown threshold intensities are made [190]. The effect of electron entrapment by a laser beam was investigated in a totally ionized plasma [191]. Here it was suggested that the entrapment current should be taken into account when analysis is made of kinetic processes in a laser plasma.

A theoretical investigation of the heating of the electron component of a plasma while under irradiation by picosecond laser pulses was made for a wide range of pulse intensities [192]. The results demonstrated that, in certain ranges of intensities, the hard bremsstrahlung radiation of the plasma was not determined by the temperature of the electron but by the energy corresponding to the electron oscillations in the laser radiation field.

Stimulated Compton scattering was observed experimentally as the mechanism playing a significant role in the process of heating plasma by intense laser beams [193]. Experiments with opposed laser beams showed that the stimulated Compton scattering can cause a significant reflection from plasma corona [194]. The effect of the reflection was found to become noticeable at laser beam intensities above $10^{15}$ W/cm$^2$.

A method to measure the temperature of a laser plasma was proposed in [195], based on the formation of a double-layer space charge close to the plasma boundary. The electromotive force of the double layer was determined by the temperature T near the laser plasma boundary, $\varepsilon = kT/e$. The presence of a secondary plasma, due to the background gas surrounding the laser plasma, allows one to measure the electromotive force as a function of time. This, in turn, provides a means of measuring the temperature of the plasma. Another plasma diagnostic technique was suggested in [196] which employed four-photon coherent light scattering by an ion acoustical wave. The use of this technique allows one to determine the plasma electron temperature, electron density, and the decay rate of the ion acoustical wave. The main advantage of this method is in the large gain obtained in the scattering signal.

The most recent experiments performed by this team [197,198] demonstrated the initiation of a thermonuclear reaction when a terephtalic polyethylene envelope was heated by laser radiation, compressing deuterium gas inside a conical target. In these experiments the total neutron yield was measured as a function of deuterium pressure, envelope thickness, target geometry, and the energy of the laser pulse. A maximum neutron yield of $5 \times 10^4$ neutrons per pulse was obtained using a neodymium glass laser with a 70 joule, 25 nanosecond pulse. The deuterium gas pressure in the lead cone was 0.5 atmospheres. The velocity of the target envelope during the action of the laser pulse was measured by the Doppler frequency shift of the reflected radiation. The maximum velocity measured was $3 \times 10^6$ cm/sec, while the maximum acceleration was determined to be $2 \times 10^{14}$ cm/sec$^2$ [197]. A decrease of the neutron output was observed with a shortening of pulse duration and can be explained by the decrease of the quantity of evaporated material of the piston and a corresponding decrease of the hydrodynamic efficiency.

Team 5. Millisecond Laser Pulses

The team was active during the period 1968-1978 and dealt with the development of high intensity neodymium glass lasers operating in the millisecond pulse regime.

Team 5 Membership List

Leading Authors

V. A. Batanov 1969-1975
F. V. Bunkin 1968-1973
V. B. Fedorov 1968-1975
B. V. Yershov 1969-1975

Authors

I. A. Bufetov 1973-1975
K. S. Gochelashvili 1973-1975
S. B. Gusev 1973-1975
V. A. Kiselev 1972-1974
P. I. Kolichnichenko 1973-1975
V. I. Konov 1968-1970
L. P. Maksimov 1969-1971
A. N. Malkov 1973-1975
Yu. P. Pimenov 1972-1975
V. V. Savranskiy 1969-1971

Experimentalist

V. A. Samokhvalov 1973-1975
S. B. Gusev 1973-1975

A total of 12 papers published under 14 authors' names during the period from 1968 to 1978 was analyzed. The following is the annual breakdown of active authors and published papers for Team 5:

| YEARS | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 |
|---|---|---|---|---|---|---|---|---|
| AUTHORS | 4 | 7 | 7 | 6 | 6 | 11 | 10 | 9 |
| PAPERS | 0 | 1 | 2 | 1 | 3 | 1 | 4 | 0 |

A three-laser system was initially investigated giving a total of approximately 10 kJ of energy output [199]. Additional experiments were later made with the three laser system optimizing the beam energy and obtaining beam intensities of $10^6$ to $10^8$ W/cm$^2$ with beam spot sizes equal to or greater than 0.5 cm in diameter. Other experiments were made with a single laser beam with low divergence with energy outputs ranging up to 3.6 kJ and light intensities up to $2 \times 10^{11}$ W/cm$^2$ [200]. Special attention has been exerted in obtaining a low divergence. This has been accomplished in the GOC-1000 type laser with flat parallel mirrors by inserting two lenses into the parallel resonator system and lowering the divergence by a factor of 7 (while the efficiency was lowered by a factor of 2) [201]. A laser using a telescopic resonator allowed one to obtain a factor of 6 or 7 reduction in divergence while lowering the efficiency by only 20%. In this case, the divergence reached $2 \times 10^{-4}$ radians (at half energy level).

Experimental data on the operating parameters of a several joule neodymium glass laser were compared to previous theoretical calculations. On the basis of the experimental data limits were established in the use of the theoretical calculations [202].

The team also made theoretical and experimental investigations on the dynamics of gases created in the process of evaporation of metals under the action of a neodymium glass laser beam in the millisecond pulse regime [203]. The heating of the gases near the target and the temperature change along the plasma discharge were determined experimentally Experiments were carried out with tungsten, lead, aluminum, brass and other metal targets with beam intensities of about $10^7$ W/cm$^2$ and beam spot size on target of approximately 1 cm in diameter [204].

A theory of the evaporation of metals was developed on the basis of a liquid-vapor phase change model. A method for an approximate solution to the Clapeyron-Clausius equation was presented permitting one to calculate the target surface temperature as a function of incident radiation with sufficient accuracy for experimental purposes. The appearance of a new effect was demonstrated when a critical value of light intensity was reached (between $10^7$ and $10^8$ W/cm$^2$) and was due to the loss of the metallic properties of the target. In this case, a "transparency wave" was created in front of which liquid metal is transformed into a liquid dielectric. When the intensity is greater than the critical value the evaporation takes place from the surface of the "transparent" (dielectric) layer, the temperature of which does not further increase but remains below a critical value [205].

The absorption of a $10^7$ W/cm$^2$ intensity laser beam by the plasma in front of a tungsten target immersed in 2.5 to 5 atmospheres of helium was also studied by the research team. The laser beam was attenuated by a factor of 5 to 10 at beam energies of 2.3 to 3.6 kJ at a helium pressure of 4 atmospheres. This corresponds to an average absorption coefficient of 0.4 to 0.6 per centimeter [206].

Other experiments were made to investigate the electrical breakdown of gases while under bombardment of a laser light beam. In the proximity of an externally produced electrical breakdown the ionized gas absorbed the laser light, forming along the laser beam axis a discharge with finite dimensions. This effect was found to exist at a threshold intensity of $10^7$ W/cm$^2$ which is lower than the threshold of the optical breakdown ($10^9$ W/cm$^2$) at atmospheric pressure in air [207].

Team 6. Laser-Target Interaction in Strong Magnetic Fields

The team pursuing the subject of strong magnetic fields and their effect on laser plasma has been publishing since 1965. The work of the team has been supervised by Prokhorov and Pashinin. The team consists of experimentalists who build their own high magnetic field equipment.

It is not clear to what extent this team is involved in Prokhorov's laser fusion activity.

The following is the organization of the team:

Team 6 Membership List

Leading Authors

S. D. Kaytmazov 1969-1978

Ye. I. Shklovskiy 1970-1978

T. B. Volyak 1969-1975

Authors

L. I. Gudzenko 1976-1978

M. S. Matyayev 1970-1974

A. A. Medvedev 1969-1975

I. V. Pogorel'skiy 1969-1971

L. Ye. Vardzigulova 1969-197[illegible]

Designer-nonauthor

Ye. N. Bol'shakov 1972-1977

Reviewers

G. A. Askar'yan 1977-1978

L. I. Gudzenko 1972-1977

P. P. Pashinin 1972-1978

A total of 10 papers published under 8 authors' names during the period from 1969 to 1978 was analyzed. The following is the annual breakdown of active authors and published papers for Team 6:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 4 | 7 | 7 | 7 | 7 | 7 | 5 | 3 | 3 | 3 |
| PAPERS | 0 | 1 | 2 | 0 | 2 | 2 | 0 | 1 | 1 | 1 |

This team was the first to observe the effect of a magnetic field on the optical breakdown threshold in gases, the results of which were published in 1967. A magnetic field of 210 kilogauss directed parallel to a laser beam ($\lambda = 1.06\ \mu$) lowered the breakdown threshold in air over a pressure range of 30 torr to 1 atmosphere. This was explained by the decrease of the electron diffusion from the focal area during application of the magnetic field [208]. Basing their work on an earlier observation of increased intensity of a laser spark when it was placed in a 200 kgauss field, the team pursued experimental investigation of the threshold of magnetic field intensity, above which the field activity affects the expansion of the spark plasma [209]. A special 400 kgauss source was built for this purpose. A review of multi-turn solenoids available at the time led to the installation of a transformer-type system [210]. Early experiments with strong magnetic fields were aimed at investigating the magnetic field effect on soft x-ray emission from laser plasma [211,212]. Later, the work focused on possibilities of increasing plasma absorption of laser emission by strong magnetic fields [213,214].

## Landau Institute of Theoretical Physics, Moscow

### Target Compression Theory

This team provides the theoretical support to Prokhorov's laser fusion research and, most probably, also to his other research activities at the Lebedev Physics Institute. The team appears to be responsible for Prokhorov's computer code work and numerical simulation experiments. The team is headed by two leading authors and includes a few supporting authors. It has been in evidence throughout the period covered here. One of the leading authors is S. I. Anisimov, a well-known leading theoretician, considered to be Prokhorov's counterpart to V. P. Silin of Basov's group.

#### Membership List

| | |
|---|---|
| Leading Authors | |
| S. I. Anisimov | 1969-1978 |
| M. F. Ivanov | 1973-1978 |
| Authors | |
| N. A. Inogamov | 1973-1978 |
| Yu. I. Lysikov | 1969-1971 |
| P. P. Pashinin | 1974-1978 |
| Ya. B. Zel'dovich | 1976-1978 |
| Computer Specialist | |
| L. N. Shur | 1976-1978 |
| Reviewer | |
| S. I. Anisimov | 1975-1978 |

A total of 12 papers published under 6 authors' names during the period from 1969 to 1978 has been analyzed. The following is the annual breakdown of active authors and published papers for the team:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 2 | 2 | 2 | 1 | 2 | 5 | 5 | 6 | 6 | 6 |
| PAPERS | 0 | 2 | 0 | 1 | 0 | 1 | 2 | 1 | 4 | 1 |

The early work of the team was analytic in nature and dealt with such problems as the expansion of a gaseous cloud into vacuum and metallic hydrogen theory analyzed from the viewpoint of laser-driven compression [215, 216]. In the gaseous cloud case, analytical solutions were given for a spheroid and a rotating elliptical cylinder. In the case of metallic hydrogen, it was shown that the required pressure could be reached by irradiating a hydrogen target with a special form of laser pulse. Of interest to laser-fusion research was the simple example of a compression of ideal gas by a spherical piston indicating the theoretical possibility of adiabatic compression.

A series of papers with the results of numerical simulation followed later. Some of this work was supported by R. Z. Sagdeyev whose interests lie in space exploration, although it was also considered by Prokhorov as part of the developing laser-fusion research [217, 218]. Thus one-dimensional simulation of high-frequency heating of Vlasovian plasma was considered from the viewpoint of instabilities due to the beam decay into Langmuir and ion-acoustic waves. Electron trapping by unstable plasma waves was postulated as the saturation mechanism. In the strong-field limit, anomalous collision frequencies were found to be of the order of twice the Langmuir plasma frequency.

Anisimov investigated the development of instability during isentropic compression of a spherical drop with an inhomogeneous initial density distribution [219]. He has attempted to show that the spherical drop was unstable, and drew the conclusion that he has verified the Rayleigh-Taylor instability hypothesis. Later he proposed, on the basis of numerical analysis, a gaseous shell target for laser-fusion experiments as a better alternative to solid targets [220]. The gaseous target, formed by point explosion in a very dense gas would provide the means of avoiding the technical difficulties of target fabrication, and would not be inferior to single solid-hydrogen shell targets. Papers of 1976 and 1977 provide the results of one-dimensional numerical modeling of simple targets and energies low enough to be comparable with the currently available experimental energies. The results show a high sensitivity of the thermonuclear yield and maximum compression rate to model parameters characterizing preheat and electron heat conduction limitations [221, 222].

New mathematical models have been constructed [223] for the solution of the compression of the target envelope and the compression of the initially homogeneous plasma cylinder (or sphere). The derived solutions allow one to look at the initial perturbations in the form of converging shock waves and nonisentropic flow. The spherical boundary between the detonation products and the surrounding gas was found to be unstable relative to small perturbations which are dependent upon angular changes [224]. This instability is analogous to the Rayleigh-Taylor instability of the boundary between two media with different densities. The most recent paper [225] investigated the mechanism of initiation and expansion of the turbulent region formed by the development of the Rayleigh-Taylor instability. The turbulent state was described by the turbulent intermixing theory permitting a one-dimensional numerical simulation [226].

## NUCLEAR PHYSICS RESEARCH INSTITUTE, MOSCOW STATE UNIVERSITY

### Optical Glass Damage by Laser Irradiation

This small experimental team has been publishing since 1973, concentrating exclusively on the investigation of the surface and volume damage of optical glass when exposed to laser radiation. The damage of the glass is determined as a function of laser beam intensity and the mode of laser operation. All the experiments were performed using a Neodymium glass laser with a maximum energy of 2 kJ and pulse durations from 1 to 10 milliseconds. The laser operated either in a spike train or in a quasi-continuous pulsed mode with a depth of modulation less than 5%. The laser radiation was focused either onto the surface or inside the volume of the glass specimen with an 80 mm lens. All the papers except the last experimented using the K-8 radiation-doped optical glass. The final paper [227] concentrated on the ZhS-12 glass as well as checking other types of glasses.

#### Membership List

Leading Authors

G. M. Fedorov 1972-1978

N. E. Kask 1972-1978

Authors

D. B. Chopornyak 1975-1978

L. S. Korniyenko 1972-1978

V. V. Radchenko 1975-1978

Reviewer

A. M. Prokhorov 1972-1974

Technician

L. F. Belov 1972-1974

A total of 6 papers published under 5 authors' names during the period from 1972 to 1978 was analyzed. The following is the annual breakdown of active authors and published papers for this team:

| YEARS | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|
| AUTHORS | 3 | 3 | 3 | 5 | 5 | 5 | 5 |
| PAPERS | 0 | 2 | 0 | 0 | 1 | 2 | 1 |

The first experimental results were published in 1973 [228] on the irradiation of K-8 optical glass with the laser beam and the determination of the threshold energy density for damaging the glass volume. In the case of the spikeless laser operation, the breakdown threshold was found to be dependent only upon the energy of irradiation. But in the case of the spike train made at the lower energy densities, the breakdown threshold was found to be dependent upon the time of exposure. Threshold intensities for glass damage, formation of melts, and discoloring of the K-8 glass were determined as a function of light radiation exposure dose in [229]. The threshold temperatures were estimated and it was shown that the residual absorption coefficient of the glass remains constant up to the intensities which produce volume damage in the glass.

The appearance of melting was considered to be due to heating the glass over the annealing temperature of 560° C [230]. In the case of pulsed laser heating, the transition temperature of the glass from the solid to liquid phase is considerably higher than the standard temperature of the K-8 glass softening point (620° C) and was found in [231] to be approximately 1000° C. This was in agreement with measurements in [229]. It was demonstrated that if the surface of the K-8 glass is pre-heated to a temperature of 600° C, the number of defects caused by mechanical surface treatment is drastically reduced [232]. Here it was assumed that the glass surface and volume damage corresponds to the start of the bubbling of gas dissolved in the glass.

The most recent experiments [227] involved the irradiation of ZhS-12 glass. Softening was observed to appear at a temperature of 1400° K. The discharge at the focal point was calculated to occur at 2700° K assuming an absorption coefficient independent of glass temperature. The plasma was found to develop in the direction opposite to the laser beam. The velocity of the absorption front was $10^3$ cm/sec at an intensity of $10^7$ W/cm$^2$.

# Kurchatov Institute of Atomic Energy

## Team 1. IREB and Laser Beam Plasma Heating

Team 1 has been active throughout the period covered in this report. The team, headed by L. I. Rudakov, specializes in the study of the energy transfer mechanism, based on the Langmuir turbulence theory, that is active in the process of interaction between intense relativistic electron beams (IREB), or laser beams, and inertial fusion targets. So far, one-dimensional simulation has been used. Part of this work has been performed in collaboration with the Institute of Applied Mathematics.

### Team 1 Membership List

Head

L. I. Rudakov 1968-1978

Leading Authors

A. A. Ivanov 1969-1975
A. S. Kingsep 1968-1978

Authors

B. V. Alekseyev 1974-1976
M. V. Babykin 1973-1975
L. M. Degtyarev 1973-1975
V. V. Gorev 1973-1975
V. I. Ivanov 1976-1978
V. G. Makhan'kev 1973-1975
A. A. Samarskiy 1972-1974
V. V. Yan'kov 1974-1976
Ye. Kh. Zavoyskiy 1973-1975

Reviewers

A. A. Ivanov 1969-1971
G. V. Nesterov 1976-1978

A total of 13 papers published under 12 authors' names during the period from 1969 to 1978 has been analyzed. The following is the annual breakdown of active authors and published papers for Team 1:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 3 | 3 | 2 | 2 | 7 | 11 | 10 | 5 | 4 | 4 |
| PAPERS | 1 | 2 | 0 | 1 | 1 | 4 | 2 | 0 | 1 | 1 |

The background material for the studies involved in Team 1 activity is the early work of Rudakov on the effect of nonlinearities on high-current stability in plasma [233] and on the collective relaxation of IREB in dense plasma targets [234]. The focus of the team's activity is the soliton theory model used to describe Langmuir turbulence in plasma. Langmuir turbulence is regarded in the context of the team's research as the most effective of the probable energy transfer mechanisms that are active in heating plasma by electron or laser beams. The approach used by the team is one-dimensional numerical simulation [235, 236, 237, 238]. A 1977 paper presented the Monte Carlo method applied to beam-target interaction, using targets of various geometry and composition 239]. The most recent paper of this team investigated the effect of nonlinear dissipation upon plasma heating in a condition of strong Langmuir turbulence [240].

Team 2. Laser-Plasma Interactions

Team 2, being in evidence since 1972, has been engaged in experimental and theoretical research on the instability problems in heating plasma by high-energy lasers, carried out as part of inertial fusion research. The team is headed by Ye. P. Velikhov. The experimental program utilizes the Myshen' facility.

One of the authors publishing in this area is A. F. Nastoyashchiy, who is not a co-author of Velikhov's team. At this time, he is included in the team by virtue of the subject matter.

A part of the research work of this team has been performed in cooperation with the Lebedev Physics Institute.

Team 2 Membership List

Head

Ye. P. Velikhov 1975-1977

Authors

V. V. Aleksandrov 1972-1977
S. I. Anisimov 1975-1977
M. V. Brenner 1975-1977
N. G. Koval'skiy 1972-1977
S. Yu. Lukyanov 1972-1974
A. F. Nastoyashchiy 1974-1978
M. I. Pergament 1975-1977
V. A. Rantsev-Kartinov 1972-1974
M. M. Stepanenko 1972-1974
V. D. Vikharev 1975-1977
A. I. Yaroslavskiy 1975-1977
V. P. Zotov 1975-1977

Reviewers

A. F. Nastoyashchiy 1975-1978
P. P. Pashinin 1975-1977
R. Z. Sagdeyev 1974-1976
V. Ye. Zakharov 1975-1977

Experimentalists

V. N. Belousov 1975-1977
M. V. Brenner 1975-1977
S. A. Chuvatin 1972-1974
A. I. Gorlanov 1972-1974

V. V. Savel'yev 1975-1977
V. N. Yufa 1975-1977
V. V. Zhuravlev 1975-1977

A total of 6 papers published under 13 authors' names during the period from 1972 to 1978 has been analyzed. The following is the annual breakdown of published papers and active authors for Team 2:

| YEARS | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | | | | 5 | 5 | 1 | 10 | 10 | 10 | 1 |
| PAPERS | | | | | 1 | 0 | 1 | 2 | 1 | 1 |

Experiments with the Myshen' I facility were performed to investigate anomalous absorption using an Nd laser at an intensity of $10^{12} - 10^{14}$ W/cm$^2$ and flat targets [241, 242]. Particular attention was paid to the 3/2 $\omega$ and 2 $\omega$ harmonics.

Nastoyashchiy's work involved the investigation of spontaneous magnetic fields generated in laser plasma and their effect on laser heating of plasma [243], and the ionization instability of the laser plasma heating process [244, 245].

## Yefremov Institute of Electrophysical Equipment, Leningrad

### Team 1. Neodymium Rod Lasers

The team was in evidence from 1969 to 1975. Starting with research on synthetic dyes for passive shutters used in Nd lasers, the team moved on to design multi-channel multi-stage neodymium rod laser systems for use in laser fusion experiments.

### Team 1 Membership List

#### Leading Authors

A. D. Starikov 1968-1975
V. A. Serebryakov 1968-1975

#### Authors

M. A. Al'perovich 1970-1972
V. I. Ardeyeva 1970-1972
L. V. Dubovoy 1973-1975
V. D. Dyatlov 1973-1975
V. I. Isayenko 1968-1972
A. I. Kiprianov 1968-1970
V. I. Kryzhanovskiy 1970-1975
I. I. Levkoyev 1968-1972
A. A. Mak 1973-1975
R. N. Medvedev 1973-1975
N. V. Monich 1968-1970
A. N. Popytayev 1973-1975
V. N. Sizov 1971-1975
A. I. Tolmachev 1968-1970
M. P. Vanyukov (deceased) 1968-1972
A. F. Vompe 1968-1970

#### Experimentalist

V. B. Ivanov 1973-1975

A total of 6 papers published under 18 authors' names during the period from 1969 to 1975 has been analyzed. The following is the annual breakdown of active authors and published papers for Team 1:

| YEARS | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 9 | 12 | 9 | 9 | 10 | 9 | 9 | | | |
| PAPERS | 1 | 0 | 2 | 1 | 0 | 2 | | | | |

The early work of the team consisted of the development of synthetic dye passive shutters for standard types of neodymium lasers [246, 247]. In 1971, the team was designing single-channel multi-staged rod laser systems of high-brightness and nsec pulse lengths for laser fusion experiments [248]. In 1972, the team developed a kJ neodymium rod laser system delivering $10^{14}$ W per pulse. The system consisted of three channels with four amplifier stages per channel, and a 60 mm output aperture [249].

In 1974, the kJ laser was used in a series of experiments with heavy targets. A single channel was used, with the energy output not exceeding 120 J. Particular attention was paid to the enhancement of laser pulse contrast which resulted in a low reflection coefficient. The relatively high neutron yield was interpreted as indicating a strong influence of the laser pulse shape on the nature of the interaction [250]. At the same time, experiments were performed with solid LiD targets, using laser intensity of $10^{13}$ - $10^{15}$ W/cm$^2$, 90 psec, and 300 J output energy [251].

Team 2. Neodymium Disc Lasers

The team, in evidence since 1974, has been investigating large-aperture neodymium disc lasers in application to laser fusion and other uses requiring low thermal deformation of the glass.

Team 2 Membership List

Head

A. A. Mak 1974-1978

Leading Authors

V. A. Bychenkov 1974-1978
B. M. Sedov 1975-1978
A. I. Stepanov 1974-1978

Authors

V. N. Alekseyev 1975-1977
A. S. Bondarev 1976-1978
L. V. Ivanushkina 1976-1978
V. I. Korolev 1976-1978
V. G. Malinin 1974-1976
Ye. G. Pivinskiy 1975-1977
L. N. Soms 1974-1976
A. D. Starikov 1975-1977
A. D. Tsvetkov 1975-1977
K. P. Vakhmyanin 1976-1978
V. I. Venglyuk 1976-1978
V. M. Volynkin 1976-1978

Supervisory Personnel

A. K. Pogedayev 1976-1978

Reviewer

V. M. Mit'kin 1974-1976

Experimentalists

V. F. Degtev 1976-1978
L. V. Karpova 1974-1976

A total of 3 papers published under 16 authors' names during the period from 1974 to 1978 has been analyzed. The following is the annual breakdown of active authors and published papers for Team 2:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | | | | | | 5 | 10 | 16 | 14 | 9 |
| PAPERS | | | | | | | 1 | 1 | 1 | |

The investigation of large-aperture disc lasers appears to be performed as a means of verifying their feasibility in overcoming the shortcomings of rod lasers, such as the thermal deformation, large transverse thermal gradients, low self-focusing threshold, etc. Consequently, attention is paid to the periodic operation of such lasers [252]. A series of tests with 120 mm discs for the final amplifier stage were reported [253], as well as the use of halogenides as disc coolants with a low coefficient of absorption [254].

## V. Ye. Zakharov's Group

### Beam-Plasma Instability Theory

V. Ye. Zakharov is unique in the organizational pattern of this research area in that he appears to head several teams in different institutes, all dealing with the subject of parametric instabilities in beam-plasma interaction. The work is based on numerical simulation methods. Zakharov has published the results of his research under the bylines of the Institute of Nuclear Physics, Novosibirsk, Computer Center of the Siberian Department, Academy of Sciences, USSR, Novosibirsk State University, Institute of Automation and Electrometry, Novosibirsk, Landau Institute of Theoretical Physics, Moscow, and Institute of Applied Mathematics, Moscow. There are three distinct teams apparent in Zakharov's research activity, each team being affiliated with a different institute.

Team 1. Institute of Automation and Electrometry, Siberian Department, Academy of Sciences, USSR, Novosibirsk

Team 1, active throughout the period from 1969 to 1978, has been performing primarily theoretical studies of plasma stability during the heating process. The work, particularly in the treatment of parametric instabilities, has paralleled that of V. P. Silin of the Lebedev Physics Institute. The approach has been generalized to both electron and laser beams as in the heating media, and appears to be aimed at various applications in fusion research.

The membership of the team, headed by V. Ye. Zakharov, indicates a close working relationship with various elements of the Novosibirsk academic complex. During the early seventies, Zakharov, V. S. L'vov, and S. S. Starobinets published under the byline of the Nuclear Physics Institute, Siberian Department, Academy of Sciences, USSR. Later, up to 1973, these authors and other members of the team published under the byline of the Computer Center of the Siberian Department, while since 1974 Zakharov, A. M. Rubenchik, and S. L. Musher have been affiliated with the Institute of Automation and Electrometry. In addition, throughout the period, some members of the team, including Zakharov, continued to publish under the byline of the Novosibirsk State University.

Team 1 Membership List

Head

V. Ye. Zakharov 1968-1978

Leading Authors

V. S. L'vov 1968-1974
S. L. Musher 1970-1976
A. M. Rubenchik 1971-1976

Authors

L. M. Al'tshul' 1976-1978
B. N. Breyzman 1972-1974
Ye. A. Kuznetsov 1976-1978
A. V. Mikhaylov 1977-1978
I. Ya. Rybak 1973-1975
A. B. Shabat 1970-1974
S. S. Starobinets 1968-1973

B. I. Sturman 1972-1975
V. V. Zautkin 1970-1973

Reviewers

A. A. Galeyev 1976-1978
V. S. L'vov 1974-1976
D. D. Ryutov 1972-1978
R. Z. Sagdeyev 1971-1973
V. D. Shapiro 1976-1978
V. I. Shevchenko 1976-1978
S. S. Starobinets 1970-1972

A total of 22 papers published under 13 authors' names during the period from 1969 to 1978 has been analyzed. The following is the annual distribution of authors and papers:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 3 | 6 | 7 | 8 | 10 | 8 | 6 | 5 | 4 | 4 |
| PAPERS | 1 | 1 | 4 | 4 | 4 | 3 | 2 | 0 | 2 | 1 |

The early research work of this team was of a general nature, dealing with such topics as nonlinear periodic phenomena due to parametric instability threshold, and electromagnetic wave interaction in nonlinear media [255, 256, 257]. The Computer Center of the Siberian Department of the USSR Academy of Sciences was used for the simulation aspects of this work. Since 1973, more specialized papers appeared, dealing with instability mechanisms in plasma heating by electron and laser beams, using numerical analysis performed at the Computer Center [258]. At the same time, exact analytical solutions were also obtained, for example, as in the study of the modulation instability investigations which paralleled the theoretical work of V. P. Silin at the Lebedev Physics Institite. The work centered on the nonlinear theory of parametric instability of electromagnetic waves in plasma with and without external magnetic field, and involved isothermal plasma turbulence, anomalous absorption, etc. The team appears to be engaged in the support of research on plasma heating by either laser or electron beams [259, 260, 261, 262, 263, 264, 265, 266].

Team 2. Institute of Nuclear Physics, Siberian Department Academy of Sciences, USSR

The team headed by V. Ye. Zakharov had been active during the period from 1969 to 1975, developing a hydrodynamic theory of plasma turbulence. The theory is based on the concept of a soliton as a one-dimensional nonlinear wave stable in the direction of propagation.

Team 2 Membership List

Head

V. Ye. Zakharov 1969-1975

Authors

B. B. Kadomtsev 1969-1971
S. V. Manakov 1972-1975
V. I. Petviashvili 1969-1971
A. M. Rubenchik 1972-1974
R. Z. Sagdeyev 1969-1971

Reviewers

V. S. L'vov 1970-1972
D. D. Ryutov 1970-1972

A total of 7 papers published under 6 authors' names during the period from 1969 to 1975 has been analyzed. The following is the annual breakdown of the active authors and published papers of Team 2:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 4 | 4 | 4 | 3 | 3 | 3 | 1 | | | |
| PAPERS | 0 | 2 | 2 | 0 | 2 | 1 | | | | |

Hydrodynamic plasma models were developed on the basis of the theory of acoustic turbulence of a compressible fluid representing the interaction of acoustic waves (acoustic noise) and of the solition theory [267, 268, 269, 270]. Later papers dealt with the theory of two-dimensional stationary self-focusing of electromagnetic waves, first developed by Zakharov and A. B. Shabat at the Institute of Applied Mathematics [271]. This theory was generalized to the case of arbitrary polarization [272]. More recent papers considered the instability of solitons in nonlinear media, stationary self-focusing, and stimulated scattering of plasma oscillations by ions [273,274].

Team 3. The Institute of Applied Mathematics

Team 3 may be doing related work for Prokhorov in numerical simulation, although not directly in support of the laser-fusion research. It is of interest to note that Zakharov's computer simulation has been performed at the Computer Center of the Siberian Department, Academy of Sciences, USSR, in Novosibirsk, and that Zakharov himself worked at the Computer Center and at the Novosibirsk State University in 1971-1972. Zakharov has also published papers on this area coauthored by members of the Landau Institute of Theoretical Physics.

Team 3 Membership List

Leading Author

V. Ye. Zakharov 1969-1978

Authors

O. B. Budneva 1974-1976
L. M. Degtyarev 1973-1976
A. F. Mastryukov 1977-1978
L. I. Rudakov 1974-1976
V. V. Sobolev 1970-1972
V. S. Synakh 1970-1976

A total of 9 papers published under 7 authors' names during the period from 1970 to 1978 has been analyzed. The following is the annual breakdown of active authors and published papers for Team 3:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 0 | 3 | 3 | 3 | 2 | 5 | 5 | 5 | 2 | 2 |
| PAPERS | 0 | 0 | 2 | 1 | 0 | 2 | 3 | 0 | 0 | 1 |

The early work of V. Ye. Zakharov has been published under the byline of the Computer Center, Siberian Department, Academy of Sciences, USSR, and during his later activity he has used the BESM-6 computer of the above mentioned facility to perform numerical simulation work [275, 276, 277]. His team's papers are dedicated to the analysis of self-focusing of light beams in nonlinear media and the collapse of Langmuir waves in plasma with and without an external magnetic field [275, 276, 278, 279, 280, 281]. Recent work has included the investigation of the transient thermal self-focusing of laser beam pulses [282].

# Physico-Technical Institute, Ukrainian Academy of Sciences, Khar'kov

## Beam-Plasma Instabilities

A small team, in evidence from 1969 to 1975, was working on the electro-dynamics of inhomogeneous plasma and, in particular, on beam-plasma instability problems. From 1969 to 1972, the work was of a general nature; in 1975, a report was published, more directly applicable to laser fusion problems and dealing with the absolute instability of focused waves in plasma.

### Membership List

Leading Authors

S. S. Moiseyev 1968-1976
N. S. Yerokhin 1968-1976

Authors

V. V. Mukhin 1974-1976
A. A. Vodyanitskiy 1969-1972
V. Ye. Zakharov 1968-1970

Supervisory Personnel

Ya. B. Faynberg 1969-1972

Reviewers

Ye. Ya. Kogan 1970-1972
V. N. Orayevskiy 1970-1972
V. D. Shapiro 1969-1971

A total of 9 papers published under 7 authors' names during the period from 1969 to 1976 has been analyzed. The following is the annual breakdown of active authors and published papers for the team:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 4 | 6 | 5 | 5 | 3 | 3 | 3 | 3 | 0 | |
| PAPERS | 1 | 3 | 3 | 0 | 0 | 1 | 1 | | | |

The general theory of inhomogeneous plasma dynamics analyzed during the early period from 1969 to 1971 included the treatment of kinetic effects as a factor in absorption and reflection of electromagnetic waves [283,284], generation of the second harmonic and decay processes in plasma [285], and wave transformation in inhomgneous plasma [284,286]. In 1975, the team published a paper on the absolute instability of focused waves in plasma applicable to laser and microwave plasma heating. The effect of two-dimensional inhomogeneity of the focused pump wave on parametric instability is investigated in [287]. The authors claim to have proved the existence of absolute instabilities caused by the capture of growing oscillations near the pump wave focus.

## Moscow Engineering Physics Institute

### Beam-Plasma Interactions

A team of this institute, in evidence from 1969 to 1975, was performing mass-spectroscopic studies of laser plasma derived from solid targets in order to investigate the interaction between high-power lasers and matter, to study the kinetics of plasma expansion, and to develop a laser-driven multi-charged ion source for use in accelerator injectors. This work throughout the above period was supervised by Basov, Krokhin, and G. N. Flerov.

### Membership List

#### Leading Authors

Yu. A. Bykovskiy 1968-1978
N. N. Degtyarenko 1968-1974
Yu. P. Kozyrev 1968-1978
S. M. Sil'nov 1968-1975

#### Authors

D. B. Anan'yin 1971-1974
V. V. Apollonov 1969-1971
V. G. Degtyarev 1970-1973
A. G. Dudoladov 1968-1970
V. I. Dymovich 1968-1970
V. S. Fetisov 1973-1975
G. N. Flerov 1972-1974
M. F. Gryukanov 1970-1971
V. L. Kantsyrev 1971-1973
K. I. Kozlovskiy 1977-1978
S. D. Laptev 1970-1973
Ye. Ye. Lovetskiy 1973-1975
V. N. Nevolin 1970-1973
B. I. Nikolayev 1968-1970
S. N. Nikolayev 1968-1970
A. N. Polyanichev 1973-1975
S. V. Ryzhikh 1968-1970
B. Yu. Sparkov 1971-1975
A. S. Tsibin 1972-1978
Ye. D. Vorob'yev 1972-1974
V. F. Yelesin 1968-1973

#### Reviewers

N. G. Basov 1973-1975
A. M. Boldin 1973-1975
O. N. Krokhin 1968-1970

A total of 13 papers published under 25 authors' names during the period from 1969 to 1978 has been analyzed. The following is the annual breakdown of active authors and published papers for the team:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 11 | 15 | 13 | 15 | 17 | 12 | 7 | 0 | 4 | 4 |
| PAPERS | 2 | 3 | 2 | 2 | 1 | 2 | 0 | 0 | 0 | 1 |

In the course of early research, measurements were made of the angular distribution of laser plasma with free-running and Q-switched lasers [288]. Particular attention was paid to the energy distribution of fast ions [289]. One of the aims of the study was the determination of the ionization potentials of elements and the recombination times of multi-charged ions [290]. A two-stage Nd amplifier was used in this work [291, 292]. In 1972, the design of a multi-charged ion source to be used in accelerator injectors emerged as a major goal of this research [293, 294].

The experience with mass-spectrometric analysis of laser plasma was the background of a later study on the expansion of recombination plasma in vacuum. Lithium plasma was used to study the dynamics of an expanding plasma bunch by numerical analysis, taking the ionization and recombination processes into account [295]. The most recent paper of the team investigated the collision of laser-derived plasma flows in conical targets [296]. The investigation was undertaken to find the limits of plasma parameter and the means of controlling these parameters primarily for the purposes of laser fusion research. A secondary purpose is the investigation of laser plasma bunches with optimized parameters for use in various applications. Of considerable interest are the cumulative effects occurring in colliding flows and affecting the plasma heating process.

The investigation involved the charge, kinetic, and geometric parameters of the ion component of laser plasma in the final expansion stages. A ruby laser beam was focused onto a hollow conical lead target. The dependence of these parameters upon the apex angle of the cone was determined and compared to the case of a flat target. The measurements were carried out using mass-spectroscopic methods. The results show the possibility of forming a narrow plasma bunch having a high degree of ionization which can be controlled by the shape of the target and the focusing conditions of the beam.

# Institute of High Temperatures, Moscow

## Parametric Instabilities

The work of the Institute pertinent to laser fusion research concerns the study of parametric instabilities in inhomogeneous plasma. The work appears to have been performed by two teams: the first team was in evidence from 1969 to 1973, and the second, from 1975 to the present.

### Team 1 Membership List

Leading Authors

A. A. Galeyev 1971-1974
R. Z. Sagdeyev 1968-1974

Authors

Yu. A. Berezin 1968-1970
V. N. Orayevskiy 1970-1973
V. V. Lisitchenko 1970-1973

Foreign Authors

G. Laval 1972-1974
T. O'Neil 1972-1974
M. N. Rosenbluth 1972-1974

### Team 2 Membership List

Authors

B. A. Al'terkop 1974-1978
V. P. Tarakanov 1974-1978
A. S. Volokitin 1974-1978

A total of 7 papers published under 11 authors' names during the period from 1969 to 1978 has been analyzed. The following is the annual breakdown of active authors and published papers for Teams 1 and 2:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 2 | 4 | 5 | 7 | 6 | 8 | 3 | 3 | 3 | 3 |
| PAPERS | 1 | 0 | 1 | 1 | 2 | 0 | 1 | 0 | 1 | |

The development of a one-dimensional nonlinear model of anisotropic plasma instability [297] has led to the consideration of anomalous absorption of electromagnetic radiation in hot plasma [298]. In 1973, the linear theory of parametric instabilities in inhomogeneous plasma was analyzed specifically with respect to the laser fusion application [299]. Parametric instabilities were considered as the basic mechanism for the absorption of laser energy by the plasma corona of an imploding deuterium target [300]. The most recent paper deals with the dynamics of strong Langmuir turbulence in the laser or electron beam field [301].

## Institute of the Physics of the Earth

### Laser Beam-Target Interaction

This team was primarily involved in theoretical and experimental investigations of the formation and properties of the plasma spark in front of a solid target when irradiated by intense laser radiation. Special attention was given to the absorption of the incident laser radiation by the plasma and the shielding it provided to the target surface. Studies were made of the thermodynamics involved in the evaporation of the hot gases and the appearance of radiative and optical detonation waves.

For most of the experimental work performed by the team, a neodymium glass laser was used with pulse length of approximately 1 microsecond, energy up to 30 joules, and spot size 5-10 mm.

### Membership List

#### Leading Author

I. V. Nemchinov 1968-1978

#### Authors

B. A. Abashkin 1968-1970
V. I. Bergel'son 1972-1976
Ya. N. Gnoyevoy 1969-1971
A. P. Golub' 1972-1975
A. F. Goucharenko 1975-1977
A. A. Kalmykov 1968-1970
V. M. Khazins 1975-1977
N. N. Koslova 1974-1976
T. V. Loseva 1973-1976
T. B. Malyavina 1971-1973
I. Ye. Markovich 1974-1978
T. I. Orlova 1973-1978
A. I. Petrukhin 1968-1978
Yu. Ye. Pleshanov 1968-1978
S. P. Popov 1969-1975
Ye. G. Popov 1968-1971
A. A. Provalov 1969-1971
V. A. Rybakov 1974-1978
V. A. Sulyayev 1969-1978
V. V. Svetsov 1973-1975
M. A. Tsikulin 1969-1971
G. G. Vilenskaya 1968-1970

Reviewers

V. I. Bergel'son 1970-1972
P. V. Kevlishvili 1974-1976
I. V. Nemchinov 1969-1976
A. I. Petrukhin 1969-1972
Yu. P. Rayzer 1969-1976
M. A. Tsikulin 1968-1970

Experimentalist

A. D. Kravchenko 1969-1971

Computation Personnel

L. P. Markelovaya 1971-1973
V. V. Novikaya 1969-1973
V. A. Nuzhniy 1973-1975
V. A. Onishchuk 1969-1973
Yu. P. Vysotskiy 1973-1975

A total of 22 papers published under 23 authors' names during the period from 1969 to 1978 has been analyzed. The following is the annual distribution of authors and papers:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | 12 | 12 | 10 | 5 | 8 | 13 | 15 | 12 | 9 | 7 |
| PAPERS | 4 | 4 | 1 | 1 | 1 | 2 | 4 | 1 | 2 | 2 |

Some of the earlier papers of the team [302, 303] were involved in plasma dynamics theory and shock wave studies. A theory was developed on the formation of the absorption spark in [304, 305, 306]. When the temperature of the vapor is close to the phase transition temperature, the vapor is weakly ionized and is almost completely transparent to the incident radiation. In this condition there is no shielding of the target by the vapor. When the vapor temperature is much greater than the phase transition temperature the vapor is highly ionized and strongly absorbs the incident radiation. In this case, the target is shielded by the vapor. The theoretical calculations agreed with experimental findings at small incident beam intensities and small beam spot sizes for the case of no shielding of the target, and at large beam intensities for the case when the target became shielded. The transition regime between the two cases mentioned was studied in [307]. The calculations of [305, 306] showed that one can expect the appearance of the shielding mechanism at beam intensities of $10^7$ W/cm$^2$ and pulse lengths from 10 to 100 μsec. In order to obtain a closer agreement between theory and experiment, additional computations were made in [308] using methods developed in [309, 310].

A number of papers written by this team were devoted to the study of the formation of the plasma spark in front of a solid target. The initiation process of the spark was studied theoretically in [311] and experimentally in [307]. The appearance of absorption of the incident radiation by the spark in air was investigated in [308]. Here the resistance of the air to the dispersion of the vapors increased the density of the spark and thus increased the absorption while the adiabatic cooling decreased.

Additional experiments were performed to investigate the shape of the plasma flare, the rise rate of the plasma front, and shock wave brightness temperature and pressure as a function of time [312]. The results showed that an absorption wave was formed at beam intensities of about $10^8$ W/cm$^2$ at the front boundary of the plasma flare. Under higher beam intensities, a transition to a so-called detonation wave condition was observed which was further complicated by the energy transfer from the continuous spectrum arising in the hot plasma.

In [313], the theoretical concept of two kinds of waves (radiative and optical detonation waves) was established. These waves form in air or other gases and move towards the laser. The dispersion velocities of the radiative wave were found to be considerably different from the velocities of the optical detonation wave. The dependence of these two types of waves upon the incident beam intensity was shown to be quite different, permitting an experimental differentiation between them. The theoretical findings of [313] were tested experimentally in [314] using a neodymium glass laser with a 0.5 microsecond pulse, intensities to 2.5 x $10^9$ W/cm$^2$ and spot size of 2 mm on tungsten and aluminum targets. The experiments were performed in air [314] and in xenon [315]. In the latter case the formation of the supersonic radiation waves appeared at intensities of

$5 \times 10^7$ W/cm$^2$ and demonstrated the ability of hampering the transmission of the laser beam. In [316] and later in [317] the effect of the radiation from the air plasma upon the target was taken into account using the concept of the vaporization wave as described theoretically in [311]. Close experimental verification of calculations in [311] were made in [318]. Further analyses made in [317] showed a marked pressure increase in the gas layer just above the target surface which was not previously observed.

The dispersion of the optical detonation wave was investigated in [319] by calculations made using the transient gas-dynamic model. A numerical analysis was made in [320] on the dispersion of a radiative wave with a detailed consideration of the spectral radiation component on the basis of the averaging method given in [321]. Another experiment performed in [322] involved the measurement of the mechanical pressure impulse exerted on a solid target by the action of the beam from a neodymium glass laser.

## Institute for Space Research, Moscow

### Parametric Instabilities

A small team from this institute has been in evidence since 1975, developing the nonlinear theory of parametric instabilities in plasma interaction with lasers and electron beams. Specifically, this theory deals with the so-called collapse of Langmuir waves as a mechanism of beam-plasma energy transfer. The theory is aimed at laser and electron-beam fusion, and ionospheric modification research.

#### Membership List

Leading Authors

A. A. Galeyev 1974-1978
R. Z. Sagdeyev 1974-1978
V. D. Shapiro 1974-1978
V. I. Shevchenko 1974-1978

Authors

V. V. Krasnosel'skikh 1976-1978
Yu. S. Sigov 1974-1976
V. I. Sotnikov 1976-1978

A total of 6 papers published under 7 authors' names during the period from 1974 to 1978 has been analyzed. The following is the annual breakdown of active authors and published papers for the team:

| YEARS | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| AUTHORS | | | | | | 5 | 5 | 7 | 6 | 6 |
| PAPERS | | | | | | | 1 | 2 | 3 | |

The team undertook the development of the nonlinear theory of parametric instabilities, which is an unexplored frontier beyond the well-known linear theory of parametric instability in inhomogeneous plasma. While the authors state that parametric interaction of electromagnetic waves with plasma is important in the research on laser fusion and on an artificial stimulation of the ionosphere with high-power radiowaves, they began this work with the cascade theory of parametric excitation of Langmuir oscillations which is applicable only to the ionospheric research [323]. This was followed by the investigation of acoustic turbulence and its effect on the collapse of Langmuir waves [324, 325]. Recent work dealt with the development of a three-dimensional turbulence theory, which is of significance to laser and electron-beam fusion research because of the need to determine effective collisionless mechanisms of energy dissipation. According to the authors, there is no well-defined theory of strong turbulence that would combine the microscopic phenomena of instability with the macroscopic characteristics, such as dissipated energy, hot-particle distribution functions, etc. [326]. The macroscopic consequences of the collapse of Langmuir waves are the relaxation of dense electron beams and the penetration of a strong electro-magnetic wave into inhomogeneous plasma [327, 328].

## APPENDIX

LIST 1. ALL PARTICIPANTS

Abashkin, B. A., 1968-1970, IPE

Afanas'yev, Yu. V., 1968-1976, FIAN, Basov, Team I
1968-1978, FIAN, Basov, Team II
1973-1976, FIAN, Basov, Team III

Ageyev, V. P., 1976-1978, FIAN, Prokhorov, Team II

Aglitskiy, Ye. V., 1969-1975, FIAN, Basov, Team I
1972-1978, FIAN, Basov, Team III

Aleksandrov, V. V., 1973-1977, FIAN, Basov, Team I
1972-1977, Kurchatov, Team II

Alekseyev, B. V., 1974-1976, Kurchatov, Team I

Alekseyev, V. N., 1975-1977, Yefremov, Team II

Al'perovich, M. A., 1970-1972, Yefremov, Team I
1974-1976, FIAN, Prokhorov, Team III

Al'terkop, B. A., 1974-1978, IHT, Team II

Al'tshul', L. M., 1976-1978, Zakharov, Team I

Anan'yin, D. B., 1971-1974, MEPI

Andreyev, N. Ye., 1968-1978, FIAN, Basov, Team I

Anisimov, S. I., 1969-1978, LITP
1975-1977, Kurchatov, Team II
1977-1978, FIAN, Prokhorov, Team IV

Anosovoy, L. M., 1972-1974, FIAN, Basov, Team I

Antonov, A. V., 1973-1975, FIAN, Baosv, Team I

Apollonov, V. V., 1969-1971, MEPI

Avdeyeva, V. I., 1970-1972, Yefremov, Team I
1974-1976, FIAN, Prokhorov, Team III

Arzuov, M. I., 1976-1978, FIAN, Prokhorov, Team II

Askar'yan, G. A., 1977-1978, Prokhorov, Team VI

Avrov, A. I., 1975-1978, FIAN, Basov, Team I

Babenko, V. A., 1970-1978, FIAN, Prokhorov, Team III

Babykin, M. V., 1973-1975, Kurchatov, Team I

Baranova, N. B., 1972-1975, FIAN, Basov, Team IV

Barchukov, A. I., 1972-1978, FIAN, Prokhorov, Team II

Bashkin, A. S., 1974-1978, FIAN, Basov, Team V

Basov, N. G., 1968-1978, FIAN

Batanov, V. A., 1969-1975, FIAN, Prokhorov, Team V

Bayanov, V. I., 1975-1977, FIAN, Basov, Team III

Baykov, I. S., 1972-1974, FIAN, Basov, Team I

Belenov, E. M., 1968-1973, FIAN, Basov, Team II
1970-1975, FIAN, Basov, Team VI

Belousov, V. N., 1975-1977, Kurchatov, Team II

Belov, B. I., 1971-1973, FIAN, Basov, Team IV

Belov, L. F., 1972-1974, NPRI

Belyayev, V. N., 1975-1977, FIAN, Basov, Team IV

Bergel'son, V. I., 1970-1976, IPE

Berezen, Yu. A., 1968-1970, IHT, Team I

Berezhnoy, I. A., 1974-1978, FIAN, Basov, Team VI

Bokov, N. N., 1976-1978, FIAN, Basov, Team II

Boldin, A. M., 1973-1975, MEPI

Bol'shakov, Ye. N., 1972-1977, FIAN, Prokhorov, Team VI

Bonchovskiy, D. F., 1973-1975, FIAN, Basov, Team IV

Bondarev, A. S., 1976-1978, Yefremov, Team II

Borovich, B. L., 1973-1975, FIAN, Basov, Team V

Boyko, V. A., 1968-1975, FIAN, Basov, Team I
1972-1978, FIAN, Basov, Team III
1974-1978, FIAN, Basov, Team VI

Brenner, M. V., 1975-1977, Kurchatov, Team II

Breyzman, B. N., 1972-1974, Zakharov, Team I

Brunin, A. N., 1974-1978, FIAN, Basov, Team VI

Buchenkov, V. A., 1974-1978, Yefremov, Team II

Budneva, O. B., 1974-1976, FIAN, Prokhorov, Team V
1974-1976, Zakharov, Team III

Bufetov, I. A., 1973-1975, FIAN, Prokhorov, Team V

Bugayev, S. P., 1974-1976, FIAN Prokhorov, Team I

Bunatyan, A. A., 1973-1978, FIAN, Basov, Team II

Bunkin, F. V., 1968-1973, FIAN, Prokhorov, Team V
1969-1978, FIAN, Prokhorov, Team IV
1972-1978, FIAN, Prokhorov, Team II

Butslov, M. M., 1972-1974, FIAN, Basov, Team IV

Bychenkov, V. Yu., 1971-1978, FIAN, Basov, Team I

Bychkov, Yu. I., 1974-1977, FIAN, Prokhorov, Team I

Bykovskiy, N. Ye., 1973-1978, FIAN, Basov, Team IV

Bykovskiy, Yu. A., 1968-1978, MEPI

Chapliyev, N. I., 1975-1978, FIAN, Prokhorov, Team VI

Chekalin, S. V., 1968-1976, FIAN, Basov, Team IV

Chernetskiy, V. D., 1976-1978, FIAN, Basov, Miscellaneous

Chernikov, A. A., 1976-1978, FIAN, Basov, Team I

Chernyshev, L. Ye., 1976-1978, FIAN, Basov, Team I

Chevokin, V. K., 1976-1978, FIAN, Basov, Team III

Chikin, R. V., 1972-1974, FIAN, Basov, Team IV

Chirkov, V. A., 1974-1977, FIAN, Basov, Team III

Chopornyak, D. B., 1975-1978, NPRI

Chugunov, A. Yu., 1974-1976, FIAN, Basov, Team III
1974-1978, FIAN, Basov, Team VI

Churilova, S. A., 1971-1975, FIAN, Basov, Team IV

Chuvatin, S. A., 1972-1974, Kurchatov, Team II

Danilychev, V. A., 1970-1978, FIAN, Basov, Team VI

Darvoyd, T. I., 1974-1976 FIAN, Prokhorov, Team VI

Datskevich, N. P., 1976-1978, FIAN, Prokhorov, Team VI

Degtev, V. F., 1976-1978, Yefremov, Team I

Degtyarenko, N. N., 1968-1974, MEPI

Degtyarev, L. M., 1973-1976, FIAN, Basov, Team I
1975-1977, FIAN, Basov, Teams II, VI
1973-1975, Kurchatov, Team I
1973-1976, Zakharov, Team III

Degtyarev, V. G., 1970-1973, MEPI

Demchenko, N. N., 1976-1978, FIAN, Basov, Team III

Divil'kovskiy, I. M., 1971-1973, FIAN, Basov, Team IV

Dolgikh, V. A., 1973-1977, FIAN, Basov, Team VI

Domrin, V. I., 1975-1977, FIAN, Basov, Team I

Drozhbin, Yu. A., 1969-1974, FIAN, Basov, Team I

Dubovoy, L. V., 1973-1975, Yefremov, Team I

Dudoladov, A. G., 1968-1970, MEPI

Duvanov, B. N., 1968-1970, FIAN, Basov, Team I
1976-1978, FIAN, Basov, Team VI

Dyatlov, V. D., 1973-1975, Yefremov, Team I

Dymovich, V. I., 1968-1970, MEPI

Fanchenko, S. D., 1972-1976, FIAN, Basov, Team IV

Favorskiy, A. P., 1975-1977, FIAN, Basov, Team II

Fayenov, A. Ya., 1972-1978, FIAN, Basov, Team III

Faynberg, Ya. B., 1969-1972, PTI Ukr AN

Fedorov, A. N., 1970-1972, FIAN, Basov, Team I

Fedorov, G. M., 1972-1978, NPRI

Fedorov, M. V., 1970-1972, FIAN, Prokhorov, Team IV

Fedorov, V. B., 1968-1975, FIAN, Prokhorov, Team V

Fedosimov, A. I., 1971-1975, FIAN, Basov, Team IV

Fedotov, S. I., 1968-1976, FIAN, Basov, Team I
1971-1977, FIAN, Basov, Team II
1975-1977, FIAN, Basov, Team III
1969-1973, FIAN, Basov, Team IV

Feoktistov, L. P., 1973-1975, FIAN, Basov, Team II

Fetisov, V. S., 1976-1978, FIAN, Basov, Team I
1973-1975, MEPI

Filippov, N. V., 1970-1978, FIAN, Basov, Team I

Filippova, T. I., 1971-1974, FIAN, Basov, Miscellaneous

Flerov, G. N., 1972-1974, MEPI

Fradkov, A. B., 1976-1978, FIAN, Basov, Miscellaneous

Frolov, V. A., 1972-1974, FIAN, Basov, Team IV
1976-1978, FIAN, Basov, Team II

Galeyev, A. A., 1976-1978, Zakharov, Team I
1974-1978, ISR
1971-1974, IHT, Team I

Galochkin, V. I., 1969-1971, FIAN, Basov, Team V

Gamaliy, Ye. G., 1973-1975, FIAN, Basov, Team I
1973-1977, FIAN, Basov, Team II
1974-1976, FIAN, Basov, Team III

Gnoyevoy, Ya. N., 1969-1971, IPE

Gochelashvili, K. S., 1973-1975, FIAN, Prokhorov, Team V

Golub', A. P., 1972-1975, IPE

Golubev, L. Ye., 1977-1978, FIAN, Basov, Team V

Goncharov, A. S., 1976-1978, FIAN, Prokhorov, Team IV

Gorbunov, L. M., 1971-1978, FIAN, Basov, Team I

Gordeyev, Ye. M., 1974-1976, FIAN, Basov, Team IV

Gorev, V. V., 1973-1975, Kurchatov, Team I

Gorlanov, A. I., 1972-1974, Kurchatov, Team II

Goucharenko, A. F., 1975-1977, IPE

Gribkov, V. A., 1968-1976, FIAN, Basov, Team I
1969-1971, FIAN, Basov, Team IV
1971-1974, FIAN, Basov, Miscellaneous

Grigor'yev, P. G., 1973-1977, FIAN, Baosv, Team V

Grigorovich, A. S., 1977-1978, FIAN, Prokhorov, Team IV

Groznov, V. M., 1973-1975, FIAN, Basov, Team I
1971-1973, FIAN, Basov, Team II
1971-1973, FIAN, Basov, Team IV

Gryukanov, M. F., 1970-1971, MEPI

Gudzenko, L. I., 1972-1978, FIAN, Prokhorov, Team VI

Gulidov, S. S., 1975-1977, FIAN, Basov, Team III

Gulin, A. V., 1975-1977, FIAN, Basov, Team II

Gusev, G. A., 1973-1978, FIAN, Basov, Team I

Gusev, S. B., 1973-1975, FIAN, Prokhorov, Team V

Guseva, O. V., 1971-1973, FIAN, Basov, Team I

Gus'kov, S. Yu., 1973-1978, FIAN, Basov, Team II

Ignat'yev, V. V., 1974-1978, FIAN, Basov, Team VI

Igoshin, V. I., 1974-1978, FIAN, Basov, Team V

Inogamov, N. A., 1973-1978, LITP

Ionin, A. A., 1972-1978, FIAN, Basov, Team VI

Ionkin, N. I., 1974-1976, FIAN, Basov, Team I

Isakov, A. A., 1974-1976, FIAN, Basov, Team II

Isakov, A. I., 1973-1975, FIAN, Basov, Team I

Isayenko, V. I., 1968-1972, Yefremov, Team I

Ivanov, A. A., 1969-1971, Kurchatov, Team I

Ivanov, M. F., 1973-1978, LITP
1977-1978, FIAN, Prokhorov, Team IV

Ivanov, V. B., 1973-1975, Yefremov, Team II

Ivanov, V. I., 1976-1978, Kurchatov, Team I

Ivanov, Yu. S., 1971-1973, FIAN, Basov, Team I
1971-1973, FIAN, Basov, Team II

Ivanova, L. I., 1971-1973, FIAN, Basov, Team III

Ivanova, T. G., 1976-1978, FIAN, Basov, Team VI

Ivanushkina, L. V., 1976-1978, Yefremov, Team II

Kadomtsev, B. B., 1969-1971, Zakharov, Team II

Kalachev, N. V., 1973-1975, FIAN, Basov, Team I

Kalinkina, T. A., 1974-1976, FIAN, Basov, Team III

Kalinin, F. V., 1977-1978, FIAN, Prokhorov, Team IV

Kalmykov, A. A., 1968-1970, IPE

Kantsyrev, V. L., 1971-1973, MEPI

Karasev, M. E., 1976-1978, FIAN, Prokhorov, Team II

Karlov, N. V., 1969-1978, FIAN, Prohkorov, Team I

Karlova, Ye. K., 1969-1978, FIAN, Prokhorov, Team I

Karpova, L. V., 1974-1976, Yefremov, Team I

Kask, N. E., 1972-1978, NPRI

Kas'yanov, Yu. S., 1976-1978, FIAN, Basov, Team IV
1977-1978, FIAN, Basov, Team I

Kaytmazov, S. D., 1969-1978, FIAN, Prokhorov, Team VI

Kazakevich, V. S., 1976-1978, FIAN, Basov, Team VI

Kazakov, A. Ye., 1969-1972, FIAN, Prokhorov, Team IV

Kazarnovskiy, M. V., 1973-1975, FIAN, Basov, Team I

Kevlishvili, P. V., 1974-1976, IPE

Khasenov, M. U., 1975-1977, FIAN, Basov, Team VI

Khazins, V. M., 1975-1977, IPE

Khodkevich, D. D., 1976-1978, FIAN, Basov, Team VI

Kholin, I. V., 1974-1978, FIAN, Basov, Team VI

Kholodenkov, L. Ye., 1976-1978, FIAN, Basov, Team VI

Kinber, B. Ye., 1973-1975, FIAN, Basov, Team IV

Kingsep, A. S., 1968-1978, Kurchatov, Team I

Kiprianov, A. I., 1968-1970, Yefremov, Team I

Kiriy, A. Yu., 1968-1978, FIAN, Basov, Team I

Kiselev, V. A., 1972-1974, FIAN, Prokhorov, Team V

Klementov, A. D., 1976-1978, FIAN, Basov, Team VI

Klyukvin, N. V., 1976-1978, FIAN, Prokhorov, Team IV

Kochetev, I. V., 1976-1978, FIAN, Prokhorov, Team I

Kogan, Ye. Ya., 1970-1972, PTI Ukr AN

Kolichnichenko, P. I., 1973-1975, FIAN, Prokhorov, Team V

Kolodnom, G. Ya., 1976-1978, FIAN, Basov, Team IV

Kologrivov, A. A., 1972-1978, FIAN, Basov, Team I

Konev, Yu. B., 1976-1978, FIAN, Prokhorov, Team I

Kononov, N. N., 1975-1977, FIAN, Prokhorov, Team II
1976-1978, FIAN, Prokhorov, Team I

Konoplev, N. A., 1972-1974, FIAN, Basov, Team I
1972-1975, FIAN, Basov, Team III

Konoshenko, A. F., 1977-1978, FIAN, Basov, Team V

Konov, V. I., 1968-1970, FIAN, Prokhorov, Team V
1972-1978, FIAN, Prokhorov, Team II

Korneyev, V. V., 1976-1978, FIAN, Basov, Team III

Korniyenko, L. S., 1972-1978, NPRI

Korobkin, V. V., 1970-1978, FIAN, Prokhorov, Team IV
1977-1978, FIAN, Basov, Team I

Korolev, V. I., 1976-1978, Yefremov, Team II

Korzhavin, V. M., 1971-1974, FIAN, Basov, Miscellaneous

Koslov, O. V., 1976-1978, FIAN, Prokhorov, Team IV

Koslova, N. N., 1974-1976, IPE

Kostin, V. V., 1976-1978, FIAN, Prokhorov, Team II

Koval'chuk, B. M., 1974-1978, FIAN, Prokhorov, Team I

Koval'skiy, N. G., 1972-1977, Kurchatov, Team II

Kovalenko, V. A., 1973-1975, FIAN, Basov, Team I

Kovalev, I. O., 1972-1974, FIAN, Prokhorov, Team I

Kovalev, V. F., 1974-1976, FIAN, Basov, Team I

Kovalevskiy, D. V., 1971-1973, FIAN, Basov, Team IV

Kovin, V. S., 1973-1975, FIAN, Prokhorov, Team III

Kovrigin, A. I., 1971-1973, FIAN, Basov, Team IV

Kovsh, I. B., 1970-1978, FIAN, Basov, Team VI

Kozlev, Yu. I., 1977-1978, FIAN, Basov, Team V

Kozlovskiy, K. I., 1977-1978, MEPI

Kozyrev, Yu. P., 1968-1978, MEPI

Kulakov, L. V., 1969-1971, FIAN, Basov, Team V

Krasnosel'skikh, V. V., 1976-1978, ISR

Krasyuk, I. K., 1968-1978, FIAN, Prokhorov, Team IV
1977-1978, FIAN, Prokhorov, Team I

Krokhin, O. N., 1968-1978, FIAN, Basov

Kruglov, B. V., 1971-1973, FIAN, Basov, Team IV

Krupnova, L. V., 1977-1978, FIAN, Basov, Team I

Kryukov, P. G., 1968-1976, FIAN, Basov, Team IV

Kryzhanovskiy, V. I., 1970-1975, Yefremov, Team I

Kudinova, M. A., 1976-1978, FIAN, Prokhorov, Team III

Kurasanov, Ye. V., 1976-1978, FIAN, Basov, Team II

Kurbatov, Yu. A., 1974-1977, FIAN, Prokhorov, Team I

Kurdyumov, Ye. P., 1973-1978, FIAN, Basov, Team II

Kurgamova, Ye. V., 1973-1975, FIAN, Basov, Team IV

Kuritsyn, V. A., 1976-1978, FIAN, Prokhorov, Team I

Kuz'min, G. P., 1969-1978, FIAN, Prokhorov, Team I
1975-1977, FIAN, Prokhorov, Team II

Kuzminov, Yu. S., 1976-1978, FIAN, Prokhorov, Team I

Kuznetsov, T. I., 1973-1975, FIAN, Basov, Team II
1973-1975, FIAN, Basov, Team IV

Kuznetsov, Ye. A., 1976-1978, Zakharov, Team I

Laptev, S. D., 1970-1973, MEPI

Larionova, V. G., 1971-1973, FIAN, Basov, Team II

Lavol, G., 1972-1974, IHT, Team I (foreign author)

Lebo, I. G., 1977-1978, FIAN, Basov, Team II

Leonov, Yu. S., 1975-1977, FIAN, Basov, Team I

Letokhov, V. S., 1968-1970, FIAN, Basov, Team IV

Levanov, Ye. I., 1971-1977, FIAN, Basov, Team II

Levkoyev, I. I., 1968-1972, Yefremov, Team I
1974-1976, FIAN, Prokhorov, Team III

Lisitchenko, V. V., 1970-1973, IHT, Team I

Lisitskiy, I. S., 1974-1976, FIAN, Prokhorov, Team I

Litvin, S. B., 1975-1977, FIAN, Basov, Team I

Lobanov, A. N., 1973-1978, FIAN, Basov, Team VI

Loseva, T. V., 1973-1976, IPE

Lovetskiy, Ye. Ye., 1976-1978, FIAN, Basov, Team I
1973-1975, MEPI

Lugovoy, V. N. 1970-1972, FIAN, Prokhorov, Team IV

Lugovskiy, V. K., 1975-1977, FIAN, Basov, Miscellaneous

Lukyanov, S. Yu., 1972-1974, Kurchatov, Team II

L'vov, V. S., 1968-1974, Zakharov, Team I
1974-1976, Zakharov, Team II

Lykov, V. A., 1976-1978, FIAN, Basov, Team II

Lysikov, Yu. I., 1969-1971, LITF

Lyubin, A. A., 1973-1975, FIAN, Prokhorov, Team II

Lyubin, A. P., 1976-1978, FIAN, Prokhorov, Team IV

Mak, A. A., 1974-1978, Yefremov, Team I
1973-1975, Yefremov, Team II
1975-1977, FIAN, Basov, Team III

Makhan'kev, V. G., 1973-1975, Kurchatov, Team I

Maksimov, L. P., 1969-1971, FIAN, Prokhorov, Team V

Malinin, V. G., 1974-1976, Yefremov, Team II

Malkov, A. N., 1973-1975, FIAN, Prokhorov, Team V

Malyavina, T. B., 1971-1973, IPE

Malyntin, A. A., 1970-1972, FIAN, Prokhorov, Team IV

Malyshev, V. I., 1969-1978, FIAN, Prokhorov, Team III

Malyutin, A. A., 1976-1978, FIAN, Prokhorov, Team IV

Manakov, S. V., 1972-1975, Zakharov, Team II

Mandel'shtam, S. L., 1973-1978, FIAN, Basov, Team III

Manylov, V. I., 1975-1977, FIAN, Prokhorov, Team I

Marchenko, V. M., 1970-1972, FIAN, Prokhorov, Team IV

Markin, Ye. P., 1973-1975, FIAN, Basov, Team V

Markov, A. N., 1976-1978, FIAN, Basov, Miscellaneous

Markovich, I. Ye., 1974-1978, IPE

Masalov, A. V., 1969-1976, FIAN, Prokhorov, Team III

Masterov, V. S., 1974-1976, FIAN, Basov, Team V

Mastryukov, A. F., 1977-1978, Zakharov, Team III

Matachun, A. T., 1973-1975, FIAN, Basov, Team I

Matveyets, Yu. A., 1968-1976, FIAN, Basov, Team IV

Matveyeva, F. I., 1975-1977, FIAN, Basov, Team I

Matyayev, M. S., 1970-1974, FIAN, Prokhorov, Team VI

Mazing, M. A., 1976-1978, FIAN, Basov, Team III

Medvedev, A. A., 1969-1975, FIAN, Prokhorov, Team VI

Medvedev, R. N., 1973-1975, Yefremov, Team I

Merkul'yev, Yu. A., 1975-1977, FIAN, Basov, Team I
1974-1976, FIAN, Basov, Team II

Mesyats, G. A., 1974-1978, FIAN, Prokhorov, Team I
1975-1977, FIAN, Prokhorov, Team II

Metev, S. M., 1976-1978, FIAN, Prokhorov, Team II

Mikerov, V. I., 1973-1975, FIAN, Basov, Team I

Mikhaylov, A. V., 1977-1878, Zakharov, Team I

Mikhaylov, Yu. A., 1973-1977, FIAN, Basov, Team I
1972-1978, FIAN, Basov, Team II
1973-1977, FIAN, Basov, Team III

Milanich, A. I., 1974-1976, FIAN, Prokhorov, Team III
1976-1978, FIAN, Basov, Team VI

Mit'kin, V. M., 1974-1976, Yefremov, Team II

Moiseyev, S. S., 1968-1976, PTI Ukr AN

Monich, N. V., 1968-1970, Yefremov, Team I

Morachevskiy, N. V., 1968-1970, FIAN, Basov, Team I

Motylev, S. L., 1977-1978, FIAN, Prokhorov, Team IV

Mukhin, V. V., 1974-1976, PTI Ukr AN

Murashkina, V. A., 1973-1975, FIAN, Basov, Team II

Musher, S. L., 1970-1976, Zakharov, Team I

Nastoyashchiy, A. F., 1974-1978, Kurchatov, Team II

Nemchinov, I. V., 1968-1978, IPE

Nesterov, G. V., 1976-1978, Kurchatov, Team I

Neuvazhayev, V. Ye., 1973-1978, FIAN, Basov, Team II

Nevolin, V. N., 1970-1973, MEPI

Nikiforov, S. M., 1976-1978, FIAN, Prokhorov, Team I

Nikitenko, A. I., 1974-1976, FIAN, Basov, Team II

Nikitin, V. Yu., 1973-1978, FIAN, Basov, Team V

Nikolayev, B. I., 1968-1970, MEPI

Nikolayev, F. A., 1973-1975, FIAN, Basov, Team I
1975-1977, FIAN, Basov, Miscellaneous

Nikolayev, S. N., 1968-1970, MEPI

Nikulin, V. Ya., 1969-1976, FIAN, Basov, Team I

Novikov, N. V., 1973-1975, FIAN, Basov, Team I
1971-1973, FIAN, Basov, Team II

O'Neil, T., 1972-1974, IHT, Team I (foreign author)

Orayevskiy, A. N., 1973-1978, FIAN, Basov, Team V

Orayevskiy, V. N., 1970-1972, PTI Ukr AN
1970-1973, IHT, Team I

Orlova, T. I., 1973-1978, IPE

Orlovskiy, V. M., 1974-1977, FIAN, Prokhorov, Team I

Oshurkova, A. N., 1974-1976, FIAN, Basov, Team III

Osiko, V. V., 1976-1978, FIAN, Prokhorov, Team I

Osipov, V. V., 1976-1978, FIAN, Prokhorov, Team I

Panteleyev, V. I., 1973-1975, FIAN, Basov, Team IV

Pasechnik, L. L., 1974-1976, FIAN, Basov, Team I

Pashinin, P. P., 1968-1978, FIAN, Prokhorov, Team IV
1977-1978, FIAN, Prokhorov, Team I
1972-1978, FIAN, Prokhorov, Team VI

Pastukhov, M. F., 1976-1978, FIAN, Prokhorov, Team IV

Pasyukova, A., 1973-1975, FIAN, Basov, Team II

Peregudov, G. V., 1974-1976, FIAN, Basov, Team III

Pergament, M. I., 1975-1977, Kurchatov, Team II

Petrov, R. P., 1972-1974, FIAN, Prokhorov, Team I

Petrukhin, A. I., 1968-1978, IPE

Petviashvili, V. I., 1969-1971, Zakharov, Team II

Pevgov, V. G., 1976-1978, FIAN, Prokhorov, Team I

Pikuz, S. A., 1972-1978, FIAN, Basov, Team III

Pimenov, V. P., 1975-1977, FIAN, Basov, Miscellaneous

Pimenov, Yu. P., 1972-1975, FIAN, Prokhorov, Team V

Piskunov, A. K., 1977-1978, FIAN, Basov, Team V

Pivinskiy, Ye., G., 1975-1977, Yefremov, Team II

Pletnev, N. V., 1976-1978, FIAN, Basov, Team IV

Plis, A. I., 1970-1978, FIAN, Basov, Miscellaneous

Podsosonnyy, A. S., 1972-1974, FIAN, Basov, Team VI

Pogedayev, A. K., 1976-1978, Yefremov, Team II

Pogorel'skiy, I. V., 1969-1971, FIAN, Basov, Team III

Poletayev, N. L., 1976-1978, FIAN, Basov, Team VI

Poluektov, I. A., 1968-1973, FIAN, Basov, Team II

Polyanichev, A. N., 1976-1978, FIAN, Basov, Team I
1973-1975, MEPI

Popov, S. P., 1969-1975, IPE

Popov, Ye. G., 1968-1971, IPE

Popov, Yu. M., 1971-1973, FIAN, Basov, Team IV

Popov, Yu. P., 1974-1977, FIAN, Basov, Team II

Popytayev, A. N., 1973-1975, Yefremov, Team I

Porodinkov, O. Ye., 1975-1977, FIAN, Basov, Team V

Prizhimov, V. V., 1974-1976, FIAN, Basov, Team I

Prokhorov, A. M., 1968-1978, FIAN

Provalov, A. A., 1969-1971, IPE

Pustovalov, V. V., 1969-1978, Basov, Team I
1974-1976, FIAN, Basov, Team III

Rabinovich, M. S., 1976-1978, FIAN, Basov, Team I

Radchenko, V. V., 1975-1978, NPRI

Ragozin, Ye. N., 1974-1976, FIAN, Basov, Team III

Ramazashvili, R. R., 1976-1978, FIAN, Basov, Team I

Raitsev-Kartinov, V. A., 1972-1974, Kurchatov, Team II

Rez, I. S., 1971-1973, FIAN, Basov, Team IV

Romanov, A. B., 1971-1976, FIAN, Basov, Team I

Rosenbluth, M. N., 1972-1974, IHT, Team I (foreign author)

Rozanov, V. B., 1971-1978, FIAN, Basov, Team II
1973-1976, FIAN, Basov, Team III
1971-1973, FIAN, Basov, Team IV

Rubenchik, A. M., 1971-1976, Zakharov, Team I
1972-1974, Zakharov, Team II

Rudakov, L. I., 1968-1978, Kurchatov, Team I
1974-1976, Zakharov, Team III

Rupasov, A. A., 1971-1978, FIAN, Basov, Team I

Ryabtsev, A. N., 1974-1976, FIAN, Basov, Team III

Rybak, I. Ya., 1973-1975, Zakharov, Team I

Rybakov, V. A., 1974-1978, IPE

Rybalov, A. M., 1974-1977, FIAN, Prokhorov, Team I

Rychkova, Ye. R., 1975-1977, FIAN, Basov, Team I
1974-1976, FIAN, Basov, Team II

Ryutov, D. D., 1972-1978, IAE SOAN, Zakharov, Team II

Ryukkert, V. V., 1971-1973, FIAN, Basov, Team I

Ryzhikh, S. V., 1968-1970, MEPI

Safronova, U. I., 1972-1974, FIAN, Basov, Team I
1970-1978, FIAN, Basov, Team III

Sagdeyev, R. Z., 1974-1976, Kurchatov, Team II
1971-1973, Zakharov, Team I
1968-1974, IHT, Team I
1969-1971, Zakharov, Team II
1974-1978, ISR

Sagitov, S. I., 1974-1976, FIAN, Basov, Team VI

Samarskiy, A. A., 1971-1978, FIAN, Basov, Team II
1972-1974, Kurchatov, Team I

Samokhvalov, V. A., 1973-1975, FIAN, Prokhorov, Team V

Savchenko, M. A., 1974-1976, FIAN, Basov, Team I

Savel'yev, V. V., 1975-1977, Kurchatov, Team II

Savranskiy, V. V., 1969-1971, FIAN, Prokhorov, Team V

Sedov, B. M., 1975-1978, Yefromov, Team II

Semenov, O. G., 1974-1976, FIAN, Basov, Team I

Semenyuk, V. F., 1974-1976, FIAN, Basov, Team I

Senatskiy, Yu. V., 1970-1978, FIAN, Basov, Team IV

Serebryakov, V. A., 1968-1975, Yefremov, Team I

Serov, R. V., 1970-1972, FIAN, Prokhorov, Team IV

Shabat, A. B., 1970-1974, Zakharov, Team I

Shapiro, V. D., 1976-1978, Zakharov, Team I
1974-1978, ISR
1969-1971, PTI Ukr AN

Sharkov, A. V., 1974-1976, FIAN, Basov, Team IV

Shatalov, G. Ye., 1974-1976, FIAN, Basov, Team II

Shatberashvili, O. B., 1971-1975, FIAN, Basov, Team IV

Shcheglov, V. A., 1972-1974, FIAN, Basov, Team IV
1970-1978, FIAN, Basov, Team V

Shchelev, M. Ya., 1976-1978, FIAN, Basov, Team III

Shchur, L. N., 1977-1978, FIAN, Prokhorov, Team IV

Shevchenko, V. I., 1976-1978, Zakharov, Team I
1974-1978, ISR

Shevel'ko, A. P., 1976-1978, FIAN, Basov, Team III
1977-1978, FIAN, Basov, Team I
1976-1978, FIAN, Prokhorov, Team IV

Shibanov, A. N., 1974-1976, FIAN, Prokhorov, Team III

Shikanov, A. S., 1970-1978, FIAN, Basov, Team I
1969-1973, FIAN, Basov, Team IV
1977-1978, FIAN, Basov, Team II

Shirbatsev, L. I., 1973-1975, FIAN, Basov, Team II

Shklovskiy, Ye. I., 1970-1978, FIAN, Prokhorov, Team VI

Shpol'skiy, M. R., 1974-1976, FIAN, Basov, Team I
1974-1976, FIAN, Basov, Team III

Shtaleva, T., 1973-1975, FIAN, Basov, Team II

Shur, L. N., 1976-1978, LITP

Sigov, Yu. S., 1974-1976, ISR

Silenok, A. S., 1976-1978, FIAN, Prokhorov, Team II

Silin, V. P., 1968-1978, FIAN, Basov, Team I

Sil'nov, S. M., 1968-1975, MEPI

Sisakyan, Ye. V., 1974-1976, FIAN, Prokhorov, Team I

Sizov, V. N., 1971-1975, Yefremov, Team I

Sklizkov, G. V., 1968-1978, FIAN, Basov

Sklovskiy, Ye. I., 1972-1977, FIAN, Prokhorov, Team VI

Skobolev, I. Yu., 1973-1975, FIAN, Basov, Team III

Skvortsov, A. B., 1975-1977, FIAN, Basov, Team V

Smirnova, Ye. A., 1972-1974, FIAN, Basov, Team IV

Sobelev, B. V., 1975-1977, FIAN, Basov, Team IV

Sobolev, V. A., 1972-1978, FIAN, Basov, Team VI

Sobolev, V. V., 1970-1972, Zakharov, Team III

Sobolevskiy, N. M., 1974-1976, FIAN, Basov, Team II

Sobel'man, I. I., 1973-1975, FIAN, Basov, Team I
1973-1975, FIAN, Basov, Team III
1973-1975, FIAN, Basov, Team IV

Soms, L. N., 1974-1976, Yefremov, Team II

Sotnikov, V. I., 1976-1978, ISR

Sparkov, B. Yu., 1971-1975, MEPI

Starikov, A. D., 1975-1977, FIAN, Basov, Team III
1975-1977, Yefremov, Team I
1968-1975, Yefremov, Team II

Starobinets, S. S., 1968-1973, Zakharov, Team I

Starodub, A. N., 1972-1978, FIAN, Basov, Team I

Startsev, S. A., 1973-1975, FIAN, Basov, Team I

Stel'makh, M. F., 1971-1973, FIAN, Basov, Team IV

Stenchikov, G. L., 1973-1978, FIAN, Basov, Team I

Stepanenko, M. M., 1972-1974, Kurchatov, Team II

Stepanov, A. I., 1974-1978, Yefremov, Team II

Stepanov, B. M., 1974-1976, FIAN, Basov, Team I
1972-1976, FIAN, Basov, Team IV

Strotseva, A. P., 1976-1978, FIAN, Basov, Team II

Sturman, B. I., 1972-1975, Zakharov, Team I

Sultanov, M. A., 1972-1974, FIAN, Basov, Team I

Sulyayev, V. A., 1969-1978, IPE

Svetsov, V. V., 1973-1975, IPE

Sychev, A. A., 1969-1978, FIAN, Prokhorov, Team III

Synakh, V. S., 1970-1976, Zakharov, Team III

Tarakanov, V. B., 1974-1978, IHT, Team II

Tikhonchuk, V. T., 1971-1978, FIAN, Basov, Team I
1974-1976, FIAN, Basov, Team III

Tikhonov, A. N., 1974-1977, FIAN, Basov, Team II

Tolmachev, A. I., 1968-1970, Yefremov, Team I
1976-1978, FIAN, Prokhorov, Team III

Tomashov, V. N., 1977-1978, FIAN, Basov, Team V

Traktirnikov, R. N., 1974-1976, FIAN, Basov, Team II

Troshagin, V. N., 1977-1978, FIAN, Basov, Team V

Tsapenko, V. P., 1971-1974, FIAN, Basov, Team I

Tsibin, A. S., 1972-1974, MEPI

Tsikulin, M. A., 1969-1971, IPE

Tsvetkov, A. D., 1975-1977, Yefremov, Team II

Tsvetkov, M. Yu., 1976-1978, FIAN, Basov, Team I

Tyurin, Ye. L., 1972-1974, FIAN, Basov, Team IV
1970-1972, FIAN, Basov, Miscellaneous

Tyurina, N. N., 1975-1977, FIAN, Basov, Team II

Urin, B. M., 1973-1977, FIAN, Basov, Team VI

Urnov, A. N., 1976-1978, FIAN, Basov, Team III

Uvarova, V. M., 1973-1976, FIAN, Basov, Team III

Vakhmyanin, K. P., 1976-1978, Yefremov, Team II

Vakulenko, A. M., 1973-1975, FIAN, Basov, Team IV

Vanyukov, M. P., (deceased), 1968-1972, Yefremov, Team I

Vardzigulova, L. Ye., 1969-1974, FIAN, Prokhorov, Team VI

Vaynshteyn, L. A., 1972-1974, FIAN, Basov, Team I
1970-1978, FIAN, Basov, Team III

Velikhov, Ye. P., 1975-1977, Kurchatov, Team II

Venglyuk, V. I., 1976-1978, Yefremov, Team II

Vikharev, V. D., 1975-1977, Kurchatov, Team II

Vilenskaya, G. G., 1968-1970, IPE

Vinogradov, A. V., 1968-1975, FIAN, Basov, Team I
1972-1977, FIAN, Basov, Team III

Vodyanitskiy, A. A., 1969-1972, PTI, Ukr AN

Volokitin, A. S., 1974-1978, IHT, Team II

Volosevich, P. P., 1971-1978, FIAN, Basov, Team II

Volyak, T. B., 1969-1975, FIAN, Prokhorov, Team VI
1977-1978, FIAN, Prokhorov, Team I

Volynkin, V. M., 1976-1978, Yefremov, Team II

Vompe, A. F., 1968-1970, Yefremov, Team I

Vorob'yev, Ye. D., 1972-1974, MEPI

Voronov, G. S., 1976-1978, FIAN, Basov, Team I

Voronov, V. V., 1976-1978, FIAN, Prokhorov, Team I

Vorontsov, D. B., 1972-1974, FIAN, Basov, Team IV

Vovchenko, V. I., 1968-1978, FIAN, Prokhorov, Team IV

Yakolev, V. A., 1969-1971, FIAN, Basov, Team I

Yan'kov, V. V., 1974-1976, Kurchatov, Team I

Yaroslavskiy, A. I., 1975-1977, Kurchatov, Team II

Yelesin, V. F., 1968-1973, MEPI

Yerokhin, A. A., 1971-1973, FIAN, Basov, Team II
1976-1978, FIAN, Basov, Team I

Yerokhin, N. S., 1968-1976, PTI, Ukr AN

Yershov, B. V., 1969-1975, FIAN, Prokhorov, Team V

Yevteyev, M. V., 1968-1972, FIAN, Prokhorov, Team IV

Yufa, V. N., 1975-1977, Kurchatov, Team II

Yukov, Ye. A., 1972-1975, FIAN, Basov, Team I
1973-1977, FIAN, Basov, Team III

Yurov, V. T., 1973-1975, FIAN, Basov, Team IV

Yuryshev, N. N., 1977-1978, FIAN, Basov, Team V

Zakharenkov, Yu. A., 1972-1978, FIAN, Basov, Team I
1977-1978, FIAN, Basov, Team II

Zakharov, S. D., 1971-1973, FIAN, Basov, Team IV
1970-1977, FIAN, Basov, Miscellaneous

Zakharov, S. M., 1968-1974, FIAN, Basov, Team I
1972-1975, FIAN, Basov, Team III
1976-1978, FIAN, Basov, Team IV

Zakharov, V. Ye., 1968-1978, IAE SOAN
1969-1975, INP SOAN
1968-1970, PTI Ukr AN
1970-1976, IAM
1975-1977, Kurchatov, Team II

Zaritskiy, A. R., 1971-1973, FIAN, Basov, Team IV

Zaroslov, D. Yu., 1972-1974, FIAN, Prokhorov, Team I

Zautkin, V. V., 1970-1973, Zakharov, Team III

Zavorotnyy, S. I., 1973-1975, FIAN, Basov, Team V

Zavoyskiy, Ye. K., 1972-1974, FIAN, Basov, Team IV
1973-1975, Kurchatov, Team I

Zel'dovich, B. Ya., 1973-1975, FIAN, Basov, Team IV

Zel'dovich, Ya. B., 1976-1978, LITP

Zherikhin, A. N., 1973-1975, FIAN, Basov, Team IV

Zhitnik, I. A., 1976-1978, FIAN, Basov, Team III

Zhuravlev, V. V., 1975-1977, Kurchatov, Team II

Zmitrenko, N. V., 1976-1978, FIAN, Basov, Team II

Zorev, N. N., 1970-1978, FIAN, Basov, Team I
1971-1973, FIAN, Basov, Team II

Zotov, V. P., 1975-1977, Kurchatov, Team II

Zuyev, V. S., 1973-1975, FIAN, Basov, Team V

Zvezdov, V. V., 1973-1975, FIAN, Basov, Team I

Zvorykin, V. D., 1974-1978, FIAN, Basov, Team VI

## LIST 2. FUNCTIONAL BREAKDOWN

### Supervisory Personnel

Afanas'yev, Yu. V., 1968-1976, FIAN, Basov, Teams I,II,III

Anisimov, S. I., 1969-1978, LITP

Andreyev, N. Ye., 1968-1978, FIAN, Basov, Team I

Basov, N. G., 1968-1978, FIAN, Group I

Bunatyan, A. A., 1973-1975, FIAN, Basov, Team II

Danilychev, V. A., 1970-1978, FIAN, Basov, Team VI

Faynberg, Ya. B., 1969-1972, PTI Ukr AN

Fedotov, S. I., 1968-1977, FIAN, Basov

Feoktistov, L. P., 1973-1975, FIAN, Basov, Team II

Gamaliy, Ye. G., 1973-1977, FIAN, Basov, Team II

Kiriy, A. Yu., 1968-1978, FIAN, Basov, Team I

Krasyuk, I. K., 1968-1978, FIAN, Prokhorov, Team IV

Krokhin, O. N., 1968-1978, FIAN, Basov

Kryukov, P. G., 1968-1976, FIAN, Basov, Team IV

Kuznetsov, T. I., 1973-1975, FIAN, Basov, Team II

Mak, A. A., 1974-1978, Yefremov, Team I

Malyshev, V. I., 1969-1978, FIAN, Prokhorov, Team III

Mandel'shtam, S. L., 1973-1978, FIAN, Basov, Team III

Murashkina, V. A., 1973-1975, FIAN, Basov, Team II

Neuvazhayev, V. Ye., 1973-1978, FIAN, Basov, Team II

Pashinin, P. P., 1968-1978, FIAN, Prokhorov

Pogodayev, A. K., 1976-1978, Yefremov, Team II

Prokhorov, A. M., 1968-1978, FIAN, Group II

Rozanov, V. B., 1971-1978, FIAN, Basov, Team II

Rudakov, L. I., 1968-1978, Kurchatov, Team I

Shibarshov, L. I., 1973-1975, FIAN, Basov, Team II

Shikanov, A. S., 1970-1978, FIAN, Basov, Team I

Silin, V. P., 1968-1978, FIAN, Basov, Team I

Sklizkov, G. V., 1968-1978, FIAN, Basov

Vaynshteyn, L. A., 1970-1978, FIAN, Basov, Team III

Velikhov, Ye. P., 1975-1977, Kurchatov, Team II

Zakharov, V. Ye., 1968-1978, IAE SOAN
1969-1975, INP SOAN
1970-1976, IAM

Zavoyskiy, Ye. K., 1972-1974, FIAN, Basov, Team IV

Zel'dovich, B. Ya., 1973-1975, FIAN, Basov, Team IV

LEADING AUTHORS

Afanas'yev, Yu. V., 1968-1976, FIAN, Basov, Team II

Andreyev, N. Ye., 1968-1976, FIAN, Basov, Team I

Anisimov, S. I., 1969-1978, LITP

Babenko, B. A., 1970-1978, FIAN, Prokhorov, Team III

Bashkin, A. S., 1974-1978, FIAN, Basov, Team V

Barchukov, A. I., 1972-1978, FIAN, Prokhorov, Team II

Batanov, V. A., 1969-1975, FIAN, Prokhorov, Team V

Boyko, V. A., 1972-1978, FIAN, Basov, Team III

Buchenkov, V. A., 1974-1978, Yefremov, Team II

Bunkin, F. V., 1972-1978, FIAN, Prokhorov, Team II
1969-1978, FIAN, Prokhorov, Team IV
1968-1973, FIAN, Prokhorov, Team V

Bychenkov, V. Yu., 1971-1978, FIAN, Basov, Team I

Bykovskiy, Yu. A., 1968, 1978, MEPI

Chekalin, S. V., 1968-1976, FIAN, Basov, Team IV

Danilychev, V. A., 1970-1978, FIAN, Basov, Team VI

Degtyarenko, N. N., 1968-1974, FIAN, Basov, Team IV

Fayenov, A. Ya., 1972-1978, FIAN, Basov, Team III

Fedorov, G. M., 1972-1978, NPRI

Fedorov, V. B., 1968-1975, FIAN, Prokhorov, Team V

Galeyev, A. A., 1974-1978, ISR
1971-1974, IHT, Team I

Igoshin, V. I., 1974-1978, FIAN, Basov, Team V

Ivanov, A. A., 1969-1975, Kurchatov, Team I

Ivanov, M. F., 1973-1978, LITP

Karlov, N. V., 1969-1978, FIAN, Prokhorov, Team I

Karlova, Ye. K., 1969-1978, FIAN, Prokhorov, Team I

Kask, N. E., 1972-1978, NPRI

Kaytmazov, S. D., 1969-1978, FIAN, Prokhorov, Team VI

Kerimov, O. M., 1970-1978, FIAN, Basov, Team VI

Kingsep, A. S., 1968-1978, Kurchatov, Team I

Konov, V. I., 1972-1978, FIAN, Prokhorov, Team II

Kozyrev, Yu. P., 1968-1978, MEPI

Krokhin, O. N., 1969-1978, FIAN, Basov, I, II

Kryukov, P. G., 1968-1976, FIAN, Basov, Team IV

Kuz'min, G. P., 1969-1978, FIAN, Prokhorov, Team I

L'vov, V. S., 1968-1974, Zakharov, Team I

Masalov, A. I., 1974-1976, FIAN, Prokhorov, Team III

Matveyets, Yu. A., 1968-1976, FIAN, Basov, Team IV

Moiseyev, S. S., 1968-1976, PTI Ukr AN

Musher, S. L., 1970-1976, Zakharov, Team I

Nemchinov, I. V., 1968-1978, IPE

Orayevskiy, A. N., 1973-1978, FIAN, Basov, Team V

Pashinin, P. P., 1968-1978, FIAN, Prokhorov, Team IV

Pikuz, S. A., 1972-1978, FIAN, Basov, Team III

Pustovalov, V. V., 1969-1978, FIAN, Basov, Team I

Rozanov, V. B., 1971-1978, FIAN, Basov, Team II

Rubenchik, A. M., 1971-1976, Zakharov, Team I

Rupasov, A. A., 1971-1978, FIAN, Basov, Team I

Sagdeyev, R. Z., 1974-1978, ISR
1968-1974, IHT, Team I

Sedov, B. M., 1975-1978, Yefremov, Team II

Senatskiy, Yu. V., 1970-1978, FIAN, Basov, Team IV

Serebryakov, V. A., 1968-1975, Yefremov, Team I

Shapiro, V. D., 1974-1978, ISR

Shevchenko, V. I., 1974-1978, ISR

Shklovskiy, Ye. I., 1970-1978, FIAN, Prokhorov, Team VI

Silin, V. P., 1968-1978, Basov, Team I

Sil'nov, S. M., 1968-1975, MEPI

Sklizkov, G. V., 1969-1978, FIAN, Basov, Team I

Starikov, A. D., 1968-1975, Yefremov, Team I

Starodub, A. N., 1972-1978, FIAN, Basov, Team I

Stepanov, A. I., 1974-1978, Yefremov, Team II

Suchkov, A. F., 1970-1978, FIAN, Basov, Team VI

Sychev, A. A., 1969-1978, FIAN, Prokhorov, Team III

Tikhonchuk, V. T., 1971-1978, FIAN, Basov, Team I

Volyak, T. B., 1969-1975, FIAN, Prokhorov, Team VI

Yerokhin, N. S., 1968-1976, PTI Ukr AN

Yershov, B. V., 1969-1975, FIAN, Prokhorov, Team V

Zakharov, V. Ye., 1970-1976, FIAN, Prokhorov, Team I

Zakharenkov, Yu. A., 1972-1978, FIAN, Basov, Team I

REVIEWERS

Afanas'yev, Yu. V., 1968-1976, FIAN, Basov, Team I
1973-1976, FIAN, Basov, Team II

Anisimov, S. I., 1975-1977, LITP

Askar'yan, G. A., 1977-1978, FIAN, Prokhorov, Team VI

Bash, A. S., 1974-1976, FIAN, Basov, Team V

Basov, N. G., 1973-1975, MEPI
1974-1976, FIAN, Basov, Team V

Bergel'son, V. I., 1970-1972, IPE

Boldin, A. M., 1973-1975, MEPI

Boyko, V. A., 1973-1978, FIAN, Basov, Team III

Bunkin, F. V., 1969-1972, FIAN, Prokhorov, Team IV

Fayenov, A. Ya., 1972-1978, FIAN, Basov, Team III
1976-1978, FIAN, Basov, Team VI

Fedorov, M. V., 1970-1972, FIAN, Prokhorov, Team IV

Fedotov, S. I., 1968-1976, FIAN, Basov, Team I
1969-1973, FIAN, Basov, Team IV

Galeyev, A. A., 1976-1978, Zakharov, Team I

Gamaliy, Ye. G., 1973-1975, FIAN, Basov, Team I
1974-1976, FIAN, Basov, Team III

Gudzenko, L. I., 1972-1977, FIAN, Prokhorov, Team VI

Igoshin, V. I., 1975-1977, FIAN, Basov, Team V

Ivanov, A. A., 1969-1971, Kurchatov, Team I

Kas'yanov, Yu. S., 1976-1978, FIAN, Basov, Team III

Kazarnovskiy, M. V., 1973-1975, FIAN, Basov, Team I

Kevlishvili, P. V., 1974-1976, IPE

Kinber, B. Ye., 1973-1975, FIAN, Basov, Team IV

Kogan, Ye. Ya., 1970-1972, PTI Ukr AN

Korobkin, V. V., 1970-1972, FIAN, Prokhorov, Team IV

Kovalenko, V. A., 1976-1978, FIAN, Basov, Team VI

Krokhin, O. N., 1968-1976, MEPI

Kryukov, P. G., 1968-1976, FIAN, Basov, Team IV

Kuznetsov, T. I., 1973-1975, FIAN, Basov, Team II
1973-1975, FIAN, Basov, Team IV

Lobanov, A. N., 1976-1978, FIAN, Basov, Team VI

Lovetskiy, Ye. Ye., 1976-1978, FIAN, Basov, Team I

Lugovoy, V. N., 1970-1972, FIAN, Prokhorov, Team IV

L'vov, V. S., 1974-1976, Zakharov, Team I
1970-1972, Zakharov, Team II

Malyutin, A. A., 1970-1972, FIAN, Prokhorov, Team IV

Mandel'shtam, S. L., 1973-1978, FIAN, Basov, Team III

Mazing, M. A., 1976-1978, FIAN, Basov, Team II

Mit'kin, V. M., 1974-1976, Yefremov, Team II

Nastoyashchiy, A. F., 1975-1978, Kurchatov, Team II

Nemchinov, I. V., 1969-1976, IPE
1975-1977, FIAN, Basov, Team VI

Nesterov, G. V., 1976-1978, Kurchatov, Team I

Orayevskiy, V. N., 1-70-1972, PTI Ukr AN

Pashinin, P. P., 1972-1978, FIAN, Prokhorov, Team VI
1975-1977, Kurchatov, Team II

Petrukhin, A. I., 1969-1972, IPE

Pikuz, S. A., 1972-1978, FIAN, Basov, Team III
1976-1978, FIAN, Basov, Team VI

Prokhorov, A. M., 1969-1978, FIAN
1972-1974, NPRI

Pustovalov, V. V., 1969-1978, FIAN, Basov, Team I
1974-1976, FIAN, Basov, Team III

Rabinovich, M. S., 1976-1978, FIAN, Basov, Team I

Ragul'skiy, N. N., 1976-1978, FIAN, Basov, Team VI

Ramazashvili, R. R., 1977-1978, FIAN, Basov, Team I

Rayzer, Yu. P., 1969-1976, IPE

Rozanov, V. B., 1973-1976, FIAN, Basov, Team III
1971-1973, FIAN, Basov, Team IV

Ryabtsev, A. N., 1974-1976, FIAN, Basov, Team III

Ryutov, D. D., 1972-1978, Zakharov, Team I
1970-1972, Zakharov, Team II

Sagdeyev, R. Z., 1974-1976, Kurchatov, Team II
1971-1973, Zakharov, Team I

Serov, R. V., 1970-1972, FIAN, Prokhorov, Team IV

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Shur, L. N., 1976-1978, LITP

Vysotskiy, Yu. P., 1973-1975, IPE

Zvedov, V. V., 1973-1975, FIAN, Basov, Team I

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Matveyeva, F. I., 1975-1977, FIAN, Basov, Team I

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## KEY TO PERIODICALS

*AE*--Atomnaya Energiya

*AZ*--Astronomicheskiy Zhurnal

*DAN SSSR*--Doklady Akademii Nauk, SSSR

*FGV*--Fizika Goreniya i Vzryva

*FP*--Fizika Plazmy

*IVUZ Fizika*--Izvestiya Vysshikh Uchebnykh Zavedeniy, Fizika

*IVUZ Radiofizika*--Izvestiya Vysshikh Uchebnykh Zavedeniy, Radiofizika

*KE*--Kvantovaya Elektronika

*KSF, FIAN*--Kratkiye Soobshcheniya po Fizike, FIAN

*OMP*--Optico-Mekhanicheskaya Promyshlennost'

*OS*--Optika i Spektroskopiya

*PMM*--Prikladnaya Matematika i Mekhanisma

*PMTF*--Zhurnal Prikladnoy Mekhaniki i Tekhnicheskoy Fiziki

*Preprint FIAN*--Preprint Fizicheskiy Institut Akademii Nauk

*Preprint IPM*--Preprint Institut Problem Mekhaniki

*Preprint ISAN*--Preprint Institut Spektroskopii Akademii Nauk

*Preprint ITF*--Preprint Institut Teoreticheskoy Fiziki

*Preprint IYaF SOAN*--Preprint Yadernoy Fiziki, Sibirskoye Otdeleniye Akademii Nauk

*Preprint OIYI*--Preprint Ob'yedinennyy Institut Yadernykh Issledovaniy

*PTE*--Pribory i Tekhnika Eksperimenta

*Trudy FIAN*--Trudy Fizicheskogo Instituta Akademii Nauk

*UFN*--Uspekhi Fizicheskikh Nauk

*ZhETF*--Zhurnal Eksperimental'noy i Teoreticheskoy Fiziki

*ZhETF Pis. Red.*--Pis'ma v Zhurnal Eksperimental'noy i Teoreticheskoy Fiziki

*ZhPS*--Zhurnal Prikladnoy Spektroskopii

*ZhTF*--Zhurnal Tekhnicheskoy Fiziki

*ZhTF Pis. Red.*--Pis'ma v Zhurnal Tekhnicheskoy Fiziki

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