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THE GDT-BASED NEUTRON SOURCE AND RELATED ISSUES (ANNOTATED BIBLIOGRAPHY)

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The GDT-based Neutron Source and Related Issues (Annotated bibliography)

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Содержание

Preface

This report follows the survey of the publications on the gas dynamic trap neutron source compiled by A.A.Anikeev and D.D.Ryutov [P.1] quite long ago. Since that time a number of publications on the subject increased considerably, especially from the experiments, so that we decided to prepare an updated version of the survey, which would serve the same purpose as the initial one did, namely to provide the reader with a guidance over the publications directly related to the key physics and technology issues of the neutron source. As in the original survey we also included some more general publications on magnetic mirror research and alternative proposals of the plasma-type neutron sources. Besides, given the subjects from the survey of A.A.Anikeev and D.D.Ryutov [P.1] we have added some more including the drivers for fission-fusion hybrids and high field superconducting solenoids, on which an impressive progress was achieved in the recent years making the neutron source more technically viable. We tried to keep the survey structured in the same manner, in which the references are grouped by subject into sections and within the sections they are ordered by the time of publication. Since some papers are relevant to several subjects, at the end of the sections the references are given to those papers which have fallen into other sections. The alphabetic author index is given at the end of the paper. The compilers acknowledge the assistance of their colleagues from the Budker Institute of Nuclear Physics.

P.1 *A.V.Anikeev, D.D.Ryutov* **The GDT-Based Neutron Source and Related Issues (Annotated bibliography).** Institute of Nuclear Physics, Novosibirsk (1993).

1 General surveys on mirror research

1.1 *Yu.V. Gott, M.S. Ioffe, V.G. Telkovsky.* **Some new results on confining of plasmas in a magnetic trap.** Nuclear Fusion: Supplement, part 3, p. 1045 (1962).
First experiments on suppression of flute plasma instability in a mirror machine with minimum-B magnetic field.

1.2 *Post R.F., Fowler T.K., Killeen J., Mirin A.A.* **Concept for a high-power-density mirror fusion reactor.** Physical Review Letters, v. 31, p. 280 (1973).
The paper discusses the advantages of the dense plasma linear fusion systems with a two-component plasma: warm tritium target and deuterons injected at 200 keV (for the domain of mirror ratios ~ 10*).*

1.3 *G.I. Dimov, V.V. Zakaidakov, M.E. Kishinevskii.* Soviet Journal of Plasma Physics, v. 2, p. 597 (1976).
First consideration of an open trap with ambipolar end plugs in Russian.

1.4 *V.V. Mirnov, D.D. Ryutov.* **Linear gas dynamic system for plasma confinement.** Sov. Tech. Phys. Lett., v. 5, p. 297 (1979).
A concept of gas dynamic trap is first presented.

1.5 *Ryutov D.D.* **Open traps with a short mean free path plasma.** In: "Mirror-Based and Field-Reversed Approaches to Magnetic Fusion" (Proceedings of the International School of Plasma Physics, Varenna, 1983) Monotypia Franchi, Citta di Castello, Italy, v. 1, p. 173 (1983).
This paper contains, in particular, a brief description of the GDT concept with a first qualitative discussion of the stabilizing effects caused by high power neutral beam injection.

1.6 *Velikhov E.P., Kartashev K.B.* **The main results of the research on fusion and plasma physics in the USSR from August 1984 to August 1985.** Voprosy Atomnoi Nauki i Tekhniki - Termoyadernyi Sintez (The Problems of Atomic Science and Technology - Thermonuclear Fusion), v. 1, p. 3 (1986) – in Russian.
A brief description of the GDT facility (Novosibirsk) and first information on the design of the theta-pinch type gas-dynamic trap with a cusp stabilizer (KP-2M project, Sukhumi) have been presented.

1.7 *Ryutov D.D.* **Physics of open traps.** Plasma Physics and Controlled Fusion, v. 28, p. 191 (1986).

In particular, the MHD stability analysis (as in [5.1.7], [5.1.5]) and a brief description of the GDT facility, are given.

1.8 *Lam K.L., Leikind B.J., Wong A.Y., Dimonte G., Kuthi A., Olson L., Zwi H.* **Mirror ratio scaling of axial confinement of a mirror-trapped collisional plasma.** Physics of Fluids, v. 29, p. 3433 (1986).
The linear dependence of the axial confinement time on mirror ratio has been demonstrated on the LAMEX device in the range of mirror ratios from 12 to 74.

1.9 *Kruglyakov Eh.P.* **Mirror research at Novosibirsk.** Plasma Physics and Controlled Fusion, v. 29, p. 1309 (1987).
Among other subjects, the GDT reactor and neutron source issues (as in [2.2], [3.1.1]), are presented.

1.10 *R.F. Post.* **The magnetic mirror approach to fusion.** Nuclear Fusion, v. 27, p. 1579 (1987).
A comprehensive survey of mirror research with a very detailed bibliography.

1.11 *Ryutov D.D.* **Axisymmetric MHD stable mirrors.** In: "Physics of Mirrors, Reversed Field Pinches and Compact Tori" (Proceedings of the International School of Plasma Physics "Piero Caldirola"), Editrice Compositori, Bologna, v. 2, p. 791 (1988).
Among the others, some stabilization techniques applicable to the gas-dynamic trap, are mentioned (favourable curvature beyond the turning points, as in [2.1], and line tying effects).

1.12 *D.D. Ryutov.* **Open-ended traps.** Sov. Phys. Uspekhi, v. 31, p. 301 (1988).
A survey that contains the basic principles of all the types of mirror traps, including the GDT.

1.13 *Berk H.L., Ryutov D.D.* **Importance of a mirror based neutron source for the controlled fusion program.** Comments on Plasma and Controlled Fusion, v. 13, p. 173 (1990).
The paper contains general argument in support of the timely development of the high-flux neutron source on the basis of mirror machines and brief description of two particular concepts of such sources: BPNS (as in [3.3.8]) and GDT (as in [3.1.1]).

1.14 *N. Hershkowitz, S. Miyoshi, D.D. Ryutov.* **Mirror devices.** Nuclear Fusion, v. 30, p. 1761 (1990).

Overview of mirror research status and chart of mirror devices that were existing at 1990.

1.15 *R.F. Post, D.D. Ryutov.* **Mirror fusion research: Update and prospects.** Comments on Plasma Physics and Controlled Fusion, v. 16, p. 375 (1995).

1.16 *A.A. Ivanov, E.P. Kruglyakov, A.V. Burdakov.* **Modern Magnetic Mirror Systems. Status and Perspectives.** 21st IAEA Fusion Energy Conference, 16 - 21 October 2006, Chengdu, China, p. paper EX/P7-9 (2006).
The paper reviews a status of experiments on modern axially symmetric magnetic mirror traps in the Budker Institute.

1.17 *A.A. Ivanov, E.P. Kruglyakov, V.A. Burdakov.* **Progress in Research on Open-Ended Magnetic Traps.** Proceedings of International Conference on Research and Applications of Plasmas, Melville, New York, 2006, AIP Conference Proceedings, v. 812, p. 3-11 (2006.
The paper reviews a progress in experiments on modern axially symmetric magnetic mirror traps in the Budker Institute.

1.18 *A.V. Burdakov, A.A. Ivanov, E.P. Kruglyakov.* **Axially Symmetric Magnetic Mirror Traps: Status and Prospects.** Fusion Sciences and Technology, v. 51, No 2T, p. 17-22 (February 2007.
The paper reviews a progress in experiments on modern axially symmetric magnetic mirror traps in the Budker Institute and their possible upgrades.

1.19 *A.A. Ivanov, E.P. Kruglyakov, A.V. Burdakov.* **Thermonuclear Prospects of Modern Mirror Systems.** 22nd IAEA Fusion Energy Conference, Book of Abstracts, 13-18 October 2008, Geneva, Swiss, p. 135 (paper IC/P4-9 (2008).
Review of the results from the two modern axisymmetric magnetic mirror systems: multi-mirror trap (GOL-3) and gas dynamic trap (GDT. Estimations of parameters of multi-mirror thermonuclear reactor and of the GDT-based neutron source are given. The status of works on the program of the GDT upgrade is presented.

1.20 *A.A. Ivanov, A.V. Burdakov, E.P. Kruglyakov.* **Modern magnetic mirrors and their fusion prospects.** Plasma Physics and Controled Fusion, v. 52, p. 124026 (2010.

This paper reviews the most important findings from recent experiments on modern magnetic mirrors, apart from tandem mirrors and rotating plasma devices.

1.21 *T.C. Simonen.* **Development and Applications of Axisymmetric Magnetic Mirror Concepts.** Fusion Science Technology, v. 57, No. 4, p. 305-311 (May 2010.
Paper describes evolution of magnetic mirrors and stabilization methods for axisymmetric devices. Suggestions about application of the simple axisymmetric configuration as a neutron source are presented.

1.22 *A.A. Ivanov.* **Perspectives of Development of Magnetic Mirror Traps in Novosibirsk.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 17-22 (January 2011.
The paper reviews the characteristic features of a volumetric neutron source based on the gas dynamic trap and the results of current experiments at GDT device on modeling of the operational regimes of the neutron source.

1.23 *D.D. Ryutov, H.L. Berk, B.I. Cohen, A.W. Molvik, T.C. Simonen.* **Magneto-hydrodynamically stable axisymmetric mirrors.** Physics of Plasmas, v. 18, p. 092301-1 - 092301-25 (2011.
A survey of MHD stabilization methods for axially symmetric mirrors. Several techniques for achieving MHD stabilization of the axisymmetric mirrors are considered, including in particular: (1) employing the favorable field-line curvature in the end tanks; (2) using the line-tying effect; (3) controlling the radial potential distribution; (4) imposing a divertor configuration on the solenoidal magnetic field; and (5) affecting the plasma dynamics by the ponderomotive force.

2 Gas-dynamic trap – general

2.1 *Mirnov V.V., Ryutov D.D.* **Linear gas-dynamic system for plasma confinement.** Sov. Tech. Phys. Lett., v. 5, p. 279 (1979).
The first presentation of the GDT concept with its distinguishing attributes: collisional confinement with a linear dependence of the confinement time on mirror ratio; large mirror ratio; axisymmetric geometry with MHD stabilization provided by the favourable curvature of the magnetic field lines beyond the mirror throat.

2.2 *Mirnov V.V., Ryutov D.D.* **Gas-dynamic trap.** Voprosy Atomnoi Nauki i Tekhniki - Termoyadernyi Sintez (The Problems of Atomic Science and Technology - Thermonuclear Fusion), v. 1, p. 57 (1980) – in Russian.
A detailed analysis of the axial confinement; reactor calculations.

2.3 *Zhitlukhin A.M., Safronov V.M., Sidnev V.V., Skvortsov Yu.V.* **Confinement of the beta∼1 plasma in the open trap.** JETP Letters, v. 39, p. 247 (1984.
The improvement of the axial confinement caused by the increase of the mirror ratio under the influence of a large plasma beta, has been documented. The feasibility of the $\beta \sim 1$ *plasma confinement in the gas dynamic trap has been demonstrated.*

2.4 *Ryutov D.D.* **Trapping of the fast atoms in a gas-dynamic trap.** Report 85-32, Institute of Nuclear Physics, Novosibirsk (1985) – in Russian
Analytical formulas describing spatial distribution of the fast ions trapped from the atomic beam in the case when the ion gyro-radius is comparable with the plasma radius; evaluation of the electron drag effect on the subsequent modification of this distribution.

2.5 *Tsidulko Yu.A.* **Removal of the impurity ions from the mirror trap with the two-component plasma by their collisions with the hot ion component.** Report 93-44, Budker Institute of Nuclear Physics, Novosibirsk (1985) – in Russian
The mechanism that causes the losses of the impurity ions through the electrostatic potential barriers near the ends of the gas-dynamic trap, is discussed. The mechanism consists in the close collisions between the impurity ions and the ions of the hot component.

2.6 *Mirnov V.V., Nagornyj V.P.* **Kinetics of the high energy ions in the gas-dynamic trap.** Voprosy Atomnoi Nauki i Tekhniki - Termoyadernyi Sintez (The Problems of Atomic Science and Technology - Thermonuclear Fusion), v. 3, p. 40 (1986) – in Russian
The ion distribution function in the range between the injection and thermal energies has been found; contribution of these "hot" ions to the fusion yield has been evaluated; ion injection at some angle to the magnetic axis as a mean of reducing the transverse pressure of the "hot" ions has been considered.

2.7 *Mirnov V.V., Ryutov D.D.* **Gas-dynamic trap.** In: “Itogi Nauki i Tekhniki - Fizika Plazmy” (“Summaries in Science and Technology - Plasma Physics”), The Publishing House of the Institute of Scientific Information, Moscow, v. 8, p. 77 (1988) – in Russian
The most detailed survey of all the physics issues related to the gas-dynamic trap performance: axial losses, MHD stability, cross-field transport, microstability of the sloshing ions, expander physics, reactor calculations. Brief summary of the neutron sorce concept. References up to 1987.

2.8 *Zukakishvili G.G., Ryzhkov V.N., Salukvadze R.G., Tikhanov Eh.K., Chkuaseli Z.D., Volosevich P.P., Galiguzova I.I., Dar'in N.A., Karpov V.Ya., Levanov E.I.* **Plasma end loss confinement studies in a linear theta pinch with magnetic mirrors.** In: “Plasma Physics and Controlled Nuclear Fusion Research”, Vienna, IAEA, v. 2, p. 359 (1989.
There has been reported of a satisfactory agreement with the gas-dynamic theory of plasma losses through the end mirrors; mirror ratio was varying between 1 and 5.

3 GDT type neutron source

3.1 Material testing

3.1.1 *Mirnov V.V., Nagornyj V. P, Ryutov D.D.* **Gas-dynamic trap with a two-component plasma.** Report INP 84-40, Institute of Nuclear Physics, Novosibirsk (1984) – in Russian
The first description of the GDT-based neutron source in the so-called 2-component version: a relatively dense and cold target deuterium plasma and the population of sloshing tritium ions (injection energy 240 keV).

3.1.2 *Kotelnikov I.A., Mirnov V.V., Nagornyj V.P., Ryutov D.D.* **New results of gas-dynamic trap research.** In: “Plasma Physics and Controlled Fusion Research”, Vienna, IAEA, v. 2, p. 309 (1985.
A brief version of the [3.1.1], plus discussion of some physics issues of gas-dynamic traps: reduction of the end-losses by attaching additional mirror cells at the ends of the device; possible stabilization of the flute perturbations by neutral beam injection (as in [1.5]); effect of magnetic field imperfections on the cross-field transport.

3.1.3 *Krivosheev M.V., Katyshev V.V.* **Parametric studies of the fusion energy producing unit on the basis of the gas-dynamic trap.** Voprosy Atomnoi Nauki i Tekhniki - Termoyadernyi Sintez (The Problems of Atomic Science and Technology - Thermonuclea Fusion), v. 2, p. 12 (1988) – in Russian
General analysis of the influence of various parameters on the cost of electricity produced on the GDT fusion reactor.

3.1.4 *Astapkovich A.M., Gromov L.A., Komarov V.M., Krasnoperov V.G., Odintsov V.N., Roslyakova N.G., Sadakov S.N., Saksaganskii G.L., Safin V.M., Serebrennikov D.V., Shimov V.G.* Report #B-0830, Efremov Institute, Leningrad (1989) – in Russian
A brief summary of the pre-conceptual design of the GDT-based neutron source, with the feasibility analysis under the constraint of employment of only the existing technologies. Identification of the key problems: choke coil durability; durability of the neutral beam injectors.

3.1.5 *Ivanov A.A., Ryutov D.D.* **Neutron sources for fusion reactor materials and component testing.** Proceedings of the International Fusion Materials Irradiation Facility (IFMIF) Workshop, San Siego, v. 2, p. 369 (1989.
A summary of the criteria for the selection of the neutron source concept.

3.1.6 *A.A. Ivanov, D.D. Ryutov.* **On the plasma neutron generators for material testing.** Report INP 89-80, Institute of Nuclear Physics (1989) – in Russian
The characteristics of the GDT-based neutron source including efficiency of neutron production are compared with those of accelerator-based neutron sources..

3.1.7 *A.A. Ivanov, D.D. Ryutov.* **Plasma-type neutron source for material studies.** Proceedings IV EPS Seminar on International Research Facilities, Zagreb, Yugoslavia, p. 247 (1989.
Comparative analysis of the GDT based neutron source and accelerator-based neutron sources for materials testing.

3.1.8 *Kotelnikov I.A., Ryutov D.D.,Tsidulko Yu.A.,Katyshev V.V., Komin A.V., Krivosheev M.V.* **Mathematical model of the GDT-based neutron source.** Report INP 90-105, Institute of Nuclear Physics, Novosibirsk (1990) – in Russian
The only more or less detailed description of the so-called 3-component

version of the GDT-based neutron source (cold target plasma and fast sloshing deuterons and tritons, with the neutron production from collisions between fast deuterons and tritons), the version which is the basis of the present approach of the Novosibirsk group.

3.1.9 *Ivanov A.A., Ryutov D.D.* **Mirror-based neutron sources for fusion technology studies.** Nuclear Science and Engineering, v. 106, p. 235 (1990.
An extended version of the report [3.1.5], with a summary of the competing proposals of the mirror-based neutron sources.

3.1.10 *Ryutov D.D.* **Mirror type neutron source.** Plasma Physics and Controlled Fusion, v. 32, p. 999 (1990.
A brief survey of the problems of the neutron sources with discussion of the issues of neutron spectra, irradiation geometry, cost of electricity and tritium; a summary of the data base for the 2-component version of the neutron source (as in [3.1.1]) and the corresponding conceptual design (as in [3.1.4]).

3.1.11 *Tsidulko Yu.A.* **Neutron flux in the mirror region of the fusion reactor on the basis of the gasdynamic trap.** Voprosy Atomnoi Nauki i Tekhniki - Termoyadernyi Sintez (The Problems of Atomic Science and Technology - Thermonuclear Fusion), v. 3, p. 39 (1990) – in Russian.
The neutron flux have been calculated for the GDT fusion reactor, with the account of adiabatic ion cooling for the strongly collisional case, and presence of a loss-cone in the velocity space for the weakly collisional regime.

3.1.12 *I.A. Kotelnikov, E.P. Kruglyakov, A.M. Kudryavtsev, V.I. Volosov, V.V. Mirnov, D.D. Ryutov, Yu.A. Tsidulko, Yu.N. Yudin, A.M. Astapkovich, V.G. Krasnoperov.* **A plasma type neutron source for fusion materials irradiation testing.** Proceedings of XVII Symposium On Fusion Technology, Rome, Italy, v. 2, p. 1394-1398 (1992).
Conceptual design of the GDT-based neutron source for fusion materials irradiation testing was developed in collaboration of the Budker Institute, Novosibirsk and Efremov Institute, Saint Petersburg. Magnet system of the neutron source utilizes the mirror coils with 25T field, which composed of SC magnets and warm inserts.

3.1.13 *A.A. Ivanov, E.P. Kruglyakov, Yu.A. Tsidulko, V.G. Krasnoperov, V.V. Korshakov.* **Conceptual design studies of GDT-based**

neutron source. Proceedings 16th IEEE/NPSS Symposium On Fusion Engineering, Urbana, USA, v 1, p. 66-69 (1995).
The paper reviews the results of the pre-conceptual design of the GDT-based neutron source. In comparison to the previous studies an up-to-date technology reducing the power consumption of the magnets and also providing its longer lifetimes were applied; the plasma parameters were revised using a self-consistent numerical model which, in particular, in contrast to that initially used, accounting for the collisions between the fast ions. Further development of the model was supported by experiments on the GDT facility at Budker Institute.

3.1.14 *A.A. Ivanov, B.V. Robouch, L. Ingrosso, J.S. Brzosko, V.I. Volosov, Yu.A. Tsidulko.* **Neutron shielding of the GDT neutron generator project. A Feasibility study.** Proceedings 16th IEEE/NPSS Symposium On Fusion Engineering, Urbana, USA, v. 2, p. 1131 - 1134 (1995).
The paper presents results of extensive neutronic studies of the neutron source test facility based on the Novosibirsk Gas Dynamic Trap (GDT). The numerical studies used the 3D-AMC-VINIA Monte Carlo code with a precise computer representation of the sensitive parts of the facility. Neutron shielding feasibility has been ascertained, and the lifetime of consumable components ensured beyond the recommended values.

3.1.15 *Korshakov V.V., Krasnoperov V.G., Muratov V.P., Ivanov A.A., Tsidulko Yu.A.* **The Electromagnet System of the Neutron Source Based on the Gas-Dynamic Trap Concept.** Plasma Devices and Operations, v. 5, No. 3, p. 181-190 (1997).
The paper reviews the design of the electromagnet system (EMS) for the 14.1 MeV neutron source based on the gas-dynamic trap concept.

3.1.16 *U. Fischer, A. Moeslang, A.A. Ivanov.* **The gas-dynamic trap as neutron source for material irradiations.** Transactions of Fusion Technology (ANS), v. 35, No. 1T, FUSTE 8(1), p. 160-164 (1999).
Detailed simulations of the GDT -based neutron source by making use of the MNCP code.

3.1.17 *A.A. Ivanov, Yu.A. Tsidulko, V.G. Krasnoperov, V.V. Korshakov.* **Design of the magnet system for neutron yield zone of the plasma neutron source based on the gas-dynamic trap.** Transactions of Fusion Technology (ANS), v. 35, No. 1T, FUSTE 8(1), p. 195-199 (1999).

A design of magnetic coils for the testing zone of the GDT-based neutron source was done.

3.1.18 *B.V. Robouch, V.V. Volosov, A.A. Ivanov, Yu.A. Tsidulko, L. Ingrosso.* **Novosibirsk GDT-NS fusion material irradiation facility: neutronic characteristics and potentialities.** Transactions of Fusion Technology (ANS), v. 35, No. 1T, FUSTE 8(1), p. 228-232 (1999).
The paper briefly recalls the results of previously reported numerical studies on the feasibility of protective neutron shielding of the vital parts of the Fusion Material Irradiation Facility (FMIF) Neutron Source (NS) based on the Novosibirsk Gas Dynamic Trap (GDT). The work stresses the neutronic potentialities of the facility. The proposed shielding ensures survival of the facility, as per project tolerances, with further shield reduction and optimization possible.

3.1.19 *U. Fischer, A. Moeslang, A.A. Ivanov.* **Assessment of the gas dynamic trap mirror facility as intense neutron source for fusion material test irradiations.** Fusion Engineering and Design, v. 48, p. 307-325 (2000).
An assessment of the GDT as intense neutron source for fusion material test irradiations.

3.1.20 *A.A. Ivanov, E.P. Kruglyakov, Yu.A. Tsidulko.* **A first step in the development of a powerful 14 MeV neutron source.** Journal of Nuclear Materials, v. 307-311, p. 1701-1704 (2002).
This paper reviews the latest results of the numerical optimization of the powerful 14MeVneutron source based on gas dynamic trap.

3.1.21 *B.V. Robouch, A.A. Ivanov, V.I. Volosov, Y.A. Tsidulko, Y.N. Zouev, L. Ingrosso, J.S. Brzosko.* **Neutronic characteristics of the Novosibirsk GDT-NS fusion material irradiation facility.** Fusion science and Technology, v. 41, No.1, p. 44-52 (2002).
A summarized update of neutronic studies on the Novosibirsk Gas Dynamic Trap (GDT) fusion material irradiation facility (FMIF) is presented.

3.1.22 *A.A. Ivanov, E.P. Kruglyakov, Yu.A. Tsidulko.* **Possible Steps in 14MeV Neutron Source Construction.** The 4th International Conference on Open Magnetic System for Plasma Confinement, July 1-4, 2002, Korea, Book of Abstracts, p. 24 (2002).

Conceivable staging in construction of the GDT-based neutron source is considered.

3.1.23 *A.A. Ivanov, E.P. Kruglyakov, Yu.A. Tsidulko.* **Options for Future Development of Mirror Type Neutron Source.** 19th IAEA Fusion Energy Conference, Lyon, France, 14-19 October 2002, Book of Abstracts, IAEA-CN-94, p. 103 (paper FT/P1-24) (October 2002).
The paper reviews different options for the parameter set of the neutron source and discuss a possibility of the electron temperature increase in the existing GDT device.

3.1.24 *A.V. Anikeev, P.A. Bagryansky, V.P. Belov, A.A. Ivanov, V.V. Mishagin, S.V. Murakhtin, N.V. Stupishin, V.V. Prikhodko, S. Collatz, K. Noack.* **Hydrogen prototype of the GDT-based neutron source: physical concepts and pre-calculation.** 33th European Physical Society Conference on Controlled Fusion and Plasma Physics, Rome, June 19-23, 2006, ECA v.30I, p. 4.078 (2006).
A concept of a hydrogen prototype of the GDT-based neutron source is presented.

3.1.25 *K. Noack, A. Rogov, A.A. Ivanov, E.P. Kruglyakov.* **The GDT as Neutron Source in a Sub-Critical System for Transmutation.** Fusion Sciences and Technology, v. 51, No 2T, p. 65-68 (February 2007).
Review of the results of calculations made for a simplified model of an actinides burner with a GDT neutron source as a driver. Important parameters of the burner are compared for two cases - when driven by a spallation or by the GDT neutron source.

3.1.26 *A. Molvik, G.L. Kulcinski, D. Ryutov, J. Santarius, T. Simonen, B.D. Wirth, A. Ying.* **A Gas Dynamic Trap Neutron Source for Fusion Material and Subcomponent Testing.** Fusion Science and Technology, v. 57, p. 369-394 (2010).
The paper reviews physics and applications of GDT-based neutron source which can support near-term tokamaks and volume neutron sources to test fusion materials.

3.2 Hybrid driver

3.2.1 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, E.P. Kruglyakov, K. Noack, A.D. Rogov, Yu.A. Tsidulko.* **The GDT based neutron**

source as a driver in a sub-critical burner of radioactive waste. In Proceedings of the 34th EPS Conference on Controlled Fusion and Plasma Physics (2-6 July 2007 Warsaw, Poland), ECA v. 31F, p. 2.014 (2007).
The numerical study compares the use of the GDT-based neutron source with that of the spallation neutron source as drivers in such a sub-critical system. Conclusions are drawn concerning a further optimization of the GDT-based neutron source for this purpose.

3.2.2 *K. Noack, A. Rogov, A.V. Anikeev, A.A. Ivanov, E.P. Kruglyakov, Yu.A. Tsidulko.* **The GDT-based fusion neutron source as driver of a minor actinides burner.** Annals of Nuclear Energy, v. 35, p. 1216-1222 (2008).
Consideration of possible re-optimization of GDT-based neutron source for application as a driver for major actinides burner.

3.2.3 *A.V. Anikeev, R. Dagan, U. Fisher.* **Numerical model of the fusion-fission hybrid system based on gas dynamic trap for transmutation of radiation wastes.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 162-165 (January 2011).
The paper presents a 3D numerical model of the neutron source for the transmutation of long-lived radioactive waste in spent nuclear fuel.

3.2.4 *A.V. Anikeev, P.A. Bagryansky,U. Fisher, K. Noack, Yu.A. Tsidulko.* **The GDT based neutron source as a driver in a sub-critical burner of radioactive wastes.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 220-222 (January 2011).
The paper considers a version of the GDT-based neutron source for hybrid fusion-fission sub-critical system for the transmutation of the long-live radioactive waste in spent nuclear fuel.

3.3 Other concepts

3.3.1 *Kesner J., Horne S.F., Pastukhov V.P.* **Cusp stabilized mirror based neutron source.** Report PFC/JA-87-7, Plasma Fusion Center, Massachusets Institute of Technology, Cambrige, Massachusets (1987).
A neutron source based on the cusp stabilized axisymmetric mirror is proposed. The supporting plasma physics arguments are presented. The design neutron wall load is in the range of 1-2 MW/m, with the total neutron power in the range of 100 MW.

3.3.2 *Futch A.H.* **LLNL neutron source design.** In: “Proceedings of the Japan-U.S. workshop P-119 on 14 MeV neutron source for material R&D based on plasma devices” (A.Miyahara and F.H.Coensgen, Eds.), Nagoya, Japan, p. 299 (1988).
Description of the Livermore concept of the neutron source (as in [3.3.5]).

3.3.3 *Kawabe T.* **Physical and engineering aspects of mirror based fusion engineering test facility.** In: “Physics of Mirrors, Reversed Field Pinches and Compact Tori” (Proceedings of the International School of Plasma Physics “Piero Caldirola”), Editrice Compositori, Bologna, v. 2, p. 711 (1988).
General overview of the FEF facility (mirror based neutron source).

3.3.4 *Coensgen F.H.* **Fusion materials irradiation facility.** Proceedings of the International Fusion Materials Irradiation Facility (IFMIF) Workshop, San Siego, v. 2, p. 343 (1989).
Some information on the Livermore proposal of the neutron source (as in [3.3.5]), with evaluation of the capital cost.

3.3.5 *Coensgen F.H., Casper T.A., Correll D.L., Damm C.C., Futch A.H., Logan B.G., Molvik A.W., Walter C.E.* **Beam plasma neutron sources based on beam-driven mirror.** Journal of Fusion Energy, v. 8, p. 237 (1989).
A concept of the neutron source based on the two-component (fast deuterons and cold tritons) approach is described. MHD stability is provided by the min-B quadrupole magnetic field. Axial thermo insulation of the target plasma is reached by using long end-sections with a collisional thermal conductivity. The strong feature of this concept is that it is based on the direct extrapolation of the successful 2XIIB experiments at Livermore.

3.3.6 *Kolesnichenko Ya.I., Nagornyj V.P.* **A neutron generator based on a thermonuclear device with a high albedo blanket.** Report INP 90-105, Institute of Nuclear Physics, Novosibirsk (1990) – in Russian.
A proposal of a tokamak neutron source with a blanket that should reflect a large fraction of the fusion neutrons, thereby increasing their flux in the test zone.

3.3.7 *Lebed' S.A.* **A compact two-component neutron source on the basis of a mirror device with RF heating.** Proceedings of

the National Conference on the Open-Ended Traps (Moscow, 1989), Publication of the Kurchatov Institute, Moscow, p. 66 (1990).
A concept of the mirror-based neutron source with the RF heating of the tritium minority, has been presented.

3.3.8 *Coensgen F.H., Casper T.A., Correll D.L., Damm C.C., Futch A.H., Molvik A.W.* **Physics data base for the beam plasma neutron source (BPNS).** In: “Physics of Alternative Magnetic Confinement Schemes” (Proceedings of the International School of Plasma Physics “Piero Caldirola”), Editrice Compositori, Bologna, p. 477 (1991).
A detailed analysis of the 2XIIB experimental results supporting the concept of the beam plasma neutron source, has been presented.

3.3.9 *Kawabe T., Hirayama S.* **Mirror based fusion plasma neutron sources for fusion materials testing.** In: “Physics of Alternative Magnetic Confinement Schemes” (Proceedings of the International School of Plasma Physics “Piero Caldirola”), Editrice Compositori, Bologna, p. 459 (1991).
Overview of various approaches to the irradiation tests of fusion materials. Comparison of the neutron spectra from different sources. Description of the new version of the FEF facility (mirror based neutron source).

3.3.10 *Kawabe T., Yamaguchi H., Mizuno N., Sagawa H., Tachikawa N., Hirayama S.* **Neutron and plasma irradiations of fusion reactor materials using fusion plasma neutron sources.** Journal of Nuclear Materials, v. 191-194, p. 1387 (1992).
The paper describes a new version of the FEF facility that employs sloshing ion technique (similar to the one adopted in GDT) for creating a peaked neutron flux. Some details of the test section design are presented, together with the information on the neutron and heat fluxes.

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4 GDT device

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A.I., Roenko V.A., Roslyakov G.V., Ryutov D.D., Shrainer K.K. **Experimental model of the gas-dynamic trap.** Report INP 86-104, Institute of Nuclear Physics, Novosibirsk (1986) – in Russian.
A rather complete description of the GDT facility design; a brief overview of the research program for this facility.

4.2 *Chebotaev P.Z.* **Trapping of high-energy atoms in the case of their off-axis injection into the gas-dynamic trap.** Report INP 86-93, Institute of Nuclear Physics, Novosibirsk (1986).
A more realistic version of the calculations of [2.4], with the account for the smooth radial distribution of plasma parameters; a brief description of the numerical codes.

4.3 *P.A. Bagryansky, V.V. Klesov et. al.* **Storage and decay of warm plasma in the GDT.** Proceedings IV EPS Seminar on International Research Facilities, Zagreb, Yugoslavia, p. 832 (1989).
Build up and decay of warm plasma in the central cell of the GDT device was studied in the regimes when the plasma was stable and unstable against excitation of flute modes.

4.4 *Ivanov A.A., Mishagin V.V., Roslyakov G.V., Tsidulko Yu.A.* **Design of the cusp stabilizer for the gasdynamic trap.** Proceedings Of the National Conference on the Open-Ended Traps (Moscow, 1989), Publication of the Kurchatov Institute, Moscow, p. 15 (1990).
Design of the magnet system for the cusp stabilizer of the GDT facility is presented.

4.5 *Zinoviev A.N., Krzhizhanovski E.R., Ivanov A.A., Klesov V.V.* **Measurements of plasma density and ion temperature using beam induced radiation spectroscopy in the Gas-Dynamic Trap.** Report INP 90-20, Institute of Nuclear Physics, Novosibirsk (1990) – in Russian.
The results of the first measurements based on the beam induced radiation spectroscopy have been reported.

4.6 *Salikova T.V.* **Data acquisition system for the GDT facility.** Report INP 92-12, Institute of Nuclear Physics, Novosibirsk (1992) – in Russian.
The data acquisition system operating within the medium RSX-11M in the CAMAC standard for the GDT facility is described. The system.

4.7 *A.V. Anikeev et. al.* **Recent results from the GDT experiment.** Proceedings of the International Conference On Open Plasma Confinement Systems, Novosibirsk, p. 283 (1993).

4.8 *A.V. Anikeev, P.A. Bagryanskii, V.N. Bocharov, P.P. Deichuli, A.A. Ivanov, A.N. Karpushov, V.V. Maksimov, A.I. Rogozin, T.V. Salikova.* **Measurement of plasma parameters in a gasodynamical confinement system with intense atomic beam injection.** Plasma Physics Reports, v. 20, No. 2, p. 176 (1994).
Detailed description of the GDT diagnostics (as in [8.4.3]).

4.9 *Anikeev A.V., Bagryansky P.A., Bender E.D., Ivanov A.A., Karpushov A.N., Shikhovtsev I.V.* **Fast titanium coating of the GDT first wall.** Proceedings XVIII Symposium On Fusion Technology, Karlsruhe, Germany, 1994, Elsevier Science B.V., v. 1, p. 459 (1994).
Description of a system of arc Ti evaporators which were used in GDT.

4.10 *A.V. Anikeev, P.A. Bagryansky, P.P. Deichuli, A.A. Ivanov, A.N. Karpushov, V.V. Maximov, I.V. Shichovtsev, N.V. Stupishin, Yu.A. Tsidulko, S.G. Voropaev, S.V. Murakhtin, K. Noack, G. Kumpf, St. Krahl, G. Otto.* **The plasma neutron source simulations in the GDT experiment.** XXIII EPS Conference On Controlled Fusion and Plasma Phys (Kiev, Ukraine,1996), Contributed Papers, v. 20C, part II, p. 684-687 (1996).
The experimental studies of the GDT plasma heated by neutron beam injection are reviewed.

4.11 *P.A. Bagryansky, A.V. Anikeev, S. Collatz, P.P. Deichuli, A.A. Ivanov, A.N. Karpushov, S.A. Korepanov, A.A. Lizunov, V.V. Maximov, S.V. Murakhtin, K. Noack, G. Otto, K.N. Saunichev, I.V. Shichovtsev, A.N. Shukaev, N.V. Stupishin.* **Recent Results of Experiments on the Gas Dynamic Trap.** Transactions of Fusion Technology (ANS), v. 35, No. 1T, FUSTE 8(1), p. 79-86 (1999).
Review of the results from the current experiments on GDT device.

4.12 *A.A. Ivanov, A.N. Karpushov, K.V. Lotov.* **Gas-dynamic trap experiment: status and perspectives.** Transactions of Fusion Technology (ANS), v. 35, No. 1T, FUSTE 8(1), p. 107-111 (1999).
The paper reports on the present status of the Gas Dynamic Trap (GDT) experiment and plasma parameters recently achieved with increased neutral beam power. Also discussed in the paper are possible

future experiments in the GDT that would contribute to establishing the required plasma physics database for the GDT-based neutron source and its Hydrogen Prototype as well.

4.13 *S.V. Murakhtin, P.A. Bagryansky, E.D. Bender, A.A. Ivanov, A.N. Karpushov, P.A. Bagryansky, A.N. Karpushov, A.A. Lizunov, V.V. Maximov.* **Cold-gas Fuelling Experiments in the Gas-Dynamic Trap.** 26th EPS Conference on Controlled Fusion and Plasma Physics (14-18 June 1999, Maastricht, The Netherlands), Contributions ECA, v. 23J, p. 1777-1780 (1999).
Review of the results from the experiments on GDT device with gas puffing from periphery.

4.14 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.N. Karpushov, V.N. Kornilov, V.V. Maximov, S.V. Murakhtin, K. Noack, A.Yu. Smirnov.* **Study of Hot-Ion Plasma Confinement in the Gas-Dynamic Trap.** 26th EPS Conference on Controlled Fusion and Plasma Physics (14-18 June 1999, Maastricht, The Netherlands), Contributions ECA, v. 23J, p. 1781-1784 (1999).
Review of the results from the current experiments on GDT device.

4.15 *A.A. Ivanov, A.V. Anikeev, P.A. Bagryansky, A.N. Karpushov, S.A. Korepanov, V.N. Kornilov, A.A. Lizunov, V.V. Maximov, S.V. Murakhtin.* **High Pressure Plasma Confinement and Stability Studies in Gas Dynamic Trap.** Transaction of Fusion Technology, v. 39, No. 1T, FUSTE8(1), p. 127-132 (2001).
The paper reviews the results obtained in the studies of high beta plasma confinement in Gas-Dynamic Trap (GDT) device with application of Ti -gettering and increase of NB injection power and duration.

4.16 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.N. Karpushov, K. Noack, S.L. Strogalova.* **Upgrade of the Gas Dynamic Trap: Physical Concepts and Numerical Models.** 28th EPS Conference on Controlled Fusion and Plasma Physics, 18-22 June 2001, Funchal, Madeira, Portugal. Contributions, ECA v. 25A, p. 121-124 (2001).
Consideration of achievable plasma parameters in GDT device after upgrade of the neutral beam injection system.

4.17 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.N. Karpushov, K. Noack, S.L. Strogalova.* **Upgrade of the gas dynamic trap: physical concept and numerical models.** Annual Report of FZR 2001, Dresden, Germany, p. 91 (2001).

Consideration of achievable plasma parameters in GDT device after upgrade of the neutral beam injection system.

4.18 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, K. Noack.* **The SHIP Experiment at GDT: Physical Concept and Pre-Calculations.** In Proceedings of the 29th EPS Conference on Plasma Physics and Controlled Fusion (Montreux, 17-21 June 2002), ECA v. 26B, p. P-4.098 (2002).
Simulations of the parameters of a synthesized hot ion plasma in a local mirror cell of GDT device.

4.19 *A. Anikeev, P. Bagryansky, A. Ivanov, K. Noack.* **The SHIP experiment at the GDT facility: concept and results of calculations.** Annual Report of FZR 2002, Dresden, Germany, p. 75 (2002).
Simulations of the parameters of a synthesized hot ion plasma in a local mirror cell of GDT device.

4.20 *A.V. Anikeev, A.A. Ivanov, P.A. Bagryansky, K. Noack.* **The SHIP experiment at the GDT Facility.** The 4th International Conference on Open Magnetic System for Plasma Confinement, July 1-4, 2002, Korea, Book of Abstracts, p. 17 (2002).
Simulations of the parameters of a synthesized hot ion plasma in a local mirror cell of GDT device.

4.21 *A.A. Ivanov.* **GDT device. Recent Results and Future Plans for GDT Upgrade.** The 4th International Conference on Open Magnetic System for Plasma Confinement, July 1-4, 2002, Korea, Book of Abstracts, p. 18 (2002).
Review of the approaches to an upgrade of the GDT device.

4.22 *A.A. Ivanov, G.F. Abdrashitov, A.V. Anikeev, P.A. Bagryansky, P.P. Deichuli, A.N. Karpushov, S.A. Korepanov, A.A. Lizunov, V.V. Maximov, S.V. Murakhtin, Yu.A. Smirnov, A.A. Zouev, K. Noack, G. Otto.* **GDT device. Recent results and future plans for GDT upgrade.** Transaction of Fusion Science and Technology, v. 43, No. 1T, p. 51-57 (2003).
The plans for future upgrade of the GDT device are discussed. It suggests considerable increase of NB injected power (up to 10MW) and extension of the pulse duration from 1ms to 3-5ms. After the upgrade, a significant increase of the electron temperature to 250-300eV could be obtained.

4.23 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, K. Noack.* **The SHIP experiment at the GDT facility, concept and results of calculations.** Transaction of Fusion Science and Technology, v. 43, No. 1T, p. 78-82 (2003).
A discussion of a plan for upgrade of the Synthesized Hot Ion Plasmoid (SHIP) experiment. It explains the concept of the SHIP experiment and presents the results of first calculations by means of ITCS modules.

4.24 *A.A. Ivanov, A.V. Anikeev, P.A. Bagryansky, P.P. Deichuli, S.A. Korepanov, A.A. Lizunov,V.V. Maximov, S.V. Murakhtin, V.Ya. Savkin, D.J. Den Hartog, G. Fiksel, K. Noack.* **Experimental Evidence of High-Beta Plasma Confinement in an Axially Symmetric Gas Dynamic Trap.** Physical Review Letters, v. 90, No. 10, p. 105002-1 - 105002-4 (2003).
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First report on achieving on-axis transverse beta (ratio of the transverse plasma pressure to magnetic field pressure) exceeding 0.4 in the fast ion turning points in the axially symmetric magnetic mirror device.

4.25 *A.V. Anikeev, P.A. Bagryansky, S. Collatz, A.A. Ivanov, K. Noack.* **The SHIP Experiment at GDT: First Experimental Activities and Results of Recent Simulations.** 30th EPS Conference on Controlled Fusion and Plasma Physics, St. Petersburg, 7-11 July 2003, ECA v. 27A, p. 2.187 (2003).
Review of the first results from the SHIP experiment on GDT.

4.26 *D. N. Stepanov, A. N. Shukaev, P. A. Bagryanskii, A. A. Lizunov, A.V. Anikeev.* **The Automation System of the Gas-Dynamic Trap Facility.** Instruments and Experimental Techniques, v. 47, No. 2, p. 174-178 (2004).
The main tasks performed for the automation of the Gas-Dynamic Trap Facility are described.

4.27 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.A. Lizunov, V.V. Maximov, S.V. Murakhtin, V.V. Prikhodko, Yu.A. Tsidulko.* **Formation and confinement of compact fast ion plasmoid in the gas**

dynamic trap. 31st EPS Conference on Plasma Physics, London, 28 June - 2 July 2004, ECA v. 28G, p. 4.217 (2004).
A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.A. Lizunov, S.V. Murakhtin, V.V. Prikhodko, S. Collatz, K. Noack. **The Compact Mirrors with High Pressure Plasmas.** In Proceedings of the 12 International Congress on Plasma Physics, (October 25 – 29, 2004, Nice, France) – http://hal.ccsd.cnrs.fr/ccsd-00001835 (2004).
This contribution explains the concept of the SHIP experiment and presents the results of SHIP simulation. The first experiments are reviewed.

4.28 *A.A. Ivanov, A. Abdrashitov, G. Abdrashitov, A. Anikeev, P. Bagryansky, A. Beklemishev, P. Deichuli, A. Ivanov, S. Korepanov, V. Maximov, S. Murakhtin, A. Lizunov, V. Prikhodko, V. Kapitonov, V. Kolmogorov, A. Khilchenko, V. Mishagin, V. Savkin, A. Shoukaev, G.I. Shulzhenko, A. Solomakhin, A. Sorokin, D. Stepanov, N.V. Stupishin, Yu. Tsidulko, A. Zouev, K. Noack, G. Fiksel, D.J. Den Hartog.* **Status of the GDT experiment and future plans.** Transactions of Fusion Science and Technology, v. 47, No 1T, p. 27-34 (2005).
Future experiments on the GDT-upgrade are discussed in the paper.

4.29 *P.A. Bagryansky, A.V. Anikeev, A.A. Ivanov, A.A. Lizunov, V.V. Maximov, S.V. Murakhtin, D.N. Stepanov, K. Noack, V.V. Prikhodko, A.L. Solomakhin.* **First results from SHIP experiment.** Transactions of Fusion Science and Technology, v. 47, No 1T, p. 59-62 (2005).
At present, the GDT facility is being upgraded. The first stage of the upgrade is the Synthesised Hot Ion Plasmoid (SHIP) experiment. The paper presents first results of plasma parameter measurements in SHIP experiment.

4.30 *A.V. Anikeev, P.A. Bagryansky, S. Collatz, K. Noack.* **Plasma simulations for the SHIP experiment.** Transactions of Fusion Science and Technology, v. 47, No 1T, p. 212-214 (2005).
The results of the recent numerical simulations of SHIP using the ITCS code system.

4.31 *G.F. Abdrashitov, A.G. Abdrashitov, P.A. Bagryansky, P.P. Deichuli, A.A. Ivanov, V.A. Kapitonov, A.V. Kireenko, A.D. Khilchenko, S.A. Korepanov, V.V. Mishagin, S.V. Murakhtin, A.N. Shukaev, A.V. Sorokin, D.N. Stepanov, N.V. Stupishin, P.V. Zubarev.* **Neutral beam injection system for the SHIP experiment.** Transactions of Fusion Science and Technology, v. 47, No 1T, p. 231-234 (2005).

4.32 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.A. Lizunov, S.V. Murakhtin, V.V. Prikhodko, A.L. Solomakhin, S. Collatz, K. Noack.* **The SHIP experiment at GDT: First experimental results.** In Proceedings of the 32nd EPS Conference on Plasma Physics, Tarragona, Spain, June 27 - July 1, 2005, ECA v. 29C, p. P-5.077 (2005).
This contribution presents the first obtained results of the SHIP experiment. The comparison with results of recent numerical simulations by means of the ITCS modules and discussion about future experimental step are also performed.

4.33 *A.A. Ivanov, A.V. Anikeev, P.A. Bagryansky, P.P. Deichuli, A.V. Kireenko, A.A. Lizunov, S.V. Murakhtin, V.V. Prikhodko, A.L. Solomakhin, A.V. Sorokin, N.V. Stupishin, S. Collatz, K. Noack.* **The experiments with compact mirror cell at GDT device.** In Proceedings of the 11-th International Conference and School on Plasma Physics and Controlled Fusion. September 11-16, 2006, Alushta (Crimea), Ukraine (2006).
This contribution presents the first obtained results of the SHIP experiment. The comparison with results of recent numerical simulations by means of the ITCS modules and discussion about future experimental step are also performed.

4.34 *A.V. Anikeev, P.A. Bagryansky, P.P. Deichuli, A.A. Ivanov, A.V. Kireenko, A.L. Lizunov, S.V. Murakhtin, V.V. Prikhodko, A.L. Solomakhin, A.V. Sorokin, N.V. Stupishin.* **The synthesized hot ion plasmoid experiment at GDT.** 33th European Physical Society Conference on Controlled Fusion and Plasma Physics, Rome, June 19-23, 2006, ECA v.30I, p. 4.077 (2006).
This contribution presents the recent results of the SHIP experiment. The comparison with results of numerical simulations by means of the ITCS modules and discussion about observation of micro-instability limits are also performed.

4.35 *A.V. Anikeev, P.A. Bagryansky, P.P. Deichuli, A.A. Ivanov, A.V. Kireenko, A.A. Lizunov, S.V. Murakhtin, V.V. Prikhodko, A.L. Solomakhin, A.V. Sorokin, N.V. Stupishin, S. Collatz, K. Noack.* **The Synthesized Hot Ion Plasmoid experiment at GDT.** Fusion Sciences and Technology, v. 51, No 2T, p. 79-81 (February 2007).
Status of the Synthesised Hot Ion Plasmoid (SHIP) experiment is considered.

4.36 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.A. Lizunov, S.V. Murakhtin, V.V. Prikhodko, A.L. Solomahin, K. Noack.* **Confinement of Strongly Anisotropic Hot-Ion Plasma in a Compact Mirror.** Journal of Fusion Energy, v. 26, p. 103-107 (June 2007).
The paper presents the results of recent study of anisotropic plasma with thermonuclear ions confined in the axially symmetric Gas Dynamic Trap (GDT) mirror. Anisotropic ions are produced by the perpendicular injection of two focused 18 keV neutral beams in the small mirror section attached to the GDT central cell.

4.37 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.V. Kireenko, A.A. Lizunov, S.V. Murakhtin, V.V. Prikhodko, A.L. Solomakhin, A.V.Sorokin1, K. Noack.* **Recent experiment with compact mirror cell at the Gas Dynamic Trap.** In Proceedings of the 34th EPS Conference on Controlled Fusion and Plasma Physics (2-6 July 2007 Warsaw, Poland), ECA v. 31F, p. 1.155 (2007).
This contribution presents the recent results of the SHIP experiment. The comparison with results of numerical simulations by means of the ITCS modules and discussion about observation of micro-instability limits are also performed.

4.38 *A.V. Anikeev, P.A. Bagryansky, A.S. Donin, A.A. Ivanov, A.V. Kireenko, A.A. Lizunov, V.V. Maximov, S.V. Murakhtin, V.V. Prikhodko, E.I. Soldatkina, A.L. Solomakhin, D. NStepanov.* **Confinement and MHD-stability of high-beta anisotropic plasma in the Gas Dynamic Trap.** In Proceedings of the 34th EPS Conference on Controlled Fusion and Plasma Physics (2-6 July 2007 Warsaw, Poland), ECA v. 31F, p. 4.015 (2007).
The results of the experiments on confinement and MHD stability of high beta anisotropic plasma in the GDT device are presented.

4.39 *A.A. Ivanov, A.V. Anikeev, P.A. Bagryansky, A.D. Beklemishev, A.S. Donin, A.V. Kireenko, K.Yu. Kirillov, M.S. Korzhavina, A.A. Lizunov, V.V. Maximov, S.V. Murakhtin, E.I. Pinzhenin, V.V. Prikhodko, V.Ya. Savkin, E.I. Soldatkina, A.L. Solomakhin, Yu.A. Tsidulko.* **Steady-state Confinement of Anisotropic Hot Ion Plasma in the Gas Dynamic Trap.** 22nd IAEA Fusion Energy Conference, Book of Abstracts, 13-18 October 2008, Geneva, Swiss, p. 118 (paper EX/P5-43) (2008).
The paper summarizes recent results obtained in the gas dynamic trap experiment.

4.40 *A.A. Ivanov, A.D. Beklemishev, E.P. Kruglyakov, P.A. Bagryansky, A.A. Lizunov, V.V. Maximov, S.V. Murakhtin, V.V. Prikhodko.* **Results of recent experiments on GDT device after upgrade of heating neutral beams.** Fusion Science and Technology, v. 57, No. 4, p. 320-325 (May 2010).
The status of the experiments on the axially symmetric magnetic mirror device gas dynamic trap after extension of neutral beam injection pulse duration from 1 to 5 ms is discussed.

4.41 *T.C. Simonen, A.V. Anikeev, P.A. Bagryansky, A.D. Beklemishev, A.A. Ivanov, A.A. Lizunov, V.V. Maximov, V.V. Prikhodko, Yu.V. Tsidulko.* **High Beta Experiments in the GDT Axisymmetric Magnetic Mirror.** Journal of Fusion Energy, v. 29, iss. 6, sp. iss. SI, p. 558-560 (December 2010).
This paper reports recent results from the Gas Dynamic Trap magnetic mirror device.

4.42 *V. Prikhodko, A. Anikeev, P. Bagryansky, A. Beklemishev, A. Ivanov, E. Kolesnikov, M. Korzhavina, I. Kotelnikov, A. Lizunov, V. Maximov, S. Murakhtin, E. Pinzhenin, A. Pushkareva, E. Soldatkina, A. Solomakhin, Yu. Tsidulko, K. Zaytsev.* **Recent experiments on Gas Dynamic Trap device.** Bulletin of the American Physical Society (52nd Annual Meeting of the Division of Plasma Physics, 8-12 November 2010, Chicago, IL, paper NP9-42), v. 55, no. 15, p. 212 (2010).
Review of current experiment on the GDT device.

4.43 *P.A. Bagryansky, A.V. Anikeev, A.D. Beklemishev, A.S. Donin, A.A. Ivanov, M.S. Korzhavina, Yu.V. Kovalenko, E.P. Kruglyakov, A.A. Lizunov, V.V. Maximov, S.V. Murakhtin, V.V. Prikhodko, E.I. Pinzhenin, A.N. Pushkareva, V.Ya. Savkin, K.V. Zaytsev.* **Confinement of hot ion plasma with** $\beta = 0.6$**=0.6 in the Gas Dynamic Trap.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 31-35 (January 2011).
High beta plasma confinement in axially symmetric GDT device was studied in the regime with sheared plasma rotation at periphery sustained by biasing of radial limiter and end plates.

4.44 *T.D. Akhmetov, A.A. Ivanov, V.V. Prikhodko.* **Possible further steps for upgrading the GDT device.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 43-46 (January 2011).

Recent upgrade of the neutral beam system has resulted in considerable improvement of the plasma parameters in the gas dynamic trap experiment. With injection of 5 ms, 20 keV, 4.5 MW neutral beams the electron temperature approaching 250 eV was obtained. At the same time maximal plasma beta attained about 60%. Further progress in plasma temperature and pressure could only be possible with considerable increase of the magnetic field in the central solenoid and re-optimization of its profile to improve stability of high-beta plasma, as well as with extension of the neutral beam pulse. Possible steps in this direction are considered in this paper.

4.45 *G.F. Abdrashitov, A.G. Abdrashitov, P.P. Deichuli, A.S. Donin, A.D. Khilchenko, A.A. Lizunov,D.V. Moiseev, S.V. Murakhtin, A.V. Sorokin,P.V. Zubarev.* **Neutral Beam system of the gas dynamic trap.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 280-282 (January 2011).
Detailed description of high power neutral beam injector system which is used in the experiments on the gas dynamic trap.

5 MHD stability and equilibrium

5.1 Theory

5.1.1 *M.N. Rosenbluth, C.L. Longmire.* **Stability of plasmas confined by magnetic fields.** Annals of Physics, v. 1, p. 120 (1957).
Stability of a boundary between plasma and vacuum in presence of non-homogeneous magnetic field is studied.

5.1.2 *M.D. Kruskal, C.R. Oberman.* **On the Stability of Plasma in Static Equilibrium.** Physics of Fluids, v. 1, p. 275 (1958).
An energy principle to study plasma stability is derived.

5.1.3 *M.N. Rosenbluth, N.A. Krall, N. Rostoker.* **Finite Larmor radius stabilization of "weakly" unstable confined plasmas.** Nuclear Fusion: Supplement, part 1, p. 143 (1962).
Effect of finite ion Larmor radius on curvature-driven flute instability is considered.

5.1.4 *V.V. Arsenin, V.A. Chuyanov.* Sov. Phys. Uspekhi, v. 20, p. 736-762 (1977).

Stabilization of MHD instability in a magnetic mirror with feedback control is considered.

5.1.5 *Nagornyj V.P., Ryutov D.D., Stupakov G.V.* **Flute instability of plasma in a gas-dynamic trap.** Nuclear Fusion, v. 24, p. 1421 (1984).
The most detailed MHD stability study, with the account for non-paraxiality effects, plasma flow, trans-alfvenic transition.

5.1.6 *Kotelnikov I.A., Roslyakov G.V., Ryutov D.D.* **Stabilization of flute perturbations in an axisymmetric open system with instreaming ions.** Sov. J. Plasma Physics, v. 13, p. 227 (1985).
Detailed analysis of the stabilization technique proposed by Rosenbluth and Longmire and consisting in matching of the turning points of the sloshing ions with the regions of a large favourable curvature of the magnetic field lines.

5.1.7 *Bushkova O.A., Mirnov V.V.* **The influence of the magnetic field configuration on the MHD stability of the gas-dynamic trap.** Voprosy Atomnoi Nauki i Tekhniki - Termoyadernyi Sintez (The Problems of Atomic Science and Technology - Thermonuclear Fusion), v. 2, p. 19 (1986) – in Russian.
The importance of a weak magnetic field region in the end-tanks for the overall stability of the GDT trap has been discovered. Evaluations of the limiting beta values are presented.

5.1.8 *Kotelnikov I.A., Roslyakov G.V., Ryutov D.D., Stupakov G.V.* **Stabilization of flute instability in axially symmetric mirror machines.** In: "Plasma Physics and Controlled Nuclear Fusion Research", Vienna, IAEA, v. 2, p. 305 (1987).
Among the other issues, there is presented an analysis of the stabilization method based on the matching of the sloshing ions turning points with the regions of a large favourable curvature of the magnetic field lines (as in [5.1.6]).

5.1.9 *Mirnov V.V.* **Equilibrium and stability of axisymmetric open traps.** In: "Theory of Fusion Plasmas 1988", Proceedings of the Joint Varenna - Lausanne International Workshop (International School of Plasma Physics, Chexbres, Switzerland, October 1988), Editrice Compositori, Bologna, p. 41 (1989).
The review of the problems concerned with equilibrium and stability of gas-dynamic trap is presented. In particular, the radial plasma density

distribution is analyzed that results from the balance of neutral injection and end losses.

5.1.10 *Kotelnikov I.A., Masliev I.E., Shaikhislamov I.F., Ryutov D.D., Yakovchenko S.G.* **Flute instability in an open system with injection of intense neutral beams.** Sov. Phys. Plasma Physics., v. 16, p. 669 (1990).
Detailed analysis of the stabilization effect first briefly mentioned in [1.5] and consisting in the radial momentum transfer from the neutral beams to the upwelling flute.

5.1.11 *Stupakov G.V.* **Trapped particle instability in a gas-dynamic trap.** Soviet Journal of Plasma Physics, v. 16, p. 275 (1990).
It is shown that the growth rate of the trapped particle instability in the gas-dynamic trap doesn't depend on the mirror ratio.

5.1.12 *Berk H.L., Ryutov D.D., Stupakov G.V., Tsidulko Yu.A.* **Instability effects caused by conducting end walls in a plasma on open field lines.** In: "Plasma Physics and Controlled Nuclear Fusion Research", Vienna, IAEA, v. 2, p. 289 (1991).
This paper contains a brief presentation of the results of [5.1.13], [5.2.7], [5.2.4]. Besides, the interference between the temperature-gradient instability [5.2.7] and the centrifugal instability in the cylindrical geometry has been studied.

5.1.13 *Berk H.L., Stupakov G.V.* **Stability of the gas-dynamic trap.** Physics of Fluids, v. B3, p. 440 (1991).
It has been shown that the proper account of the sheath characteristics at the conducting end-walls may considerably reduce the predicted stabilizing contribution of the outflowing ions (for the curvature driven flute-like perturbations).

5.1.14 *Kotelnikov I.A., Yakovchenko S.G.* **Ponderomotive stabilization of interchange modes in mirrors during the ICRF heating.** Report INP 91-53, Institute of Nuclear Physics, Novosibirsk (1991) – in Russian.
A specific features of the minority ion heating scheme of [8.2.2] are discussed. It is shown that this force stabilizes flute modes at the plasma column periphery.

5.1.15 *Stupakov G.V.* **Transit particle stabilization in mirror machines.** In: "Physics of Alternative Magnetic Confinement Schemes"

(Proceedings of the International School of Plasma Physics "Piero Caldirola"), Editrice Compositori, Bologna, p. 765 (1991).
The continuation of the study of [5.1.13].

5.1.16 *Tsidulko Yu.I.* **Resistive ballooning mode in the gasdynamic trap.** Report 92-10, Institute of Nuclear Physics, Novosibirsk (1992) – in Russian.
This paper is devoted to the study of the ballooning instability caused by resistive decoupling of the unstable central part of the GDT and the stabilizing expander region – the effect that can be important at low plasma temperatures.

5.1.17 *Schetnikov A.I.* **Magnetic field distorsions in the cusp.** Report INP 86-46, Institute of Nuclear Physics, Novosibirsk (1992) – in Russian.
The effects of the magnetic fields imperfections in the cusp stabilizer on the equilibrium and transport in the main cell, have been studied.

5.1.18 *A.A. Ivanov, A.N. Karpushov.* **Simulation of the dynamic transition across the MHD stability border for plasma in GDT device during the atomic beams injection.** Report INP 96-2, Institute of Nuclear Physics, (1996) – in Russian.
The paper reviews the results of numerical simulation of crossing the MHD stability boundary in the GDT experiment during accumulation of fast ions produced by neutral beam injection. The model includes the effect of line tying to the plasma gun installed in the end tank, radial plasma transport and plasma feeding with gas injection from periphery.

5.1.19 *P.A. Bagryansky, A.D. Beklemishev, M.S. Chaschin, E.I. Soldatkina.* **Radial Electric Fields and Radial Currents in the Gas Dynamic Trap.** Fusion Sciences and Technology, v. 51, No 2T, p. 337-339 (February 2007).
In recent experiments on the GDT device the plasma confinement is shown to improve drastically with strong application of different potentials to the end plates and the limiter. We present experimental and theoretical description of how these potentials influence the plasma rotation, show that the measured plasma potentials indicate presence of global ($m \sim 1$) modes, and that sufficiently high gradients of potential provide the internal transport barrier by reducing convection.

5.1.20 *A.D. Beklemishev, M.S. Chaschin.* **Effect of Rotation on Plasma Stability in the Gas-Dynamic Trap.** Plasma Physics Reports, v. 34, No. 5, p. 422-430 (May 2008).

The effects of the centrifugal force and finite Larmor radius on plasma stability in the gas-dynamic trap are considered in the paper.

5.1.21 *A.D. Beklemishev, P.A. Bagryansky, M.S. Chaschin, E.I. Soldatkina.* **Vortex Confinement of Plasmas in Symmetric Mirror Traps.** Fusion Science and Technology, v. 57, No 4, p. 351-360 (May 2010).
It is shown that shear flows in axisymmetric mirror machine, driven via biased end plates and limiters, in combination with finite-Larmor-radius effects could efficiently confine high-beta plasmas radially.

5.1.22 *I.A. Kotelnikov, P.A. Bagryansky, V.V. Prikhodko.* **Formation of a magnetic hole above the mirror-instability threshold in a plasma with sloshing ions.** Physical Review E, v. 81, p. 067402-1 - 067402-4 (2010).
Within the framework of paraxial approximation it is shown that in an anisotropic plasma with sloshing ions confined an open-ended system a magnetic hole is formed near the turning point of the sloshing ions above the threshold of the mirror instability.

5.1.23 *A.D. Beklemishev, P.A. Bagryansky, V.V. Prikhodko.* **Application of electrode-driven shear flows for improved plasma confinement.** Problems of Atomic Science and Technology, iss. 6, p. 8-10 (2010).
Paper describes theoretical model of so-called "vortex confinement" mechanism and results of numerical simulations. Also brief comparison with resent experimental results of GDT device is presented.

5.1.24 *I.A. Kotelnikov.* **Equilibrium of High-Beta Plasma with Sloshing Ions Above the Mirror Instability Threshold.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 47-50 (January 2011).
Within paraxial approximation it is shown that in an anisotropic plasma confined an open-ended system with β above the mirror instability threshold a "magnetic hole" is formed near the turning point of the sloshing ions.

5.1.25 *A.D. Beklemishev.* **Tail-Waving System for Active Feedback Stabilization of Flute Modes in Open Traps.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 90-93 (January 2011).
A new method of feedback plasma control in magnetic mirrors is proposed for stabilization of flute modes.

See also [3.1.2], [3.1.8].

5.2 Experimental

5.2.1 *Bagryansky P.A., Ivanov A.A., Klesov V.V., Koz'minykh Yu.L., Kotelnikov I.A., Krasnikov Yu.I., Podyminogin A.A., Rogozin A.I., Roslyakov G.V., Ryutov D.D.* **First experiments on the gas-dynamic trap.** In: "Plasma Physics and Controlled Nuclear Fusion Research", Vienna, IAEA, v. 3, p. 467 (1987).
A brief description of the GDT device (Institute of Nuclear Physics, Novosibirsk) and a report on the experimental study of the effect of magnetic field geometry in the end tanks on the MHD stability.

5.2.2 *Bagryansky P.A., Ivanov A.A., Klesov V.V., Koz'minykh Yu.L., Kotelnikov I.A., Krasnikov Yu.I., Podyminogin A.A., Rogozin A.I., Roslyakov G.V., Ryutov D.D.* **The gas-dynamic trap experiment.** In: "Physics of Mirrors, Reversed Field Pinches and Compact Tori" (Proceedings of the International School of Plasma Physics "Piero Caldirola"), Editrice Compositori, Bologna, v. 2, p. 635 (1988).
A detailed experimental study of the MHD stability of a cold plasma, with mode analysis revealing a flute structure of the perturbations. Clear demonstration of the stabilizing effect of the outflowing plasma. Photograph of the facility.

5.2.3 *Bagryansky P.A., Ivanov A.A., Klesov V.V., Koz'minykh Yu.L., Kotelnikov I.A., Krasnikov Yu.I., Podyminogin A.A., Rogozin A.I., Roslyakov G.V.,Tsidulko Yu.A.* **Storage and decay of warm plasma in the GDT.** Proceedings of XIX International Conference on Phenomena in Ionized Gases, Belgrade, p. 832 (1989).
The MHD stability of the GDT plasma at the mirror ratios below than 25, has been reported, together with some details of the active corpuscular diagnostics used in these experiments.

5.2.4 *Bagryansky P.A., Ivanov A.A., Karpushov A.N., Klesov V.V., Kotelnikov I.A., Krasnikov Yu.I., Rogozin A.I., Roslyakov G.V., Tsidulko Yu.A., Breun R.A., Molvik A.W., Casper T.A.* **Experimental MHD stability limit in the gas-dynamic trap.** In: "Plasma Physics and Controlled Nuclear Fusion Research", Vienna, IAEA, v. 2, p. 655 (1991).
Stability margin in the axially symmetric gas-dynamic trap has been studied. Stability integral was changed by: 1) deliberately producing a region of a large unfavourable curvature in the confinement region; 2) varying the mirror ratio and, thereby, the stabilizing contribution

of the plasma flow beyond the mirror point. Qualitative agreement with theory has been found, though quantitatively the stability margin appeared to be somewhat smaller than in theory. The discrepancy has been later resolved in [5.2.7].

5.2.5 *Ivanov A.A., the GDT Experimental Physics Group.* **Experimental and theoretical studies of a neutron source based on gas-dynamic trap.** In: “Physics of Alternative Magnetic Confinement Schemes” (Proceedings of the International School of Plasma Physics “Piero Caldirola”), Editrice Compositori, Bologna, p. 443 (1991).
A brief description of the GDT neutron source, plus description of experimental results related to MHD stability, plasma potential distribution beyond the mirror points, ICR plasma heating and injection of the sloshing ions.

5.2.6 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, S.V. Kuz'min, T.V. Salikova.* **Experimental study of the spectrum of large-scale stable modes in the gas-dynamic trap.** Report INP 91-78, Institute of Nuclear Physics (1991) – in Russian.
Growth rates of several first large-scale flute modes were measured in GDT by using an azimuthal array of Langmiur probes for different pressure-weighted curvatures. The measured growth rate were found to be in a good agreement with the results of numerical simulations, which took into account the finite ion Larmor radius effects and boundary conditions at conductive radial limiter.

5.2.7 *Anikeev A.V., Bagryansky P.A., Ivanov A.A., Kuzmin S.V., Salikova T.V.* **Experimental observation of non-MHD effects in the curvature driven flute instability.** Plasma Physics and Controlled Fusion, v. 34, p. 1185 (1992).
A detailed experimental study of the FLR and plasma rotation effects on the flute-like perturbations in the GDT facility. A remarkable agreement with the FLR theory has been recorded.

5.2.8 *Anikeev A.V., Bagryansky P.A., Ivanov A.A., Kuzmin S.V., Salikova T.V.* **Experimental observation of non-MHD effects in the curvature-driven flute instability.** Plasma Physics and Controlled Fusion, v. 34, no. 7, p. 1185-1199 (1992).
Azimuthal spectra of unstable curvature-driven flute modes in the gas-dynamic trap (GDT) were measured and found to be consistent with theory, which includes the finite ion Larmor radius (FLR) terms.

5.2.9 *A.V. Anikeev et. al.* **MHD-stability of a cusp-anchored gas-dynamic trap.** Proceedings of the International Conference On Open Plasma Confinement Systems, Novosibirsk, p. 303 (1993).
Review of the results from the experiments on GDT device with a cusp end cell.

5.2.10 *A.A. Ivanov.* **Experiments on the Gas-Dynamic Trap that illustrate MHD stability theory.** Bulletin of the American Physical Society, v. 38, p. 2072 (1993).
Review of the experimental results from the GDT device, which supports MHD stability theory based on a criterion of pressure weighted curvature of magnetic field lines.

5.2.11 *A.A. Ivanov, A.V. Anikeev, P.A. Bagryansky, V.N. Bocharov, P.P. Deichuli, A.N. Karpushov, V.V. Maximov, A.A. Pod'minogin, A.I. Rogozin, T.V. Salikova, Yu.A. Tsidulko.* **Experimental study of curvature-driven flute instability in the gas-dynamic trap.** Physics of Plasmas, v. 1, iss. 5, p. 1529-1535 (1994).
Extensive study of MHD stability limits in axially symmetric device and comparison with pressure-weighted curvature stability criterion.

5.2.12 *Anikeev A.V., Bagryansky P.A., Deichuli P.P., Ivanov A.A., Karpushov A.N., Maximov V.V., Pod'minogin A.A., Shichovtsev I.V., Stupishin N.V.* **Stability of the neutral beam heated plasma in the cusp-anchored gas-dynamic trap.** In: Proceedings of XXI EPS Conference On Controlled Fusion and Plasma Physics 1994, Montpellier, Contributed papers, v. 18C (1994).
A.V. Anikeev, P.A. Bagryansky, P.P. Deichuli, A.A. Ivanov, A.N. Karpushov, V.V. Maximov, A.A. Pod'minogin, N.V. Stupishin. **MHD stability of plasma anchored by cusp cell in GDT device.** Report INP 94-90 Institute of Nuclear Physics (1994) – in Russian.
Experimental study of MHD stability of the GDT device with a cusp end cell.

5.2.13 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov.* **Measurements of plasma equilibrium response to external multipole magnetic fields in an axisymmetric mirror.** Report INP 95-5 Institute of Nuclear Physics (1995).
Measurements of plasma equilibrium in axisymmetric mirror with dipole and quadrupole perturbations of magnetic field and comparison with theory.

5.2.14 *Anikeev A.V., Bagryansky P.A., Ivanov A.A., Kotelnikov I.A.* **Measurements of plasma equilibrium response to external multipole magnetic fields in an axisymmetric mirror.** Plasma Physics and Controlled Fusion, v. 37, p. 1239-1247 (1995).
Measurements of plasma equilibrium in axisymmetric mirror with dipole and quadrupole perturbations of magnetic field and comparison with theory.

5.2.15 *A.V. Anikeev, P.A. Bagryansky, E.D. Bender, P.P. Deichuli, A.A. Ivanov, A.N. Karpushov, V.V. Maximov, A.I. Rogozin, I.V. Shikhovtsev, N.V. Stupishin, S.G. Voropaev, A.A. Podminogin, S.V. Murakhtin, K. Noack, H. Kumpf, G. Otto, S. Krahl.* **Energy balance and stability of GDT plasma under intense neutral beam heating.** 22nd EPS Conference on Controlled Fusion and Plasma Physics (Bournemouth, UK, 2-7 July 1995), Contributed papers, v. 19C, part IV, p. IV-193 (1995).
Comparison of experimentally measured energy balance and stability limits in GDT with the results of numerical simulations using a Monte-Carlo code.

5.2.16 *A.V. Anikeev, P.A. Bagryansky, P.P. Deichuli, A.A. Ivanov, A.N. Karpushov, V.V. Maximov, I.V. Shichovtsev, N.V. Stupishin, Yu.A. Tsidulko, S.G. Voropaev, S.V. Murakhtin, K. Noack, G. Kumpf, St. Krahl, G. Otto.* **Plasma Confinement and Stability Studies in the Gas-Dynamic Trap Experiment.** Proceedings Of 16-th International Conference On Fusion Energy (Montreal, Canada, 1996), IAEA, v. 2, p. 283-291 (1997).
Review of the results from the current experiments on GDT device.

5.2.17 *A.V. Anikeev, P.A. Bagryansky, P.P. Deichuli, A.A. Ivanov, A.N. Karpushov, V.V. Maximov, A.A. Podyminogin, N.V. Stupishin, Yu.A. Tsidulko.* **Observation of magnetohydrodynamic stability limit in a cusp-anchored gas-dynamic trap.** Physics of Plasmas, v. 4, No. 2, p. 347-354 (1997).
Measurements of MHD stability limit in GDT with a cusp end cell and comparison with theory based on energy principle.

5.2.18 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.A. Lizunov, V.V. Prikhodko, A.L. Solomakhin, A.A. Zuev.* **Recent Results on RF-Heating and MHD-Stability Study in GDT.** 28th EPS Conference on Controlled Fusion and Plasma Physics, 18-22 June 2001, Funchal,

Madeira, Portugal. Contributions, ECA v. 25A, p. 1561-1564 (2001).
The results of current experiments on GDT.

5.2.19 *A.A. Ivanov, P.A. Bagryansky, A.A. Lizunov, A.L. Solomakhin, A.A. Zuev.* **Effect of Limiter Biasing on Plasma MHD-Stability in GDT Device.** 19th IAEA Fusion Energy Conference, Lyon, France, 14-19 October 2002, Book of Abstracts, IAEA-CN-94, p. 64 (paper EX/P5-12) (October 2002).
Influence of the radial electric field on the MHD-stability was studied in the GDT using a set of electrically biased radial limiters and segmented end walls. Possible stabilization mechanism is considered in the paper.

5.2.20 *P.A. Bagryansky, A.A. Ivanov, A.A. Lizunov, A.A. Zuev.* **Experiments with Controllable Application of Radial Electric Fields in GDT Central Cell.** Fusion Science and Technology, v. 43 no. 1T, p. pp. 152-156 (2003).
Influence of the radial electric field on the MHD-stability was studied in the GDT using a set of biased end plates and a limiter to control radial profile of the plasma potential.

5.2.21 *P.A. Bagryansky, A.D. Beklemishev, E.I. Soldatkina.* **Influence of Radial Electric Field on High-Beta Plasma Confinement in the Gas Dynamic Trap.** Fusion Sciences and Technology, v. 51, No 2T, p. 340-342 (February 2007).
A positive influence of radial electric field on the plasma confinement was studied in detail.

5.2.22 *V.V. Prikhodko, P.A. Bagryansky, A.D. Beklemishev, E.Yu. Kolesnikov, I.A. Kotelnikov, V.V. Maximov, A.N. Pushkareva, E.I. Soldatkina, Yu.A. Tsidulko, K.V. Zaytsev.* **Low-frequency oscillations of plasma in the Gas Dynamic Trap.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 94-97 (January 2011).
Study of low frequency oscillations of radial magnetic field in the GDT experiment in the presence of fast sheared plasma rotation at periphery.

5.2.23 *A.V. Sidorov, P.A. Bagryansky, A.D. Beklemishev, I.V. Izotov, V.V. Prikhodko, S.V. Razin, V.A. Skalyga, V.G. Zorin.* **Non-Equilibrium Heavy Gases Plasma MHD-Stabilization in Axisymmetric Mirror Magnetic Trap.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 112-115 (January 2011).
Experimental observations of the shear flows influence on the

confinement in the mirror trap of the dense non-equilibrium helium and nitrogen plasma created under conditions of the electron cyclotron resonance (ECR) gas in an ECR heavy multicharged ion sources.

See also [5.1.19], [5.1.21], [5.1.23].

6 Kinetic stability

6.1 Theory

6.1.1 *I.S. Chernoshtanov, Yu.A. Tsidulko.* **Alfven Ion-Cyclotron Instability in a Mirror Trap with Highly Anisotropic Plasma.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 116-119 (January 2011).
The Alfven ion cyclotron instability is studied for mirror-confined bi-Maxwellian highly anisotropic plasmas.

6.2 Experimental

6.2.1 *A.V. Anikeev, P.A. Bagryansky, I.S. Chernoshtanov, M.S. Korzhavina, V.V. Prikhodko, Yu.A. Tsidulko.* **Study of Microinstabilities in Anisotropic Plasmoid of Thermonuclear Ions.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 104-107 (January 2011).
Experimental observation of Alfven ion cyclotron instability in the anisotropic synthesized hot ion plasmoid (SHIP)in a mirror cell installed at one side of the GDT device. To determine type and the parameters of the developing perturbations a set of high-frequency electrostatic and magnetic probes was used.

7 Confinement

7.1 Power balance

7.1.1 *A.V. Anikeev et. al.* **Energy and particle balance of the GDT plasma.** Proceedings of the International Conference On Open Plasma Confinement Systems, Novosibirsk, p. 319 (1993).
Assessment of energy and particle balances in the GDT plasma heated by neutral beam injection.

7.1.2 *A.V. Anikeev, P.A. Bagryansky, P.P. Deichuli, A.A. Ivanov, A.N. Karpushov, G.I. Kuznetsov, A.A. Lizunov, V.V. Maximov, S.V. Murakhtin, K. Saunichev, N.V. Stupishin, K. Noack.* **Studies of axial confinement and transverse transport in the GDT experiment.** XXIII EPS Conference On Controlled Fusion and Plasma Phys (Kiev, Ukraine,1996), Contributed Papers, v. 20C, part II, p. 688-691 (1996).
An assessment of the axial and transverse plasma losses in the GDT experiment.

7.1.3 *A.V. Anikeev, P.A. Bagryansky, P.P. Deichuli, A.A. Ivanov, A.N. Karpushov, A.A. Lizunov, V.V. Maximov, I.V. Shichovtsev, N.V. Stupishin, Yu.A. Tsidulko, S.V. Murakhtin, K. Noack, G. Otto.* **Experimental studies of plasma confinement and heating in the gas dynamic trap.** IAEA Technical Committee Meeting "Innovative approaches to fusion energy" (Pleasanton, California, USA, 1997) Contributed Papers, p. 120-123 (1997).
Review of the results from the current experiments on GDT device

7.1.4 *A.V. Anikeev, P.A. Bagryansky, P.P. Deichuli, A.A. Ivanov, A.N. Karpushov, S.A. Korepanov, A.A. Lizunov, V.V. Maximov, S.V. Murakhtin, K. Saunichev, K. Noack, G. Otto.* **High Power Neutral Beam Heating Experiments in the Gas Dynamic Trap.** XXIV EPS Conference On Controlled Fusion and Plasma Physics (Berchtesgaden, Germany, June 1997), Contributed Papers, v. 21C (1997).
Review of the results from the current experiments on GDT device with high power neutral beam injection.

7.1.5 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.N. Karpushov, S.V. Korepanov, A.A. Lizunov, V.V. Maximov, A.A. Podyminogin, S.V. Murakhtin, K. Noack.* **Energy confinement of finite β plasma in the gas dynamic trap.** 998 ICPP & 25th EPS CCFPP (Prague, 1998), Contributed papers, ECA v. 22C, p. 627-630 (1998).
Review of the results from the current experiments on GDT device to study energy balance of high-beta plasma.

7.1.6 *A.N. Karpushov, A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, S.A. Korepanov, A.A. Lizunov, V.V. Maximov, S.V. Murakhtin, K. Noack, K.N. Saunichev.* **Energy Confinement of the High-β Two-Component Plasma in the Gas Dynamic Trap.** Transactions of Fusion Technology (ANS), v. 35, No. 1T, FUSTE 8(1), p. 190-194 (1999).

Review of studies of neutral beam heated high-β two-component plasma in Gas-Dynamic Trap experiment. The diagnostic set enabled us to characterize the different energy losses channels in the GDT. The energy balance models were applied for analysis of plasma heating.

7.1.7 *A.A. Ivanov, A.V. Anikeev, P.A. Bagryansky, P.P. Deichuli, A.N. Karpushov, S.A. Korepanov, A.A. Lizunov, V.V. Maximov, S.V. Murakhtin, N.V. Stupishin, I.V. Shikhovtsev, K. Noack, G. Otto.* **Experiments on high-β plasma confinement in gas dynamic trap.** Proceedings of 17-th International Conference On Fusion Energy (18-24 October 1998, Yokohama, Japan), IAEA, v. 3, p. 875 (1999).
The paper reports on the present state of the Gas Dynamic Trap (GDT) experiment and plasma parameters recently achieved with increased neutral beam power.

7.1.8 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.N. Karpushov, V.V. Maximov, S.V. Murakhtin.* **Hot-Ion Plasma with High Energy Content in a Gas-Dynamic Trap.** Plasma Physics Report, v. 25, No. 6, p. 451-460 (1999).
Results are presented from experiments on the production of a dense hot-ion plasma in a gasdynamic trap. Optimization of the plasma-heating conditions permitted obtaining an energy content of 600-800 J in the fast-ion population at a density of about $1 \cdot 10^{13}$ cm^{-3} and an average energy of 5-8 keV. The value of the plasma β (the ratio of the plasma pressure to the magnetic pressure) near the turning points of fast ions exceeded 20%.

7.1.9 *A.V. Anikeev, A.N. Karpushov, K. Noack, S.L. Strogalova.* **An integrated transport code system for multicomponent plasmas in the gas-dynamic trap.** Report INP 2000-4, Institute of Nuclear Physics, Novosibirsk (2000) – in Russian
A model for numerical simulation of multi-component plasma in GDT is presented.

7.1.10 *A.N. Karpushov, A.V. Anikeev, K. Noack, S.L. Strogalova.* **Integrated transport code system for multicomponent high-β plasmas in the gas-dynamic trap.** 27th EPS Conference on Controlled Fusion and Plasma Physics, 12-16 June 2000, Budapest, Hungary, Contributions, ECA v. 24B, p. 920-923 (2000).
A model for numerical simulation of multi-component plasma in GDT is presented. The fast ions are simulated by using a Monte-Carlo code.

7.1.11 *A.V. Anikeev, A.N. Karpushov, S. Collatz, K. Noack, G. Otto, S.L. Strogalova.* **An Integrated Transport Code System for the Calculation of Multi-component, High-β Plasmas in the Gas Dynamic Trap.** Transaction of Fusion Technology, v. 39, No. 1T, FUSTE8(1), p. 183-186 (2001).
A description of an integrated code system, which is used to simulate fast ions and warm target plasma in GDT experiment.

See also [5.2.15], [5.2.16].

7.2 Sloshing ions

7.2.1 *Kotelnikov I.A., Schetnikov A.I.* **Adiabaticity of fast ions motion in a gas-dynamic trap.** Report INP 87-10, Institute of Nuclear Physics, Novosibirsk (1987).
The influence of the magnetic field ripple (caused by the discreteness of the coils) and of the regions with a large curvature of the magnetic field lines on the adiabaticity of the sloshing ions is studied

7.2.2 *Bagryansky P.A., Ivanov A.A., Klesov V.V., Koz'minykh Yu.L., Krasnikov Yu.I., Rogozin A.I., Roslyakov G.V., Tsidulko Yu.A.* **Formation of population of sloshing ions in a gas-dynamic trap.** Proceedings XIX International Conference on Phenomena in Ionized Gases, Belgrade, p. 940 (1989).
First publication on the measurements of the angular and spatial distribution of the sloshing ions in the GDT; no anomalous effects have been detected

7.2.3 *Bagryansky P.A., Ivanov A.A., Klesov V.V., Koz'minykh Yu.L., Krasnikov Yu.I., Krzhizhanovskij E.R., Rogozin A.I., Roslyakov G.V., Tsidulko Yu.A.* **Experiments on neutral beam injection in a gas-dynamic trap.** In: “Plasma Physics and Controlled Nuclear Fusion Research”, Vienna, IAEA, v. 2, p. 483 (1989).
A report on the experiments on the neutral beam injection into the GDT. Formation of the sloshing ion population with the average energy of 6 keV and angular spread of less than 5 grad has been documented. There haven't been revealed any indications of the anomalous losses or anomalous scattering of the sloshing ions

7.2.4 *P.A. Bagryansky, V.V. Klesov et. al.* **Formation of sloshing ion population in the GDT.** Proceedings IV EPS Seminar on

International Research Facilities, Zagreb, Yugoslavia, p. 940 (1989).
The paper presents the first results obtained in the experiments with the injections of short pulse (0.25mc) neutral beams into GDT plasma.

7.2.5 *Bagryansky P.A., Ivanov A.A., Karpushov A.N., Klesov V.V., Koz'minykh Yu.L., Krasnikov Yu.I.* **Plasma energy balance in the GDT with neutral beam injection.** Proceedings of the National Conference on the Open-Ended Traps (Moscow, 1989), Publication of the Kurchatov Institute, Moscow, p. 18 (1990).
The first study of the energy balance in the GDT in the course of the NB injection. While fast ion behavior was found to be very close to the classical, electron temperature was lower by a factor of 2 than according to the classical calculations. In the later experiments [7.2.3], the electron temperature was raised to the classical value by improving the vacuum conditions and removing all the material objects (like probes) from the plasma interior.

7.2.6 *A.V. Anikeev et. al.* **Characterization of sloshing ions in the GDT experiment.** Proceedings of the International Conference On Open Plasma Confinement Systems, Novosibirsk, p. 311 (1993).
The characteristics of fast ions produced by neutral beam injection in GDT device were measured with a specially developed set of diagnostics.

7.2.7 *A.A. Ivanov, K.V. Lotov.* **Ballistic bunching of fast ions trapped in the mirror trap.** Report INP 96-33, Institute of Nuclear Physics, (1996) – in Russian.
A possibility of considerable transitory increase of the neutron production in the testing zones the GDT-based neutron source is considered. To provide this increase it is proposed to modulate the energy of injected neutral beams thus producing ballistic bunching of the fast ions in their turning points.

7.2.8 *A.A. Ivanov, K.V. Lotov.* **Ballistic bunching of fast ions in a mirror trap.** Transactions of Fusion Technology (ANS), v. 35, No. 1T, FUSTE 8(1), p. 353-357 (1999).
The fast ions produced inside a mirror trap by neutral beam injection could form periodic short-lived density peaks near a turning point if the injection energy is properly modulated in time. Achievable parameters of fast ion bunches thus formed are analysed in this paper. See [7.2.7].

7.2.9 *A.V. Anikeev, K. Noack, G. Otto.* **Numerical Studies of Neutron Distributions in GDT Experiment.** 26th EPS Conference on

Controlled Fusion and Plasma Physics (14-18 June 1999, Maastricht, The Netherlands), Contributions ECA, v. 23J, p. 1497-1500 (1999).
Monte-Carlo simulations of D-D neutron fields in the GDT experiment.

7.2.10 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.N. Karpushov, S.A. Korepanov, V.V. Maximov, S.V. Murakhtin, A.Yu. Smirnov, K. Noack, G. Otto.* **Investigation of fast ion confinement in the gas-dynamic trap.** Preprint Budker INP 99-9 (1999).
Review of the results from the experiments on GDT device to study fast ion confinement and to compare with the results obtained by numerical simulations.

7.2.11 *A.V. Anikeev, K. Noack, G. Otto.* **Computation of Fusion Product Distributions in GDT Experiments.** In “Institute of Safety Research, Report January 1998-June 1999”, FZR-273, p. 111-116 (1999).
Monte-Carlo simulations of D-D neutron fields in the GDT experiment.

7.2.12 *A.A. Ivanov, K.V. Lotov.* **Ballistic bunching of fast ions in a mirror trap.** Plasma Physics and Controlled Fusion, v. 42, p. 1077-1090 (2000).
Theoretical consideration of a possibility to form periodic transitory density peaks near a turning point of GDT if the neutral beam energy is properly modulated in time. Thus produced ballistic bunching of deuterium and tritium ions results in periodic short bursts of neutron radiation with intensity 1.5 times higher than the average level. Also, the bunching could serve as a precise plasma diagnostic in mirror traps. See [7.2.8].

7.2.13 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.N. Karpushov, S.A. Korepanov, V.V. Maximov, S.V. Murakhtin, A.Yu. Smirnov, K. Noack, G. Otto.* **Fast ion relaxation and confinement in the gas-dynamic trap.** Nuclear Fusion, v. 40, No. 4, p. 753-765 (April 2000).
Studies of the relaxation and confinement of hot anisotropic ions in the GDT experiment are presented. For numerical studies of the fast ion dynamics a Monte Carlo code based on the theory of two body Coulomb collisions has been elaborated.

7.2.14 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.N. Karpushov, V.N. Kornilov, A.A. Lizunov, V.V. Maximov, K. Noack.* **Study of the Axial Distribution of DD Reaction Intensity in the GDT Experiments.** 27th EPS Conference on Controlled Fusion and Plasma

Physics, 12-16 June 2000, Budapest, Hungary, Contributions, ECA v. 24B, p. 924-927 (2000).
Measurements of axial profile of D-D reaction yield in the GDT experiment.

7.2.15 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.N. Karpushov, V.N. Kornilov, V.V. Maximov, K. Noack.* **Axial distribution of DD neutron yield in GDT under skew injection of deuterium neutral beams.** Transaction of Fusion Technology, v. 39, No. 1T, FUSTE8(1), p. 213-216 (2001).
Measurements of axial profile of DD neutron reaction yield in GDT device using a collimated detector of energetic protons.

7.2.16 *P.A. Bagryansky, A.V. Anikeev, A.A. Ivanov, V.V. Maximov, S.V. Murakhtin, K. Noack.* **Axial Profile measurement of DD product yield in the GDT central cell.** Transaction of Fusion Science and Technology, v. 43, No. 1T, p. 259-261 (2003).
A description of the experiments to demonstrate the peaking up of the DD reaction yield near the fast ion turning points that represents the essential feature of the GDT-based neutron source.

7.2.17 *V.V. Maximov, A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.A. Lizunov, S.V. Murakhtin, K. Noack, V.V. Prikhodko.* **Spatial profiles of fusion product flux in the gas dynamic trap with deuterium neutral beam injection.** Nuclear Fusion, v. 44, issue 4, p. 542-547 (2004).
A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.A. Lizunov, V.V. Maximov, K. Noack, V.V. Prikhodko, D.N. Stepanov. **Spatial Profiles of the DD Product Yield in the GDT Experiments.** 30th EPS Conference on Controlled Fusion and Plasma Physics, St. Petersburg, 7-11 July 2003, ECA v. 27A, p. 2.190 (2003).
The axial profile of DD fusion product fluxes has been measured and found to be strongly peaked in the same regions. The characteristics of the profiles are consistent with the classical mechanism of fast ion relaxation caused by two-body Coulomb collisions with plasma particles.

7.2.18 *A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, A.A. Lizunov, V.V. Maximov, S.V. Murakhtin, V.V. Prikhodko.* **Study of fast ion profiles in the gas dynamic trap.** Transactions of Fusion Science and Technology, v. 47, No 1T, p. 92-95 (2005).
In the gas dynamic trap experiment with 17 keV and 4.5 MW deuterium

neutral beam injection the spatial profile of fast ion density has been studied by different methods: MSE spectroscopy, active charge-exchange diagnostic and measurement of DD fusion product fluxes. ions.

7.2.19 *S.V. Murakhtin, V.V. Prikhodko.* **Energy analyzer for hot ion density profile measurements in GDT.** Transactions of Fusion Science and Technology, v. 47, No 1T, p. 315-317 (2005).
A neutral particle analyzer in combination with a charge-exchange target produced by injection of a diagnostic neutral beam is used at GDT experiment to measure density profile of fast ions.

7.2.20 *V.V. Prikhodko, A.V. Anikeev, P.A. Bagryansky, A.A. Lizunov, V.V. Maximov, S.V. Murakhtin, Yu.A. Tsidulko.* **Formation of a Narrow Radial Density Profile of Fast Ions in the GDT Device.** Plasma Physics Reports, v. 31, No 11, p. p. 969-977 (2005).
Study of formation of radially narrow density profiles in the GDT device.

7.2.21 *G. Fiksel, B. Hudson, D.J. Den Hartog, R.M. Magee, R. O'Connell, S.C. Prager, A.D. Beklemishev, V.I. Davydenko, A.A. Ivanov, Yu.A. Tsidulko.* **Observation of Weak Impact of a Stochastic Magnetic Field on Fast-Ion Confinement.** Physical Review Letters, v. 95, iss. 12, p. 125001-1 - 125001-4 (2005).
Fast ions are observed to be very well confined in the Madison Symmetric Torus reversed field pinch despite the presence of stochastic magnetic field. The fast-ion energy loss is consistent with the classical slowing down rate, and their confinement time is longer than expected by stochastic estimates.

7.2.22 *P.A. Bagryansky, V.V. Maximov, E.I. Pinzhenin, V.V. Prikhodko.* **DD product yield in the GDT central cell.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 256-258 (January 2011).
The report presents the recent results of experiments with deuterium neutral beam injection in the Gas Dynamic Trap device.

See also [5.2.15], [4.24], [5.1.22], [5.1.24].

7.3 Axial confinement

7.3.1 *Kotelnikov I.A., Ryutov D.D.* **Effects of ambipolar potential in a two-component gasdynamic confinement system.** Sov. J. Plasma

Physics, v. 11, p. 655 (1985).
Analysis of the axial plasma losses from GDT in the presence of electrostatic potential peaks near the turning points of the sloshing ions.

7.3.2 *Mirnov V.V., Tkachenko O.A.* **Electrostatic potential distribution in the gas-dynamic trap.** Report 85-32, Institute of Nuclear Physics, Novosibirsk (1985) – in Russian.
The paper contains a theoretical analysis of the potential distribution in the mirror and expander regions of the gas dynamic trap, with the account for the presence of the Yushmanov ions.

7.3.3 *A.V. Anikeev, P.A. Bagryansky, A.D. Beklemishev, P.P. Deichuli, A.A. Ivanov, A.N. Karpushov, V.V. Maximov, N.V. Stupishin, A.A. Podminogin.* **Characterization of the plasma endlosses in the gasdynamic trap.** XXII Conference on Phenomena in Ionized Gases (Hoboken, USA July 31 - Aug. 4, 1995) Contributed Papers, v. 3, p. 81-82 (1995).
An axial plasma losses through the end mirror of GDT were measured and compared with the theory.

7.3.4 *A.V. Anikeev, P.A. Bagryansky, G.I. Kuznetsov, N.V. Stupishin.* **Longitudinal confinement of particles and energy in a gas-dynamic trap.** Report INP 98-73, Institute of Nuclear Physics, Novosibirsk (1998) – in Russian.
A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, G.I. Kuznetsov, N.V. Stupishin. **Longitudinal Plasma Confinement in the Gas Dynamic Trap.** Transactions of Fusion Technology (ANS), v. 35, No. 1T, FUSTE 8(1), p. 126-130 (1999).
Anikeev A.V., Bagryansky P.A., Kuznetsov G.I., Stupishin N.V. **Longitudinal confinement of particles and energy in a gas-dynamic trap.** Plasma Physics Report, v. 25, No. 10, p. 775-782 (1999).

7.3.5 *A.V. Anikeev, P.A. Bagryansky, A.D. Beklemishev, A.A. Lizunov, V.V. Maksimov, S.V. Murakhtin, V.V. Prikhodko, A.L. Solomakhin.* **Suppression of Longitudinal Losses in a Gas Dynamic Trap by Using an Ambipolar Mirror.** Plasma Physics Reports, v. 36, No. 5, p. 381-389 (2010).
An effect of ambipolar potential peaks on axial plasma losses in a gas-dynamic trap was investigated.

See also [7.2.5].

7.4 Radial confinement

7.4.1 *Kotelnikov I.A.* **The effect of the magnetic field errors on the transport processes in long solenoids.** Report INP 88-74, Institute of Nuclear Physics, Novosibirsk (1988) – in Russian
The neoclassical transport caused by non-axisymmetric magnetic field errors is studied. The tolerances to the magnetic field imperfections have been evaluated.

7.4.2 *Berk H.L., Ryutov D.D., Tsidulko Yu.A.* **Temperature-gradient instability caused in plasma by conducting end surfaces.** JETP Letters, v. 52, p. 23 (1991).
The first paper on the instability potentially important for the GDT and caused by the interplay of two factors: non-uniformity of the electron temperature in radial direction and the presence of Debye sheaths on the conducting end-walls. Finite beta effects briefly discussed.

7.4.3 *Berk H.L., Ryutov D.D., Tsidulko Yu.A.* **Temperature-gradient instability induced by conducting end walls.** Physics of Fluids, v. B3, p. 1346 (1991).
Detailed analysis of the low beta case for the same instability as in [7.4.2], with the account for FLR effects and the finite resistivity of the end surface.

7.4.4 *Ryutov D.D., Weiland J.* **Velocity shear effects in the problem of the electron temperature gradient instability induced by conducting end-walls.** Report CTH-IEFT/PP-1992-14, Chalmers University of Technology, Gothenburg, Sweden (1992).
The interrelation between the temperature-gradient instability as in [7.4.2], [7.4.3] and the hydrodynamic Kelvin-Helmholtz instability has been analyzed.

See also [5.1.11], [5.1.17], [5.2.19], [5.2.20], [5.1.19], [5.2.21], [5.1.20], [5.1.21], [5.1.23].

8 Related technologies

8.1 Beams

8.1.1 *P.P. Deichuli, V.I. Davydenko, A.A. Ivanov, S.A. Korepanov, V.V. Mishagin, A.V. Sorokin, N.V. Stupishin, G.I. Shulzhenko.* **High power hydrogen neutral beam injector with focusing for plasma heating.** Review of Scientific Instruments, v. 75, iss. 5, p. 1816-1818 (2004).
A description of a high power neutral beam injector with particle energy of 25 keV, a current of 60 A, and several milliseconds pulse duration. Six of these injectors are planned to be used for the upgrade of the neutral beam system of a gas dynamic trap device.

8.1.2 *G.F. Abdrashitov, A.G. Abdrashitov, A. Anikeev, P. Bagryansky, P. Deichuli, A. Donin, V. Kapitonov, A. Lizunov, S. Murakhtin, V. Prikhodko, V. Savkin, A. Solomakhin, A. Sorokin, N. Stupishin, S. Collatz, K. Noack.* **First Experiments With Powerful NB Injection On GDT-Upgrade.** 21st IAEA Fusion Energy Conference, 16 - 21 October 2006, Chengdu, China paper EX-C (2006).
First experiments with extended neutral beam injection at the GDT device.

8.1.3 *V.I. Davydenko, A.A. Ivanov, I.A. Kotelnikov, M.A. Tiunov.* **Pierce electrodes for a multi-gap accelerating system.** Preprint Budker INP 2006-011, Novosibirsk (2006).
Application of quasi-Pierce electrodes at the beam periphery of multi-aperture ion optical system is considered to improve angular divergence of the ion beam.

8.1.4 *T.D. Akhmetov, V.I. Davydenko, A.A. Ivanov.* **Model of Neutral-Beam Propagation in a Duct with Scrapers.** IEEE Transactions on Plasma Science, v. 36, No. 4, p. 1545-1551 (2008).
A model of propagation of a neutral beam with geometric focusing and angular divergence in a duct is described. Numerical code is applied to calculation of current-density profiles and power loads on circular scrapers due to neutral particles.

8.1.5 *A.A. Ivanov, V.I. Davydenko, P.P. Deichuli, V.P. Belov, V.V. Kobets, V.V. Mishagin, I.V. Shikhovtsev, A.V. Sorokin, A.V. Stupishin, B. Schweer, R. Uhlemann.* **Focused Neutral Beam With Low Chaotic Divergence For Plasma Heating And Diagnostics in**

Magnetic Fusion Devices. 22nd IAEA Fusion Energy Conference, Book of Abstracts, 13-18 October 2008, Geneva, Swiss, p. 67 (paper FT/P2-30) (2008).
A series of neutral beam injectors has been developed in the Budker Institute of Nuclear Physics, Novosibirsk for plasma heating and diagnostics in modern fusion devices. Ion optical system of these injectors is optimized to produce ion beams with low angular divergence. In order to provide beam focusing, the grids are formed as spherical segments. Such geometrically focused beams are neutralized in a gas target and subsequently are used to heat or diagnose plasma. For diagnostic purposes these beams are advantageous when high spatial resolution is necessary. In many cases such focused beam with small divergence are also necessary for plasma heating in the machines with narrow ports through which only small size, high power density beams can be transported.

8.1.6 *A. Sorokin, V. Belov, V. Davydenko, P. Deichuli, A.A. Ivanov, A. Podyminogin, I. Shikhovtsev, G. Shulzhenko, N. Stupishin, M. Tiunov.* **Characterization of 1 MW, 40 keV, 1 s neutral beam for plasma heating.** Review of Scientific Instruments, v. 81, No 2, p. 02B108 (2010).
A description of an injector of neutral beam with geometrical focusing for plasma heating in moderate-size plasma devices. The neutral beam power is 1 MW, pulse duration is 1 s, beam energy is 40 keV, and angular divergence is 1.2°.

8.1.7 *V.I. Davydenko, A.A. Ivanov, P.P. Deichuli, V.P. Belov, A.I. Gorbovsky, V.V. Mishagin, I.V. Shikhovtsev, A.V. Sorokin, A.V. Stupishin, G.I. Shulzhenko, G. Fiksel, B. Shweer.* **Development of Focused Neutral Beams with Small Angular Divergence for Plasma Heating and Diagnostics.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 128-131 (January 2011).
Review of the works on development of neutral beams with ballistic focusing for plasma heating and diagnostic.

8.1.8 *V.I. Batkin, V.B. Bobylev, A.V. Burdakov, V.I. Davydenko, A.A. Ivanov, V.A. Kapitonov, K.I. Mekler, S.V. Polosatkin, V.V. Postupaev, A.F. Rovenskih, N.V. Sorokina, Yu.S. Sulyaev, Yu.A. Trunev.* **Development of New Neutral Beam Injection System on GOL-3 Facility.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 262-264 (January 2011).

This paper presents a status of development of neutral beam injection system for GOL-3 facility.

8.2 Auxiliary heating

8.2.1 *Garina S.M., Grishanov N.I., Elfimov A.G., Potapenko I.F.* **RF plasma heating in the gas-dynamic trap.** Proceedings of the National Conference on the Open-Ended Traps (Moscow, 1989), Publication of the Kurchatov Institute, Moscow, p. 82 (1990).
Numerical analysis of the fast and slow magnetosonic wave absorption is presented.

8.2.2 *Kotelnikov I.A., Yakovchenko S.G.* **Quasistatic theory of ion-cyclotron plasma heating in open magnetic confinement system.** Soviet Journal of Plasma Physics, v. 17, p. 177 (1991).
Heavy minority scheme of the ICRF heating is considered for the experimental situation typical for the Gas-Dynamic Trap. The theory predicts a high efficiency of this heating scheme.

8.2.3 *V.E. Moiseenko, A.A. Ivanov, A.V. Anikeev, P.A. Bagryansky.* **Antenna for Electron Component Heating in the Gas-Dynamic Trap.** 12-th Topical Conference on RF Power in Plasmas (Savannah, GA, 1997), in AIP Conference Proceedings, v. 403, AIP, New York, p. 479-482 (1997).
Numerical simulations of an antenna coupling with plasma and optimization for electron heating.

8.3 Pumping

8.3.1 *P.A. Bagryanskii, E.D. Bender, A.A. Ivanov, A.N. Karpushov, S.V. Murakhtin, K. Noack, S. Krahl, S. Collatz.* **Effect of Wall Conditioning on Neutral Gas Transport in the Gas-Dynamic Confinement System.** Plasma Physics Report, v. 23, No. 11, p. 903-910 (1997).
The effect of titanium conditioning of the chamber wall on the plasma confinement in a gas-dynamic confinement system is studied. A comparison of the numerical results with the experimental data shows that the recycling coefficient of the chamber wall coated with titanium is close to unity.

8.3.2 *A.A. Ivanov, P.A. Bagryansky, E.D. Bender, S.V. Murakhtin, S. Collatz, K. Noack, A.N. Karpushov, St. Krahl.* **Wall conditioning and neutral gas transport at the GDT facility.** Transactions of Fusion Technology (ANS), v. 35, No. 1T, FUSTE 8(1), p. 370-374 (1999).
The effect of wall conditioning on a plasma was studied in the Gas Dynamic Trap device using titanium coating of the containment wall. The comparison of the results numerical simulation with the experimental data are presented.

8.3.3 *P.A. Bagryansky, E.D. Bender, A.A. Ivanov, A.N. Karpushov, S.V. Murakhtin, K. Noack, St. Krahl, S. Collatz.* **Effect of fast Ti-deposition on gas recycling at the first wall and on fast ion losses in the GDT experiment.** Journal of Nuclear Materials, No 265/1-2, p. 124-133 (1999).
Fast Ti-deposition was applied in the gas-dynamic trap (GDT) facility in the regimes with 14-17.5 keV, 2.5-4 MW neutral beam (NB) injection to control gas recycling at the first wall and thereby reduce charge-exchange losses of energetic ions. The comparison of the numerical results with the experimental data shows that the recycling coefficient of the chamber wall which has been freshly coated by titanium is close to that of the pure metallic surface.

8.4 Diagnostics

8.4.1 *Drachev V.P., Krasnikov Yu.I., Bagryansky P.A.* **Dispersion interferometer for controlled nuclear fusion devices.** Review of Science Instruments, v. 64, p. 1010 (1993).
A dispersion interferometer for density of line density at the GDT facility is described.

8.4.2 *A.I. Rogozin, A.A. Ivanov.* **Measurements of plasma density profile in the GDT using a neutral beam probe.** Proceedings of XXI International Conference On Phenomena In Ionized Gases, Bohum, Germany, v. III, p. 427 (1993).
Description of a neutral beam supported diagnostic for measurements of radial profile of plasma density in the GDT experiments. First observation of growth of large scale perturbations in the MHD unstable regimes of operation.

8.4.3 *P.A. Bagryansky, V.N. Bocharov, P.P. Deichuli, A.A. Ivanov, A.N. Karpushov, V.V. Maximov, A.I. Rogozin, T.V. Salikova.* **The diagnostic complex of GDT device for studying of plasma heating during the injection of powerful atomic beams.** Report INP 93-70, Institute of Nuclear Physics (1993) – in Russian.
Survey of the diagnostics used for experiments at GDT device to study MHD stability boundaries, characteristics of unstable perturbations and plasma energy balance with neutral beam injection.

8.4.4 *A.I. Rogozin, A.A. Ivanov.* **Active corpuscular diagnostics of plasma density profile in gasdynamical confinement system.** Plasma Physics Reports, v. 20, No. 2, p. 165-167 (1994).
Description of a neutral beam supported diagnostic for measurements of radial profile of plasma density in the GDT experiments. First observation of distortions of the density profile during plasma decay in the MHD unstable regimes of operation.

8.4.5 *V.I. Davydenko, A.A. Ivanov, A.N. Karpushov, A.I. Rogozin, N.V. Stupishin, I.V. Shikhovtsev.* **Measurements of Fast-Ion Parameters in the GDL Device by Means of an Auxiliary Target.** Plasma Physics Report, v. 23, No. 5, p. 396-399 (1997).
In the present work, the diagnostics for measuring local ion energy and pitch-angle distribution functions in GDT plasma is described.

8.4.6 *P.P. Deichuli, A.A. Ivanov, N.V. Stupishin.* **Measurements of the Ambipolar Potential Profile in the Expander of a Gas-Dynamic Trap by Means of a Local Gas Target.** Plasma Physics Report, v. 24, No. 8, p. 662-666 (1998).
Results of measurements of the potential profile along the axis of the expander of a gas-dynamic trap are presented. A potential at a given point of the expander was measured using a local gas target. The target was produced by a pulsed gas puffing through a glass capillary, whose position along the axis of the confinement system was varied from shot to shot. Cold ions produced via charge exchange and ionization of the particles of a gas cloud were accelerated by an ambipolar electric field. Their energy, which was measured at the end wall by an electrostatic analyzer, corresponded to the potential at the point of charge exchange.

8.4.7 *A.V. Anikeev, P.A. Bagryansky, P.P. Deichuli, A.A. Ivanov, A.N. Karpushov, S.V. Korepanov, S.V. Murakhtin.* **Diagnostics for measurement of high β plasma parameters in the gas dynamic**

trap. 998 ICPP & 25th EPS CCFPP (Prague, 1998), Contributed papers, ECA v. 22C, p. 1498-1501 (1998).
The new diagnostics based on neutral beam injectors that were installed on the GDT-device in Budker Institute of Nuclear Physics (Novosibirsk, Russia) for measurement of high-β plasma parameters are presented.

8.4.8 *P.A. Bagryansky, Yu.A. Tsidulko, A.A. Ivanov, S.A. Korepanov, P.P. Deichuli.* **The measurements of plasma density profile in GDT using diagnostic injector DINA-5.** Transactions of Fusion Technology (ANS), v. 35, No. 1T, FUSTE 8(1), p. 345-348 (1999).
A diagnostic based on neutral beam injector DINA-5 is developed and applied for the plasma density measurements at midplane of Gas Dynamic Trap (GDT') experiment. The space resolution of the method was estimated to be about 2 cm. The duration of the beam (up to 4 ms) is large enough to overlap the duration of the GDT shots.

8.4.9 *V.I. Davydenko, A.A. Ivanov.* **Development of Neutral Beam Injectors for Plasma Diagnostic in Budker Institute of Nuclear Physics.** Abstract of the 9-th International Conference on Ion Sources, Oakland, California, September 2001, p. 55 (September 2001).
Review of achievements in development of neutrals beams for plasma diagnostics.

8.4.10 *A.A. Ivanov, A.A. Lizunov, P.P. Deichuli, S.A. Korepanov, P.A. Bagryansky, V.Ya. Savkin, G. Fiksel, D. Den Hartog.* **Local Measurements of Plasma Beta in GDT Using MSE Diagnostic.** The 4th International Conference on Open Magnetic System for Plasma Confinement, July 1-4, 2002, Korea, Book of Abstracts, p. 23 (2002).
Measurement of local plasma beta in GDT using motional Stark effect diagnostic.

8.4.11 *A. A. Ivanov, V.I. Davydenko, P.P. Deichuli, S.A. Korepanov, V.V. Mishagin, A.A. Podminogin, I.V. Shikhovtsev, B. Schweer, A. Kreter, R. Uhlemann.* **Diagnostic Neutral Beams For Plasma Studies in Magnetic Fusion Devices.** 19th IAEA Fusion Energy Conference, Lyon, France, 14-19 October 2002, Book of Abstracts, IAEA-CN-94, p. 101 (paper FT/P1-18) (October 2002).
A description of a neutral beam developed in the Budker Institute, Novosibirsk to diagnose the plasma in modern fusion experiments with the the maximum beam energy upto 55 keV and an ion current is up to 3 A (for hydrogen).

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Implementation of a spectral motional Stark effect diagnostic for spatially localized measurements of magnetic field on the Gas-Dynamic Trap (GDT) magnetic mirror device is reviewed.

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A review of hydrogen beam injectors, which have been developed in Budker Institute of Nuclear Physics, Novosibirsk, for plasma diagnostic in magnetic fusion devices.

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A dispersion interferometer based on CO2 laser for measurements of plasma line density in the gas dynamic trap (GDT) experiment has been developed with sensitivity $< n_e l >_{min} \approx 1 \cdot 10^{13}\ cm^{-2}$, *temporal resolution* $\approx 50\ ns$.

8.4.16 *P.A. Bagryansky, A.D. Khilchenko, A.N. Kvashnin, A.A. Lizunov, R.V. Voskoboynikov, A.L. Solomakhin, H.R. Koslovsky, TEXTOR team.* **Dispersion interferometer based on a CO2 laser for TEXTOR and burning plasma experiments.** Review of Scientific Instruments, v. 77, p. 053501-1 - 053501-7 (2006).
A dispersion interferometer based on a continuous-wave CO_2 *laser source* ($\lambda = 9.57 \mu m$) *with double plasma passage for measurements of the line-integrated electron density in the TEXTOR tokamak and the GDT linear system is described and tested.*

8.4.17 *V.I. Davydenko, A.A. Ivanov, S.A. Korepanov, I.A. Kotelnikov.* **Precise formation of geometrically focused ion beams.** Review of Scientific Instruments, v. 77, p. 03B902-1 - 03B902-3 (2006).
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8.4.18 *V.I. Davydenko, A.A. Ivanov, I.V. Shikhovtsev, A.V. Sorokin, R. Uhlemann.* **Beam formation by ion optical system with slit finite length apertures.** Review of Scientific Instruments, v. 79, No 2, p. 02B720 (2008).
Ion beam formation by four-electrode ion optical system with slit finite length apertures is considered.

8.4.19 *Khil'chenko A.D., Kvashnin A.N., Zubarev P.V., Moiseev D.V., Kovalenko Yu.V., Ivanenko S.V.* **Data recording system of a dispersion interferometer based on a CO2 laser.** Instruments and Experimental Techniques, v. 52, No. 3, p. 382-393 (2009).
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Application of a dispersion interferometer for measurement of plasma density and control of plasma position on present and future fusion devices is considered.

8.4.21 *S. Polosatkin, V. Belykh, V. Davydenko, A. Ivanov, G. Fiksel, V. Kapitonov, A. Khilchenko, V. Khilchenko, V. Mishagin, M. Tiunov.* **Advanced Neutral Particle Analyzer for Fusion Plasma Diagnostics.** Transactions of Fusion Science and Technology, v. 59, No. 1T, p. 259-261 (January 2011).
A neutral particle analyzer has been designed and fabricated to measure the ion energy distributions of both bulk plasma ions as well of fast ions created by neutral beam injection with temporal resolution 1-5 microsec in GOL-3 and GDT experiments.

8.4.22 *A.A. Lizunov, D.J. Den Hartog, A.S. Donin, A.A. Ivanov, V.V. Prikhodko.* **Multi-point measurement of $|B|$ in the gas-dynamic trap with a spectral motional Stark effect diagnostic.** Review of Scientific Instruments, v. 82, p. 086105-1 - 086105-3 (2011).
A description of an upgraded spectral motional Stark effect diagnostic which has been installed on the gas-dynamic trap (GDT) experiment to enable spatially resolved measurement of $|B|$.

See also [4.8].

8.5 Magnetic fields (superconducting magnets)

8.5.1 *M.N. Wilson.* **NbTi superconductors with low ac loss: A review.** Cryogenics, v. 48, iss. 7-8, p. 381-395 (July – August 2008).
A review of development of technology of filamentary composite wires, with NbTi filaments embedded in a matrix of copper. Problems of non-uniform current distribution between the wires, which can prevent magnets from reaching their full current, particularly with the largest cables are considered.

8.5.2 *P. Komarek, E. Salpietro.* **Review of European Activities in Superconductivity for Thermonuclear Fusion, in the Light of ITER.** IEEE/CSC & ESAS EUROPEAN SUPERCONDUCTIVITY NEWS FORUM, no. 4 (April 2008).
The papers reviews major activities of EURATOM on the development of conductors and the toroidal field coils for large fusion devices including the modular stellarator W7-X and ITER.

8.5.3 *U.P. Trociewitz, M. Dalban-Canassy, M. Hannion, D.K. Hilton, J. Jaroszynski, P. Noyes, Y. Viouchkov, H.W. Weijers, D.C. Larbalestier.* **35.4T field generated using a layer-wound superconducting coil made of (RE)Ba2Cu3O7-x (RE = rare earth) coated conductor.** Applied Physics Letters, v. 99, iss. 20, p. 202506 (2011).
The limits of layer wound (RE)Ba2Cu3O7-x (REBCO, RE=rare earth) coils in a high magnetic field environment >30T were studied using a series of small insert coils which have been built and characterized in background fields. One of the coils repeatedly reached 35.4T using a single 100m length of REBCO tape wet wound with epoxy and nested in a 31T background magnet.

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The GDT-based Neutron Source and Related Issues (Annotated bibliography)

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