Foreword

Artur Malaquias

The second IAEA Research Co-ordination Meeting (RCM) of the Co-ordinated Research Project (CRP) on Dense Magnetized Plasma (DMP) was held in the city of Kudowa Zdrój, Poland from 1 to 3 of June, 2005. Mr. Artur Malaquias, from the IAEA, was the Director of the meeting, Prof. Vladimir Gribkov – the Chairman of the meeting, and Dr. Marek Scholz and Dr. Ryszard Miklaszewski – the Chair and Co-Chair of the organizing committee.

The purpose of the meeting was two-fold:

1. To review the work performed during the contract period since the last RCM in Vienna in December 2003 and to give an overview of the last 3½ years of CRP activities.
2. To plan future individual and joint activities for the next two-year period of the CRP extension.

The research activities reported at the Meeting were performed in various laboratories: Warsaw, Poland (Institute of Plasma Physics and Laser Microfusion – IPPLM, and International Centre for Dense Magnetized Plasmas – ICDMP, UNESCO, Warsaw, Poland), Moscow, Russia (Institute of Metallurgy and Material Sciences – IMMS, Moscow Physical Society – MPS, Moscow State University – MSU), Ferrara, Italy (Ferrara University – FU), Singapore (Nanyang Technological University – NTU), Beijing, China (Tsingua University – TU), St. Petersburg, Russia (Physico-Technical Institute – PTI), Tallinn, Estonia (Tallinn Pedagogical University – TPU), Bucharest, Romania (University of Bucharest – UB), Yuseong, Daejeon, Republic of Korea (Korea Atomic Energy Research Institute – KAERI) – a total of 12 institutions from 8 countries.

The specific research objectives of this CRP fall into three categories: i) assessment of driver technology of Plasma Focus (PF) devices, ii) auxiliary systems and interface issues, and iii) assessments and testing of new technologies and applications of DMP devices.

i) Comparative assessment of driver technology. – To review and summarize the current status of key technologies of DMP devices including energy storage, switches, master trigger, chambers, target fabrication and inserting systems, etc. Being the Dense Plasma Focus (DPF) one of the most promising DMP devices for near-term applications, with energy supply system on the level of several kJ, it is supposed to develop the following topics in the framework of this CRP:
   - design, construction and operation of new PF devices based on a new technology, possessing a long lifetime and permitting high repetition rate;
   - design, construction and operation of PF chambers fitted to different nuclear and plasma physics applications exploring the generated beams of neutrons, X-rays, fast electrons ion and plasma streams;

ii) Interface issues. – To identify and co-ordinate research addressing and resolving interface issues between the PFs and other DMP device components and target systems.

iii) Assessments and testing of new technologies and applications of DMP devices. – To investigate possible applications at the present level of development and to evaluate the environmental, safety and economical aspects of candidate DPF and other device designs for different applications.

A list of the main topics of research under the CRP is presented in Table I. The main topics are divided in sub-topics each representing the object areas of research.

The contents of this special issue condensate the description of the research performed under this CRP, reported in over more than 43 papers and/or conference communications.

A short summary of the Meeting is given below.

The first report made by Dr. A. V. Dubrovsky (MPS, Moscow, Russia) presents the activity devoted mainly to the following points:

1. Design and construction of the chambers intended for the new Dense Plasma Focus device – PF-6 – recently put into operation at the IPPLM, Warsaw, and PF-10, prepared for the operation at the Institute for Theoretical and Experimental Physics, Moscow, Russia. These chambers are especially constructed, to suit a particular application: neutron production, generation of powerful beams of plasma and fast ions, creation of flashes of soft or hard X-rays. One of their main features is that they are manufactured by a laser and e-beam welding technique, thus they have no any rubber o-rings and can demonstrate a long lifetime with reliable and reproducible operation.

2. Design and construction of interface parts for DPF devices intended for material science experiments – sample holders, revolving supports, current connectors, etc.
3. Results on the PF-6 and PF-10 initiations and on material science experiments made together with other participants of the CRP.

The second report was presented by Dr. E. I. Toader (UB, Bucharest, Romania). It was devoted to experiments made with the reflex discharge plasma as a potential source of negative ions. The study is motivated by the need for high energy neutral particle beams for heating plasma within controlled nuclear fusion machines. The reflex discharge plasma is analyzed as a possible source of negative ions. Particularly, the reporter was interested in the internal parameters in the case of the hydrogen reflex discharge plasma. It was shown that the optimum discharge conditions are obtained for pressure values around 1.0 Pa, the negative ion density is as high as 0.8×10^{17} m^{-3}, the cold electron density is 4.24×10^{18} m^{-3}, the cold electron temperature is 0.776 eV, the negative ion fraction increases from 1.4% for $p = 0.1$ Pa to almost 2.2% within the pressure range 1–4 Pa, and the positive ion density scales with power.

The third report was made by Dr. Byung-Hoon Oh (KAERI, Yuseong-Gu, Daejeon, Republic of Korea). This team operates a large beam facility, which has been designed and constructed to test Neutral Beam Injection System for KSTAR tokamak, but also it could be applied to other areas in the near future. The high power ion beams have a large potential to be applied to a lot of areas such as fusion energy generation, material science, intensive heat flux source, and so on. The recent activities are concentrated on completion of the development of the large beam facility. Tests of the facility provided during the last years have shown that optimization of the device is needed. The parameters of two tested regimes of the device look as follows:

– 87 kV, 17.5 A, 0.5 s, hydrogen beam. Limit is a break down in the ion source.
– 60 kV, 14.0 A, 10 s, long pulse beam. Limit comes from the cooling system.

The fourth presentation, made by Dr. Chengmu Luo (TU, Beijing, China), was devoted to a new gas-puff pinch device. The capacitor bank consists of four capacitors of 4 μF. A field distortion switch is connected to each energy storage capacitor to reduce the total inductance of discharge circuit. A hollow gas shell is produced by an injection of gas through a supersonic nozzle from a fast-acting electromagnetic valve. The mass of the gas shell can be varied using different plenum pressure and changing the time delay between the beginning of gas injection and the initiation of the discharge. Through the radial windows of the discharge chamber, the laser light injects into and out of the Z-pinch plasma region to be studied. In our experiments, the capacitor bank was charged to 22 kV. The peak discharge current is about 210 kA with a quarter period of 2.4 ms. Laser interferometry and PIN-diodes/Ross-filter technique are the main methods of diagnostics. The device is very good for educational tasks.

The fifth lecturer, Dr. S. V. Springham (NTU, Singapore), reports his new results on track detector technique used for investigation of fast ions produced within a DPF including fusion products. An automated system of track detector interrogation has been demonstrated. A main result on the investigated phenomena is that the beams of fast ions have a shallow structure. It is probably a new experimental evidence on the validity of the gyrating-particle hypothesis of the neutron production mechanism in DPF.

The sixth rapporter, Prof. V. A. Gribkov, gave a description of the PF-6 and PF-10 devices made by an IPPLM team in cooperation with ICDMP and MPS groups. First results on the operation of the devices were presented. Maximum current of 750 kA reached at the PF-6 device is the record one for the installations of this energy level. It is designed for a repetitive mode of operation. The only reason why this regime is not available at the moment is a lack of funds for a proper charger of the device. Diagnostics of both types of plasma – primary (pinch) plasma and the secondary (irradiated target) one – was the important point of the report. Results on several applications based on this device and on the PF-1000 facility have been presented. These results received in fields of pulsed radiation physics (material sciences, short-lived isotope production) and radiation chemistry (X-ray microlithography, radioenzymology) demonstrate one common feature – the effects received depend not only on the dose possessed by the samples but also on the dose power. Usually, the main intrinsic feature of these experiments is that the absolute dose needed for the effect is much lower than in the case of isotope or classical accelerator cases.

Interpretation of these results was made on the basis of the principle of pulse radiation physics (chemistry, enzymology, etc.) in its perfect sense formulated in the course of the works made during this CRP Programme: overlapping of the interaction micro-volumes (e.g. spurs at water radiolysis) activated during the time interval short compared with the reciprocal processes (e.g. the end of reactions with free radicals).

The seventh lecturer was Prof. Ü. Ugaste (TPU, Tallinn, Estonia). His report was concentrated mainly on theoretical problems of diffusion of the implanted ions within the irradiated samples. The redistribution of deuterium implanted into iron-based alloys by plasma beam interaction with the alloy surface was analytically investigated. To solve this problem, a new method of the stochastic dissipation rates treatment in the diffusion zone at the superposition of thin material layers was worked out with a necessary computer simulation program.

As a result, it was shown that deuterium implanted into a surface layer may redistribute very quickly even at low temperatures, and most of the implanted particles diffuse into the body of the specimen.

On the basis of the exact expression for the current (flux), it has been found a number of co-operation (collective) effects displayed in these conditions when an "instant" pulse of ions injects into the bulk of material during a period short compared with the characteristic diffusion time:

(i) a resonant-like behavior of absolute negative mobility at intermediate values of switching rate;

(ii) the existence of a negative differential resistance;
(iii) for large values of the switching rate and a low temperature, the current is, at some values of the tilting force F, very sensitive to a small variation of F – a phenomenon called "hypersensitive differential response";
(iv) for certain parameters, there is a finite interval of the tilting force where the current is very small compared to that in the surroundings (the effect of "disjunct windows").

It seems that the last mentioned behavior is a new anomalous transport phenomenon for Brownian particles (e.g. implanted into specimen during the process of irradiation).

The eighth speaker was Dr. E. V. Dyomina (IMMS, Moscow, Russia). Her report was connected with post-irradiation materials tests. The first analysis of the Eurofer surface made by optical microscopy and a strong damage of SiC samples after their irradiation at the PF-6 device and PF-1000 facility have shown that the character of action is quite similar in both cases of small and large devices. It results from the fact that the samples were positioned in a PF-6 chamber much closer to the plasma and beam generation zone. Of course, the area of the intensive action here is much smaller compared with the PF-1000 device.

At the PF-1000 facility, a tube made of low activated austenitic steel 25Cr12Mn20W was irradiated. A relief of the surface both inside and outside of the tubes has been investigated. Also micro-hardness of the surface layer was measured in all cases. Both internal and external surfaces have wave-like relief with droplets, influxes and ridges. Father away from the irradiation source the elements of the surface relief become smaller, i.e. the topographic structure of irradiated surface becomes more dispersible. Craters were formed at both irradiated surfaces. Bubbles and rings were observed mainly on the cold part of the tube on the outside surface.

As for the micro-hardness of the irradiated tubes, it was found that it can be increased under certain conditions. It is important for the technology of hardening of surface layer in hard-to-reach parts of different components of machines.

The ninth reporter was Dr. M. Scholz (ICDMP, Warsaw, Poland). His report was devoted mainly to the improvements of the PF-1000 facility, physics of hard radiations production, and diagnostics of two plasmas – a primary pinch plasma and secondary target one. For a period of three years, a considerable upgrading of the device has been executed. It results in formidable improve-ments of neutron (1 order of magnitude) and other hard radiation (fast ion beams, plasma streams, etc.) generation. E.g. an implosion velocity was increased up to ca. 5×10^7 cm/s. Application of this facility to the radiation material tests was described in the context of plasma/beams parameters.

Dr. A. V. Voronin (PTI, St. Petersburg, Russia) was the last speaker. He described results on the elaboration of plasma injector design for use with the Globus-M facility. The goals of the project are:
(i) development of double-stage plasma source;
(ii) investigation possibilities of injection of dense, highly ionized having high kinetic energy plasma clusters into spherical tokamak Globus-M;
(iii) study of plasma clusters capture by the magnetic field;
(iv) experimental investigation of cluster interaction with magnetized high temperature plasma including study of controlling of plasma density profile efficiency.

A novel type of plasma source for DMP clusters production and acceleration was developed and used in plasma fuelling experiments. Optimization of pulsed coaxial accelerator parameters by means of numerical calculations was performed. An experimental test bed was developed for investigation of intense plasma jet generation. As a result, better parameters of power supply to generate a plasma jet with minimal impurity contamination and maximum flow velocity were determined. This resulted in increasing the plasma velocity from 30 km/s up to 150 km/s in the test bed experiments. Measurements of plasma jet parameters and specific properties of the plasma gun were presented (distribution of pressure across the jet cross section, flow velocity and plasma density, recombination length of the jet, energy and temperature of the flow). The improved sources generate a hydrogen plasma jet with a density of 2×10^{22} m^{-3}, the total number of accelerated particles being $>10^{19}$, during <50 ms.

Table I. Indexed list of CRP research topics

Topic	Sub-topic
1. Drivers and accelerators	1.1 – Power supply 1.2 – Electrodes 1.3 – New driver concepts 1.4 – Ion/neutral sources 1.5 – Beam line components
2. Chambers & targets	2.1 – Chamber development 2.2 – Target manipulation
3. Interface issues & plasma wall interaction	3.1 – System integration 3.2 – Plasma facing components
4. Discharge physics and control	4.1 – Formation 4.2 – Confinement 4.3 – Pinch and target plasma characterization 4.4 – Target irradiation control
5. Theory and numerical modelling	5.1 – DMP simulation 5.2 – Interaction processes 5.3 – Transport processes within the targets
6. Applications	6.1 – Neutron sources 6.2 – X-ray sources 6.3 – Ion/neutral and electron beam sources 6.4 – Tokamak fuelling and heating
7. Development of diagnostics	7.1 – Optical 7.2 – X-ray diagnostics 7.3 – Neutron and particle diagnostics 7.4 – Electric and magnetic probes 7.5 – Activation and gamma spectroscopy
8. Materials test and development	8.1 – Fusion-grade materials irradiation 8.2 – Bio-materials irradiation 8.3 – New materials 8.4 – Isotopic production
9. Material post-irradiation diagnostics	9.1 – Solid state material diagnostics 9.2 – Biological material diagnostics 9.3 – Radiation chemistry materials
10. Expertise exchange, excellence education, knowledge transfer	10.1 – Joint experiments 10.2 – Joint database 10.3 – Workshops 10.4 – Post-graduate programmes 10.5 – Plasma physics schools 10.6 – Under-graduated programmes