Załącznik nr 3b

Self presentation

Providing a description of scientific achievements,

in particular defined in Article 16 paragraph 2 of the Act of 14 March 2003 r.

Dr Aneta Malinowska

Plasma Studies Division (TJ5)
National Centre for Nuclear Research (NCBJ)
Otwock, 2016

3. Autoreferat w języku angielskim

Contents

3. Autoreferat w języku angielskim

1. NAME AND SURNAME

ANETA MALINOWSKA (Banaszak)

2. SCIENTIFIC DEGREES

PhD	2008	Doctor of physical sciences, National Cetre for Nuclear Research (NCBJ), former The Andrzej Sołtan Institute for Nuclear Studies, Świerk, doctoral thesis: *„Study of fusion reaction protons emitted from Plasma Focus divice“.* supervisor: Prof. dr hab. Marek Sadowski reviewers: Prof. dr hab. Zbigniew Kłos Dr hab. Jerzy Wołowski.
MSc	1999	Master of Science in Physics, Specialization: Solid State Physics, Szczecin University of Technology, master thesis: *„Seasonal changes of light attenuation coefficient in selected points of the Oder river“* supervisor: Barbara Pawlak
	1997	Bachelor's degree in Physics, University of Szczecin, Bachelor's thesis: *„Analogies of the physics teaching in the Primary School“* supervisor: Tadeusz Molenda

3. EMPLOYMENT

15.X.2008 – up to now	adiunctus, Plasma Studies Division, National Centre for Nuclear Research (NCBJ), former The Andrzej Sołtan Institute for Nuclear Studies, Świerk.
28.IX.2004-14.X.2008	physicist, Plasma Studies Division, National Centre for Nuclear Research (NCBJ), former The Andrzej Sołtan Institute for Nuclear Studies, Świerk.
1.X.1999-27.IX.2004	doctoral studies, Plasma Studies Division, National Centre for Nuclear Research (NCBJ), former The Andrzej Sołtan Institute for Nuclear Studies, Świerk.

4. DESCRIPTION OF THE ACHIEVEMENT FOR THE HABILITATION QUALICATION

Scientific achievement resulting from art. 16 paragraph 2 of the Act of 14 March 2003 on the academic degrees and academic titles and degrees and title in art (Dz. U. No. 65, item 595) is a series of monothematic publications entitled:

SPECTROMETRIC ANALYSIS OF CHARGED PARTICLES BY THE USE OF SOLID STATE DIELECTRIC DETECTOR AND ITS USE IN PHYSICAL EXPERIMENTS WITH A SPECIAL CONSIDERATION IN STUDY OF NUCLEAR REACTION IN PLASMAS.

4.1. LIST OF MONOTHEMATIC SERIES OF PUBLICATIONS REPRESENTED OF SCIENTIFIC ACHIEVEMENT

Scientific achievement is based on a monothematic series of eleven publications. The all papers have been published in reviewed journals with international circulation:

[B1] **A. Malinowska**, A. Szydłowski, M. Jaskóła, A. Korman, B. Sartowska, M.J. Sadowski, J. Badziak, J. Żebrowski, *Calibration and application of modern track detectors CR-39/PM355 in nuclear physics and high temperature plasma experiments*, **Nukleonika 53** (2008) S15 – S19.

[B2] **A. Malinowska**, A. Szydłowski, K. Malinowski, M.J. Sadowski, J. Żebrowski, M. Scholz, M. Paduch, E. Zielińska, M. Jaskóła, A. Korman, *Application of SSNTDs for measurements of fusion reaction products in high-temperature plasma experiment*, **Rad. Meas. 44** (2009) 878 – 880.

[B3] **A. Malinowska**, A. Szydłowski, M. Jaskóła, A. Korman, K. Malinowski, M. Kuk: *Calibration of new batches and a study of applications of nuclear track detectors under harsh condition of nuclear fusion experiments,* **Nucl. Instr. & Meth. B 281** (2012) 56 - 63.

[B4] **A. Malinowska**, A. Szydłowski, M. Jaskóła, A. Korman, *Influence of high temperature on solid state nuclear track detector parameters*, **Rev. Sci. Instrum. 83**, (2012) 093502-1 – 093502-4.

[B5] **A. Malinowska**, A. Szydłowski, M. Jaskóła, A. Korman, B. Sartowska, T. Kuehn, M. Kuk, *Investigations of protons passing through the CR-39/PM-355 type of Solid State Nuclear Track Detectors,* **Rev. Sci. Instrum. 84** (2013) 073511 – 073515.

[B6] A. Picciotto, D. Margarone, A. Velyhan, P. Bellutti, J. Krasa, A. Szydlowski, G. Bertuccio, Y. Shi, A. Mangione, J. Prokupek, **A. Malinowska**, J. Ullschmied, G. Korn, *Boron-Proton Nuclear Fusion Enhancement induced in silicon targets by Low Contrast Pulsed Laser*, **Phys. Rev. X. 4** (2014) 031030-1 – 031030-8.

[B7] **A. Malinowska**, M. Jaskóła, A. Korman, A. Szydłowski, M. Kuk, *Characterization of solid state nuclear track detectors of the polyallyl-diglicol-carbonate (CR-39/PM-355) for light chargetd particle spectroscopy*, **Rev. Sci. Instrum. 85** (2014) 123505 – 123508.

[B8] D. Margarone, A. Picciotto, A. Velyhan, J. Krasa, M. Kucharik, A. Mangione, A. Szydlowski, **A. Malinowska**, G. Bertuccio, Y. Shi, M. Crivellari, J. Ullschmied, P. Bellutti, G. Korn, *Advanced scheme for high-yield laser driven nuclear reactions*, **Plasma Phys. Control. Fusion 57** (2015) 014030-1 – 014030-7.

[B9] **A. Malinowska**, M. Jaskóła, A. Korman, A. Szydłowski, M. Kuk, *Charged projectile spectrometry using the CR-39/PM-355 type of Solid State Nuclear Track Detector*, **Nukleonika 60** (2015) 591 – 596.

[B10] A. Szydłowski, **A. Malinowska**, M. Jaskóła, K. Szewczak, A. Korman, M. Paduch, M. Kuk, *Influence of soft X-ray radiation on the parameters of tracks induced in CR-39 and PM-355 solid state nuclear track detectors*, **Rad. Meas. 83** (2015) 26 – 30.

[B11] **A. Malinowska**, M. Jaskóła, A. Korman, A. Szydłowski, K. Malinowski, M. Kuk, *Change in the sensitivity of PM-355 track detectors for protons after long – term storage*, **Rad. Meas. 93** (2016) 55 – 59.

Descriptive and percentage, that determines the contribution of me in the formation the aforementioned publications are presented in **Appendix No. 7** „*The list of published manuscripts*“. In **Appendix No. 6** is a detailed list of citations of these works „*List of citations of publications by the database of Web of Science dated 01.12.2016.*

Statements of coauthors determine the individual contribution of each of them in the formation the above-mentioned publications have been attached in the **Appendix No. 5** „*Statements of coauthors*“.

3. Autoreferat w języku angielskim

The above results have been collected in the years 2008-2016 and have been contributed to a lot of people who I wish to thank greatly. Special thanks for the willingness and the way in which passed on their knowledge and experience I give to Prof. Marian Jaskóła and Dr hab. Adam Szydłowski.

4.2. INTRODUCTION

One of the most developed current EU programs with high potential for innovation includes research related to fusion energy. The growing economy in Poland and all over the world depends on different sources of energy. The current energy requirements are met mainly by fossil fuels (petroleum, coal and natural gas), which account for 80% of the total energy production. However, the resources of oil and natural gas will gradually run out and significantly contribute to the emission of gases causing the greenhouse effect. It is known that the demand for energy continues to grow. Provides that it will rise twice over the next 50 years, mainly due to the population growth and also increase the well-being of societies of developing countries, it can lead to an energy crisis. Of particular importance in order to ensure in the future an efficient and safe for people and the environment, sources of energy will have a fusion energy using the energy given off as a result of thermonuclear fusion, hydrogen isotope such as deuterium and tritium. From the reaction of synthesis you will be able to get a lot more energy than fission of heavy nuclei in nuclear power stations, using the rich and generally available deposits of natural resources, such as water containing deuterium and lithium used to produce tritium. A by-product of nuclear fusion is helium, which does not pollute the environment.

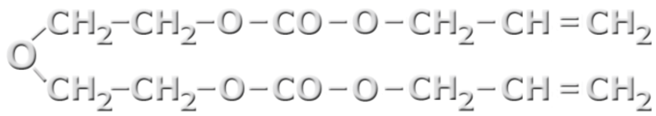
FUSION REACTIONS

Reaction	Emitted energy (MeV)
D + D → ^{3}He (0,82) + n (2,45)	3,27
D + D → T (1,00) + p (3,03)	4,03
D + T → ^{4}He (3,52) + n (14,08)	17,60
D + ^{3}He → ^{4}He (3,70) + p (14,70)	18,40

In fusion reactions the long-life isotopes are not produced. Radioactive tritium used as fuel breaks down relatively quickly (half-time is 12.6 years), and during decay it emits beta radiation (electrons with low energy). Since tritium is produced in the reactor, there is no need to provide the raw material for the plant. The fuel consumption will be very low. To generate 7 billion kWh of energy, the power plant with a capacity of 1 GW will need about 100 kg of deuterium and 3 tons of lithium. To produce the same amount of energy by traditional coal-fired power plants are needed about 1.5 million tons of the raw materials. Development of these studies has led to increasing interest in the ^{11}B (p, α) 2α fusion reaction, which is currently investigated on various laser systems with different size and power. On the basis of these reactions it is also considered the concept of building so called - "Ultra Clean nuclear reactor".

Knowledge of the most important parameters of the plasma such as temperature, density and radiation losses is very important for the understanding of plasma behavior in various experimental systems as well as from the point of view of the feasibility and exploration of the proposed devices in the future. Plasma confined by a magnetic field and held in a stainless steel chamber (e.g.tokamak, stellerator) usually has extreme parameters and therefore conventional methods of measurement do not apply in their determination. Thus, plasma diagnostics being developed tend to have the innovative nature and always are used to study some physical processes, from which one can draws information on individual parameters. Nuclear Track Detectors (NTD) appear to be an alternative approach to surmount this problem. Recently we developed passive techniques of ion measurements, which do not intervene in the area of the plasma and do not disturb its stability and behavior. Using these methods, information about the parameters and plasma behavior in specific conditions is gained from the analysis of the radiation and particles emitted from the plasma.

The main scientific aim is to investigate the spectroscopic properties of the Solid State Nuclear Track Detector (SSNTD) for plasma experiments and to demonstrate the wide range of applications of such detectors. SSNT detector - Polyallyl diglycol carbonate (PADC):



can be a very effective tool in experimental study of thermonuclear fusion reactions occurring in various plasma devices such as: tokamak, stellarator or laser-based systems. The main advantages of this detector are as follows: 1). It can register charged products of fusion reactions, such as protons, alpha particles or tritons with the efficiency equal to ~ 100%; 2). It is resistant to harsh conditions existing within these devices as elevated temperature, high vacuum, alternating and high magnetic fields; 3). This detector is insensitive to electromagnetic radiation such as UV, X, γ, and also to electrons.

Plasma physics is not the only field in which nuclear track detectors are used. Other areas of science and technology, in which this type of detectors are used as an important research tool are nuclear physics, physics of cosmic radiation, dosimetry of ionizing radiation, geology, medicine and environmental protection.

4.3. DISCUSSION OF THE RESULTS

4.3.1. SPECTROMETRIC ANALYSIS OF CHARGED PARTICLES BY MEANS OF THE SOLID STATE DIELECTRIC DETECTOR

When a suitable detector is selected e.g. for measurement of ions escaping from a high-temperature plasma, attention should be paid to the fact that it will be operated in hash conditions and it must cope with a variety of constraints such as: vacuum, high temperatures, strong magnetic fields, a strong background radiation (mainly gamma radiation and neutron), etc. For example, semiconductor detectors such as germanium, silicon and, recently used, diamond are the most frequently used for the measurement of charged particles. Semiconductor detectors are characterized by a good energy resolution about 10 keV and time resolution of approximately 10 ns. In practice such good parameters are hindered by strong x-ray radiations. Another inconvenience is the fact that in the case of a large stream of ions the pulses overlap and the detector saturates. Solid State Nuclear Track Detectors (PADC) appear to be an alternative approach to surmount this problem.

The application of different kind of the Solid State Nuclear Track detector (PADC) depends among other things on their parameters which include: the energy resolution, linearity over a wide range of projectile (electromagnetic radiation) energy, high detection efficiency for charged particles and electromagnetic radiation of energy covering a broad domain, long lifetime, resistance to different environments, production costs and running costs, etc: (the list of different parameters can be very long).

To use of SSNTDs in an optimal way and to take the full advantage of their properties, they should be precisely tested before using in experiment. In our laboratory, work related to examining the properties of the dielectric track detector of CR-39/PM-355 type have been conducted for several years, so we were able to gather a very large collection of data on the characteristics of the detector, with particular regard to the usefulness of this detector to spectrometric analysis of fast charged particles. Moreover, some of the experiments were designated to investigate sensitivity of the detector on external factors such as ambient temperature, X-rays and gamma rays. We determined and compared the calibration diagrams of detectors from different suppliers (produced at different times during the years 2000 to 2013). In this way I found relation between changes in production processes and detection efficiency of track detector. It was also examined so-called "aggeing effect" ("aging" the detector), ie. changes in the properties of the detector due to the passage of time between production processes and use of track detector. In addition, we are determined the rates of the detector etching such as a V_B, V_T, V_B / V_T.

I plot a series of calibration curves for newly purchased Solid State Track Detector of the CR-39/PM-355 type (Fig.1 left side). The main aim of this work was to find characteristics of the detector, which could be used to identify registered ions in respect of their energy as well as their mass and charge (track diameters and mean gray level). Some rectangular samples of the CR-39/PM-355 type detector were first irradiated in a vacuum chamber with almost mono-energetic light ions like H^+–, and $^4He^+$. Ions of different energies were provided by a particle accelerator. The irradiation was made at almost normal incidence on the SSNTD samples by ions elastically scattered from suitable thin target foils (Au, C). During these irradiations ion energy values were changed in step of 200–300 keV in the energy interval from 200 keV to 2 MeV. Alpha particles with energy of a few MeV can also be obtained from some natural α-sources such as an ^{241}Am (5.486 MeV), ^{212}Po (8.78 MeV), ^{212}Bi(6.05 MeV), ^{239}Pu(5.15 MeV). The ion fluxes are measured using e.g. a Si surface barrier detector in order to measure the energy spectra of the incident ions and to control counting rates over the track detector area. The fluxes of the projectiles that hit the track detector samples should not exceed (2–4) × 10^4 particles/cm^2. After the irradiation, samples are chemically etched in steps in a 6.25 N water solution of NaOH at a temperature of 70 ± 1°C. The etching procedure is interrupted every 2 h, the SSNTD samples are washed and dried, and track parameters are measured under a Nikon type (Japan) optical microscope fitted with an objective lens of 2 times magnification. The track detector read-out are made using a semiautomatic system composed of the optical microscope connected to a PC by means of a CCD camera

(Nikon DS.-Fi2, 5.24 Mpix) and suitable software (Nikon – NIS – Elements BR 4.00.03 – 64 bit). Etched tracks are counted automatically in 10 different fields taken randomly surrounding the center of the detector. The etched tracks appear as dark spots on a bright background. Because the angle of incidence of the projectiles reaching the detector surface are almost perpendicular we observe that the shape of the etch pit is almost circular (we select only tracks of circularity C = 0.8–1. The circularity is defined as C = (4π × [Area]/[Perimeter]^2) and ranges from 0 (infinitely elongated polygon) to 1 (perfect circle)). To analyze the etching tracks I use another program, ImageJ. The microscope image processing is a broad term that covers the use of digital image processing techniques to analyze images obtained from a microscope.
The obtained calibration diagrams present track diameters (D) as a function of projectile energy (E) and etching time (t). These diagrams show that track diameters increase very fast in the region of relatively low particle energies [B1], [B3], [B7], [B9], [B11]. When the maxima are reached the track diameters decrease monotonically with a further increase of the projectile energy. In the D(E, t) decreasing region (D(E) versus projectile energy E) the D(E, t) the obtained dependences approximately reflect the stopping power curve (i.e. dE/dx vs projectile energy dependence). Generally the variation of the diagram presenting track diameter versus particle energy is similar to the behavior of the Bragg curve. Figure 1 (on the left side) shows an example of diagram presenting diameters of craters induced by protons, deuterons and alpha particles vs energy of these projectiles.

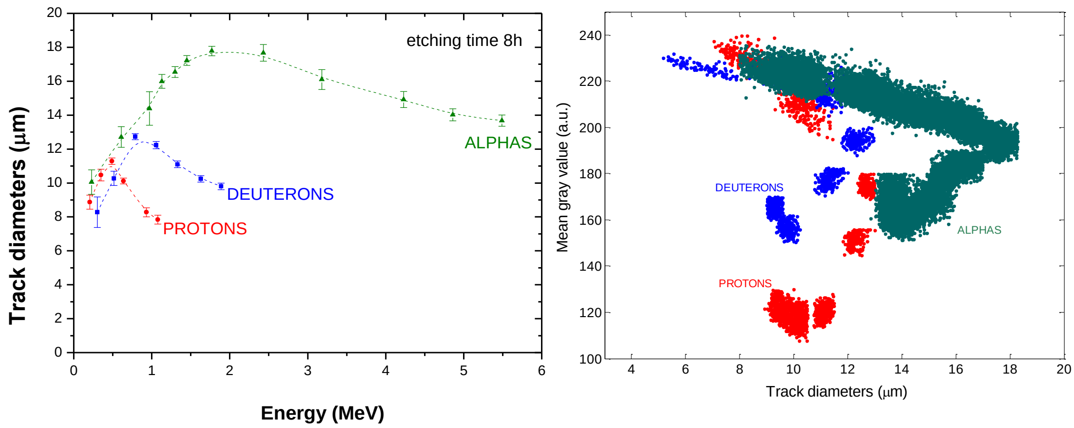


Fig. 1. Track diameters presented vs particle energy. Two-dimensional distribution of the mean grey level values as a function of track diameter.

The determined calibration data also present that tracks of the same track diameter can be produced by projectiles of different incident energies, which makes it difficult to determine unambiguously the particle energy basing only on these diagrams. The etch pits produced by protons, deuterons and alpha particles with energies above the maximum may have diameters equal to those produced by projectiles with energies below maximum. Taking into consideration this ambiguity one can conclude that measurement of track diameter is not enough to determine the projectile energy. In order to overcome this ambiguity, I propose to perform additionally an analysis of the track grayness to estimate the so called track mean gray level (Fig.1 on the right side) [B7], [B9]. The degree of gray specifies approximately the amount of light that passes through the track surface in its observation under an optical microscope. The so-called mean gray level is the mean value of the gray level in the eight-bit color scale (0-black - 255 white). This parameter has been set previously by other authors, according to a review of the literature, for craters created by alpha particles, but I use such parameters the first time for tracks created in the CR-39/PM-355 detector by protons and deuterons. It was estimated that on the basis of knowledge of these two parameters, the energy resolution of the CR-39/PM-355 detector used for analyzing the light ions (p, d, α) is close to ΔE ~ 50 keV. The results are very important, especially for plasma experiments, because during most of them both protons, deuterons and α particles are analyzed in the first place [B3]. Generally, the energy resolution of the tested detectors is influenced by different factors, like variation of the V_B values (bulk etch rate), even if the same detector material as well as etching conditions (temperature, NaOH concentration and duration of etching time) are used, and also by differences associated with the PM-355 material production procedure (V_B). It is also important to select appropriate input parameters like circularity, size, threshold etc. for the image processing software.

The detection efficiency of a nuclear track detector of the CR-39/PM-355 type is estimated on the basis of track density (i.e. number of traces visible on the unit surface of the detector). Using such detectors I was able to determine the density of particle tracks up to 5 x 10^7 particles per square centimeter. The results of our tests, carried out up to now, indicate that under optimal etching conditions of such detector its detection efficiency is ~ 100%. These results were obtained taking into account the number of Silicon semiconductor detector counts, which was used as a monitor of the stream and the energy spectrum of the ions obtained from the ion accelerator that irradiated the investigated detector samples. The estimated magnitude of the detection efficiency does not depend on the type and energy of the particles in a fairly wide range of their energy (for protons, for example in the energy range of 0.1 to ~ 8 MeV).

It was also investigated that the detection properties of CR-39/PM-355 detectors from different batches differ significantly and that detectors purchased at different times reveal craters of various diameters (for the same ion and the same etching time) B[3].

Due to the fact that I calibrated every newly purchased batch of detectors we collected a lot of calibration curves (since 1990), the answer does not create major difficulties.

I can see that the calibration characteristics determined for each individual detector batch differ significantly. This means that samples taken from different deliveries present craters of different sizes even when they are irradiated with the same ions and etched for the same time. This could confirm the supposition that various manufacturing procedures were used to produce these detectors. The suggestion recommending the precise calibration of each detector delivery seems to be well-founded. The obtained data from track diameters measurements show that the PM-355 detectors manufactured in 2010 reveal tracks almost 30% larger than the detectors produced in 2000. This difference is more evident for α particle craters than for craters induced by protons and deuterons. The ratios of a particle track diameters in these two detectors Ø(2010)/Ø(2000) are in the range 1.30–1.35 and do not noticeably depend on the detector etching time, whereas for the deuteron craters this ratio is equal to about 1.25 [B3]. We noticed that with increasing of track diameters increases also reduced etching rate of the detector, which is a function of sensitivity $V = V_T/V_B$. It is defined as the ratio of the etching rate along the axis of the track V_T (track etch rate) to etching rate of non exposed surface of the detector V_B (bulk etch

rate). We have shown that the V_B value of the detector will not change significantly from 1.5 to 1.65 µm/ h for a various batch of the detector, therefore, this parameter can not be crucial determinant of the sensitivity of such detector.
We also investigated the influence of high temperatures on tracks induced in solid state nuclear track detectors of the CR-39/PM-355 type [B4].

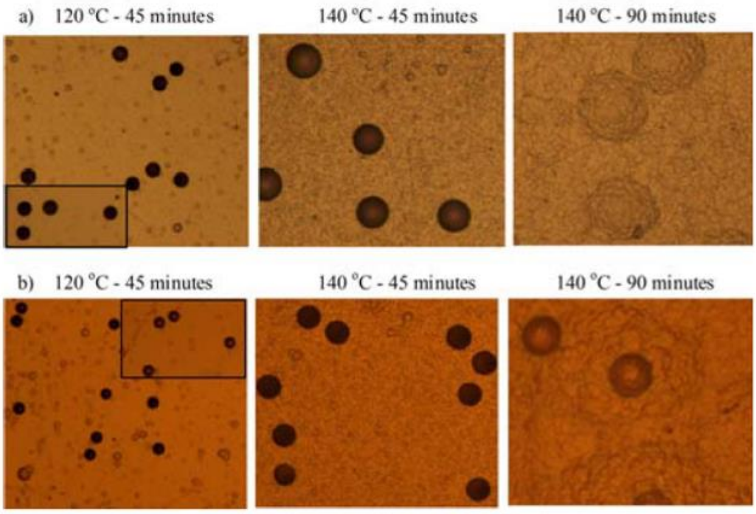
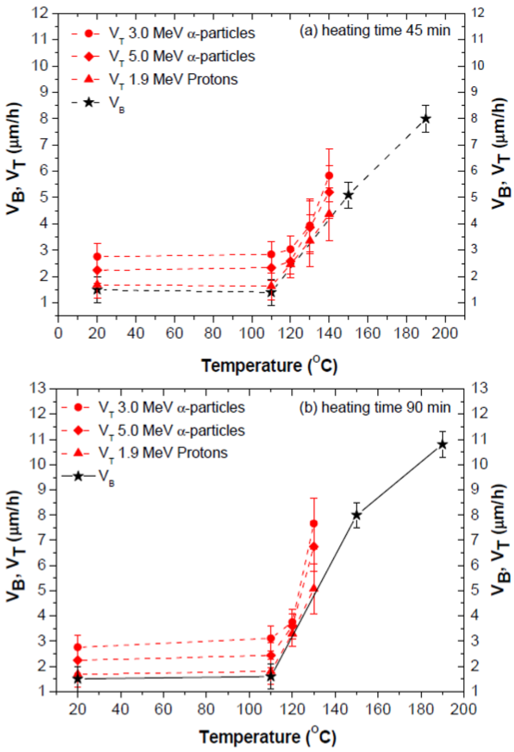


Fig. 2. Sample photos of tracks observed in PM-355 detector samples which were etched for 5 h. The tracks were induced by: (a) 3.0 MeV α particles, (b) 5.0 MeV α particles.

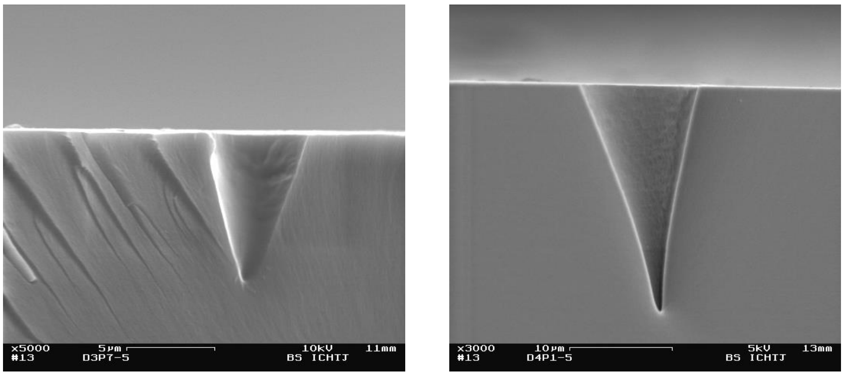


Rys. 3. The bulk etch rates V_B of PM-355 detector material and track etch rate values V_T as determined for craters induced by protons and α particles. The detector samples were etched for 5 h and the diagrams are presented versus the heating temperature for two different heating times: (a) 45 min and (b) 90 min.

The results of the measurements show that in the sample which was kept at room temperature and those in the samples heated to temperatures lower than 120˚C are nearly identical, meaning that the craters were not deformed at temperatures below 120˚C, regardless of the heating time. The samples which were heated at temperatures of 140˚C and above present craters that are considerably deformed and their diameters are noticeably enlarged. The craters disappeared totally in the samples which were kept in the oven at temperatures of 180˚C and 190˚C for a time longer than 30 min (Fig.2).
This is due to the increase in the bulk etch rate V_B values, which becomes equal to the track etch rate V_T values of PM-355 detector material. This means that the sensitivity function $V = V_T/V_B$ is going to unity and the tracks induced by the investigated projectiles (i.e., protons and α particles) tend to disappear at these temperatures in PM-355 detector material (Fig.3).
The track etch rate V_T of the PM-355 material was calculated for proton and α particle induced craters using the standard method proposed by Fleischer (1975) [B4], [B5].
This method consists in the measurement of the track diameter D(t) during the time of the etching process t:

$$V_T = V_B \frac{1 + \left(D(t)/2 \cdot V_B \cdot t\right)^2}{1 - \left(D(t)/2 \cdot V_B \cdot t\right)^2}$$

where D(t) is the measured track diameter and t the detector etching time. Fleischer formula is correct, assuming that the shape of the crater inside the detector is conical. This assumption was confirmed by us during testing of craters profile using scanning electron microscopy (SEM) (Fig.4).



Rys. 4. Sample of pictures presented craters of alpha particles of energy 5.5 MeV.

Determining the V_B and V_T values has a great importance. These magnitudes could be used to evaluate the sensitivity function $V=V_T/V_B$ of the tested detectors. Knowledge of the sensitivity function has a fundamental importance for the theoretical description of the track formation mechanism and track properties.
In 2014 it was also examined (in a large percentage by me) influence of soft X-ray radiation on craters induced in SSNTDs by energetic α particles and protons of energy in the MeV range [B10]. We checked two types of the detectors: one of the PM-355 (manufactured by the Pershore Company (England)) and another of the CR-39 (TASTRAK) (bought from the Track Analysis Systems Limited (England)) type, in order to verify and compare their resistance to the harsh conditions of high-

temperature plasma experiments. It was found that the etch pits in the samples that absorbed some doses of the X ray radiation are bigger and their diameters differ noticeably from pits produced by the same projectiles in the original (not irradiated) detectors. This difference is greater for craters produced by lower energy projectiles (0.5 MeV protons) and decreases for craters induced by more energetic projectiles (1.2 and 1.9 MeV protons) (Fig.5). The CR-39 (TASTRAK) detector is more resistant to X ray radiation than the PM-355 one. Due to this fact the first type of the detector get higher interest on our side, and we plan to use this type for future plasma experiments. The measurements in this direction are continued.

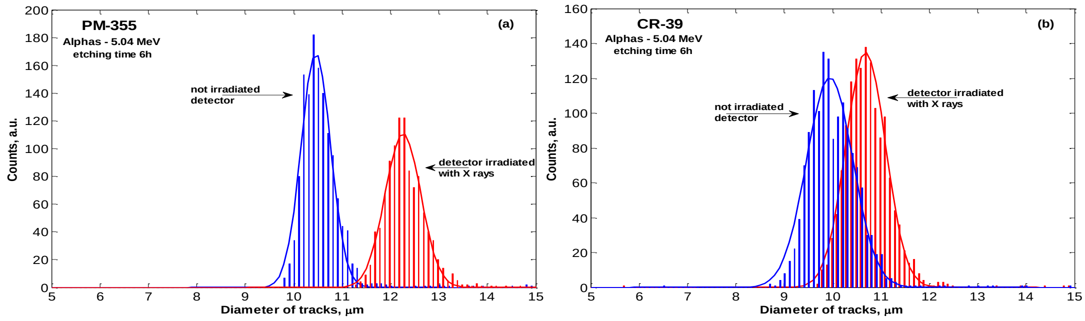
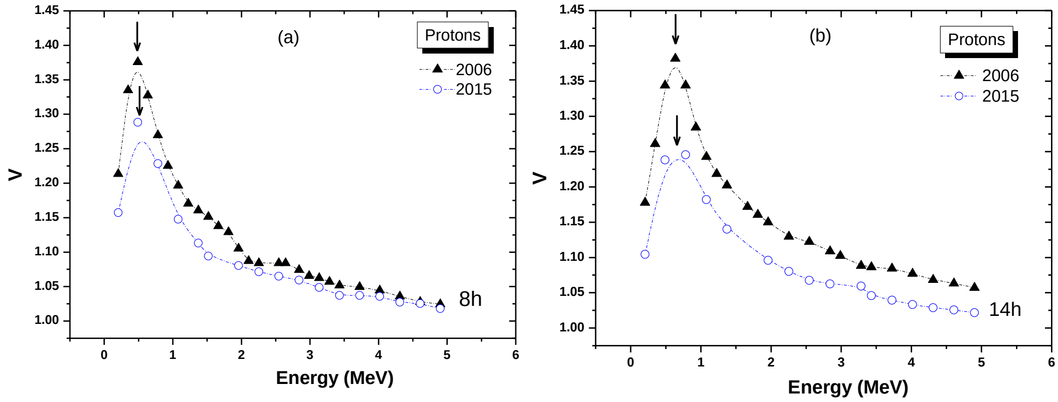


Fig. 5. Histograms of crater diameters as measured in PM-355 and CR-39 detector samples which were first irradiated with 5.04 MeV alpha particles and then exposed to X ray radiation delivered by an X ray tube. The blue curves represent histograms of crater diameters measured in the samples which were not exposed to the X ray radiation.

In one recently performed work, I determined so-called "ageing effect" B[11]. How much ageing (none irradiated samples), fading (irradiated samples) and other factors can affect the calibration factor and in consequence the precision of the measurements is a fundamental question. Some papers state that ageing and fading effects can produce a decrease in the detector sensitivity (lower V_T/V_B) leading to an under or over estimation of the radiation dose and other measurements. I assemble the results of the detailed measurements of etch pit diameters D(E, t) which were performed for proton tracks in 2006 and 2015, i.e. track diameter D(E, t) versus proton energy and etching time values. The obtained results describe, that the track diameter increases very quickly in the region of relatively low proton energies. When the maxima are reached the track diameters decrease monotonically with a further increase of projectile energy. After storage of the irradiated samples at room temperature in the absence of light the etch pit diameters of protons are reduced by about 10 ÷ 20% over a period of about 9 years; assuming a linear dependence the track diameters decreased about 1 ÷ 2% per year. The reduction in track diameters versus proton energy is about constant for 8 h etching time but for 14 h etching time the diameters decreased considerably versus energy of proton from 15% to about 30% in the 9 years of the storage period. I also measuremed the values of the bulk etch rates V_B in 2006 and 2015 year. The obtained results are practically identical $V_B = 1.65 \pm 0.2$ mm/h in 2006 and in 2015 $V_B = 1.62 \pm 0.2$ mm/h). The ratio of the old V_B (2006) to the new V_B value (2015) is practically equal to unity within 2-3 percent. This indicates that the V_B values are not affected by the ageing effect and remain practically constant for this material. The values of the sensitivity function V obtained in 2006 and 2015 are presented in Fig. 6(a, b) versus proton energy and etching time t = 8 and 14 h.



Rys. 6. (a, b). Variation of the sensitivity function $V=V_T/V_B$ measured in2006 and 2015 for different etching times (8 and 14 h). The arrows on the figures indicate the positions of the maxima of the sensitivity function.Zmiana funkcji czułości $V=V_T/V_B$ w okresie od 2006 do 2015 dla różnych czasów trawienia detektora.

The experimental errors in the determination of the sensitivity function V are of the order of 10-15%. Generally, the sensitivity function for protons represents a small loss of sensitivity with storage time. Assuming a linear dependence the reduction in the V function is about 1-2% per year. The smaller loss of sensitivity with storage time for proton projectiles in comparison to particles can be explained by lower ionization density for proton projectiles relative to particles in the region of projectile latent trails. Higher density of ionization results in a greater probability of recombination and in decreased track diameters and in consequence in a decrease of the sensitivity function V_T / V_B.

The obtained results were published in the following reviewed journals:

[B1] **A. Malinowska**, A. Szydłowski, M. Jaskóła, A. Korman, B. Sartowska, M.J. Sadowski, J. Badziak, J. Żebrowski, *Calibration and application of modern track detectors CR-39/PM355 in nuclear physics and high temperature plasma experiments*, Nukleonika 53 (2008) S15 – S19.

[B3] **A. Malinowska**, A. Szydłowski, M. Jaskóła, A. Korman, K. Malinowski, M. Kuk: *Calibration of new batches and a study of applications of nuclear track detectors under harsh condition of nuclear fusion experiments,* Nucl. Instr. & Meth. B 281 (2012) 56 – 63.

[B4] **A. Malinowska**, A. Szydłowski, M. Jaskóła, A. Korman, *Influence of high temperature on solid state nuclear track detector parameters*, Rev. Sci. Instrum. 83, (2012) 093502-1 – 093502-4.

[B5] **A. Malinowska**, A. Szydłowski, M. Jaskóła,. A. Korman, B. Sartowska, T. Kuehn, M. Kuk, *Investigations of protons passing through the CR-39/PM-355 type of Solid State Nuclear Track*

Detectors, Rev. Sci. Instrum. 84 (2013) 073511 - 073515.

[B7] **A. Malinowska**, M. Jaskóła,. A. Korman, A. Szydłowski, M. Kuk, *Characterization of solid state nuclear track detectors of the polyallyl-diglicol-carbonate (CR-39/PM-355) for light chargetd particle spectroscopy,* Rev. Sci. Instrum. 85 (2014) 123505 – 123508.

[B9] **A. Malinowska**, M. Jaskóła, A. Korman, A. Szydłowski, M. Kuk, *Charged projectile spectrometry using the CR-39/PM-355 type of Solid State Nuclear Track Detector,* Nukleonika 60 No3 (2015) 591 – 596.

[B10] A. Szydłowski, **A. Malinowska**, M. Jaskóła, K. Szewczak, A. Korman, M. Paduch, M. Kuk, *Influence of soft X-ray radiation on the parameters of tracks induced in CR-39 and PM-355 solid state nuclear track detectors*, Rad. Meas. 83 (2015) 26–30.

[B11] **A. Malinowska**, M. Jaskóła, A. Korman, A. Szydłowski, K. Malinowski, M. Kuk, *Change in the sensitivity of PM-355 track detectors for protons after long – term storage*, Rad. Meas. 93 (2016) 55 –59.

The most important results were also presented at several conferences:

1. **A. Malinowska**, A. Szydłowski, M. Jaskóła, A. Korman, M. Kuk. Application of SSNTDs for corpuscular diagnostics in plasma experiments. Deformation of craters by heat effects, 25th Int. Conf. on Nuclear Tracks in Solids, 4–9 Sept. 2011, Puebla, Mexico – **Oral.**
2. A. Szydłowski, **A. Malinowska**, M.Jaskóła, A.Korman, M.Kuk. Further investigation of modern SSNTDs, Int. Conf. PLASMA 2011, “Research and Applications of Plasmas”, 12 – 16 Sept. 2011, Warsaw, Poland – **Poster.**
3. **A. Malinowska**, M. Jaskóła, A. Korman, A. Szydłowski, M. Kuk. Characterization of Solid State Nuclear Track Detectors of the CR-39/PM-355 type for light charged particle spectroscopy, 26th Int. Conf. on Nuclear Tracks in Solids, 15-19 Sept. 2014, Kobe, Japan – **Oral**.
4. **A. Malinowska**, M. Jaskóła, A. Korman, A. Szydłowski. Charged projectile spectrometry using the CR-39/PM-355 type of solid state nuclear track detector, NUTECH-2014, Intern, Conf. on Development and Applications of Nuclear Technology, 21-24 Sept. 2014, Warsaw, Poland – **Oral**.
5. A. Szydłowski, **A. Malinowska**, M. Jaskóła, K. Szewczak, A. Korman, M. Paduch. Influence of intense soft X-ray radiation on the parameters of tracks induced in CR-39 and PM-355 solid state nuclear track detectors, 26th Int. Conf. on Nuclear Tracks in Solids, 15-19 Sept. 2014, Kobe, Japan – **Poster.**
6. **A. Malinowska,** M. Jaskóła**,** A. Szydłowski. Change in the sensitivity of solid state nuclear track detectors for ions emitted from plasma, 18th International Conference on the Physics of Highly Charged Ions, 11-16 Sept. 2016, Kielce, Poland – **Poster.**

4.3.2. APPLICATIONS OF SOLID STATE DETECTORS

One of the very important reason for carrying out discussed test measurements is an increasing interest in the p + ^{11}B nuclear reaction. This reaction was first performed in 1930 by Oliphant and Rutherford. Interest from the scientific community in this reaction is now increasing due to the possibility of producing energetic alpha particles without neutron generation. On the basis of this reaction it is also considered the concept of ultra-pure nuclear reactor ("Ultra Clean reactor"). The first experimental demonstration of obtaining nuclear reaction described above, was carried out at the picoseconds lasef with the power density of 2 x 10^{18} Wcm^{-2}. Emission performance of alpha particles from boron enriched polymer shield after exposure to such laser beam was about 10^3 per steradian. In similar experiments, using the more sophisticated experimental systems, the performance was of the order of 10^7 per steradian. The main aim of the research, in which we are going to participate is to obtain high-performance of alpha particles from the p + ^{11}B reaction occurring in different targets, including the Silicon targets, with previously will be defunded hydrogen and thereafter will be implanted boron.

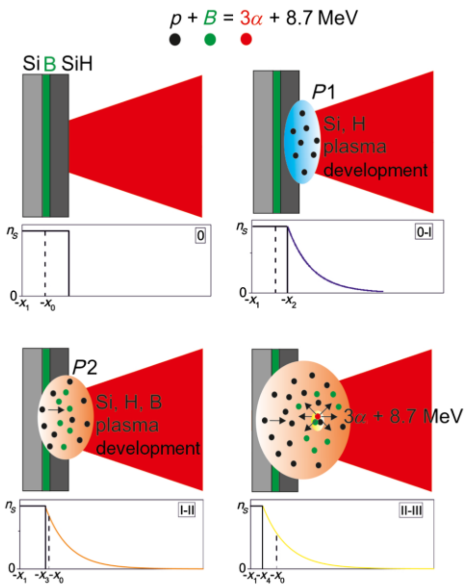


Fig. 7. Laser-target, laser-plasma, and proton-boron interactions in the 2-ns range before the maximum laser intensity.

A simplified picture describing mechanism of the long laser-pulse interaction with the H-enriched and B-doped silicon target (Si-H-B) is sketched in Fig. 7. At a time of 2 ns before the maximum intensity, the laser pulse starts to interact with the Si-H layer causing ablation and ionization of the target material during the 0-I period (the laser fluence is about 30 Jcm^{-2}, i.e., well above the ablation threshold for Si, thus sweeping away the Si-H layer on the target surface. The target ablation continues during the I-II period affecting the implanted boron layer, as clearly demonstrated by the hydrodynamic simulations shown in Fig. 8. In fact, the ablation depth estimated numerically is around 10 μm at the end of this period; thus, the B plasma has clearly developed and protons are already accelerated from the Si-H inner layer.

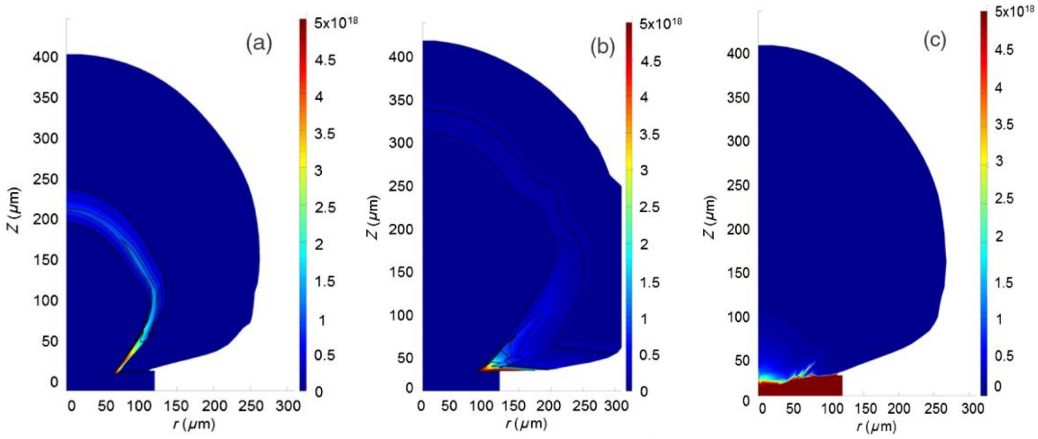


Fig. 8. 2D PALE hydrodynamic simulations of the boron plasma expansion after the action of the laser pulse (in the range 1–1.85 ns) for (a) the B layer implanted in the SiH substrate, (b) the B layer deposited on the SiH substrate, and (c) the B layer diffused in the SiH substrate.The gradients cale on the right-hand side shows the B-plasma density.

Z parameter in above figure is the plasma-expansion longitudinal direction (parallel to the target normal) and *r* is the plasma-expansion transverse direction (parallel to the target surface). The simulations take into account the time evolution of the laser pulse in the range 1–1.85 ns. It is clearly shown that after 1.85 ns, the B plasma is better confined (200 μm from the target surface) and has a higher density (approximately 10^{18} cm^{-3}) in (a) than in (b) and (c). Thus, in (a), the accelerated protons can subsequently interact with higher-density plasma and have a higher probability to induce nuclear reactions than in (b) and (c).

Our team (with a large participation of me) is involved in the measurements of fast protons and alpha particles, which are substrates and products of the test reactions. The present experiment was carried out on PALS laser system in Institute of Plasma Physics (IPP) in Prague [B6], [B8].

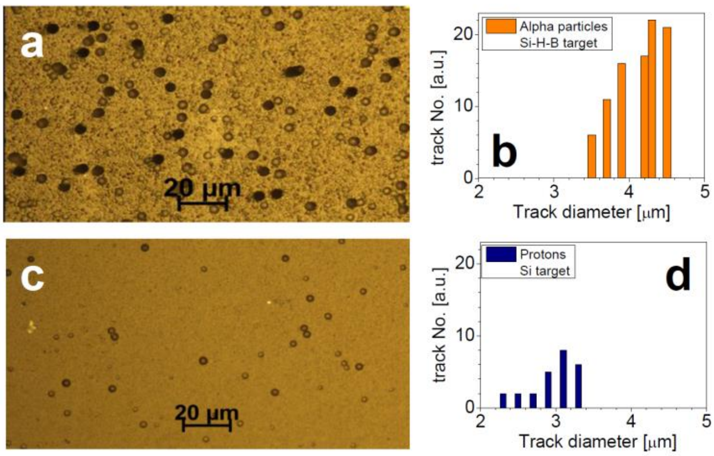
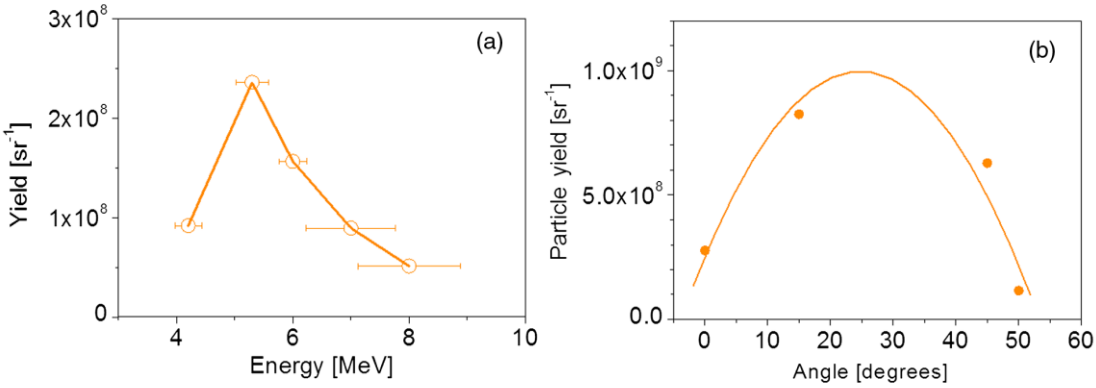


Fig. 9. Examples of craters produced by incident protons (small light craters) and alpha particles (large black craters) for (a) the Si-H-B target and (b) the corresponding histograms of particle crater diameters. (c) Craters produced by incident protons for the Si target and (d) corresponding histograms of particle crater diameters.

Three different kinds of target were applied and each of them was firstly saturated with hydrogen (up to a density of 10^{20} atoms H/cm^3), then boron atoms were doped by implantation of 50 keV boron ions. Used in the experiment CR-39/PM-355 detector samples simultaneously recorded tracks induced by primary protons and tracks produced by those α particles which were born in the p + B → 3α nuclear reactions. The α-particle tracks were distinguished from proton-induced tracks on the basis of the previously obtained calibration diagrams (Fig. 9).
Angular distributions of the α – particles which were emitted from the target were measured using a few detector samples deployed at different angles to the target normal. The distribution shows a maximum yield of about 10^9 particles per steradian, as shown in Fig. 10 (b). The method of differential energy filtering of ions, which induces tracks in calibrated detectors, allows us to determine also their energy distribution, shown in Fig. 10 (a). The energy of alpha particles ranges from 4 to 8 MeV with a maximum at around 4.5 MeV.



Rys. 10. (a) Alpha-particle energy distribution obtained from PM-355 analysis using detectors shielded with different Al filter thicknesses (6–20 μm) and placed at an angle of about 45° with respect to the laser-incident direction in the same laser shot. (b) Alpha particle angular distribution obtained from PM-355 analysis using detectors placed at different angles with respect to the laser-incident direction in the same laser shot.

The results obtained by the use of the track detector were confirmed by other participants who used quite different measurement techniques e.g. Thomson parabola spectrometer (Fig. 11(a)) and TOF measurements by the use silicon carbide detectors (SiC detector) etc. (Fig. 11(b)).
We have experimentally demonstrated the possibility of enhancing the ^{11}B(p,α)2α fusion reaction induced by high intensity laser pulses interacting with solid targets. A fusion rate of about 10^9 alpha particles per steradian per pulse was achieved by using low-contrast, long laser pulses and advanced targets. The high-current proton beam generated by the long (nanosecond) laser pulse presented an optimal energy distribution with a plateau around the maximum of the nuclear-reaction cross section. Furthermore, the multilayer target geometry with a high boron concentration at a given depth of the hydrogenated silicon sample allowed the nuclear reaction to occur when the boron-ion density was still very high (i.e., still close to the target surface), thus ensuring a very high-fusion rate. The obtained results showed that in the targets, in which B ions were implanted to a depth of about 190 nm occurred approximately $4\text{x}10^8$ acts of p + ^{11}B reaction. Maximum flow of α particles were at ~ 10^9 per steradian, registered in position close to 0^0 - relative to the perpendicular to the target.

Record number of reaction acts was associated with the use of laser of about average power of 2 TW and intensity of 3 x 10^{16} W/cm^2.

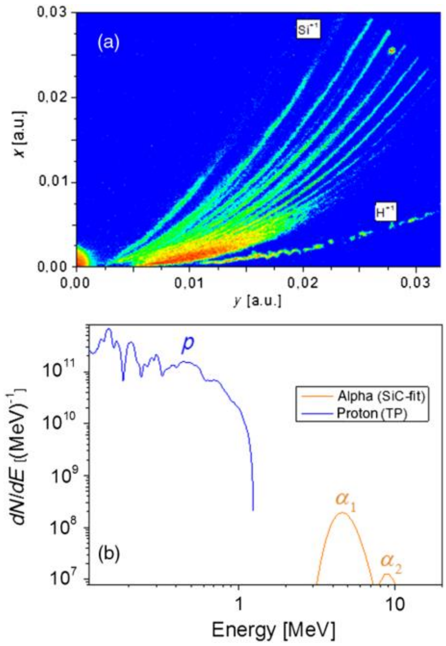


Fig. 11. (a) Typical TP spectrometer images showing the presence of backward-accelerated protons and heavier plasma ions. The corresponding proton-energy distribution and the comparison with the alpha-particle one (obtained by fitting the TOF spectrum) are shown in (b).

In the ENEA laboratory Frascati, where we conducted preliminary measurements of the p + ^{11}B reaction products , it was observed several orders of magnitude less acts of reaction (Fig. 12).

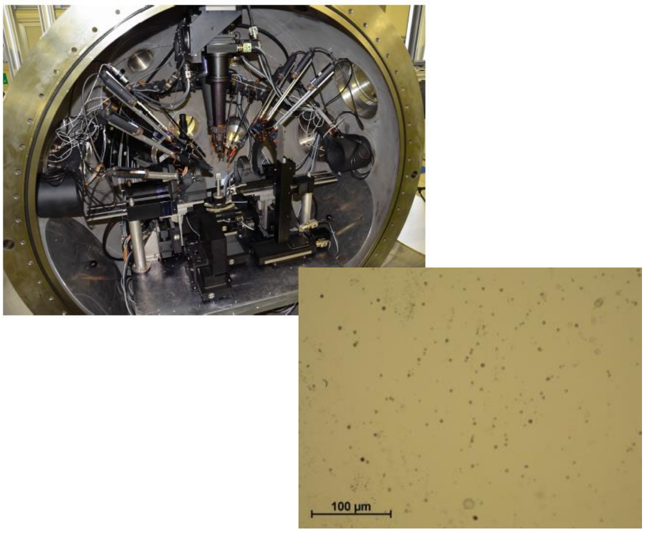


Fig. 12. Example photos of the ABC laser system and image of craters produced by protons.

The number of protons were estimated at 3 × 10^7 particles per steradian. To confirm the results presented above, we are planning further experiments, which will include studying reaction of p + ^{11}B and its products within other large laser systems, such as: Phelix at GSI in Germany and ABC in the laboratory ENEA in Frascati.

The purpose of the High Power Laser Laboratory (HPLL) at the Institute of Plasma Physics and Laser Microfusion (Fig. 13) is to study (with a large participation of myself) interactions of ultra-intense laser with plasma, which consists in researching two main fields of generation of ultra-short X-ray pulses and Laser acceleration of particles [1].

Fig. 13. IPPLM Laser Laboratory and important parts of Femto-Second Laser system.

Although research into femtosecond lasers is commonly associated with the studies of physical phenomena related to inertial confinement fusion — especially in fast ignition, particle acceleration for ICF — it can be also applied for the investigation of wake field acceleration, photo-induced material modifications due to ultrashort pulses, photonic crystals fabrication, and fiber Bragg grating inscription.
The energy spectra of fast ions (protons) emitted from the plasma were investigated by two types of SiC detectors (high energy range) and IC—ion collectors (low energy range).

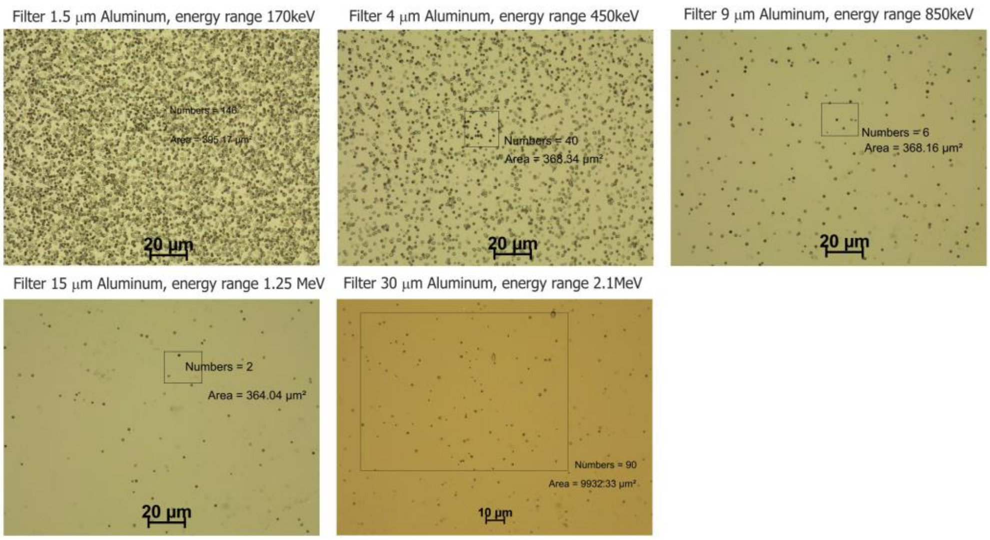


Fig. 14. Ion Track Detectors covered by different filters and irradiated by a stream of protons from several laser pulses.

These detectors operated on the basis of the time-of-flight method and allowed to determine the following parameters: velocity distribution, ion spectrum, average velocity and energy, and absolute ion current charge. By the use of the Solid State detectors of the CR-39/PM-355 type, the absorption method (using a Aluminium foil of different thickness), the information about the spectrum of ions is also obtained (Fig.14). By application of the filters with increasing width (1.5 μm up to 30 μm) the images corresponding to ions of energy greater than 170, 450, 850 keV, 1.25 and 2.1 MeV were obtained. The obtained results allowed to measure approximate energy spectra of the emitted particles and confirmed the presence of high energy protons of energy above 2.1MeV. This value is consistent with the record from the SiC detectors [1].

An important my scientific achievement for which we obtained a distinction (as a team) given by the a committee of the Scientific Council and the Director of the National Centre for Nuclear Research as a "scientific achievement in 2014 year," was to develop the results and obtain information about the p + ^{11}B reaction.

The obtained results were published in the following reviewed journals:

[B6] A. Picciotto, D. Margarone, A. Velyhan, P. Bellutti, J. Krasa, A. Szydlowski, G. Bertuccio, Y. Shi, A. Mangione, J. Prokupek, **A. Malinowska**, J. Ullschmied, G. Korn, *Boron-Proton Nuclear Fusion Enhancement induced in silicon targets by Low Contrast Pulsed Laser,* Phys. Rev. X. 4 (2014) 031030-1 – 031030-8.

[B8] D. Margarone, A. Picciotto, A. Velyhan, J. Krasa, M. Kucharik, A. Mangione, A. Szydlowski, **A. Malinowska**, G. Bertuccio, Y. Shi, M. Crivellari, J. Ullschmied, P. Bellutti, G. Korn, *Advanced scheme for high-yield laser driven nuclear reactions*, Plasma Phys. Control. Fusion 57 (2015) 014030-1 – 014030-7.

1. M. Rosiński, J. Badziak, P. Parys, A. Zaras-Szydlowska, L. Ryć, L. Torrisi, A. Szydłowski, **A. Malinowska**, B. Kaczmarczyk, J. Makowski, A. Torrisi, *Acceleration of protons in plasma produced from a thin plastic or aluminum target by a femtosecond laser,* J. Instrum. 11 (2016) CO5017-1 – CO5017-8.

and presented at the conference:

1. D.Margarone, A.Picciotto, V.Velyhan, J.Krasa, M.Kucharik, M.Morrissey, A.Mangione, A.Szydłowski, **A.Malinowska**, G.Bertuccio, Y.Shi, M.Crivellari, J.Ullschmied, P.Bellutti, G.Korn. Advanced scheme for high-yield laser driven proton-boron fusion reaction, High Power Laser for Fusion Research III; 07-12 February 2015, San Francisco, USA – **Oral**.
2. **A. Malinowska**, A. Szydłowski, M. Jaskóła. Wzrost zainteresowania reakcją syntezy 11B(p, α)2α, czy uda się powrócić do koncepcji zbudowania ultra czystego reaktora jądrowego? Polski wkład w badania, XLIII Zjazd Fizyków Polskich, 06-11 September 2015, Kielce, Poland – **Oral**.

Some specific properties, such as low cost, high detection efficiency of heavy charged particles, low sensitivity to fast electrons, and the fact that measurements of charged

particles by means of the dielectric track detectors are not affected by electromagnetic radiation (X, γ) and E-M noise intensely emitted by each plasma device meant that interest in this type of detectors has increased significantly in recent years. NTD have found widespread application in the measurements of fast ions emitted from the hot plasma produced e.g. in tokamaks or generated by laser pulse. Plasma physics is not the only field in which nuclear track detectors are used. Other areas of science and technology, in which this type of detectors are used as an important research tool are nuclear physics, physics of cosmic radiation, dosimetry of ionizing radiation, geology, medicine and environmental protection.
Recently I have participated in the work carried out in collaboration with the laboratory for heavy ion research at the University of Warsaw. The irradiation of living matter with charged particles has become increasingly interesting for medical applications like radiotherapy, radioprotection and space radiobiology. In this field, particle accelerators are helpful owing to the wide range of available ions, energies and flux or dose fractionation. Usually, two types of configuration are used: micro/nano beams and broad beams [B1]. A micro-beam can precisely target a defined point on a cell or a group of cells. The intensity and distribution of the scattered ions was measured by means of a surface-barrier Si detector with a 0.5 mm collimator. The ion beam profiles, as measured by the Si detector in two dimensional (x, y) intensity distributions (Fig. 15(a)). The measured beam uniformity was better than ± 2.5%. The beam uniformity was also checked also by using a nuclear track detector of the CR-39/PM-355 type. After the irradiation the detector samples were etched under standard conditions for 2 h. In figure 16 one can recognize a clear 1 × 1 cm^2 collimated beam. The measured beam profile distributions in two axes (x, y) are presented in figure 15(b). The achieved beam uniformity was about ± 3%, in quite good agreement with the results obtained using a time-consuming surface barrier silicon detector [B1].

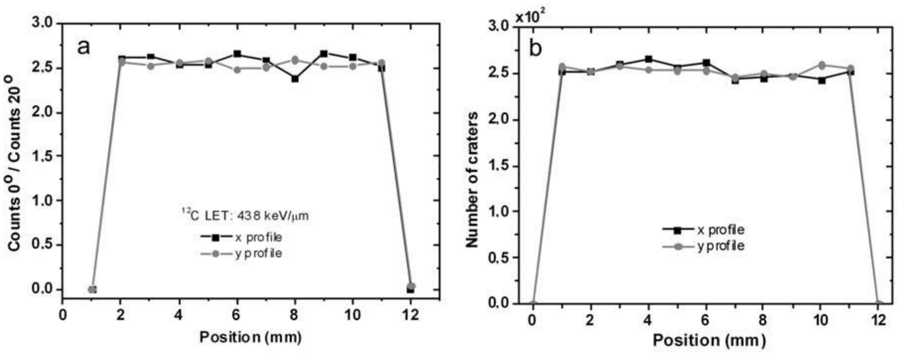


Fig. 15. Profiles of ion beams measured using: a – Si detector; b – PM-355 detector.

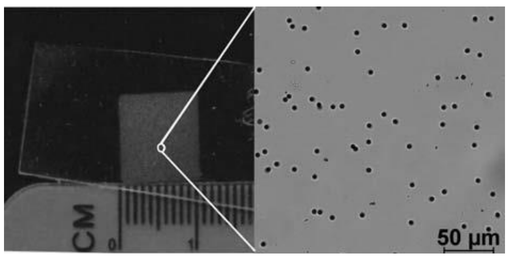
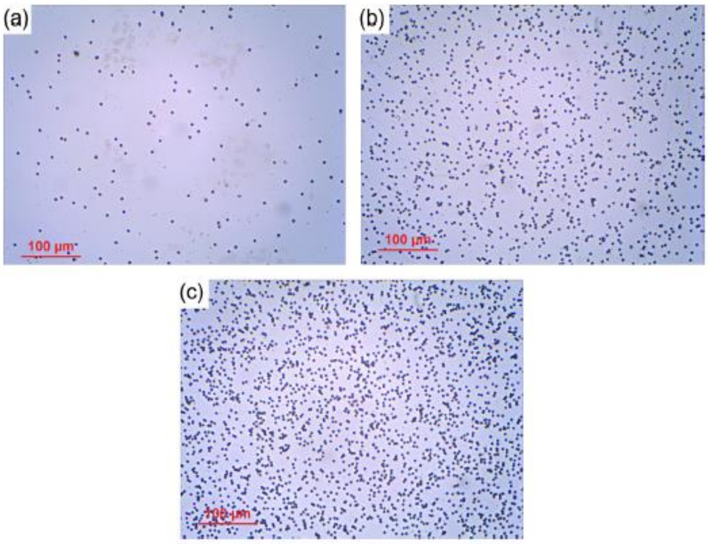


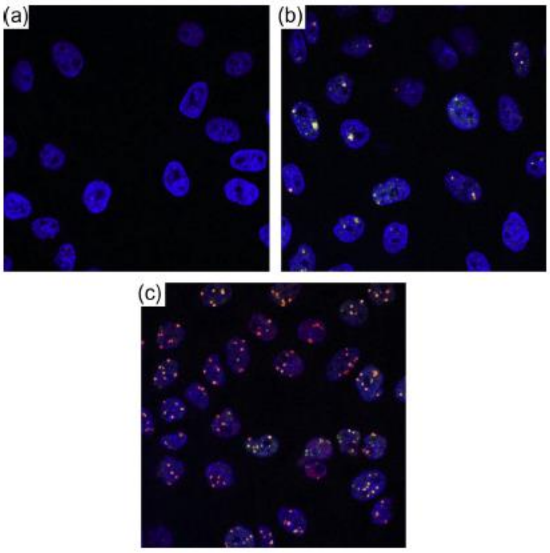
Fig. 16. Picture of ion beams profiles measured by the CR-39/PM-355 detector.

At the same collaboration I also have participated in the work were the main aim was to verify various dosimetry methods in the irradiation of biological materials with a

^{12}C ion beam at the Heavy Ion Laboratory of the University of Warsaw [2]. To this end the number of ions hitting the cell nucleus, calculated on the basis of the Si-detector system used in the set-up, was compared with the number of ion tracks counted in irradiated Solid State Nuclear Track Detectors and with the number of ion tracks detected in irradiated Chinese Hamster Ovary cells processed for the γ-H2AX assay (Fig. 17, 18) [2].



Rys. 17. The results of the PM-355 track detectors irradiated with: (a) 0.05 Gy, (b) 0.5 Gy, (c) 1 Gy of ^{12}C ions – results after 2 h of etching.



Rys. 18. CHO-K1 cells nuclei processed for γ-H2AX assay: (a) control cells, (b) cells irradiated with 1 Gy and (c) cells irradiated with 4 Gy of ^{12}C ions.

We also used the dielectric detectors to doses of so-called Photo-neutrons. Such measurements were done in the Cancer Center Medical Accelerator Varian type Clinac 2300 C/D-S [3]. The obtained results report on a positive attempt on the applicability of PM-355 solid-state nuclear track detectors as integrated neutron fluence sensors for monitoring the level of neutrons during full radiotherapy treatment of prostate cancer patients using the IMRT technique with 15 MeV X rays (Fig. 19). To verify the results obtained with the SSNTDs, they were irradiated together with a Ni sample with neutrons emitted from a ^{252}Cf source. Consistent results were achieved: ~1.6 x 10^9 neutrons/cm^2 from the Ni sample, and ~1.4 x 10^9 neutrons/cm^2 from the track detector samples, which were placed in the same position and irradiated for the same period of time. It has been shown that both investigated detectors can be used as individual patient detectors for total fluence estimation during radiotherapeutic treatment with 15 MV X rays [3].

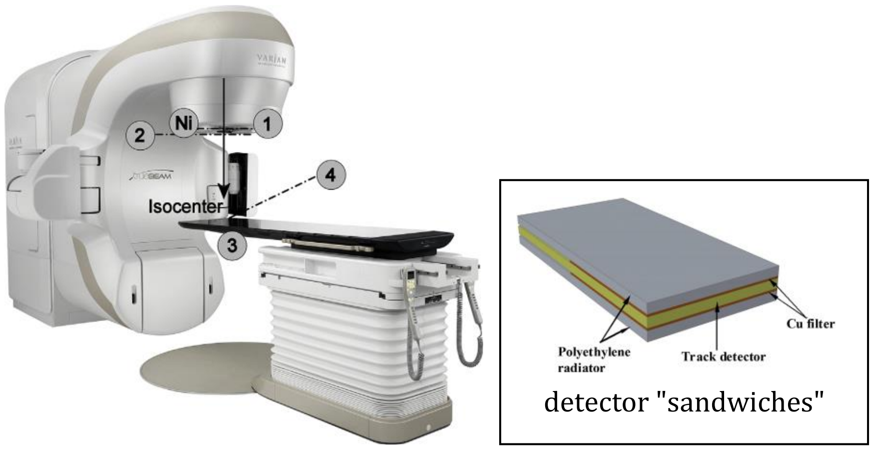


Fig. 19. Scheme of the placement of detector "sandwiches" around the accelerator head and in the patient plane. Samples #1 and "Ni" were located near the accelerator head. Sample #2 was located about 100 cm from the conversion target, samples #3 and #4 were placed in the patient plane.

Figure 20 presents diagrams of the total neutron fluence recorded by the particular samples as a function of their distance from the accelerator conversion target.

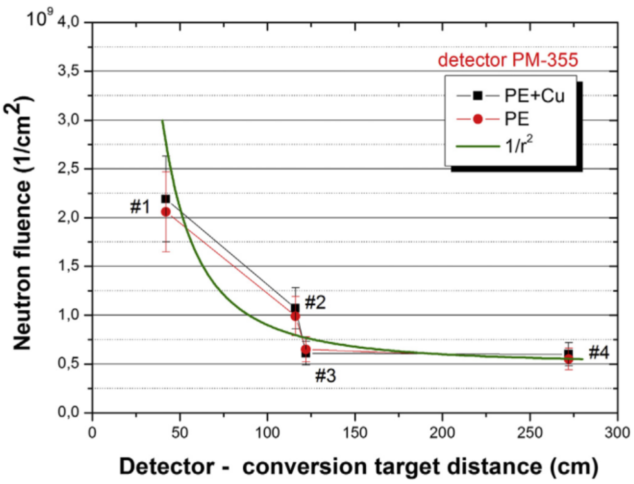


Fig. 20. Total neutron fluences recorded by the samples versus the distance from the accelerator conversion target. Detector numbers correspond to the locations shown in Fig. 19.

The total fluences of photo-neutrons impinging on the detectors were estimated by comparing the track densities in the samples irradiated with the accelerator neutrons to the track densities in the samples irradiated with neutrons from the ^{252}Cf source.

The determined track densities were divided by the estimated neutron detection efficiencies, which were equal to 7.0 x 10^{-2} for detectors equipped with the PE radiator and 1.0 x 10^{-3} for bare detectors (masked with a Cu filter). The total neutron fluences decrease with distance in approximately an inverse square proportion [3].

All of the earlier studies demonstrated the wide range of applications of dielectric track detector.

The obtained results were published in the following reviewed journals:

[B1] **Malinowska**, A. Szydłowski, M. Jaskóła, A. Korman, B. Sartowska, J. Sadowski, J. Badziak, J. Żebrowski, *Calibration and application of dern track detectors CR-39/PM355 in nuclear physics and high perature plasma experiments*, Nukleonika 53 (2008) S15 – S19.

2. U. Kaźmierczak, D. Banaś, J. Braziewicz, J. Czub, M. Jaskóła, A. Korman, M. Kruszewski, A. Lankoff, H. Lisowska, **A. Malinowska**, T. Stępkowski, Z. Szefliński, M. Wojewódzka, *Dosimetry in radiobiological studies with heavy ion beam of the Warsaw cyclotron*, Nucl. Instr. & Meth. B 365 (2015) 404 – 408.

3. A. Szydłowski, M. Jaskóła, **A. Malinowska**, S. Pszona, A. Wysocka-Rabin, A. Korman, K. Pytel, R. Prokopowicz, J. Roztkowska, W. Bulski, M. Kuk, *Application of nuclear track detectors as sensors for photoneutrons generated by medical accelerators*, Rad. Meas. 50 (2013) 74 – 77.

and presented at the conference:

1. **A. Malinowska,** A. Szydłowski, M. Jaskóła**,** A. Korman, B. Sartowska**,** M.J. Sadowski, J. Badziak, J. Żebrowski, "Calibration and application of modern track detectors CR-39/PM355 in nuclear physics and high temperature plasma experiments", Recent Developments and Applications of Nuclear Technologies, 15-17 September,2008, Białowieża, Poland – **Oral**.
2. U.Kaźmierczak, D.Banaś, J.Braziewicz, J.Czub, M.Jaskóła, A.Korman, M.Kruszewski, A.Lankoff, H.Lisowska, **A.Malinowska**, T.Stępkowski, Z.Szefliński, M.Wojewódzka, "Dosimetry in radiobiological studies with heavy ion beam of the Warsaw cyclotron", 19th International Conference on Ion Beam Modification of Materials, 14-19th Sept. 2014, Leuven, Belgium – **Poster**.
3. U.Kaźmierczak, D.Banaś, J.Braziewicz, J.Czub, M.Jaskóła, A.Korman, M.Kruszewski, A.Lankoff, H.Lisowska, **A.Malinowska**, T.Stępkowski, Z.Szefliński, M.Wojewódzka, "Dozymetria promieniowania jonizującego w badaniach radiobiologicznych w ŚLCJ UW", XLIII Zjazd Fizyków Polskich, 06-11 September, 2015, Kielce, Poland – **Oral**.
4. A. Szydłowski, **A. Malinowska**, M. Jaskóła, K. Szewczak, A. Korman, M. Paduch, "Influence of intense soft X-ray radiation on the parameters of tracks induced in CR-39 and PM-355 solid state nuclear track detectors", 26th Int. Conf. on Nuclear Tracks in Solids, 15-19 September 2014, Kobe, Japan – **Poster**.

4.4. CONCLUSIONS

The presented work were intended to demonstrating that the dielectric track detector (NTD) can be used for measurements of charged particles in a wide range of energy, from several keV to few MeV. This detector was chosen as one of the most sensitive to heavy ions, and test measurements were designed to allow assessment of the possibilities of its application in the spectrometric measurement, to determine the type and energy of the particle. These types of measurements are often made within large plasma devices, in which the detectors are placed inside the vacuum chamber, and the information about the registered particles are obtained for example on the basis of recorded tracks.
The result of the work was, moreover, used to determine sensitivity of the detector to external factors such as ambient temperature, X-rays and gamma rays. We determined and compared calibration diagrams of different detectors supply. In this way I found relation between changes in production processes and track detector detection performance. It was also examined so-called "aggeing effect" ie. changes in the properties of the detector due to the passage of time between production processes and test measurements. In addition, we determined the rates of the detector etching such as a V_B, V_T, V_B /V_T.
All of the results wil allow to apply the tested track detector in a wide range of research with special consideration for studies of nuclear reactions occuring in the plasma.

Knowledge of the most important parameters of the plasma such as temperature, density and radiation losses is very important for the understanding of plasma behavior in various experimental systems as well as from the point of view of the feasibility and exploration of the proposed devices in the future. Plasma confined by a magnetic field and held in a stainless steel chamber usually has extreme parameters and therefore conventional methods of measurement do not apply in their determination. Thus, plasma diagnostics, being under development tend to have the innovative nature and always are used to study some physical processes, of which one can draws information on individual plasma parameters. Nuclear Track Detectors (NTD) appears to be an alternative approach to surmount this problem.
Currently, I developed methods for detection of neutrons using the new dielectric detector CR-39 (TASTRAK). By using the CR-39 (TASTRAK) detector it will be possible to measure streams and angular distributions of emitted neutrons in order to estimate the number of nuclear reactions occurring in the generated plasma, separated fusion energy, and to determine the mechanism of nuclear interactions and energy distributions of ions involved in the nuclear reaction.

I have shown that NTD could be used not only in the field of plasma physics , but also in dosimetry of ionizing radiation or medicine. Other areas of science and technology, in which this type of detectors are used as an important research tool, are nuclear physics, physics of cosmic radiation, geology and environmental protection.

Precious experience resulting from the research carried out is the cooperation with the Institute of Plasma Physics and Laser Microfusion in Warsaw and other research centers, i.e., IPP Prague, GSI laboratory in Germany and ENEA Frascati, which increases the possibility of conducting future joint research by national and international research centers in the framework of the European fusion reactor, strengthens the integration of the Polish scientific community and its importance in the international arena.

5. DESCRIPTIONS OF OTHER SCIENTIFIC ACHIEVEMENTS

5.1. THE ACTIVITIES CARRIED OUT PRE - PHD

Higher education graduated from the Faculty of Electrical Engineering Technical University of Szczecin in the direction of Technical Physics in June 1999 (under maiden name A. Banaszak). The obtained results contained in the prepared MSc thesis titled: "Seasonal Changes of Light Attenuation Coefficient in Selected points of the Oder" were published in the reviewed journal:

B. Pawlak, R. Gąsowski, **A. Banaszak**, A. Andrzejewska: *Seasonal Changes of Light Attenuation Coefficient in Selected Points of the Oder River in the Szczecin Region, Poland*, **Polish Journal of Environmental Studies 12** No.2 (2003) 221-226.

After passing the MSc exam 1 October 1999 I was admitted to the doctoral studies at the National Center for Nuclear Research (formerly IPJ) at the Plasma Research division (P5). I was responsible for the measurements of primary ions, electrons, and the reaction products emitted from the plasma produced in the Plasma Focus facilities of different size. In September 2004 I received employment at the position in Physics in the same division.

In the years 2004 - 2008 actively participated in a number of plasma experiments, in the international groups, performed within the PF-360 facility (operated at NCBJ in Swierk) and PF-1000 facility (operated at IPPLM in Warsaw). The main measuring tools have been solid-state nuclear track detectors (SSNTD's), and particularly track detectors of the CR-39 and PM-355 type. In numerous plasma laboratories, dispersed all over the world, there are carried out extensive studies concerning the collection of information about properties and parameters of various high-temperature deuterium plasma discharges. Such information can be gained from measurements of different products of fusion reactions. Particular attention is often paid to measurements of fast neutrons, which are studied with different spatial- and temporal-resolutions. Measurements of fast protons, which are produced in the second reaction channel, have so far brought smaller attention. On the other hand, the fast protons can be measured with better spatial- and energetic-resolution than the fusion neutrons. From measurements of an angular distribution of the fusion protons by the use ion cameras it is possible to determine the spatial distribution of sources (micro-regions), in which the fusion reaction occur, as well as to estimate their efficiency and micro-structure. Moreover, from studies of energetic distributions of the fusion protons one can also estimate which nuclear processes (e.g. thermonuclear reactions or beam-target interactions) are responsible for the observed emissions of fast neutrons and protons.

Taking into consideration the situation described above, the main aim of my Ph.D. thesis became an analysis of problems connected with measurements of protons from reactions occurring inside high-temperature deuterium plasma produced within PF-type experiments: „Experimental study of fusion reactions protons emitted from Plasma Focus device" under the supervision of prof. Dr. hab. Marek Sadowski. The degree of doctor of physical sciences in the field of plasma physics was given 14

October 2008 to a resolution of the Scientific Council in the Andrzej Sołtan Institute for Nuclear Studies.
The obtained results presented above are published in the amount of **28** positions (including **5** position as first author) (**Appendix No. 7** „*The list of published manuscripts*“) in reviewed journals and presented at national and international conferences, symposia and meetings of the Expert Meeting organized by ICDMP (International Centre for Dense Plasmas Magnetize). A total of **54** collected works were presented in the form of Invitated lectures, Orals and Posters (**Appendix No. 1**).
Additionally habilitant was actively involved in organizing international conferences in the area of Plasma Physics:

International Conference Plasma 2003 *"Research and Applications of Plasmas"*, Warsaw, Poland, September 9 – 12, 2003, Local Committee.

The 2nd German-Polish Conference on Plasma Diagnostics for Fusion and Applications, Cracow, Poland, September 8 – 10, 2004, Local Committee.

5.2. THE ACTIVITIES CARRIED OUT AFTER THE PHD

The main aim of the research work after obtaining the degree of doctor of physical sciences in 2008, was to continue studies of the characteristics of track detector CR-39/PM-355 and especially its properties spectrometry for the analysis of fast charged particles. These works were related to the implementation of the international project entitled: „Development of the selected diagnostic techniques (Cherenkov detectors, SSNTD, and Fusion neutron detectors) within a frame of EURATOM nuclear Fusion programme”. This project was part of the 7th Framework Programme – NCBJ (Europen Atomic Energy Community EURATOM) - FU06-CT-2004-00081 carried out in 2005-2007 and FU07-CT-2008-00061 carried out in 2008-2012. My participation in this project was associated with the 5th task entitled: “*Applications of solid-state nuclear track detectors (SSNTDs) for fast ion and fusion reaction product measurements in tokamaks (TEXTOR, MAST, ASDEX)*”. As head of task I was responsible for perform the test the properties of new generation of track detectors CR-39/PM-355. Within the above-discussed European program track detectors were used in the experiments performed in tokamak TEXTOR at the Institut für Plasma Physic, Forschungszentrum in Juelich, Germany (Association EURATOM–FZJ). I personally participated in several experimental sessions lasting one or two weeks each, and several consultations (scientific meeting) among others in Brussels, because the experiments were carried out in close collaboration with scientists from the department of physics at the Royal Military Academy (Association LPP, ERM/KMS, EURATOM–Belgian State Association). The PM–355 detector used in the TEXTOR experiment is a modified version of the CR–39 material. The PM-355 detector type appeared to be a quite useful diagnostic tool for Tokamak experiments to measure electrically charged particles, both fusion reaction products as well primary ions.
In the same project supervised the design and construction of pinhole camera in collaboration with the Czech EURATOM Association in Prague for the measurements of primary ions and fusion reactions products. These measurements will be performed on the COMPASS Tokamak using such ion pinhole camera equipped with a nuclear track detector (CR-39/PM-355) (Fig. 21). Additionally some

calculations of proton and other ion trajectories are been performed using the Gourdon code to support the planed experiments.

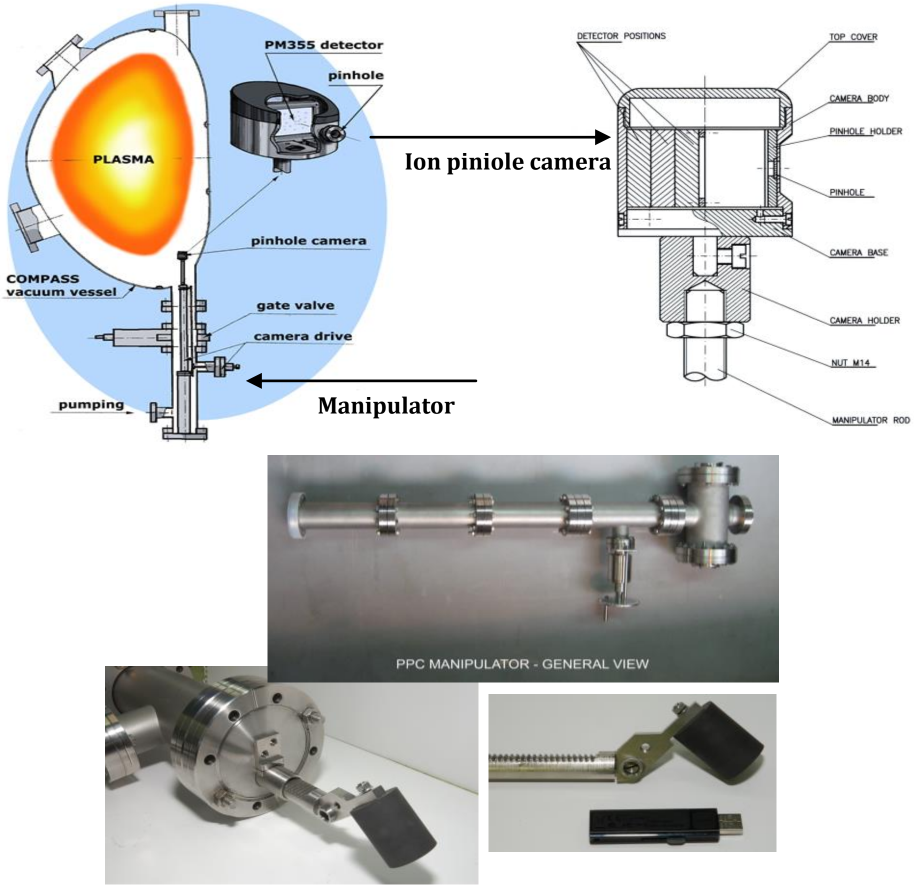


Fig. 21. Specially designed ion pinhole camera dedicated for COMPASS tokamak.

I personally participated in few consultations (scientific meeting) lasting one weeks each in close collaboration with scientists from IPP Prague.

From 2014 - 2015 I participated in the project "Strengthening the innovation capacity of the center in Świerk in the development of technologies using ionizing radiation", co-financed by the European Union. The work, that I was doing an adjunct - Head of the topic - "Plasma diagnostic systems and data acquisition". In this project I participated in the development agreements plasma diagnostics and data acquisition, I was responsible for the supervision, implementation and commissioning.

The work, presented above which was carried out at the National Centre for Nuclear Research allowed me to publish total amount of **24** publications (including **13** items after obtaining a doctoral degree) (**Appendix No. 7**). We collected a total numer of **46** publications published in revised journals from the so-called Philadelphia list, such as:

Physics Review X – 1 publication, publised after obtainind a doctoral degree;

Plasma Physics and Controlled Fusion – 1 publication, publised after obtainind a doctoral degree;

Radiation Measurements – 12 publications, including 6 items after obtaining a doctoral degree;

Review of Scientific Instruments – 3 publications, publised after obtainind a doctoral degree;

Nuclear Instruments and Methods in Physics Research Section B – 2 artykuły, publications, publised after obtainind a doctoral degree;

The total numer of cited references according to Web of Science (WoS) amounts to **283**, therein without self-citations amounts to **215**. **Hirch index** according to Web of Science (WoS) is **10**. Descriptive and percentage, that determines my contribution in the formation of the aforementioned publications are presented in **Appendix No. 7** „*The list of published manuscripts*“. In **Appendix No. 6** is a detailed list of citations of these works „*List of citations of publications by the database of Web of Science dated 1.12.2016r.* Total impact factor according to the Journal Citation Report (JCR) list is **27.91** ; **Phys. Rev. X. - IF 8.701 from 2011 –** is not listed (JCR).

I also try to take an active part in the scientific life of their discipline through active participation in scientific conferences both international and national. The results of the research, the implementation of which I participated after obtaining a doctoral degree, was presented in the form of 6 lectures, including 3 delivered by me personally in oral form (**Appendix No. 8**) and 7 presented in a poster form at national and international conferences, congresses and symposia devoted to plasma physics and the track detectors.

In addition, since 2008, I was selected by the organization, a member of the international organization of scientists: **International Nuclear Track Society**, and through own accession belong to the **Plasma Physics Section** of the Committee of Physics at the Polish Academy of Sciences (since 2005).
My scientific achievements have been appreciated by the committee of the Scientific Council of the National Centre for Nuclear Research, in the form of individual scientific award for scientific achievements gained in 2011-2014 and 2014-2016 respectively accorded - 2014 and 2016 years and the award team by Director of the National Centre for Nuclear Research for scientific achievement in 2014 for the work about: *"Research reaction Si target saturated with hydrogen and doped with boron in a laser PALS in Prague"* in 2015 year (**Appendix No. 11**). In 2015 also I was accorded a grant habilitation for two years at the National Centre for Nuclear Research.

In addition, I am the author of several reviews of works sent to recognized scientific journals belonging to the Philadelphia list like Radiation Measurements, Nukleonika as regular paper.

Being a participant in study at the University of Szczecin, I conducted teaching of the basics of Physics at the primary school. Due to the nature of the scientific unit, teaching achievements include:
In 2015, I was a Scientific Supervisor Mr. Tomasz Zwaliński student of the Faculty of Mechatronics at the Warsaw University of Technology, who on the basis of the collected data prepared a master thesis titled: *"Model of personal neutron detector"*. The work included a model of personal neutron detector consists of a track detector of

CR-39 type coated with a material containing boron and to test the response of the material in the standard fields of neutron radiation. My role was to deliver of knowledge on the dielectric track detectors and methods for their treatment. Help in assembly of the necessary scientific literature.
In 2015, I was a Scientific Supervisor Mr. Paweł Podrygus, student of the Faculty of Nuclear Physics at the Warsaw University, the acquired skills concerning the calibration of a new type of track detector CR-39 type (TASTRAK), scored laboratory within the framework of the program of academic study.
I offer my support PhD students. In 2014 doctoral thesis MSc Roch Kwiatkowski entitled: "Analysis of the latest measurements of ions, electrons and visible radiation of plasma obtained from PF-360 and PF-1000 devices", I to deliver of my knowledge and experience on development methods and analysis of the obtained experimental results on the Plasma Focus devices.