ANNUAL REPORT
2000
PLEASE BE AWARE THAT ALL OF THE MISSING PAGES IN THIS DOCUMENT WERE ORIGINALLY BLANK
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FOREWORD

Institutes, which are not intimately coupled to higher education, can crudely be divided into two groups: those which concentrate on the fundamental research in a particular discipline of science and those involved in the R & D phase, associated with a particular field of application. A balanced mix of the two is rare, so rare in fact, that if such an unorthodox organization is set, it has hard time in adapting to the rules of financing. The same difficulty applies to cross-disciplinary hybrids. And all that in spite of the lip service of various decision-taking bodies that it is the cross-disciplinary harmonious transfer of ideas-to-research-to-development-to production which is the ultimate objective of their policies.

Our institute has the mixed fortune of being such a mix of basic research, of multidisciplinary research & development and even of production of some end products. We take pride in doing so in a relatively harmonious way on a satisfactory level. But we also take heavy beating because we do not fit to the schematic rules of financing. Yet we are convinced that this way of doing research in non-educational scientific institutions is right, that in the long run it is the most efficient one and that if the rules limit this efficiency, it is the rules which ought to be changed. However up-hill struggle that is!

The Readers of this Report are invited to take a look at this mixture of ours. They can begin with e.g. the account of the work concerning testing the Standard Model, searching for the Higgs boson or for the supersymmetric particles – the front line in the elementary particle physics of the day. Or with the preparations for the presumable front line of to-morrow the new projects at the LHC (Large Hadron Collider). The technology pull that these projects exert is difficult to measure and likewise difficult to overestimate.

Leaving the accelerator-produced particles and going to still higher energies, we learn about the cosmic rays in the “knee region” \(10^{15} - 10^{17}\) eV from the cosmic showers (the KASCADE collaboration) or inquire the Nature about the possible correlation of some cosmic radiation with the solar activity.

One front-line in the low energy nuclear physics nowadays is the quest for the heaviest nuclear species - one of the specialities of our theory group. This group is known for its close contacts with experimentalists around the world. Recently, they highlighted these contacts by suggesting a new method to improve the mass determination for heavy nuclides from the Schottky noise signals in a storage ring.

We move on to the plasma physics. The physics of the fourth state of matter, dominating in the Universe, the physics of non-linear phenomena, the physics of the XXI century. The physics closely linked to nuclear sciences and yet distinctly different. The physics which has numerous technological spin-offs, be it because of the experimental techniques it develops or of the phenomena it discovers. It is good to see that we are strongly entrenched in this field and have justified appetites for more.

We focus now on the materials science done with nuclear techniques. We are pleased to note that our implantation techniques develop well and are now applied to e.g. hardening the steel edges. And we brag a bit about our latest work on the new crystallographic forms of uranium compounds after having done experiments we now propose explanations.

The experimental physicist needs detectors. Ever better, bigger, more sophisticated. We have a strong group pursuing this improvement task, especially with respect to the scintillators. It was rewarding to learn that the international community has appreciated this effort. The appreciation came from the IEEE/Nuclear and Plasma Science Society with the award of their prestigious prize “to Marek Moszyński for outstanding contributions to the modern scintillation detector and its application in physics experiment, nuclear medicine and other fields of use”.

Almost any development in experimental techniques of nuclear physics results very quickly in new techniques in medicine, in the diagnostics as well as in therapy. Our miniature X-ray tube for brachytherapy, nick-named “the photon needle”, gained a nomination for the prestigious “Polish product of the future” award. We hope that it will soon become a useful tool in the hands of physicians. The traditional line of our medical applications is the development and production of linear electron accelerators for tumor therapy. Our 10 MeV “Neptun” accelerator has got a significant face-lifting this year and the construction of a new 6-to-15 MeV machine is well advanced. We hope this will meet the needs of our customers in Poland and abroad.

Last but not least I’d like to mention the quickly increasing flow of people passing the premises of our Training Department. The number of school students visiting us last year reached unprecedented level of 2500, there were also courses and trainings for various professionals. We consider this activity as an additional but important way of paying back “the tax-payer” for the support we are getting and also as our contribution to fight “the anti-nuclear fobia”.

Have a nice reading

[Signature]

Professor Ziemowid Sujkowski
I. GENERAL INFORMATION

The Institute is a state owned laboratory. It carries out pure and applied research on subatomic physics, i.e. elementary particle, low and high energy nuclear physics, plasma physics and related fields.

The Institute specializes in accelerator physics and technology, material research with nuclear techniques, the development of spectrometric techniques, nuclear electronics and also in applications of nuclear techniques to environmental research, nuclear medicine etc.

Apart from the scientific departments, there is a separate production unit operating within the Institute - ZdAJ (the Establishment for Nuclear Equipment). The unit specializes in medical equipment, notably in the production of linear electron accelerators for oncology.

The main site of the Institute is Świerk near Otwock, but some of its departments (P-I, P-VI, P-VIII) are located in Warsaw, PL-00-681 Warsaw, 69 Hoża street, and one (P-VII) in the city of Łódź, PL-90-950 Łódź, 5 Uniwersytecka street.

1. MANAGEMENT OF THE INSTITUTE

Director

Professor Ziemowid SUJKOWSKI
phone: (22) 718-05-83
e-mail: sujkowsk@ipj.gov.pl

Deputy Director, Research and Development

Professor Marek MOSZYŃSKI
phone: (22) 718-05-86
e-mail: marek@ipj.gov.pl

Deputy Director, Economy and Marketing

Assoc.Professor Zbigniew WERNER
phone: (22) 718-05-56
e-mail: wernerz@ipj.gov.pl

Scientific Secretary

Dr. Danuta CHMIELEWSKA
phone: (22) 718-05-85
e-mail: danka@ipj.gov.pl
2. **SCIENTIFIC COUNCIL**

The Scientific Council was elected on the 7th of May 1999 by the scientific, technical and administrative staff of the Institute. The Council has the right to confer PhD and *habilitation* degrees in physics (DSc).

**Representatives of scientific staff:**

Helena Białkowska, Assoc.Prof.
Wiesław Czarnacki, Dr.
Stanisław Gębalski, MSc.
Michał Gryziński, Assoc.Prof.
Marian Jaskóła, Professor
Rościsław Kaczarowski, Assoc.Prof.
Tadeusz Kozłowski, Dr.
Stanisław Kulinski, Professor, Deputy Chairman
Jerzy Langner, Dr.
Leszek Łukaszuk, Professor, Deputy Chairman
Marek Moszyński, Professor

Marian Pachan, MSc.
Jerzy Piekoszewski, Professor
Stanisław Pszona, Dr.
Wojciech Ratynski, Professor
Marek Sadowski, Professor, Deputy Chairman
Adam Sobczewski, Professor
Ryszard Sosnowski, Professor, Chairman
Joanna Stepaniak, Professor
Ziemowid Sujkowski, Professor
Grzegorz Wilk, Assoc.Prof.
Sławomir Wycech, Professor

**Representatives of technical personnel:**

Genowefa Fajkowska, Eng.
Edward Fronczak, technician
Bogdan Gas, Eng.
Andrzej Hilger, MSc.
Jan Kopeć, Eng.
Jolanta Mozdrzecka, MSc.
Jacek Pracz, MSc.
Anna Sidor
Iwona Żawrocka, MSc.
Zbigniew Żero, Eng.

**External members:**

Andrzej Budzanowski, Professor  - Institute of Nuclear Physics,(IFJ), Cracow
Andrzej Chmielewski, Assoc.Prof.  - Institute of Nuclear Chemistry (IChTJ), Warsaw
Tomasz Czosnyka, Assoc.Prof.  - Heavy Ion Laboratory, Warsaw University
Jacek Fijuth, Assoc.Prof.  - Institute of Oncology, Warsaw
Janusz Mika, Professor  - Institute of Atomic Energy (IEA), Warsaw
Zdzisław Pawłowski, Professor  - Warsaw Technical Institute
Stanisław Rohoziński, Professor  - Institute of Theoretical Physics, Warsaw University
Janusz Zakrzewski, Professor  - Institute of Experimental Physics, Warsaw University
3. DEPARTMENTS OF THE INSTITUTE

- DEPARTMENT OF NUCLEAR REACTIONS (P-I)
  Head of Department – Assoc. Prof. Krzysztof RUSEK

- DEPARTMENT OF NUCLEAR SPECTROSCOPY AND TECHNIQUE (P-II)
  Head of Department - Dr. Tadeusz KOZŁOWSKI

- DEPARTMENT OF DETECTORS AND NUCLEAR ELECTRONICS (P-III)
  Head of Department – Assoc. Prof. Zbigniew GUZIK

- DEPARTMENT OF RADIATION SHIELDING AND DOSIMETRY (P-IV)
  Head of Department - Dr. Stanislaw PSZONA

- DEPARTMENT OF PLASMA PHYSICS AND TECHNOLOGY (P-V)
  Head of Department - Professor Marek SADOWSKI

- DEPARTMENT OF HIGH ENERGY PHYSICS (P-VI)
  Head of Department - Professor Jan NASSALSKI till Oct. 10
  Assoc. Prof. Helena Białkowska since Oct. 10

- DEPARTMENT OF COSMIC RAY PHYSICS (P-VII)
  Head of Department – Dr. Jacek SZABELSKI

- DEPARTMENT OF NUCLEAR THEORY (P-VIII)
  Head of Department – Assoc. Prof. Grzegorz WILK

- DEPARTMENT OF MATERIAL STUDIES (P-IX)
  Head of Department - Professor Jerzy PIEKOSZEWSKI

- DEPARTMENT OF ACCELERATOR PHYSICS AND TECHNOLOGY (P-X)
  Head of Department – MSc. Marian PACHAN

Other units:

- DEPARTMENT OF TRAINING AND CONSULTING
  Director - Professor Ludwik Dobrzyński tel.718-05-70, 718-05-71, 718-05-72

- ESTABLISHMENT FOR NUCLEAR EQUIPMENT (ZdAJ)
  Director, MSc. Jacek PRACZ tel.718-05-00, 718-05-02

- TRANSPORT DIVISION (ZTS)
  Director, Civ.Eng. Bogdan GAS tel.718-06-16, fax 048-22-718-06-15
4. **SCIENTIFIC STAFF OF THE INSTITUTE**

**PROFESSORS**

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Department</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>BŁOCKI Jan</td>
<td>Theoretical Nuclear Physics</td>
</tr>
<tr>
<td>2</td>
<td>DĄBROWSKI Janusz (**)</td>
<td>Theoretical Nuclear Physics</td>
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<td>3</td>
<td>DOBRZYŃSKI Ludwik</td>
<td>Solid State Physics</td>
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<td>4</td>
<td>INFELD Eryk</td>
<td>Plasma Physics and Nonlinear Dynamics</td>
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<td>5</td>
<td>JASKÓŁA Marian</td>
<td>Low Energy Nuclear Physics</td>
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<tr>
<td>6</td>
<td>KULIŃSKI Stanisław</td>
<td>Accelerator Techniques and Physics</td>
</tr>
<tr>
<td>7</td>
<td>ŁUKASZUK Leszek</td>
<td>Particle Physics</td>
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<td>8</td>
<td>MARCINKOWSKI Andrzej</td>
<td>Low Energy Nuclear Physics</td>
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<tr>
<td>9</td>
<td>MOSZYŃSKI Marek</td>
<td>Nuclear Electronics, Technical Physics</td>
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<tr>
<td>10</td>
<td>MRÓWCZYŃSKI Stanislaw(**)</td>
<td>Particle Physics</td>
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<td>11</td>
<td>NASSALSKI Jan</td>
<td>Particle Physics</td>
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<td>12</td>
<td>PIEKOSZEWSKI Jerzy</td>
<td>Solid State Physics</td>
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<td>RATYŃSKI Wojciech</td>
<td>Low Energy Nuclear Physics</td>
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<td>SADOWSKI Marek</td>
<td>Plasma Physics</td>
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<td>15</td>
<td>SIEMIARCZUK Teodor</td>
<td>Particle and High Energy Nuclear Physics</td>
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<td>16</td>
<td>SOBIECZEWSKI Adam</td>
<td>Theoretical Physics, Member of the Polish Academy of Sciences</td>
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<td>SŁOWOWSKI Ryszard</td>
<td>Particle Physics, Member of the Polish Academy of Sciences</td>
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<td>18</td>
<td>STEPANIAK Joanna</td>
<td>High Energy Nuclear Physics</td>
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<td>19</td>
<td>SUJKOWSKI Ziemowid</td>
<td>Low Energy Nuclear Physics</td>
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<td>20</td>
<td>SZEPYCKA Maria</td>
<td>Particle Physics</td>
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<td>TUROS Andrzej</td>
<td>Solid State Physics</td>
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<td>WILCZYŃSKI Janusz</td>
<td>Low Energy Nuclear Physics</td>
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<td>23</td>
<td>WYCECH Sławomir</td>
<td>Nuclear and Particle Physics</td>
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**CONTRACT PROFESSORS**

<table>
<thead>
<tr>
<th>No.</th>
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<tr>
<td>1</td>
<td>GAWIN Jerzy</td>
<td>Cosmic Ray Physics</td>
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<td>MOROZ Zbigniew (**)</td>
<td>Low Energy Nuclear Physics</td>
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<td>3</td>
<td>ZUPRAŃSKI Paweł</td>
<td>High Energy Nuclear Physics</td>
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**ASSOCIATE PROFESSORS and DSc**

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<tr>
<td>1</td>
<td>BIAŁKOWSKA Helena</td>
<td>High Energy Nuclear Physics</td>
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<td>Particle Physics</td>
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<td>3</td>
<td>GRYZIŃSKI Michał</td>
<td>Plasma Physics and Atomic Physics</td>
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<td>GUZIK Zbigniew</td>
<td>Nuclear Electronics</td>
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<tr>
<td>5</td>
<td>JAGIELSKI Jacek( **)</td>
<td>Solid State Physics</td>
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<td>6</td>
<td>KACZAROWSKI Rościsław</td>
<td>Low Energy Nuclear Physics</td>
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<td>MANKIEWICZ Lech</td>
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<td>8</td>
<td>RUSEK Krzysztof</td>
<td>Low Energy Nuclear Physics</td>
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<td>9</td>
<td>RONDIO Ewa</td>
<td>Particle Physics</td>
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<td>10</td>
<td>SANDACZ Andrzej</td>
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<td>SLAPA Mieczysław (**)</td>
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<td>13</td>
<td>SOWIŃSKI Mieczysław (**)</td>
<td>Applied Nuclear Physics</td>
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</table>
14. SZCZEKOWSKI Marek  
15. SZYMANOWSKI Lech (*)  
16. WERNER Zbigniew  
17. WIBIG Tadeusz  
18. WILK Grzegorz  
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20. WROCHNA Grzegorz  
21. WRZECIONKO Jerzy  
22. ZABIEROWSKI Janusz  
23. ZWIĘGŁŃSKI Bogusław  

Particle Physics  
Theoretical Nuclear Physics  
Solid State Physics  
Cosmic Ray Physics  
Particle Physics  
Particle Physics  
Particle Physics  
Theoretical Nuclear Physics  
Cosmic Ray Physics  
Nuclear Physics

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3. BALCERZYK Marcin (*)  
4. BARANOWSKI Jarosław  
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6. BIEŃKOWSKI Andrzej (**)  
7. BORSUK Stanisław  
8. CHARUBA Jacek  
9. CHMIELOWSKI Władysław (*)  
10. CHMIELEWSKA Danuta  
11. CZARNACKI Wiesław  
12. CZYŻEWSKI Tomasz  
13. FILIPKOWSKI Andrzej †  
14. GAWLIK Grzegorz (**)  
15. GOKIELI Ryszard (*)  
16. GOLDSTEIN Piotr  
17. GÓRSKI Maciej  
18. JAKUBOWSKI Lech  
19. JERZYKIEWICZ Andrzej  
20. KOCIĘCKA-MECHANIŚZ K.  
21. KORMAN Andrzej  
22. KOWALSKI Marian (*)  
23. KOZŁOWSKI Tadeusz  
24. KUPŚĆ Andrzej (*)  
25. KUREK Krzysztof  
26. LANGNER Jerzy  
27. LUDZIEJEWSKI Tomasz  
28. MACISZEWSKI Wiesław  
29. MARIŃSKI Bogdan  
30. MYŚLEK-LAURIKAINEN B.  
31. NAWROT Adam

32. NOWICKI Lech  
33. PACHAN Marian (**)  
34. PATYK Zygmunt  
35. PIECHOCKI Włodzimierz  
36. PIOTROWSKI Antoni (**)  
37. PŁAWSKI Eugeniusz  
38. PŁÓCIENNICKI Weronika  
39. POLAŃSKI Aleksander (*)  
40. PREIBISZ Zygmunt (**)  
41. PSZONA Stanisław  
42. RABIŃSKI Zygmunt  
43. ROŻYNEK Marek  
44. RUCHOWSKA Ewa  
45. RURARZ Edward (**)  
46. SENATORSKI Andrzej (**)  
47. SERNICKI Jan  
48. SKŁADNIK-SADOWSKA E. (**)  
49. SKORUPSKI Andrzej (**)  
50. SMOLAŃCZUK Robert  
51. SZABELSKA Barbara  
52. SZABELSKI Marek  
53. SZLEPER Michał  
54. SZYDŁOWSKI Adam  
55. SZYMAŃSKI Piotr (*)  
56. SZYMČZYK Władysław  
57. TRZCIŃSKI Andrzej  
58. WINCZEL Krzysztof  
59. WOJTOWSKA Jolanta(‡)  
60. WOLSKI Dariusz  
61. ZALEWSKI Piotr  
62. ZYCHOR Izabella

(*) on leave of absence  
(**) part-time employee  
(†) deceased Sept. 24
### 5. VISITING SCIENTISTS

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Institution</th>
<th>Date</th>
<th>Institute Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Cathers P.</td>
<td>Florida State University Tallahassee, USA</td>
<td>Jan. 6-26</td>
<td>P-I</td>
</tr>
<tr>
<td>2.</td>
<td>Świątecki W.</td>
<td>Lawrence Berkeley Laboratory, USA</td>
<td>Jan. 23-30</td>
<td>P-II</td>
</tr>
<tr>
<td>5.</td>
<td>Tazzari S.</td>
<td>University of Roma, Italy</td>
<td>Feb.21-23</td>
<td>P-V</td>
</tr>
<tr>
<td>6.</td>
<td>Daria G.</td>
<td>University of Roma, Italy</td>
<td>Feb.21-23</td>
<td>P,-V</td>
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<tr>
<td>7.</td>
<td>Koshechy E.</td>
<td>Kharkiv State University, Kharkiv, Ukraine</td>
<td>Feb.28-March 4</td>
<td>P-I</td>
</tr>
<tr>
<td>8.</td>
<td>Chernievsky V.</td>
<td>Inst. for Nuclear Research, Ukraine</td>
<td>Feb 28-March 4</td>
<td>P-I</td>
</tr>
<tr>
<td>9.</td>
<td>Rudchik A.</td>
<td>Inst. for Nuclear Research, Kiev, Ukraine</td>
<td>March 2-3</td>
<td>P-I</td>
</tr>
<tr>
<td>10.</td>
<td>Tazzari S.</td>
<td>Sincrotrone Trieste, Italy</td>
<td>March 23-24</td>
<td>P-X</td>
</tr>
<tr>
<td>11.</td>
<td>D'Auria G.</td>
<td>Sincrotrone Trieste, Italy</td>
<td>March 23-24</td>
<td>P-X</td>
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<td>12.</td>
<td>Klamra W.</td>
<td>Royal Inst. of Technology, Stockholm, Sweden</td>
<td>April 4-14</td>
<td>P-III</td>
</tr>
<tr>
<td>13.</td>
<td>Loiseau B</td>
<td>University of Paris, France</td>
<td>April 4-5</td>
<td>P-V</td>
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<tr>
<td>14.</td>
<td>Taran A.</td>
<td>Inst. of Physics and Technology, Ukraine</td>
<td>April 5-13</td>
<td>P-V</td>
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<tr>
<td>15.</td>
<td>Capdevielle J.N.</td>
<td>Collège de France, Paris, France</td>
<td>April 6-20</td>
<td>P-VI</td>
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<tr>
<td>16.</td>
<td>Koval N.</td>
<td>High Current Electronics Inst., Tomsk, Russia</td>
<td>April 10-16</td>
<td>P-V</td>
</tr>
<tr>
<td>17.</td>
<td>Shamin P.</td>
<td>Inst. of High-Current Electronic, Russia</td>
<td>April 10-16</td>
<td>P-V</td>
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<tr>
<td>18.</td>
<td>Trzaska W.</td>
<td>University of Jyväskylä, Finland</td>
<td>April 18</td>
<td>P-I</td>
</tr>
<tr>
<td>19.</td>
<td>Abrosimov V.</td>
<td>Inst. for Nuclear Research, Ukraine</td>
<td>April 25-May 1</td>
<td>P-II</td>
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<tr>
<td>20.</td>
<td>Oganessian J.</td>
<td>Joint Inst. for Nuclear Research, Dubna, Russia</td>
<td>May 4-5</td>
<td>P-VIII</td>
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<tr>
<td>21.</td>
<td>Itkis G.</td>
<td>Joint Inst. for Nuclear Research, Dubna, Russia</td>
<td>May 4-5</td>
<td>P-VIII</td>
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<td>22.</td>
<td>Rudchik A.</td>
<td>Inst. for Nuclear Research, Kiev, Ukraine</td>
<td>May 15-June 4</td>
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<td>23.</td>
<td>Ormelchuk S.</td>
<td>Inst. for Nuclear Research, Ukraine</td>
<td>May 15-June 4</td>
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<tr>
<td>24.</td>
<td>Rossi C.</td>
<td>Sincrotrone Trieste, Italy</td>
<td>May 17-19</td>
<td>P-X</td>
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<tr>
<td>25.</td>
<td>Demetriou P.</td>
<td>Inst. of Nuclear Physics, Athens, Greece</td>
<td>May 22-28</td>
<td>P-I</td>
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<td>26.</td>
<td>Gaete P.</td>
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6. GRANTS

LIST OF RESEARCH PROJECT (GRANTS) REALIZED IN 2000

1. INTERACTION OF STRANGE PARTICLES WITH ATOMIC NUCLEI
   Principal Investigator: Professor J. Dąbrowski
   Grant No. 2P03B04812

2. STUDY OF THE ATOMIC INNER-SHELL (L,M) IONISATION INDUCED BY IONS WITH Z ≥ 3 IN HEAVY ELEMENTS
   Principal Investigator: Prof. M. Jaskóla
   Grant No. 2P03B06514

3. STUDY OF STRUCTURE OF STRONGLY IONISED HEAVY IONS AND DYNAMICS OF THEIR INTERACTION WITH ATOMS
   Principal Investigator: Dr. P. Rymuza / Prof. Z. Sujkowski
   Grant No. 2P03B116115

4. PRODUCTION MECHANISM OF SUPERHEAVY ELEMENTS
   Principal Investigator: Dr. R. Smolańczuk
   Grant No. 2P03B09915

5. INVESTIGATION OF NEW SCINTILATION TECHNICS AS USED IN SPECTROMETRY OF NUCLEAR RADIATION IN PHYSICS, NUCLEAR TECHNICS AND IN NUCLEAR MEDICINE
   Principal Investigator: Prof. M. Moszyński
   Grant No. 8T10C00515

6. PRECISE MEASUREMENT OF CP VIOLATION IN K° DECAYS
   Principal Investigator: Dr. E. Rondio
   Grant No. 2P03B07615

7. NEW HIGH EFFICIENCY SCINTILLATORS FOR GAMMA AND X-RAYS DETECTION IN POSITRON EMISSION TOMOGRAPHS AND DIGITAL RADIOGRAPHY
   Principal Investigator: Dr. M. Balcerek
   Grant No. 8T11E02515

8. STUDIES OF RADIOACTIVE NUCLEI
   Principal Investigator: Prof. A. Sobieczewski
   Grant No. 2P03B11715

9. MULTITASK SPECTROSCOPY SYSTEM FOR CONTROL AND MEASUREMENTS OF RADIOACTIVE CONTAMINATION
   Principal Investigator: MSc. St. Borsuk
   Grant No. 8T11E035 98C/4046

10. EXPERIMENTAL AND COMPUTATIONAL MODELLING OF DISTRIBUTION OF DOSES ABSORBED BY BLOOD VESSEL IN INTRAVESSEL BRACHYTHERAPY
    Principal Investigator: Dr. St. Pszona
    Grant No. 4P05C01417

11. DESIGN OF ELECTRON ACCELERATOR FOR RADIOTHERAPY WITH 6 MEV AND 15 MEV PHOTONS
    Principal Investigator: MSc. J. Pracz and MSc. J. Bigolas
    Grant No. Z230/T11/99/13
12. DYNAMICS OF FUSION AND DEEP INELASTIC REACTIONS
   Principal Investigator: Prof. J. Bfocki
   Grant No. 2P03B05419

13. THERMALLY ACTIVATED TRANSFORMATIONS IN A^{III}B^{V} SEMICONDUCTOR COMPOUNDS
   Principal Investigator: Prof. A. Turos
   Grant No. 8T11B02818

14. STUDIES OF THE GLUON POLARIZATION IN THE NUCLEON
   Principal Investigator: Assoc. Prof. A. Sandacz
   Grant No. 2P03B11319

15. INVESTIGATION OF K_{s} \rightarrow \pi^{\pm} \bar{\pi}^{\mp} e^{\pm} e^{-}, K_{s} \rightarrow \pi^{\pm} \bar{\pi}^{\mp} e^{\pm} e^{-} DECAYS IN NA48 EXPERIMENT
   Principal Investigator: Prof. J. Nassalski
   Grant No. 2PO3B11719

In addition to the above, several of our scientists are principal investigators in grants coordinated by other institutions.
LIST OF RESEARCH PROJECTS GRANTED BY INTERNATIONAL ORGANIZATIONS

1. MACROSCOPIC NUCLEAR DYNAMICS WITH INCLUSION OF FLUCTUATIONS AND SHELL EFFECTS
   Principal Investigator: **Prof. J. Blocki**
   Polish-American agreement nr PAA/DOE-98-343

2. EXPERIMENTAL RESEARCH ON OPTIMISATION OF NEUTRON YIELD FROM PF-360 MACHINE (USA)
   Principal Investigator: **Prof. M. Sadowski**
   Project No. SPC-99-4088

3. A COMPACT, PORTABLE AND ECONOMICAL HIGH POWER INDUCTIVE ENERGY STORAGE GENERATOR – DEVELOPMENT AND APPLICATION
   Principal Investigator: **Prof. M. Sadowski**
   Contract No. IC15-CT97-0705

4. COMPILATION AND EVALUATION OF HIGH ENERGY GAMMA-RAY STANDARDS FROM NUCLEAR REACTIONS
   Principal Investigator: **Prof. A. Marcinkowski**
   IAEA Contract No. 10314/RBF

5. SPECIFICATION OF RADIATION QUALITY AT NANOMETER SCALE
   Principal Investigator: **Dr. St. Pszona**
   Grant No. ERB CI PDCT 930407
   ERB F14 P-CT 96-044/Sub. 1

6. APPLICATION OF MEV ION BEAMS FOR DEVELOPMENT AND CHARACTERIZATION OF SEMICONDUCTOR MATERIALS
   Principal Investigator: **Prof. A. Turos**
   IAEA Contract No. 10035/RBF

7. PRODUCTION OF 3 PCS PULSE SHAPE DISCRIMINATOR MODULES, TYPE NDE 202
   Principal Investigator: **Dr. D. Wolski**
   Order No. 130671, agreement with Univ. of Birmingham

8. INVESTIGATIONS OF NUCLEAR REACTIONS WITH LOOSELY BOUND NUCLEI
   Principal Investigator: **Prof. K. Rusek**
   Agreement with JINR, Dubna

9. CONSTRUCTION OF THE DETECTOR FOR THE ALICE EXPERIMENT AT CERN LHC
   Principal Investigator: **Prof. T. Siemiarczuk**
   Agreement with JINR, Dubna
7. SCIENTIFIC DEGREES

DSc theses

1. OLEG MAZONKA (Institute for Nuclear Studies, Świerk)  
   Stochastic Effects; Application in Nuclear Physics.

2. MAREK PAWŁOWSKI (Institute for Nuclear Studies, Świerk)  
   A locally conformal invariant model for fundamental interactions – theoretical analysis and experimental consequences.
II. REPORTS ON RESEARCH

1 DEPARTMENT OF NUCLEAR REACTIONS

Head of Department: Dr Krzysztof Rusek
phone: (22) 621-38-29
e-mail: rusek@fuw.edu.pl

Overview

The last year of the twentieth-century was productive for our Department. Although the name of the Department suggests that we are all involved in investigations of nuclear reactions, in fact our activities are spread over three major domains: nuclear, atomic and material physics. Some of the projects we were involved in the last year have been realized using national facilities and accelerators, like the Van de Graaff accelerator of our Department at 69 Hoza Street, Warsaw Cyclotron U-200P of Warsaw University, and compact C30 cyclotron of our Institute at Świerk. Other projects were done abroad, using facilities of the Gesellschaft für Schwerionenforschung in Darmstadt, Institute de Physique Nucleaire at Orsay, and Universitaet Erlangen – Nürnberg in Erlangen. We carried out our work in close collaborations with physicists from many laboratories, Polish and foreign.

• Low energy nuclear reactions

In collaboration with scientists from Ukraine experiments, using heavy ion beam provided by the Warsaw Cyclotron, was started. The aim of the experiments is to study nuclear reactions leading to the exotic light nuclei in exit channels and energy dependence of the nucleus - nucleus interaction.

Efforts were made to develop a multistep direct model of nuclear reactions. In the model contributions due to the low energy collective excitations were taken into account. Good agreement with the experimental data was achieved.

• Multifragmentation of relativistic heavy ions

ALADIN Collaboration studied multifragmentation reactions induced by relativistic heavy ions. The main activities of our scientists concentrated on an upgrade of the detecting system in order to replace photo multipliers with large area avalanche photodiodes in the central section of the TOF-wall. Some tests of the photodiodes manufactured by Advanced Photonix Inc. were performed using standard p- and γ-sources.

• Structure of a nucleon

Decay properties of the Roper resonance were studied. A signature of coherent pion production in the excitation of α – particles scattered from protons has been found. It offers a means to separate the excitation of the proton from that of the α – particle in the measured decay.

• Atomic physics

Ionisation probabilities in collision of heavy ions from several heavy atoms were measured. A novel method of analysis of multiple ionisation effects was developed.

• Materials research

Crystallochemical studies of U₃O₇ showed that this uranium-oxygen system forms polytypes that differ by the stacking manner of identical cluster layers. Seven basic sequences of these layers were determined.

Samples of a human brain were investigated by means of PIXE method. Accumulation of variety of elements in brain tissue was studied. It was found that the concentration of zinc dramatically increases with age. This can be related to the increasing with age probability of Parkinson’s disease.

The following reports present results and major successes that we achieved in the year 2000.
1.1 Scattering of $^{11}$B Ions from $^{12}$C at 49 MeV


We have built and tested an experimental setup consisted of a $\Phi = 80$ cm scattering chamber and three charged-particle telescopes. Two of the telescopes consisted of an ionization chamber filled with pure argon and silicon surface barrier detectors, 0.5 mm thick, to stop the scattered ions. In the third one a thin silicon detector served as $\Delta E$ counter, followed by a 0.5 mm silicon detector.

200 $\mu$g/cm$^2$ carbon foil was used as a target. This experiment was a part of a long-range joint project "Nuclear reactions leading to the exotic light nuclei in exit channels".

In Fig. 1 is shown a typical $\Delta E \times E$ spectrum measured by the one of gas-silicon telescopes. Good mass resolution enabled us to register F, O, N, C, B, Be and Li ions emerged from the target. Extracted energy spectra of $^{11}$B (lower panel) and $^{12}$C (upper panel) ions are shown in Fig. 2.

Part of the data collected in the experiment was processed and angular distributions for elastic scattering of $^{11}$B from $^{12}$C (Fig. 3) and for inelastic scattering leading to the excitations of both projectile and the target were obtained. These data, as well as data obtained previously by other authors will be analyzed by means of optical model calculations. The aim of this analysis is to investigate an energy dependence of the optical model potential for this scattering system. The effects of the inelastic scattering and transfer reactions on the process of elastic scattering will also be studied. In the forthcoming year we plan to perform experiments with $^{11}$B beam scattered on $^{13}$C targets.

Fig. 1 Two-dimensional spectrum measured for $^{11}$B + $^{12}$C scattering system at laboratory scattering angle of 15 deg.

Fig. 2 Energy spectra of $^{12}$C and $^{11}$B ions.

Using this setup we investigated elastic and inelastic scattering of $^{11}$B ions from $^{12}$C nuclei at energy of 49 MeV. Boron beam was provided by the Warsaw Cyclotron U-200P. Self-supporting

\[\begin{align*}
\text{11B} + \text{12C} &\rightarrow \text{X} + \text{E} = 49 \text{ MeV} \\
\text{\Theta = 15.0 deg} &\rightarrow \text{C, Be, Li ions emerged from the target.}
\end{align*}\]
1.2 Cross Sections for the Multistep Direct Neutron Scattering on Niobium
by A. Marcinkowski, P. Demetriou, B. Mariński

A closed-form one-step direct (1SD) reaction cross section was expressed as a sum of contributions due to incoherent excitation of particle-hole (ph) pairs of high orbital angular momentum transfer \( l \) and to coherent excitation of collective vibrations of low multipolarity \( \lambda = l \) \[1\]. This cross section is used in calculations of multistep direct (MSD) reaction cross sections in the framework of the theory of Feshbach, Kerman and Koonin \[2\]. The MSD cross sections become enhanced since they contain the enhanced, non-DWBA matrix elements involving the biorthogonally conjugated wave functions. The calculations reveal the relative contributions of the multi-phonon, multi-particle-hole and the multitude of mixed particle-hole-phonon excitations in the continuum. The partial cross sections due to the 3SD reactions are shown in Fig. 1.

![Fig. 1 Mixed particle-hole-phonon components of the 3SD cross section.](image1)

When all the processes relevant to direct reactions up to the fourth step are taken into account, the experimental cross sections for the \( ^{93}\text{Nb}(n,n')^{93}\text{Nb} \) inelastic scattering at incident energy of 26 MeV \[3\] are well reproduced.

The collective one-phonon cross sections exhaust the dipole, quadrupole, octupole and hexadecapole energy weighted sum rule's (EWSR's) limits and the 1SD incoherent ph excitations observe the limits for the transferred orbital angular momenta \( l > 4 \). The results show substantial contributions from multistep reactions.

The relative contribution due to the mixed phonon-particle-hole excitations increases with increasing number of reaction steps, since the decreasing energy available at each stage of the multistep reaction favors low energy collective excitations. For the same reason, the multi-ph cross sections decrease faster than the multi-phonon ones.

The overall enhancement of the 2SD, 3SD and 4SD cross sections as compared with cross sections calculated with use of the normal DWBA matrix elements amounts 3.5, (3.5)\(^2\) and (3.5)\(^3\), respectively. As a result the non-DWBA matrix elements provide MSD cross sections that fit the data (see Fig. 2) while the normal DWBA matrix elements are too small. The large MSD cross sections support the concept of gradual absorption \[4,5\] into the quasibound compound states up to the fourth stage of the reaction at incident energy of only 26 MeV.

![Fig. 2 Comparison of calculations with experiment.](image2)


\(^{1}\) Institute of Nuclear Physics, NCSR Demokritos, Athens, Greece
1.3 Interplay of Equilibrium and Nonequilibrium Phenomena in the Nuclear Liquid-Gas Phase Transition

by A. Trzcinski and B. Zwieglik for the ALADIN Collaboration

The ALADIN Collaboration activities in the year 2000 concentrated on the following issues:

(i) Interpretation of the experimental data collected in the S117 experiment performed in 1995 and preparation of publications [1,2],

(ii) Data reduction from the experiments S185-I, II and S204 performed with the INDRA multidetector in 1998 and 1999, respectively,

(iii) Upgrade of the ALADIN spectrometer detecting system intended to meet the goals of the experiment S254 "Mass and Isospin Effects in Multifragmentation", whose proposal has been presented to the GSI PAC and approved for execution.

In this note we make a brief presentation of (i) to elaborate in more detail on (ii) and (iii) in the two consecutive research notes.

Fig. 1 (a) Energy spectra of protons for different \( Z_{\text{bound}} \) bins. (b)-(e) Temperature and yield ratios resulting from Maxwell-Boltzmann fits to experimental LP spectra (open and closed symbols) and BUU calculations (crosses) as functions of \( Z_{\text{bound}} \).

In the experiment S117 we have the system \(^{197}\text{Au} + ^{197}\text{Au}\) in two centrality and energy regimes. We address here the particle spectra emitted by the target residue at 1000 MeV/nucleon, measured with the aid of high resolution telescopes set at \( \theta_{\text{lab}}=150^\circ \) to the beam direction (see Fig. 1a). The spectra are sorted according to the \( Z_{\text{bound}} \) value, measured event wise with the ALADIN spectrometer. \( Z_{\text{bound}} \) is defined as the sum of the atomic numbers of all projectile fragments with \( Z \geq 2 \). Because of the symmetry of the collision system, the mean values of \( Z_{\text{bound}} \) for the target and the projectile spectators within the same event class have been assumed to be identical. \( Z_{\text{bound}} \) is inversely correlated with the impact parameter engaged in a collision, hence with the excitation energy initially reached by the spectators. The neutron results (Figs. 1 b-d) are from our previous experiment [3]. The light-particle spectra (represented by protons in Fig. 1a) reveal two components attributed to preequilibrium and equilibrium emission, respectively. The inverse slope parameters, \( T_{h,0} \), of these components (Figs. 1b, 1c and 1e) are extracted from the fits with a sum of two Maxwell-Boltzmann distributions. The low temperature component, \( T_{h,0} \), corresponding to the equilibrium proton emission, is indicated with the dotted line, while the high temperature component, \( T_{h,0} \), corresponding to the preequilibrium one, with the dashed line for the spectrum in bin \( 70 \leq Z_{\text{bound}} \leq 80 \). Solid lines represent their sum for this and the remaining \( Z_{\text{bound}} \) bins in
The total yields, \( Y_{\text{thr}} \), whose ratios are displayed in Fig. 1d, result from integration of \( \sigma_{\text{thr}} \) over \( E_p \). The relative intensities of the low-temperature components \( Y_{\text{h}0}/Y_{\text{h}10} \) (Fig. 1d) decrease rapidly with decreasing \( Z_{\text{bound}} \), so that they become hardly distinguished in the experimental spectra with \( Z_{\text{bound}} \leq 20 \), as one may see for protons in Fig. 1a. The average mass number of a residue with which one deals for \( 0 \leq Z_{\text{bound}} \leq 10 \) is about 40 and the average excitation energy per nucleon therein \( \langle E_p \rangle/Y_{\text{thr}} \approx 24 \text{ MeV} \), well within the gas branch of the caloric curve [4].

The magnitude of the fitted ratio \( Y_{\text{h}0}/Y_{\text{h}10} \) at these low \( Z_{\text{bound}} \) values, where the signature of the evaporative events gradually disappears, critically depends on the assumed shape of \( \sigma_{\text{thr}} \) at low \( E_p \). We have performed BUU calculations for \( \sigma_{\text{thr}} \) with the code BUU255 of Danielewicz [5] in order to gain insight into the Coulomb effects using realistic assumptions. A soft equation of state has been assumed and the internal cascade was followed up to 50 fm/c, guided by the considerations contained in [5]. The BUU-predicted Coulomb holes at low proton energies appear much shallower than those resulting from the Maxwell-Bollzmann fits to experimental data with the assumed barrier heights of a few MeV. Therefore, the relative yields \( Y_{\text{h}0}/Y_{\text{h}10} \), for \( Z_{\text{bound}} \leq 20 \), indicated in Fig. 1d, are rather upper bounds to the true ones. A disappearance of the evaporative component from the nucleon spectra may indicate, therefore, that the residue lifetime becomes too short to reach thermalization above some limiting excitation energy within the gas branch of the caloric curve. This might be a natural consequence of disappearance of a multifragmentation barrier, created at lower excitation energies by the attractive interfragment interactions. Above this critical energy the created systems disassemble on a time scale shorter than \( =50 \text{ fm/c} \).

1.4 Multifragmentation Experiments with the INDRA Multidetector*

by A. Trzciński, J. Lukasik, W. F. J. Müller, W. Trautmann and B. Zwiegiński for the INDRA-GSI Collaboration

INDRA [1], the most advanced among the existing multidetectors, has been transferred at the end of 1997 to GSI to execute the series of three experiments at the heavy-ion (HI) energies inaccessible at GANIL, its host laboratory. Two experiments have been performed in 1998. The first one, S185-I, was intended to provide multifragmentation systematics in \( ^{197}\text{Au} + ^{197}\text{Au} \) collisions in the energy range 40-150 MeV/nucleon. The GANIL data for this reaction were limited in projectile energy to 35 MeV/nucleon, therefore S185-I opened-up for a detailed and precise study the entire rise-and-fall of multifragment production seen in the central collisions [2] in this energy range. We expect also to gain insight into an evolution of flow energy in vicinity of the onset of radial flow. The second experiment, S185-II, was intended to gain information on isospin effects in multifragmentation. Collisions of \( ^{124}\text{Xe} \) and \( ^{124}\text{Xe} \) ions with \( ^{116}\text{Sn} \) and \( ^{124}\text{Sn} \) targets, widely differing in neutron number, were studied in the above energy range. Some results for the system \( ^{197}\text{Au} + ^{197}\text{Au} \) have been presented at the Conference [3].

The third experiment, S204, was executed in 1999. We have studied \( ^{12}\text{C} + ^{197}\text{Au} \) collisions at the \( ^{12}\text{C} \) projectile energies of 95, 300, 600, 1000 and 1800 MeV/nucleon and \( ^{12}\text{C} + ^{112,124}\text{Sn} \) at 300 and 600 MeV/nucleon for both \( ^{12}\text{C} \) targets. This experiment had several objectives. We intended to investigate thermally driven multifragmentation, only little distorted by collective flow effects. We want to
acquire the knowledge on how the preequilibrium and equilibrium phenomena are manifested in these asymmetric systems as compared with $^{197}$Au + $^{197}$Au at 1000 MeV/nucleon (see the preceding research note). Finally, we want to compare with the EOS Collaboration results, which studied $^{197}$Au+$^{12}$C at 1000 MeV/nucleon in the inverse kinematics at the Berkeley Bevalac.

![Graph showing comparison of calibration coefficients](image)

Fig. 1 Comparison of the calibration coefficients (open and closed points) obtained with the aid of the two methods described in the text for the modules in rings 6 and 7.

An important task, only partly completed, is calibration of energy scale of the 336 individual detection modules of INDRA. The SINS equip developed the method of calibration of CsI(Tl) modules for rings 6-12 (forward hemisphere) employing recoil protons from the $^{12}$C + $^1$H elastic and inelastic scattering at $E(12$C) = 30 MeV/nucleon. The device axial symmetry permits to detect these events selectively by requiring a coincidence between both interaction products. The slope coefficient (in channels/MeV) of the calibration line is determined by fitting the proton spectrum, simulated with the aid of a Monte-Carlo method, to the measured one for each individual module. The spectra referred to here originated from the fast component of the scintillation light. The above procedure, when applied to the total light – a sum of suitably weighted fast and slow components, which are available from INTRA as separate signals, permits to obtain a valid calibration for other particles besides protons. Birks' formula, relating differential light output, $dL/dx$, to differential energy loss, $dE/dx$, is utilized for this purpose [4]. Fig. 1 presents a comparison of the calibration coefficients obtained with the aid of two methods. Closed points are from the fits of the Monte-Carlo simulated total light yield to the proton total light spectra from $^{12}$C+$^1$H at 30 MeV/nucleon. Open points result from the fits of proton total light spectra produced in Xe+Sn at 50 MeV/nucleon in S185-II at GSI to the spectra for the same particle, colliding nuclei and bombarding energy obtained in the course of the 1-st campaign at GANIL. GANIL data were calibrated using the products of $^{16}$O fragmentation at 95 MeV/nucleon, separated in magnetic rigidity with the magnetic spectrometer ALPHA. For protons in rings 6-12, the former set of coefficients, being more precise, provides a reference for the latter. However, the latter has wider application, permitting to obtain calibration coefficients for rings 13-17 and particles other than protons.


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1.5 Upgrade of the ALADIN Spectrometer Detecting System for the Experiments with Secondary Radioactive Beams*


The conclusions of the Collaboration Meeting held October 4-6, 1999 at Rauschholzhausen have been cast into a proposal of an experiment at SIS “Mass and Isospin Effects in Multifragmentation”, which was submitted to the GSI PAC. A total of 14 days of measuring time with primary beams of $^{197}$Au and $^{124}$Sn, and with secondary beams of $^{124}$La and $^{106}$Sn in the energy range 0.6 to 1 GeV/u were approved for the experiment S254. The data are expected to serve as a general basis for the study of isotopic effects in multifragmentation and to resolve existing ambiguities in the interpretation of the caloric curve of nuclei. In order to meet the goals put forward in the proposal the performance of the MUSIC-III detector and the time-
of-light (TOF) wall of the ALADIN spectrometer will be significantly improved by the upgrade that is presently under way.

A new set of proportional counters is constructed for the MUSIC-III chamber and a new readout system based on the 14-bit flash-ADCs. The 14-bit ADCs digitize the signals coming either from the charge-sensitive preamplifiers at the anodes of the ionization sections or from the current-sensitive preamplifiers at the electrodes of the proportional sections of the detector. A prototype two-stage preamp based on the current-feedback operational amplifier MAX4180ESA of MAXIM was developed for the latter purpose at SINS. It uses a single integrating RC-circuit in between these two stages for pulse shaping, thus permitting to employ a galvanic coupling from the input to output. An excellent overload performance is achieved in this way, necessary to resolve two pulses widely differing in amplitude, which arrived close-by in time. The output push-pull stage is designed to drive a twisted-pair cable connecting to the remote flash-ADC.

We intend to replace photomultipliers (PMs) with large area avalanche photodiodes (LAAPDs) in the central section of the ALADIN TOF-wall to eliminate PM saturation effects caused by the large dynamic range of light signals excited by multifragmentation products in the BC-408 plastic scintillators. The necessary prerequisite for implementing this alternative is demonstration that LAAPDs can offer a comparable (or superior) to PMs timing performance for 25 MeV protons, the lightest particle and lowest energy to be dealt with in S254. To this end we perform a comprehensive study of SD630-70-74-510 (windowless), produced by Advanced Photonix Inc.

The initial stage of our study, using radioactive sources with the LAAPD held at room temperature, was devoted to several factors, which are known to influence time resolution. The first was light transport to the photodiode sensitive area. Light transport needs to be treated with due care since only 1520 e-h pairs/MeV of the electron energy deposited in the scintillator are found to be created in the photodiode.

Tests of the prototype proportional counter using a batch of 12 preamps were performed at GSI with an alpha source of $^{241}$Am in a vacuum chamber filled to 500 mbar with the P10 gas. Fig. 1 shows the position spectrum reconstructed from the signals of the anode wires. Work on the preamp is presently underway aimed at improving its noise performance and implementing a digital control of its gain and the quiescent output voltage level.

This should be compared with 37000 e-h pairs/MeV typically measured with CsI(Tl) [1]. The second factor studied was a preamplifier selection to find one with the rise time matching that of a current pulse from the BC-408+LAAPD combination. Time spectra were measured in two detector configurations. The first one used a sample BC-408 of 50 mm length coupled to the LAAPD and a BaF$_2$ crystal coupled to the PM XP2020Q, which were optically separated. The coincidence curve for the $\gamma$-$\gamma$ coincidences from the $^{59}$Co source, which we got with the ORTEC preamp, had 2.0 nsec FWHM as compared with 1.1 nsec obtained with the CATSA, therefore we used only the latter one in the further measurements. The second configuration used a BC-408 sample of 40 mm length inserted between these two photo sensors and
read by them from both ends. The scintillator was excited with \( \gamma \)-rays from \( ^{60}Co \) and \( \beta \)-particles from a \( ^{90}Sr/^{90}Y \) source. The threshold of amplitude selection in the LAAPD branch was set about 20\% below the endpoint of the respective spectrum. The former yielded FWHM of 1.3 nsec while the latter 1.1 nsec, when measured without a silicone pad interface, the improvement resulting from the increase by nearly 1 MeV of the deposited electron energy in the scintillator. The resolution with \( ^{90}Sr/^{90}Y \) is further reduced to 700 psec (see Fig. 2) when the silicone rubber pad is inserted.


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2) Advanced Photonix Inc., 1240 Avenida Acaso, Camarillo, CA 93012, USA
3) This work was supported in part by the Scientific and Technological Cooperation Joint Project with Germany for the years 1997-2000 ("Elementary Reactions", FKZ-Nr: POL-196-96).

1.6 Data Analysis Techniques for Extracting Gamow-Teller Strengths from \( 0^\circ \)(p,n) Data

by C.D.Goodman\(^1\), M.Bhattacharya\(^1,2\), M.B.Auferheide\(^3\), S.D.Bloom\(^3\) and P.Zuprański

Structure overlap matrix elements for the Gamow-Teller (GT) operator between various nuclear states provide particularly interesting nuclear structure information because these matrix elements simply and directly show the relationships between the quantum states of neutrons and of protons in nuclei. Beyond the inherent nuclear structure interest in measuring GT matrix elements there are applications of GT measurements in neutrino physics and in astrophysics. Neutrino detection by absorption of neutrons on nuclei occurs through Fermi and GT transitions, and some detection schemes rely exclusively on GT transitions. Some steps in astrophysical nucleosynthesis occur through electron absorption and emission in GT transitions. The density of hot electron in a stage of supernova explosions is controlled by electron capture into GT states.

Beta decay is the most reliable way to measure GT matrix elements. However, its applicability is very limited and, in particular, it is not useful for measuring GT giant resonances or GT transitions involved is some neutrino detectors.

Charge-exchange reactions offer an alternative without the energy limitations of beta decay. However, reaction theory does not have the precision required to convert reaction cross sections to GT matrix elements with the desired accuracy. We have worked out techniques to obtain absolute normalizations for Gamow-Teller strength functions from (p,n) spectra. A method of using data taken at two different proton energies and a method using polarization transfer data can be used. Both methods require determining the number of counts due to a Fermi transition, which is usually not completely resolved. We have analyzed methods of normalizing to unresolved peaks and handling the peak shapes encountered in real time-flight spectra.

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3) Lawrence Livermore National Laboratory, Livermore, California, U.S.A.

1.7 Coherent Pion Decay of the \( \Delta \) Resonance Excited in the Projectile in the Reaction \( \alpha + p \rightarrow \alpha + n + \pi^+ \)

by W.Augustyniak and P.Zuprański for the SPESIV-\( \Pi \) Collaboration\(^*\)

Decay properties of the Roper resonance \( N(1440 \text{ MeV}) \) excited in the inelastic scattering of alpha particle have been measured at the French National Laboratory SATURNE by SPESIV-\( \Pi \) Collaboration.

Beams of \( \alpha \) particles accelerated to an energy of 4.2 GeV by the SATURNE-MIMAS (accelerator-storage ring) system impinged on a liquid hydrogen target. Alpha particles inelastically scattered at 0.8\(^\circ\) were measured in a magnetic spectrometer SPESIV of a momentum resolution \( \Delta p/p = 0.04\% \). Four momenta of decay products were measured in a Forward Spectrometer. A given energy loss of \( \alpha \) particle may be due either to the excitation of the target proton or to the excitation of one nucleon in the incident \( \alpha \) particle to \( \Delta \) resonance with subsequent pion emission to the \( \alpha \) ground state. Due to nucleon-nucleon interaction the excitation of one nucleon can be transmitted to neighboring nucleons. This transmission proceeds through a coherent superposition of \( \Delta \)-hole states that can be truncated at a certain stage by \( \Delta \) decay. Pions from that decay carry off information on \( \Delta \)-hole interaction in nuclear medium. It has been argued that the spin longitudinal part of this \( \Delta \)-hole interaction is attractive, leading to softening of nuclear response to
spin–isospin excitation. General features of those coherent pions emitted from the chain of \( \Delta \)-hole states are:

1. they should carry off the whole excitation energy leading to the ground state of the excited nucleus.

2. their angular distribution for spin longitudinal excitation should be in the rest frame of the excited nucleus peaked along the transferred momentum.

We have made an attempt to look for those features in the pion decay of the excited \( \alpha \)-particle.

The pions are accompanied by \( \alpha \) particles detected in the SPESIV spectrometer which means that they bring the excited \( \alpha \) to the ground state.

The cosine of the angle between the pion momentum and the transferred momentum in the rest frame of the \( \alpha \) is shown in Fig. 1. A characteristic feature of preferred emission of pions along the momentum transfer is clearly seen. The cosine distribution does not continue to an angle of 0 degree between the pion momentum and the momentum transfer. This is due to energy and angular limitations of the detecting Forward Spectrometer.

A clear signature of coherent pion production in the projectile excitation in the reaction \( \alpha + p \) has been distinguished. This signature offers a means to separate in the measured resonance decays the excitation of the target from that of the projectile.

![Cosine of the angle between the emitted \( \pi^* \) and the transferred momentum in the rest frame of \( \alpha^* \).](image)

**Fig. 1** Cosine of the angle between the emitted \( \pi^* \) and the transferred momentum in the rest frame of \( \alpha^* \).

1.8 Configurations of Highly Excited States of Fast Sulphur Ions Passing Through a Carbon Target


Swift heavy ions slowing down in matter (among other effect) cause the emission of x-rays characteristic of both the projectiles and the target atoms due to the filling of inner-shell vacancies. The competition between ionisation, excitation, capture, losses and decay processes leads to an equilibrium distribution of excited state in the moving projectile passing thin target foils. The measured K x-rays emitted by the projectiles reflect all these processes [1].

Sulphur ions with incident energies of 99.2 MeV and 121.6 MeV, obtained from the U-200P cyclotron at Heavy Ion Laboratory of Warsaw University, were used to bombard a self-supported carbon foils of thickness in the range 14-100 \( \mu g/cm^2 \). K x-rays, emitted by highly ionised sulphur projectiles passing carbon foils have been measured by a Si(Li) spectrometer with 170 eV energy resolution. The energy calibration of x-ray spectra was obtained with an uncertainty of \( \pm 2.5 \) eV. The measurement energy shift (relative to the diagram energy) of \( K_o \) and \( K_0 \) satellite and \( K_a \) and \( K_h \) hypersatellite x-ray lines and their relative intensities are presented in Table 1. A typical x-ray spectrum is shown in Figure 1. Measured shifts of satellite and hypersatellite K x-ray lines are significant and generally constant within the target thickness range used and are independent of beam energy. This indicates that the K x-rays are emitted from ions in equilibrium state.

![Typical x-ray spectrum emitted by S ions at 99.2 MeV passing through carbon foil of thickness 13.9 \( \mu g/cm^2 \) recorded by a Si(Li) detector-(black points) together with resolved individual K x-ray transitions (dashed lines).](image)

**Fig. 1** Typical x-ray spectrum emitted by S ions at 99.2 MeV passing through carbon foil of thickness 13.9 \( \mu g/cm^2 \) recorded by a Si(Li) detector-(black points) together with resolved individual K x-ray transitions (dashed lines).
On the basis of measured $K_a$ and $K_p$ energy shifts of satellite and hypersatellite x-rays and their intensity ratios, the single configuration Dirack-Fock calculation (performed within MCDF method) \[2\] was used to predict the initial electronic configuration of sulphur projectile in the carbon target. These configurations play a dominant role in the production of the measured $K$ x-ray lines. The success of the proposed model in reproducing the energy shift values led us to apply this model for evaluating the theoretical values of relative intensities of satellite and hypersatellite $K_a$ and $K_p$ lines with the additional assumption that in the configurations producing these lines the $2p$, $3p$, and $4p$ or $5p$ states are singly occupied.

Table 1 The measured energy shifts and relative intensities values for sulphur ions passing through the carbon foils of various thicknesses for two incident energies.

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<th>C thickness (µg/cm²)</th>
<th>Shift (eV)</th>
<th>Intensity ratio</th>
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1.9 Universal Scaling of the M - N- Shell Ionisation Probabilities Measured in Collisions of O, Si and S Ions with Heavy Atoms

Multiple ionisation probabilities in collisions of 0.3-2.2 MeV/u O, Si and S ions with Ta, Au, Bi, Th and U targets was studied. As a result of relaxation of multiple ionised atoms, the so-called "satellite" x-ray transition are observed. The x-ray spectra were measured by Si(Li) detector for different $L_y$, $L-M$, $N$, O) transitions and were analysed using the method described in [1]. We found that the $L_y$, $L-N$, O) x-rays are best suited for a determination of the ionisation probabilities. In order to interpret the measured ionisation probabilities for M and N shells during L x-ray emission, the measured probabilities have to be corrected for the effect of the vacancy rearrangement single-hole the radiative, Auger, Coster-Kronig and super- Coster-Kronig rates for M- and N - shells, were scaled proportionally to the number of available electrons transition.

The ionisation probability for the zero impact parameter can be calculated using "geometrical model" (GM) developed by Sulik et al [2]. They showed that the ionisation probability at the zero impact parameter is given, for an arbitrary shell n, by a universal function $p(0,X_n)$ of the main scaling parameter $X_n$ used in approach [2]: $X_n = 4(Z_i/v_i n) V(G(V))^{15}$ (where $Z_i$ is the projectile charge, $V = v_i/v_2$ is the ratio of the projectile and target electron velocities, $G(V)$ is the universal function in the BEA
approach [3] and n is the principal quantum number of a given shell).

![Graph](image)

Fig. 1 Measured ionisation probabilities for M- and N- shells plotted as the reduced probabilities p(0)/(Z/n)^3 versus the scaling parameter V-UA = v1/v2n-UA in comparison with the predictions of the universal scaling of the ionisation probabilities at the zero impact parameter according to the SCA-UA calculations [4].

The multiple ionisation of atoms by charged particles can be treated within the first-order approach using the semiclassical approximation (SCA) [4]. The SCA approach can also be used for a description of the ionisation probabilities at near zero impact parameters for higher projectiles energies, unless the perturbation is small, i.e. Z <= Z_0. The SCA ionisation probabilities should exhibit approximate universal scaling with respect to the relative velocity in the UA limit, i.e. V-UA = v1/v2n-UA.

Figure 1 present the measured ionisation probabilities, corrected for the vacancy rearrangement compared with the predictions of the GM and SCA-UA calculation by plotting the experimental data versus the scaling parameter of these theories.

In summary, the developed method of analysis of multiple ionisation effects in the x-ray spectra excited in ion - atom collisions allowed us to study systematically the multiple ionisation in outer M- and N- shells of heavy atoms by impact of energetic O, Si and S ions. Both the non - perturbative "geometrical model " and the first - order based SCA - UA calculations describe quite satisfactory the measured ionisation probabilities. We found that the data exhibit approximate universal scaling for M - and N- shells versus appropriate dynamic scaling variables.

1.10 The PIXE Analysis of White and Gray Matter of Human Brain Samples

by M.Boruchowska\(^1\), M.Lankosz\(^2\), A.Adamek\(^3\), A.Korman

Literature studies [1,2] indicate that environmental factors affect elemental concentration in human central nervous system tissue. Correlation has been reported between the alteration of selected trace element concentrations in human brain tissue and certain neurological diseases. On the strength of these observations the necessity of studying the sources of these abnormalities is obvious. It is important to verify, for instance, the effect of a patient's age or environmental factor on accumulation of the elements in brain tissue. The main goal of these preliminary studies was to evaluate approaches for quantitative analysis of medical material using PIXE technique with taking need of the effect of patient age and regional distribution of elements in human brain.

Human brain tissue samples were taken at autopsies. After lyophilization each sample was homogenized and approximately 250 mg was pressed into a pellet 1.3 cm in diameter without any additions.

In the PIXE technique a proton beam of 2.0 MeV energy collimated to 2 mm diameter was used for irradiation of the medical samples. The typical PIXE spectrum for human brain tissue recorded by Si (Li) spectrometer was shown in Fig. 1.

![Graph](image)

Fig. 1 PIXE spectrum for white matter of human brain tissue.
The wide age range of patients (71 years) allows a check of the effect of a patient's age on the accumulation of elements in brain tissue. However, an increase of concentration with age was observed only for zinc in the white matter of the brains. According to Fig. 2, values of mass fraction varied from about 1.11 mg/kg for the 17 year old patient to 54 mg/kg for 88 year old patient. These results are not readily interpretable due to the small number of analyzed cases. However zinc is one of the elements that may be related to Parkinson's disease [3], which also progresses with age. Studies of a larger number of samples are necessary and will be performed.


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1.11 Polytypic Structures of U₃O₇
by L. Nowicki, A. Turos, F. Garrido, L. Thomé

Many inorganic compounds form polytypes, i.e. crystalline structures that differ by the stacking manner of identical mono- or poly-atomic layers. It is generally believed that the mean layer-layer repetition period (interlayer spacing) in polytypic structures is either not affected or is changed very little by variability of the stacking pattern. In the case of U₃O₇, which is a structural derivative of UO₂ formed upon its oxidation, a much stronger influence on the layer spacing and on the intra-layer interatomic distances is exerted by the formation of Bevan-type cuboctahedral clusters [1]. Variability of the axial ratio c/a, which discriminates U₃O₇ from other UO₂-related oxygen-excess compounds, occurred to be a consequence of structural polytypism of U₃O₇ ascertained recently by Nowicki et al. [2].

Since the late 40-s, when the first reports on UO₂-lattice deformations were published, variability of c/a in products of UO₂ oxidation was ascribed to unknown arrangements of oxygen atoms. Meanwhile, the structure of βU₄O₉ was determined [1] basing on Bevan's principle of formation of anion-excess fluorite-like phases. The two products of UO₂ oxidation: U₄O₉ with a = b = c, and U₃O₇ with tetragonal deformed cells, are built according to a common crystallochemical rule, as postulated in ref. [2]. In both compounds additional oxygen atoms combine with those of the original UO₂ structure to form 13-atomic cuboctahedral clusters. The clusters are arranged in a superstructure and their centers form a lattice of crystallographically equivalent positions located at some holes of the UO₂ structure. For βU₄O₉ the cluster concentration is small enough to arrange the clusters in a cubically symmetric scheme. For U₃O₇, the closest intercluster distance is reduced to approximatively 860 pm and the constraints imposed by the UO₂ lattice on the clusters arrange them into tetragonal, monoclinic or triclinic structures. It was shown that U₃O₇ form polytypes which differ by the stacking manner of identical (001) cluster layers. The detailed analysis of possible stacking patterns resulted in the determination of seven basic sequences. Two of them were ascribed to the polymorphs with extreme lattice deformations, i.e. βU₄O₉ with elongated cells and αU₃O₇ with shortened cells. The first belongs to the P2₁/m space group with cuboctahedral clusters forming zigzag chains along the z direction. The second is essentially isostructural with Ca₂YbF₇ (C a = Y b = U, F = O). These deformations of the ionically-bond UO₂ structure as well as its contraction typical for U₄O₉ can be explained by a common oxygen-clustering structural approach.
Fig. 1 illustrates the characteristic shift between two adjacent cluster layers. This shift can have 4 equivalent directions: $x$, $-x$, $y$, and $-y$ leading to various stacking sequences. This explains peculiar polymorphism of $U_3O_7$. Fig. 2 shows one of the basic polytypic arrangements of clusters.

Fig. 1 Two adjacent layers of cuboctahedral oxygen clusters in $U_3O_7$ structures. Small cubes show unit cells of the matrix structure, i.e. that of $UO_2$. Positions of cluster centers are marked with gray circles. The $z$-projections of layers do not coincide, being shifted by a vector, which magnitude equals half of $UO_2$ lattice parameter.

Fig. 2 A perspective view of a $5 \times 5 \times 15$ supercell of one of the seven basing $U_3O_7$ structures. Black circles show the cluster centers. Although the shape of rectangular parallelepiped is inherited from the matrix lattice, the structural symmetry is reduced to $P\bar{T}$ space group, thus it belongs to the triclinic syngony.


1) Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, CNRS-IN2P3, Orsay, France
LIST OF PUBLICATIONS

FRAGMENT KINETIC ENERGIES AND MODES OF FRAGMENT FORMATION
T. Odeh, ..., A. Trzcinski, ..., and B. Zwegiński, et al.

MEASUREMENT OF GAMOW-TELLER STRENGTH FOR $^{176}$Yb $\rightarrow$ $^{176}$Lu AND THE EFFICIENCY OF A SOLAR NEUTRINO DETECTOR
M. Bhattacharya, C. D. Goodman, R. S. Rahtuwan, M. Pularczyk, A. Garcia, J. Rapaport, I. J. Van Heerden and P. Župrka

OBSERVATION OF PERIPHERAL LOCALIZATION IN POLARIZED NUCLEAR REACTIONS
E. E. Bartosz, P. Daithers, K. W. Kemper, F. Maréchal, D. Robson, G. Gravert, K. Rusek

MULTISTEP DIRECT REACTIONS AT LOW ENERGIES
P. Demetriou, A. Marcinkowski, B. Mariański

BREAKUP COUPLINGS IN $^4$He $+$ $^4$He ELASTIC SCATTERING
K. Rusek and K. W. Kemper

STRUCTURE OF THE $P_{11}(1440)$ RESONANCE FROM $\alpha$-p AND $\alpha$-N SCATTERING
H. P. Morsch and P. Župrka

LOW-LYING STATES OF $^{131}$Sb STUDIED IN THE $^{132}$Sb(p,t) REACTION

ONE- AND TWO-STEP MECHANISMS OF THE $^7$Be($^{12}$C,$^9$B)$^8$B REACTION AT $E_{\text{cm}}(^{12}$C) = 65 MeV AND THE ENERGY DEPENDENCE OF $^{11}$B + $^8$B INTERACTIONS

POLYTYPIC ARRANGEMENTS OF CUB OCTAHEDRAL OXYGEN CLUSTERS IN U$_3$O$_7$
L. Nowicki, F. Garrido, A. Turos and L. Thomé

CHANNEL COUPLING EFFECTS IN RESONANT BREAKUP OF 42 MeV $^7$Li WITH $^{56}$Ni TARGET
Dhruba Gupta, C. Samanta, A. Chatterjee, K. Rusek and Y. Himbeinashi

UNIVERSAL SCALING OF THE M- AND N- SHELL IONIZATION PROBABILITIES MEASURED IN COLLISIONS OF O, SI AND S IONS WITH HEAVY ATOMS

M-X-RAY PRODUCTION CROSS-SECTIONS FOR 0.2–2 MeV DEUTERONS

ANALYSIS OF DEFECTS IN MULTICOMPONENT CRYSTALS BY ION CHANNELING
A. Stonert, A. Turos, L. Nowicki and B. Breger,

CHARACTERIZATION OF InGaN/GaN HETEROSTRUCTURES BY MEANS OF RBS/CHANNELING
L. Nowicki, R. Ratajczak, A. Stonert, A. Turos, J. M. Baranowski, R. Banasik and K. Pakula,

SOLID STATE EFFECTS IN L-O X-RAY TRANSITIONS INDUCED BY O, SI AND S IONS IN HEAVY METALS

ATOMIC TRANSPORT EFFECTS IN Kr-ION BOMBARDED ZrO$_2$/Fe TERNARY SYSTEM
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Nucl. Instr. and Meth. B166 (2000) 128
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EXPLORING THE COLLECTIVE SPIN-ISOSPIN LONGITUDINAL RESPONSE OF NUCLEI WITH COHERENT PION PRODUCTION IN (3He,t)n
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INDRA@GSI- A STUDY OF THE REACTION MECHANISM OF COLLIDING NUCLEI FOR A WIDE RANGE OF ENERGY AND MASS
K. Turzo for the ALADIN and INDRA Collaborations

CHARACTERIZATION OF IMPLANTED SEMICONDUCTORS BY MEANS OF WHITE-BEAM AND PLANE-WAVE SYNCHROTRON TOPOGRAPHY
K. Witeńska, W. Wierzchowski, W. Graeff, A. Turzo, R. Grötzschel
J. Synchrotron Rad. 7 (2000) 318

APPLICATION OF BRAGG-CASE SECTION TOPOGRAPHY FOR STRAIN PROFILE DETERMINATION IN A\textsuperscript{108}B\textsuperscript{11} IMPLANTED SEMICONDUCTORS
K. Witeńska, W. Wierzchowski, W. Graeff, A. Turzo

INTERPLAY OF EQUILIBRIUM AND NONEQUILIBRIUM PHENOMENA IN THE NUCLEAR LIQUID-GAS PHASE TRANSITION
B. Zwiegieniński, ..., A. Trzciński, ..., Hongfei Xi, et al.
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DATA ANALYSIS TECHNIQUES FOR EXTRACTING GAMOW-TELLER STRENGTH FROM 0\textsuperscript{(p,n)} DATA
Ch. D. Goodman, M. Bhattacharya, M. B. Außerheide, S. D. Bloom, P. Zuprański
Nucl. Instr. and Meth., (in press)

COMPOSITIONAL DEPENDENCE OF DEFECT MOBILITY AND DAMAGE BILDUP IN Al\textsubscript{x}Ga\textsubscript{1-x}As
A. Stonert, A. Turzo, L. Nowicki, B. Breeger, E. Wendler, W. Wesch
Nucl. Instr. and Meth. B. (in press)

ADVANTAGE OF PM-355 NUCLEAR TRACK DETECTOR IN LIGHT-ION REGISTRATION AND HIGH-TEMPERATURE PLASMA DIAGNOSTICS
A. Szydlowski, A. Banaszak, T. Czyżewski, I. Fijal, M. Jaskóła, A. Korman, M. Sadowski
Radiation Measurements, (in press)

HYDROGEN-ION IMPLANTATION IN GaAs
G. Gawlik, A. Stonert, A. Turzo, J. Jagielka, S. Bedell, W. A. Lanford
Vacuum, (in press)

STRUCTURAL AND MICROMECHANICAL PROPERTIES OF ION-BEAM MIXED TUNGSTEN-ON-STEEL SYSTEM
J. Jagielka, A. Fiągowska, W. Maz, E. Richter, G. Gawlik, A. Turzo,
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SYNCHROTRON INVESTIGATIONS OF STRAIN PROFILES IN IMPLANTED SEMICONDUCTORS
K. Witeńska, W. Wierzchowski, A. Turzo, W. Graeff, R. Grötzschel
Vacuum, (in press)

HIGH-RESOLUTION MEASUREMENTS OF Th AND U L-X-RAYS INDUCED BY ENERGETIC O IONS
Physica Scripta, (in press)

SYNCHROTRON STUDIES OF In\textsubscript{x}Ga\textsubscript{1-x}As
W. Witeńska, W. Wierzchowski, W. Graeff, A. Turzo, R. Grötzschel
J. Alloys and Compounds, (in press)
OTHER PAPERS

FRAGMENT KINETIC ENERGIES AND MODES OF FRAGMENT FORMATION
T.Odeh, ... A.Trzcinski, ... and B.Zwieginski, et al.  
GSI - Report 2000-10 (March 2000)

RECOMMENDED CROSS SECTIONS FOR THERMAL NEUTRON CAPTURE BY $^{14}\text{N}$, $^{35}\text{Cl}$, $^{40}\text{Ti}$ AND $^{54}\text{Cr}$, FOR RESONANCE CAPTURE OF PROTONS BY $^{14}\text{N}$, $^{28}\text{Na}$ AND $^{27}\text{Al}$, AND THE RATIOS OF INTENSITIES FROM MULTI-$\gamma$ CASCADES FOLLOWING PROTON CAPTURE  
B.Mariainski, A.Marcinkowski   
Report IPJ (Z-1) - No 01/2000, April 2000

PARTICIPATION IN CONFERENCES AND WORKSHOPS

LATEST RESULTS FROM SPE5 4n  
W.Augustyniak (oral)  
International Workshop on Baryon Excitations, Jilich, May 2-3, 2000

EXCLUSIVE STUDY OF THE REACTION $p(a,a')X$ IN THE REGION OF ROPER RESONANCE  
G.D.Alkhazov, W.Augustyniak, ..., P.Zupranski, et al. (oral)  
International Workshop on Baryon Excitations, Jilich, May 2-3, 2000

STRUCTURE OF THE $P_1(1440)$ RESONANCE FROM $\alpha-p$ and $\alpha-n$ SCATTERING  
H.P.Morsch and P.Zupranski (oral)  
International Workshop on Baryon Excitations, Jilich, May 2-3, 2000

EXPLORING THE COLLECTIVE SPIN-ISOSPIN LONGITUDINAL RESPONSE OF NUCLEI WITH COHERENT PION PRODUCTION IN ($^4\text{He},\alpha$)  
J.L.Boyard, ..., W.Augustyniak, ..., P.Zupranski, et al.  
6th International Workshop on Production, Properties and Interaction of Mesons, Cracow, Poland, May 19-23, 2000

INTERPLAY OF EQUILIBRIUM AND NONEQUILIBRIUM PHENOMENA IN THE NUCLEAR LIQUID-GAS PHASE TRANSITION  
B.Zwieginski (invited talk)  

CROSS SECTIONS OF MULTISTEP DIRECT REACTIONS AT LOW ENERGIES  
A.Marcinkowski  
Int. Confr. On Reaction Mechanisms, Varenna, June 5–9, 2000

STRUCTURAL AND MICROMECHANICAL PROPERTIES OF ION-BEAM MIXED TUNGSTEN-ON-STEEL SYSTEM  
J.Jagielka, A.Piątkowska, W.Mat, E.Richter, G.Gawlik, A.Turos (invited talk)  

SYNCHROTRON INVESTIGATIONS OF STRAIN PROFILES IN IMPANTED SEMICONDUCTORS  
W.Wierzchowski, A.Turos, K.Wieska, W.Graeff (invited talk)  

HYDROGEN-ION IMPLANTATION IN GaAs  
G.Gawlik, A.Stonet, A.Turos, S.Bedell, W.L.Lanford (poster)  

LATERALLY STRUCTURED SURFACES OF GaAs(100) CHARACTERIZED BY CONVENTIONAL AND SYNCHROTRON X-RAY METHODS  
K.Mazur, J.Snus, F.Eichhorn, A.Turos (oral)  

SYNCHROTRON STUDIES OF InGaAs  
K.Witeska, W.Wierzchowski, W.Graeff, A.Turos, R.Groetzschel (oral)  

X-RAY FLUORESCENCE LOCAL ANALYSIS OF MEDICAL MATERIALS  
M.Boruchowska, M.Lankosz, D.Adamiec, A.Korman (poster)  

TWO-STEP PROCESSES IN THE $^1\text{H}(^4\text{He},^4\text{He})^1\text{H}$ REACTION  
K.Rusk, K.W.Kemper, R.Wolski (poster)  
Nucleus-Nucleus Collisions 2000, Strasbourg, July 3-7, 2000

ANALYSIS OF NONLINEAR DOSE DEPENDENCE OF IMPLANTATION INDUCED STRAIN IN SEMICONDUCTORS  
W.Wierzchowski, K.Witeska, A.Turos, W.Graeff (invited talk)  
The Third World Congress of Nonlinear Analysis – WCNA-2000, Catania, Italy, July 19-26, 2000
HIGH-RESOLUTION MEASUREMENTS OF Th AND U L X-RAYS INDUCED BY O IONS
10th International Conference on the Physics of Highly Charged Ions, Berkley, USA, July 30 – August 3, 2000

DETERMINATION OF THE CHEMICAL COMPOSITION PROFILE IN As+ IMPLANTED InGaAs/InP BY MEANS OF X-RAY DIFFRACTION
J.Gaca, W.Wójcik, A.Turos (poster)
XIX European Crystallographic Meeting, Nancy, France, August 25-31, 2000

ADVANTAGE OF PM-355 NUCLEAR TRACK DETECTOR IN LIGHT-ION REGISTRATION AND HIGH-TEMPERATURE PLASMA DIAGNOSTICS
A.Szydłowski, A.Banaszak, T.Czyżewski, I.Fijal, M.Jaskóla, A.Korman, M.Sadowski (oral)
20th Int. Conf. on Nuclear Tracks in Solids, Portoroz, Slovenia, 28 Aug. – 1 Sep. 2000

COMPOSITIONAL DEPENDENCE OF DEFECT MOBILITY AND DAMAGE BILDUP IN Al,Ga,As
A.Stonert, A.Turos, L.Nowicki, B.Breeger, E.Wendler, W.Wesch (poster)
Int. Conf. On Ion Beam Modification of Materials, Porto Alegre, Brazil, September 4 – 9, 2000

DETERMINATION OF THE INTERPLANAR SPACING PROFILE IN As+ IMPLANTED InGaAs/InP SUPERLATTICE CRYSTAL BY MEANS OF X-RAY DIFFRACTION AND RBS METHODS
J.Gaca, W.Wójcik, A.Turos (poster)

APPLICATION OF BRAVAG-CASE SECTION TOPOGRAPHY FOR STRAIN PROFILE DETERMINATION IN A15B7 IMPLANTED SEMICONDUCTORS
K.Witeska, W.Wierzchowski, W.Graeff, A.Turos (poster)

CLUSTER STRUCTURE OF LIGHT NUCLEI
K.Rusck, K.W.Kemper, R.Wolski (oral)
New Challenges in Nuclear Theory, Kazimierz Dolny, Sept. 21-24, 2000

NUCLEAR SPECTROSCOPY BY MEANS OF (p,a) REACTIONS ON MAGIC AND NEAR MAGIC NUCLEI: 112Sn(p,a)140In
14th International Spin Physics Symposium, Osaka, Japan, October 16-21, 2000

LECTURES, COURSES AND EXTERNAL SEMINARS

Structural derivatives of uranium dioxide: U3O7 and U4O9
L.Nowicki, UW Warsaw, Feb. 2000

Ionization of internal atomic shell by heavy ions with Z>3
M.Jaskóla, Inst. of Physics, Milano University, May 8, 2000

Clusters in light nuclei
K.Rusck, UU Warsaw, Oct. 27, 2000

Trace elements analyses using the PIXE method
M.Jaskóla, Inst. of Physics, Milano University, Nov. 8, 2000

Calibration of CsI detectors with use of protons from the 1H(12C,12C)1H elastic and inelastic scattering
A.Trzciński, GSI Darmstadt, Nov. 15, 2000

INTERNAL SEMINARS

Nuclear Physics at Florida State University
P.Cathers, IPJ Warsaw, Jan. 25, 2000

Crystallographical perfection of surface layers studied by RBS/c technique
R.Ratajczak, IPJ Warsaw, Feb. 29, 2000

The new one-step direct cross section and the calculation of multistep direct reactions
A.Marcinkowski, IPJ Warsaw, April 4, 2000

What’s new in Jyväskylä
W.Trzaska, IPJ Warsaw, April 18, 2000

Threshold anomaly and energy dependence of 11B + 14C interaction
"He – what is inside?"
K. Rusek, IPJ Warsaw, Nov. 14, 2000

a) in Polish
b) in English

PARTICIPATION IN PROGRAM AND ORGANIZING COMMITTEES OF CONFERENCES

P. Żupański – Chairman of Plenary Session “Structure of the Roper Resonance”
International Workshop on Baryon Excitations, Jülich, May 2-3, 2000

A. Turos – Chairman of Plenary Session

A. Turos – Member of Organizing Committee, Chairman of Plenary Session

A. Turos – Member of Organizing Committee
V Int. Conf. on High Resolution X-Ray Diffraction and Topography, Jaszowiec, Sept. 13-15, 2000

LECTURES

PHYSICS FOR ENGINEERS
Białyostok University of Technology
K. Rusek

INTRODUCTION TO PHYSICS
Military University of Technology, Warsaw
A. Korman, T. Czyżewski

MATHEMATICAL STATISTICS
Warsaw School of Economy and Informatics
B. Mariański

PERSONNEL

Research scientists
Witold Augustyniak, Dr.
Andrzej Bieńkowski, Dr., 3/5, since June 1
Tomasz Czyżewski, Dr.
Marian Jaskoła, Professor
Andrzej Korman, Dr.
Andrzej Marcinkowski, Professor
Bohdan Mariański, Dr.
Lech Nowicki, Dr.
Renata Ratajczak, MSc.
Krzysztof Rusek, Assoc. prof.
Anna Stonert, MSc.
Andrzej Turos, Professor
Andrzej Trzebiński, Dr.
Bogusław Zwięgiński, Assoc. prof.
Paweł Żupański, Professor

PhD student
Izabela Fijal, MSc.
Andrij Mykulak, MSc. since Oct. 1

Technical and administrative staff
Władysław Mielczarek 1/2
Wiesław Pietrzak
Mieczysław Poliński, Eng.
Zbigniew Szczepaniak

Dorota Dobrowolska 3/4
Tadeusz Jaworski, till April 30
Ryszard Kacprzak
Edward Kamiński, Eng.
Grażyna Kęsik, Eng.
Overview

During the last year, research activities of our Department were mostly continuations of our previous studies on medium and low energy nuclear physics, atomic physics and selected applications of nuclear physics.

Experiments in the medium energy physics are carried out using large facilities: ANKE in KFA Jülich (Germany), SINDRUM II and PIBETA at PSI Villigen (Switzerland). They are concentrated on searches of kaon production by fast protons, a neutrinoless (Standard Model forbidden) nuclear muon-electron conversion and a very precise measurement of the pion beta decay.

Our low energy physicists continue the collaboration with Heavy Ion Laboratory of Warsaw University, and the use of large international gamma multidetector facilities like GAMMASPHERE. They are studying properties of the excited states of nuclei produced by heavy ion reactions - in particular the low-lying levels in $^{125}$La, the isomeric state in $^{134}$Nd and the lifetimes of high spin states in $^{182}$Os and $^{183}$Ir. The experimental study of $^{124}$Sn + $^{64}$Ni reaction was performed in LNS, Catania (Italy) at 35 MeV/nucleon incident energy, but the data are still analysed.

The theoretical work is devoted to study of fusion of heavy nuclei with the particular interest in production of new isotopes with very small probabilities and the light particle emission.

The beams at PSI are used for studies of the X-ray spectra induced by heavy ion collisions, and in particular to determine the multiple ionisation cross sections of L, M, N and O shells.

Our C30 proton cyclotron delivers beam to study modification of optical properties of laser crystals in collaboration with Military Technical Academy and Institute of Electronic Technology of Materials in Warsaw, and to produce isotopes for perturbet angular correlations studies of material properties in collaboration with Jagiellonian University in Cracow.

The low background gamma detection facility of our Department is used to measure radioactive contamination of environment, and in particular the ground level air pollution.

Our new group of X-ray tube developments concentrated on further improvements of the so called photon needle for the potential applications in the brachytherapy of brain tumors.

Financial support received from the State Committee for Scientific Research and Maria Sklodowska-Curie Polish-American Foundation is acknowledged.
2.1 The ANKE Spectrometer at COSY-Jülich
by I.Zychor for the ANKE collaboration

The magnetic spectrometer ANKE, installed in the COSY-Jülich ring in 1998, is used to detect products from proton induced reactions at internal targets. ANKE (Apparatus for Nucleonic and Kaonic Ejectiles) consists of three magnets, which allow the separation of ejectiles emitted from thin targets, and of a detection system placed around the magnets [1].

The first ANKE experimental program on K^± meson production in proton-nucleus collisions close and far below the free nucleon-nucleon threshold at 1.58 GeV was continued in 2000. Measurements of inclusive kaon momentum spectra in the forward direction performed with carbon, copper and gold targets at beam energies from 1.0 to 2.3 GeV are now being analyzed [2].

In 2001 an investigation of the nature of a(980) mesons in the reaction pp→dα^0 is the main experiment with the participation of the IPJ group. The branching ratio α^0→π^±η/K^+K^- will be measured with a cluster jet target (luminosity ~3x10^35) [3].

More information about ANKE can be found on the WWW page:
http://ikpdl5.ikp.kfa-juelich.de:8085/doc/Anke.html


2.2 Search for Muon-Electron Conversion on Gold
by T.Kozlowski and I.Zychor for SINDRUM Collaboration

Observation on solar and atmospheric neutrinos indicate that neutrinos mix so that lepton flavor would not be conserved. SINDRUMII tests lepton-flavor conservation by a search for μ-e conversion in muonic atoms. This process would result in electrons of fixed momentum (depending on atomic number) around 100 MeV/c.

In recent years a dedicated beam line was brought into operation in the πE5 area of PSI. The major element is a 9 m long superconducting magnet. In spring 2000, after a long series of modifications, reliable operation of this PMC beam solenoid was obtained. In the following months data were taken on gold target.

See Fig.1 for a description of the experimental setup.

Fig. 1 The SINDRUMII spectrometer during the year 2000 measurements. Muons are transported (from the left) to the target with the help of a solenoid coupled directly to the spectrometer magnet.

Fig. 2 Momentum distribution for three different beam momenta and polarities: (i) 53 MeV/c negative, optimized for μ^- stops, (ii) 63 MeV/c negative, optimized for π^- stops, and (iii) 48 MeV/c positive for μ^+ stops. The μ^- data were taken at the reduced magnetic field.

Radiative pion capture (RPC), followed by an e^+e^- pair production, can be a major source of background. A pion reaching the gold target has a chance of O(10^-4) to produce an electron in the energy region of interest, so the pion stop rate has to be kept below one every ten minutes. At the PMC entrance the beam contains similar amounts of muons and pions. Since the pion range in matter is about half as large as the range of muon of the same momentum the pion contamination can be reduced strongly with the help of
a moderator at the PMC entrance. Only one out of $10^5$ pions may cross this moderator and then 99.9% will decay before reaching the target. This arrangement required a very careful adjustment.

During an effective measuring period of 81 days $4 \times 10^{13}$ muons stopped in the gold target. Fig. 2 shows preliminary electron momentum distributions. The main spectrum, taken at 53 MeV/c, shows the steeply falling distribution from muon decay in orbit. Two events were found at higher momenta, but just outside the region of interest. They might be induced by cosmic rays or RPC, because both processes result in flat momentum distribution as shown by the data taken at 63 MeV/c. The agreement between measured and simulated positron distributions from $\mu^-$ decay gives us confidence in the momentum calibration.

Presently we are still studying the various rates and efficiencies that enter the calculation of the branching ratio. As a preliminary result we obtain a 90% C.L. upper limit below $5 \times 10^{13}$. This constitutes an improvement by two orders of magnitude of our previous best result on a heavy target.

2.3 A Precise Measurement of the $\pi^- \rightarrow \pi^0 e^+\nu$ Pion Beta Decay Rate

by T. Kozłowski for PIBETA Collaboration

The PIBETA experiment at PSI Villigen (Switzerland) aims to measure the rare pion beta decay ($\pi^- \rightarrow \pi^0 e^+\nu$) branching ratio with an accuracy of about 0.5% in the current phase of the project. Owing to low theoretical uncertainties the result will determine the Vud element of the CKM matrix and test the "new" physics beyond the SM.

The PIBETA detector system assembly was finished in 1998. The heart of the detector is a 3π spherical calorimeter consisting of 240 pure CsI crystals. Pions are slowdowned in the active degrader and stopped in the active target at the center of the sphere, surrounded by a charged particle tracking system consisting of 20-bar scintillator hodoscope and two concentric cylindrical wire chambers. Two-photon rate from the $\pi^0$ decay is normalized to the positron rate from the $\pi^+ \rightarrow e^+\nu$.

![Fig. 1 γ-γ opening angle distribution projected from the analyzed fraction of our 2000 data set.](image)

![Fig. 2 Distribution of time difference between pion stops and CsI calorimeter for pion beta events. The decay time of the exponential curve is 26 ns.](image)

![Fig. 3 Distribution of energy deposited in the CsI calorimeter for pion beta events.](image)

Our most important accomplishment in 2000 is the acquired statistics of clean pion beta events, keeping the experiment on schedule. With <40% of the data replayed and the most stringent off-line cuts we find >14,000 clean events. Relaxing the software cuts (under study) results in ~20% more final events in the current sample. Typical energy, timing and opening angle spectra are shown in Fig. 1-3. We found that signal to background ratio is safely larger than 250.

During the year 2000 we successfully continued taking data at a pion stop rate of ~9x10^7/s. We have also: (i) fully automatized the timing offset adjustment and detector gain matching procedures, (ii) implemented the domino sampling chip readout for all PMT signals, and (iii) completed implementation of near-100% experiment automation, requiring that only a single experimenter be physically present and on call at the PSI site while running.
We have simultaneously recorded a large set of radiative decay events for the processes $n^+ \rightarrow e^+ \nu \gamma$ and $\mu^+ \rightarrow e^+ \nu \nu \gamma$. The PIBETA experiment will increase the world data set for these processes by more than an order of magnitude. We anticipate significant physics results from the analysis of these data.

In summary, during the year 2000 the apparatus was stable and performed as designed and on schedule. We are currently in the process of evaluating first result for the pion beta decay branching ratio.

2.4 Potential Energy of Composite Nuclear Systems

by J.Błócki, L.Shvedov, J.Wilczyński

Good knowledge of the potential energy surface in the deformation space corresponding to different shapes of a nucleus-nucleus system is very important in dynamical description of heavy-ion collisions. Almost 20 years ago an extensive atlas of nuclear deformation energies for volume conserving nuclear systems was produced [1]. In this approach the liquid drop model was used, so the deformation energy was a sum of only the Coulomb and surface terms, calculated for uniformly charged drops. This gave us a qualitative picture of general characteristics expected in collisions of different nuclear systems. However, due to the assumed sharp surface, the liquid-drop-model estimates of one of the most important quantity, the interaction barrier, were rather unrealistic. Therefore later, the model has been improved by replacing the surface term by the folding energy [2]. This modification has led to a significant change of the potential energy landscape, especially in the vicinity of the interaction barrier, i.e., in the configuration of two touching nuclei.

Complex dynamical calculations with the use of the folding potential energy and inclusion of statistical effects have been done last year. They showed quite a discrepancy between the experimental and calculated excitation functions, especially in the region of low incident energies [3]. This discrepancy could not be removed with the potential energy used in our calculations. For example, in the $^{86}$Kr + $^{136}$Xe reaction, the lowest point in the deformation space which has to be surpassed in order to achieve fusion (saddle point), according to the calculations, was at about 200 MeV, whereas experimental points extend down to 195 MeV.

Quite recently we realized that nuclear structure effects, such as shell corrections, even-odd effects and congruence energy, which were not accounted for in our macroscopic calculations of the potential energy, significantly influence the height of the saddle point. Therefore we have proposed the following scheme for the calculations: As previously, we calculate the macroscopic potential energy as a sum of the Coulomb and folding terms in the entire deformation space. Then we compare the calculated value for the compound-nucleus sphere with the correct energy determined by the corresponding difference of the ground-state masses (with shell effects, which are treated separately, excluded). The difference between both energies is incorporated, as a correction, over the entire deformation space and attenuated by a geometrical factor determined by the "window opening" defined in Ref. [1]. As for the shell corrections, we use the method of attenuation described in [3], but with realistic microscopic energies SO taken from the tables of Myers and Świątek [4], instead of a simple phenomenological model used previously [3]. The ground-state masses of the compound nuclei, if unknown experimentally, are also taken from the Myers-Świątek tables [4], based on the Thomas-Fermi gas model, which was found to predict nuclear masses with very good accuracy.

![Fig. 1 Two-dimensional map of the potential-energy surface for the $^{86}$Kr + $^{136}$Xe system as a function of the dimensionless variables $\rho$ and $\lambda$, representing the relative distance and size of the “neck” between the two fragments, respectively.](image)
2.5 Calculations of the Pre-Scission and Post-Scission Neutron Multiplicities in the $^{58}\text{Ni} + ^{208}\text{Pb}$ Reaction at 8.86 A MeV

by K. Siwek-Wilczyńska, J. Wilczyński

Below we give a short description of our simulations of the neutron multiplicities measured in the $^{58}\text{Ni} + ^{208}\text{Pb}$ reaction at 8.86 MeV/A by Donadille et al. [1]. For such a heavy system, the reaction mechanism is somewhat ambiguous because formation of the composite system does not guarantee that the system will eventually fuse. Therefore in our simulations we considered two scenarios: the fusion-fission scenario (in which the compound-nucleus fission is assumed), and the fast fission scenario (in which the time evolution of the combined system is entirely described with deterministic dynamics). For distinction between these two types of reactions we used predictions of the dynamical code HICOL in which one-body dissipation mechanism is assumed. This macroscopic and deterministic code predicts fusion for all partial waves below a limiting value $l_{\text{lim}}$, and fast-fission-like processes (in case of heavy systems) for higher partial waves. The limiting angular momentum for fusion of the $^{58}\text{Ni} + ^{208}\text{Pb}$ system at 8.86 MeV/A was found to be $l_{\text{lim}} = 30\ h$, provided a reduced strength of energy dissipation during the approach stage is assumed, an effect needed to explain the observed nearly symmetric mass division of the fast fission products. Higher partial waves are predicted to lead to fast fission processes. In order to match the largest mass asymmetry of the fragments accepted in the experiment, $\Delta A = 30$, the entrance channel angular momentum cannot exceed a value of $l = 120\ h$. Therefore, according to the model predictions, the fast fission processes associated with the measured neutron multiplicities cover the entire range of partial waves $30 < l < 120$ and thus are expected to give a dominating contribution to the neutron multiplicities (in comparison with the compound-nucleus-fission reactions limited to nearly central collisions at $l < 30$).

The pre-scission neutron multiplicity for the fast fission component in the angular momentum window $30 < l < 120$ was calculated according to the method described in [2]. However a new "differential" Monte Carlo method of simulating the time sequence of the cascade was introduced. This new approach is essential in description of statistical cascades emitted from rapidly evolving systems in which excitation energy is generated in the time scale comparable with the decay rate, or faster. The excitation energy generated in the colliding system along the whole trajectory prior to reseparation was calculated using the code HICOL.

Pre-scission neutron multiplicities corresponding to the compound-nucleus-fission processes expected to take place in nearly central collisions at $l < 30\ h$ were calculated as described in Ref. [3]. Time sequence of light-particle evaporation cascades in competition with fission was traced in a Monte Carlo code in which the fission width is hindered according to the Kramers-Grange-Weidenmüller formalism. Thus the number of neutrons emitted on the way to the saddle point can determine a value of the dimensionless dissipation coefficient $\gamma$ in the Kramers hindrance factor.

![Pre-scission neutron multiplicity](image)

Fig. 1 Correlation between the pre-scission and post-scission neutron multiplicities for the $^{58}\text{Ni} + ^{208}\text{Pb}$ reaction at 8.86 MeV/A, deduced with the "backtracing" method by Donadille et al [1]. The experimental distributions are compared with our simulations of the fast fission processes for $30 < l < 120$ (black stripe) and fusion-fission processes ($l < 30$) for two values of the dissipation coefficient: $\gamma = 5$ corresponding to one-body dissipation (black circle on the left hand side) and $\gamma = 11$ (black circle on the right hand side).

After overcoming the saddle point, some additional pre-scission neutrons are evaporated during the descent from the saddle point to scission, and contribute to the measured pre-scission multiplicity. The additional saddle-to-scission neutron multiplicity was calculated in the same way as for the fast fission processes, i.e., with the "differential" evaporation code coupled to the HICOL dynamics.
In order to compare results of our simulations with experimental information on the correlation between the pre-scission and post-scission neutron multiplicities, we complemented our results with calculations of the post-scission multiplicities. The two-dimensional correlation between the pre-scission and post-scission multiplicities deduced from the "backtracing" analysis of the data for the $^{58}\text{Ni} + ^{208}\text{Pb}$ reaction at 8.86 MeV/A is shown in Fig. 1 and compared with results of our calculations.

### 2.6 Fusion Energy Thresholds Calculated with an Adiabatic Nucleus-Nucleus Potential

by J.Wilczyński, K.Siwek-Wilczyńska

We analyse existing data on fusion excitation functions from the point of view of determination of fusion energy thresholds which can be identified with the lowest barriers in the fusion barrier distributions. As an experimental value of the fusion energy threshold, $E_{\text{thr}}$, we define the energy at which the measured fusion cross section equals to the s-wave absorption cross section:

$$
\sigma_{\text{th}} = \pi\lambda^2 = \pi\hbar^2/(2\mu E_{\text{th}}),
$$

where $\lambda$ is the wavelength of the fusing system, and $\mu$ its reduced mass. We have checked that for all excitation functions measured with sufficient precision, the fusion energy-threshold, determined according to the above criterion, perfectly coincides with the low-energy edge of the fusion-barrier distribution. Data for about 50 systems, for which the sub-barrier part of the excitation function had been precisely measured at least down to the threshold limit given by Eq. (1), were taken for the analysis. For references concerning the experimental data, see the recent review article [1].

We compare experimental values of the fusion energy thresholds, defined according to the criterion (1), with barrier heights calculated assuming the adiabatic fusion potential. Following the idea of Refs. [2] and [3], we use only the known characteristics of the system at the beginning of nuclear interaction (contact force) and in the final state of the equilibrated compound nucleus. Smooth interpolation between these two reference points is done without free parameters assuming that an effective one-dimensional potential has the Woods-Saxon shape:

$$
V_0(r) = V_0(1 + \exp[(r-R_0)/a]),
$$

The depth of the nuclear potential, $V_0$, is determined by the ground-state energy of the compound nucleus (with its intrinsic Coulomb energy $C_{\text{en}}$ and shell correction $S_{\text{en}}$, subtracted) taken relative to the sum of the ground-state energies of the two separated nuclei, also with subtracted intrinsic Coulomb energies $C_1$ and $C_2$, but shell corrections included:

$$
V_0 = (M_1 + M_2 - M_{\text{en}})c^2 + C_{\text{en}} - C_1 - C_2 + S_{\text{en}},
$$

where $\gamma$ is the surface tension coefficient.

As it is seen from Fig. 1, the calculated adiabatic barrier heights are very well correlated with the experimental fusion thresholds. For comparison, the barriers calculated with the Bass potential [5] are also shown in Fig. 1. Obviously, they are much higher than the experimental fusion thresholds because parameters of the Bass potential are chosen to fit the mean, single-barrier values.

$$
V_0 = (M_1 + M_2 - M_{\text{en}})c^2 + C_{\text{en}} - C_1 - C_2 + S_{\text{en}},
$$

The diffuseness parameter $a$ in Eq. (2) is determined by the strength of the nucleus-nucleus attractive force in the contact configuration $R_0 = R_1 + R_2$, calculated [4] in frame of the liquid-drop model:

$$
V_0 = V_0(R_1+R_2)*(16\gamma R_1 R_2),
$$

where $\gamma$ is the surface tension coefficient.

Our analysis of the correlation between the experimental and calculated fusion energy thresholds extends to as heavy systems as $^{48}\text{Ca} + ^{238}\text{U}$. This correlation can be extrapolated to still heavier systems,
thus providing support for predictions of close-contact energy thresholds in reactions considered for future experiments on synthesis of new superheavy elements.


2.7 M-(SUB) Shell Ionization in Collisions of Carbon Ions with Palladium


High resolution x-ray spectroscopy of palladium bombarded with energetic ions makes possible to resolve the M-(sub)shell satellite structure in the KB$_2$ x-ray group. The structure is due to the simultaneous removing of the K-shell electron and of several outer-shell (M, N) electrons. Thanks to the closed-shell electronic configuration of palladium [4d$^{10}$] the structure of the spectrum is much simpler than that for the other mid-Z atoms with one or two open subshells. Therefore these studies provide a useful test for the theoretical multiconfiguration Dirac-Fock calculations (MCDF) [1] of multiply ionized atoms.

The KB$_2$ x-ray spectra of $^{46}$Pd target bombarded with 20.8 MeV/amu $^{12}$C ions were measured with a high-resolution transmission bent crystal spectrometer operated in the modified DuMond slit geometry [2] at the Paul Scherrer Institute in Villigen, Switzerland. The KB$_2$L$^6$M$^4$ line (see Fig. 1) is found to be significantly broadened. The line can be resolved into at least two components corresponding to ionization of 3p and 3d electrons.

The measured spectra were corrected for the self-absorption in the target and for the electron rearrangement occurring prior to the x-ray emission. The spectra were analyzed by means of a least-squares fit program using a single Voigt function resulting from the folding of a Lorentzian (the fixed width corresponding to particular initial and final states for singly ionized atom) and of a Gaussian of adjusted width. The latter was let free in the fit. The contribution of the 3s hole to M$^1$ satellite line is too small to weigh significantly in the fit. Therefore, the energy of the transition KB$_2$L$^6$M$^4$N$^1$ was fixed according to the MCDF calculations (34.9 eV). The results obtained with this method are shown in table I in the second column.

<table>
<thead>
<tr>
<th>Transition type</th>
<th>Expt</th>
<th>MCDF theory</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N$^0$</td>
</tr>
<tr>
<td>KB$_2$L$^6$M$^4$</td>
<td>38.4 (1.7)</td>
<td>34.9</td>
</tr>
<tr>
<td>KB$_2$L$^6$M$^4$</td>
<td>28.3 (2.3)</td>
<td>28.3</td>
</tr>
<tr>
<td>KB$_2$L$^6$M$^4$</td>
<td>32.5 (0.8)</td>
<td>30.8</td>
</tr>
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</table>

* The average value for KB$_2$L$^6$M$^1$

The experimental data are compared to the MCDF calculations. Good agreement with theory is obtained assuming the presence of one additional N-shell spectator vacancy.


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2.8 Investigation of the Low-Lying Levels in $^{125}\text{La}$

by R.Beraud$^1$, G.Canchel$^1$, Ch.Droste$^2$, A.Emsallem$^1$, R.Kaczarowski, M.Kisielik$^5$, A.Kordyasz$^4$, M.Kowalczyk$^2$, J.Kownacki$^2$, T.Morek$^2$, S.G.Rohozisz$^5$, E.Ruchowska, J.Srebrny$^{3,5}$, K.Starosta$^{2,5}$, A.Wasilewski and M.Wolińska$^4$

The $^{125}\text{La}$ level scheme has been already investigated via in-beam reaction studies [1-2] as well as via the $\beta^+/EC$ decay of on-line mass-separated $^{125}\text{Ce}$ [3]. However, the low energy part of the scheme still cannot be considered as a final one. The 107 keV, E3 isomeric transition with half-life $T_{1/2}$=390 ms, observed in the radioactive decay of $^{125}\text{Ce}$ and assigned firmly to $^{125}\text{La}$, has not yet been placed in this level scheme [3]. It is worth noting that no common transitions were observed in this radioactive decay study and the in-beam studies [1-2]. Also systematics presented in Fig. 1 shows that the position of the 3/2$^+$ level considered as the lowest state of the 3/2$^+$ rotational band in $^{125}\text{La}$, both in relation to the 11/2$^-$ state and in relation to other members of the 3/2$^+$ rotational band, does not follow the trend observed in the heavier La nuclei, in contrast to smooth behaviour $E(I)$ - $E(11/2^-)$ energy difference in the decoupled band. It supports suggestion that the lowest part of the $^{125}\text{La}$ level scheme is not a complete one.

Low energy part of the $^{125}\text{La}$ level scheme has been investigated at Heavy Ion Laboratory in Warsaw with the aim to resolve still existing ambiguities as well as to identify possible isomeric states with low excitation energies in $^{125}\text{La}$.

High spin states in $^{125}\text{La}$ were populated with the $^{112}\text{Sn}(^{18}\text{O},2n)^{125}\text{La}$ reaction at an incident beam energy of 80 MeV. The macro structure of the beam with macro pulses of 1.3 ms and separation periods of 3.7 ms was utilised in search for isomeric transition. Two $^{112}\text{Sn}$ targets of thickness 3 and 10 mg/cm$^2$ were used. The prompt and delayed $\gamma$-radiation was studied using the OSIRIS array which comprises 7 Compton-suppressed HPGe detectors. The experimental setup was carefully optimised to ensure in-beam observation of the low energy $\gamma$-rays, down to energy of about 30 keV. The $\gamma$-ray singles spectra and $\gamma$-$\gamma$ coincidences were collected in the list mode during and between the beam macro-pulses. The prompt and delayed coincidence events were sorted off-line into two-dimensional coincidence matrices.

Two new $\gamma$-transitions, 57.2 and 299.4 keV, were assigned to $^{125}\text{La}$. In addition, a delayed 107 keV $\gamma$-transition, already identified as an isomeric transition in $^{125}\text{La}$ [3], was observed also in our experiment. Intensity relations derived from our data suggest that this transition deexcites the lowest state of the decoupled band built on the h$_{11/2}^-$, 1/2$^+$[550] proton configuration in $^{125}\text{La}$. At this moment, these three transitions are not yet firmly placed in the $^{125}\text{La}$ level scheme. It is interesting to note that the energy difference, $E_{11/2}^- - E_{3/2}^+$, decreases in $^{127,129,131}\text{La}$ isotopes with decreasing mass number (see Fig. 1c). If this trend persists further to $^{125}\text{La}$ then the 11/2$^-$ state in this nucleus would be positioned well below the 3/2$^+$ state. A detailed data analysis is in progress.

Fig. 1 a) Systematics of rotational level energies relative to energy of the 11/2$^-$ state for the 1/2$^+$[550] rotational band in odd La isotopes; b) energies of the E2 transitions within the band built on the 3/2$^+$ level; c) energy difference between the rotational 11/2$^-$, 1/2$^+$ [550] state and 3/2$^+$ band head.


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2.9 Investigation of the $K^\pi = 8^-$ Isomer in $^{134}$Nd

by T. Morek$^1$, J. Srebrny$^1$, Ch. Droste$^1$, M. Kowalczyk$^1$, E. Ruchowska, R. Kaczarowski, J. Kownacki$^1$, M. Kisielinski$^2$, A. Kordyasz$^2$, and M. Wolińska$^2$

We extended our investigations of properties of the $K^\pi = 8^-$ isomers in the $N = 74$ isotones [1] to the decay of the 2293 keV, $T_{1/2} = 410 \mu$s isomer in $^{134}$Nd. The isomer has been studied at Heavy Ion Laboratory in Warsaw.

We extended our investigations of properties of the $K^\pi = 8^-$ isomers in the $N = 74$ isotones [1] to the decay of the 2293 keV, $T_{1/2} = 410 \mu$s isomer in $^{134}$Nd. The isomer has been studied at Heavy Ion Laboratory in Warsaw.

The $K^\pi = 8^-$ isomers in $^{130}$Ba, $^{132}$Ce, $^{134}$Nd, $^{136}$Sm, and $^{138}$Gd isotones decay via forbidden E1 transitions with a degree of K-forbiddenness of $\nu = 7$ to the $8^+$ members of the ground state rotational band. The E1 transition rates and respective reduced hindrance factors $f_7$ (full circles in Fig. 1) vary significantly from isotone to isotone. Their behaviour can be explained by a band mixing mechanism involving mixing of the ground state band and s-band [1,2]. Results of the band mixing calculations are shown as solid line in Fig. 1. Second isomeric decay branch which leads via M2(+E3) transitions with K-forbiddenness of $\nu = 6$ to the $6^+$ member of the ground state band is known only for the isotones in $^{130}$Ba, $^{132}$Ce, and $^{134}$Nd. The corresponding reduced hindrance factors $f_6$ are marked by squares in Fig. 1 (for the last two nuclei the experimental points indicate only lower limits of $f_6$ because the M2/E3 mixing ratios are not known for the respective $\gamma$-transitions). The same band mixing mechanism, which successfully explained the behaviour of reduced hindrance factors $f_6$, does not reproduce correctly the experimental values of the $f_6$

hindrance factors (dashed line in Fig. 1). Experimental information on the third isomeric decay branch going through E3 transitions with $\nu = 3$ to the $5^+$ levels of the $\gamma$-band is even more scarce. Such transitions are known only in $^{130}$Ba and $^{132}$Ce. The corresponding reduced hindrance factors $f_3$ are marked by triangles in Fig. 1. In Ref. [1] it was suggested that low values of $f_3$ may result from the K=4 admixtures to the wave functions of the $K^\pi = 5^+$,2 states which are predicted by the Davydov-Filipov model for the $\gamma$-deformed nuclei. More experimental data are needed to verify this hypothesis.

The aim of our experiment was to search for the $8^-$ $\rightarrow$ $5^+$ isomeric E3 transition in $^{134}$Nd. The $^{134}$Nd nuclei were produced in the $^{208}$Sn($^{23}$Ne,4n)$^{134}$Nd reaction at a beam energy of 100 MeV. Pulsed beam was used with macro-pulses 1 ms wide separated by 4 ms gaps. The singles spectra and $\gamma$-$\gamma$ coincidences were measured between the beam macro-pulses using the multidector OSIRIS array consisting of 7 Compton-suppressed HPGe detectors. The $\gamma$-$\gamma$ coincidence events were sorted off-line into a two-dimensional coincidence matrix.

Statistics accumulated during one week measurements still did not allow for observation of the E3, 596 keV transition expected to deexcite the $K^\pi = 8^-$ isomer to the $5^+$ rotational level of the $\gamma$-band. However, it was possible to estimate the upper limit of intensity of this E3 transition and thus to obtain the lower limit of $f_3 = 9.5$ for its reduced hindrance factor. This value is considerably higher than the corresponding $f_3$ values of 6.5 and 6.7 found for the respective E3 transition in $^{130}$Ba and $^{132}$Ce. The present experiment shows that the E3, $8^-$ $\rightarrow$ $5^+$ isomeric transition is more strongly forbidden in $^{134}$Nd than in lighter $N = 74$ isotones. Such high degree of the forbiddenness cannot be easily understood considering only the role of $\gamma$-deformation. Further studies are needed to obtain precise information on wave functions of the isomeric state itself and states populated via isomeric transitions.


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2.10 Total Routhian Surface Calculations for Neutron-Rich $^{149}$Ce

by R.Kaczarowski, W.A.Płociennik, A.Syntfeld$^1$, H.Mach$^2$, W.Kurciewicz$^3$, B.Fogelberg$^2$ and P.Hoff$^3$

An extensive total Routhian surface (TRS) calculations (see ref.1) were performed for the $^{149}$Ce nucleus with the aim to compare theoretical predictions with the results of experimental studies of the high spin states in this nucleus [2,3] and the recent studies of the $^{149}$La $\beta$-decay carried out at the R2-0 reactor in Studsvik using the OSIRIS on-line fission product mass separator [4]. In the latter study tentative assignment of spin and parity for several low-spin levels has been proposed and some ambiguities in the interpretation of the level scheme $^{149}$Ce were resolved allowing for a comparison with theoretical predictions.

The calculated equilibrium deformation parameters of the positive-parity rotational band at $\hbar\omega$= 0.075 MeV lie around the values of $\beta_2$=0.228, $\gamma$=-0.2° and $\beta_4$=0.085 while for the negative-parity rotational band these parameters are close to the values of $\beta_2$=0.224, $\gamma$= 0.1° and $\beta_4$=0.080. Both total Routhian surfaces minima are well defined and show no indication of $\gamma$-softness. They remain pretty stable with increasing rotational frequency up to $\hbar\omega$ = 0.5 MeV.

The main components of the wave functions of the lowest positive and negative parity bands are, the $3/2^+$, $5/2^-$ and $3/2^-$, $1/2^-$ configurations, respectively in agreement with the Coriolis mixing calculations [4]. Relatively large calculated values of the hexadecapole deformation parameter, especially for the positive-parity band, and, simultaneously, low values of the $\gamma$ non-axial deformation are worth to note. In order to check the possibility that the obtained large values of the hexadecapole deformation parameter are generated by the neglected higher order multipole expansion terms, e.g. $\beta_6$, in our TRS model calculations, additional calculations were performed minimizing potential energy of the lowest positive and negative states as a function of $\beta_2$, $\beta_3$, $\beta_4$, $\beta_6$ and $\beta_8$ deformation parameters at $\hbar\omega$ = 0 MeV. The resulting $\beta_3$ and $\beta_4$ parameters did not change significantly in the presence of higher multipole terms. Other calculated deformation parameters were very close or equal to zero.

The calculated values of the angular momentum $<I_z>$ as a function of rotational frequency $\hbar\omega$ are shown in Fig.1 for both positive- and negative-parity rotational bands. Similarly to simple Cordtis mixing calculations a sizeable signature splitting is predicted only for the positive parity band. The backbending for the negative parity band is predicted at much lower frequency of about 0.20 MeV than for the positive parity band (about 0.33 MeV). The experimental data (full circles and squares) for the rotational band built on the $3/2^-$, 133.5 keV level with new spin and parity assignments proposed in Ref. [4] match very well theoretical predictions only if the high spin structure represents the positive parity band. Consequently, it excludes the possibility that the rotational band observed in experiment has a negative parity. Also the backbending frequency observed in the experiment (0.30 MeV), agrees only with the prediction for the positive-parity band, although is about 0.03 MeV lower than the calculated value. Moreover, the only experimental point (full triangle) for the ground state rotational band also agrees very well with theoretical predictions for the negative parity band. The obtained good agreement fully supports the interpretation of the level scheme of $^{149}$Ce nucleus presented in [4].

![Fig. 1](image_url) The calculated and experimental values of the total angular momentum as a function of rotational frequency for both signatures of the lowest positive and negative-parity bands.

[4] A.Syntfeld, et al., to be published

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$^3$ Department of Chemistry, University of Oslo, P.O. Box 1033, Blindern, N-0315 Oslo, Norway
2.11 Level Structure of $^{182}$Ir at High Angular Momentum


Structure of the high spin states in $^{182}$Ir has been studied at the Argonne National Laboratory. Details of experiment were already described in ref.[1]. About 114 millions of $\gamma$-$\gamma$-t coincidence events were recorded during the experiment. Only events with multiplicity $M \geq 5$ registered by the BGO array and with multiplicity $M \geq 2$ registered by Ge detectors were collected and sorted into several prompt, delayed and prompt-delayed $\gamma$-$\gamma$ coincidence matrices as well as into a $\gamma$-t coincidence matrix. Thorough analysis of these matrices allowed for extending of three previously known rotational bands in $^{182}$Ir bands [2] up to a spin of $J = 27\hbar$ and an excitation energy of about 5.8 MeV. In addition, two new strongly-coupled bands, built on short living isomeric states and a new decoupled band were also identified. More than 90 new $\gamma$-transitions have been placed in the level scheme of $^{182}$Ir.

Properties of kinematical and dynamical moments of inertia, Routhians and alignments in all rotational bands in $^{182}$Ir are carefully analysed in the aim to understand internal structure and backbending properties of these bands. An example is shown in Fig. 1, where values of alignment, $i(\omega)$, are plotted as a function of rotational frequency $\hbar \omega$ for the three most strongly fed rotational bands in $^{182}$Ir. A reference values of $J_0 = 23.6$/MeV and $J_1 = 127.5$/MeV, deduced from ground state rotational band in the even-even $^{180}$Os core nucleus, were used in calculations. Values of $K = 0, 3$ and $5$ for band A, B and C, respectively, were assumed according to ref. [2]. One can note distinctively different behaviour of alignments in these bands reflecting differences in their internal structure. A comparison with similar plots for rotational bands built on single quasi-particle proton and neutron states in $^{181}$Ir and $^{181}$Os, respectively, may lead to identification of proton and neutron configuration involved in the respective 2-quasiparticle configurations in $^{182}$Ir.


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Fig. 1 Plots of alignments $i(\omega)$ vs. $\hbar \omega$ of $\gamma$ transitions in three bands in $^{182}$Ir. Different signatures within a given band are denoted by squares and stars. A reference values of $J_0 = 23.6$/MeV and $J_1 = 127.5$/MeV, obtained from even-even $^{180}$Os core nucleus, were used in calculations. Values $K = 0, 3$ and $5$ for Band A, B and C, respectively, were assumed according to ref. [2].
2.12 Lifetime Measurement of the High-spin States in $^{182}$Os and $^{183}$Ir


Lifetimes of the high spin states in $^{182}$Os and $^{183}$Ir have been investigated via the $^{150}$Nd($^{34}$S, 4$n$)$^{182}$Os and $^{168}$Nd($^{34}$Cl, 4$n$)$^{183}$Ir reactions using the recoil-distance Doppler-shift technique. A 164 MeV $^{35}$S and 169 MeV $^{34}$Cl beams were provided by the Argonne Tandem Superconducting Linear Accelerator System (ATLAS). The target was enriched $^{186}$Nd (0.9 mg/cm$^2$) thick evaporated onto stretched 1.5 mg/cm$^2$ Au foil and covered with thin (0.06 mg/cm$^2$) Au layer to prevent oxidation. The measurements were performed using the Notre Dame plunger device in conjunction with the Argonne-Notre Dame BGO y-ray facility consisting of 12 Compton-suppressed HPGe detectors (25% nominal efficiency), four at each of the following angles: 34.5, 90, and 145.5 degrees with respect to the beam direction, and a 50-element BGO inner array working as a multiplicity filter. Runs of approximately 3 hours were taken at 18 target-stopper distances, ranging from 17.3 µm to 10399 µm. The events with multiplicity M>5 were stored on magnetic tapes and sorted off-line into individual spectra for different Ge detector angles and different target-stopper distances.

To enhance the y-transitions from $^{182}$Os and $^{183}$Ir, only events with multiplicity of y-rays registered in the BGO ball M≥14 were taken into account during off-line analysis. The y-spectra analysis was performed using the GP2 program from the RADWARE software package [1]. Shifted and unshifted decay curves for individual transitions have been fitted using the computer code LIFETIME, which allows to take into account a variety of experimental corrections [2]. The preliminary results for $^{182}$Os and $^{183}$Ir are presented in Table 1 and Table 2, respectively. The deduced B(E2) values permit to extract quadrupole moments Qo for yrast rotational band and consequently, for estimating Qo values in backbending region around spin value of 14 and 29/2 in $^{182}$Os and $^{183}$Ir, respectively.

Table 1 Mean lifetimes of excited levels and deduced Qo values in the yrast band in $^{182}$Os.

<table>
<thead>
<tr>
<th>Level</th>
<th>$E_y$(keV)</th>
<th>$\tau$(ps)</th>
<th>B(E2) [eVb]$^3$</th>
<th>Qo [b]</th>
</tr>
</thead>
<tbody>
<tr>
<td>22$^*$</td>
<td>712.0</td>
<td>≤1.3</td>
<td>≥0.34</td>
<td>≥3.1</td>
</tr>
<tr>
<td>20$^*$</td>
<td>623.3</td>
<td>0.9(3)</td>
<td>1.0(3)</td>
<td>5.2(8)</td>
</tr>
<tr>
<td>18$^*$</td>
<td>537.1</td>
<td>2.0(3)</td>
<td>0.91(11)</td>
<td>5.1(3)</td>
</tr>
<tr>
<td>16$^*$</td>
<td>479.3</td>
<td>4.3(3)</td>
<td>0.74(6)</td>
<td>4.6(2)</td>
</tr>
<tr>
<td>14$^*$</td>
<td>494.6</td>
<td>3.6(3)</td>
<td>0.76(6)</td>
<td>4.7(2)</td>
</tr>
<tr>
<td>12$^*$</td>
<td>534.2</td>
<td>4.9(5)</td>
<td>0.38(4)</td>
<td>3.3(2)</td>
</tr>
<tr>
<td>10$^*$</td>
<td>534.2</td>
<td>2.3(5)</td>
<td>0.82(18)</td>
<td>4.9(6)</td>
</tr>
<tr>
<td>8$^*$</td>
<td>484.0</td>
<td>4.1(6)</td>
<td>0.73(11)</td>
<td>4.7(4)</td>
</tr>
<tr>
<td>6$^*$</td>
<td>393.7</td>
<td>6.8(10)</td>
<td>1.2(2)</td>
<td>6.3(5)</td>
</tr>
<tr>
<td>4$^*$</td>
<td>273.2</td>
<td>64(6)</td>
<td>0.76(7)</td>
<td>5.2(2)</td>
</tr>
<tr>
<td>2$^*$</td>
<td>126.8</td>
<td>1210(100)</td>
<td>0.76(6)</td>
<td>6.2(3)</td>
</tr>
</tbody>
</table>

Table 2 Mean lifetimes, B(E2) values and quadrupole moments in the yrast band in $^{183}$Ir nucleus.

<table>
<thead>
<tr>
<th>Level</th>
<th>$E_y$(keV)</th>
<th>$\tau$(ps)</th>
<th>B(E2) [eVb]$^3$</th>
<th>Qo [b]</th>
</tr>
</thead>
<tbody>
<tr>
<td>45/2$^*$</td>
<td>695.0</td>
<td>≤2.6</td>
<td>≥0.19</td>
<td>≥2.4</td>
</tr>
<tr>
<td>41/2$^*$</td>
<td>625.6</td>
<td>0.8(6)</td>
<td>1.1(8)</td>
<td>5.5(20)</td>
</tr>
<tr>
<td>37/2$^*$</td>
<td>579.3</td>
<td>2.3(3)</td>
<td>0.53(7)</td>
<td>3.9(3)</td>
</tr>
<tr>
<td>33/2$^*$</td>
<td>561.8</td>
<td>1.6(3)</td>
<td>0.91(17)</td>
<td>5.1(5)</td>
</tr>
<tr>
<td>29/2$^*$</td>
<td>550.6</td>
<td>2.2(3)</td>
<td>0.74(10)</td>
<td>4.6(3)</td>
</tr>
<tr>
<td>25/2$^*$</td>
<td>508.1</td>
<td>2.8(5)</td>
<td>0.84(16)</td>
<td>5.0(5)</td>
</tr>
<tr>
<td>21/2$^*$</td>
<td>424.5</td>
<td>6.6(6)</td>
<td>0.87(8)</td>
<td>5.1(2)</td>
</tr>
<tr>
<td>17/2$^*$</td>
<td>308.8</td>
<td>28(2)</td>
<td>0.95(7)</td>
<td>5.4(2)</td>
</tr>
<tr>
<td>13/2$^*$</td>
<td>168.8</td>
<td>278(25)</td>
<td>1.3(1)</td>
<td>6.5(3)</td>
</tr>
</tbody>
</table>


1) Physics department, Argonne National Laboratory, Argonne, IL60439, USA
2) Physics Department, University of Notre Dame, Notre Dame, IN46556, USA

2.13 Family of X-Ray Tubes for Medical Applications

by M. Słapa, W. Straś, M. Snopek, and M. Traczyk

Technological progress in new materials has made feasible to develop new types of X-ray tubes particularly useful in medical applications. Within the reported period research and development activities of the X-ray tubes group concentrated in the following areas:

- needle-like anode X-ray tubes
• cascade-type X-ray tubes for up to 100 kV anode biases
• "photon needle" instruments
• medical set for brachytherapy of brain tumors by means of the photon needle.

New cylindrical-geometry acceleration chamber for needle-like anode X-ray tubes was developed. The tubes equipped with acceleration chambers of the new type exhibit better coaxiality and symmetry of the electron beam than the tubes equipped with acceleration chambers of the old design (flat geometry).

Design of a cascade-type X-ray tube for up to 100 kV anode biases was developed and a tube model was built. The tube may be extremely useful for destroying cancer tumors larger than 30 mm across.

Stability and reliability of the photon needle, as well as effectiveness of its shields were tested. The instrument design has been updated. The updated model was nominated to the ,,Polski Produkt Przyszłości 2000" contest and was presented in some TV shows (on the WOT and TVP1 channels).

Cooperation with Neurosurgery Clinics of the 10th Military Clinic Hospital in Bydgoszcz has been established. It resulted in start of joint development of a medical set for brachytherapy of brain tumors by means of the photon needle. Suitable grant proposal has been submitted to the Committee of Scientific Research. The preliminary results were presented on the 3rd Medical Physics Symposium in Wisła [1].


2.14 Energy Resolution of Parallel-Plate Avalanche Counters at Moderate Specific Ionization
by J. Sernicki

Parallel-plate avalanche counters (PPAC) have been recognized as excellent timing detectors for years [1, 2]. Moreover, the counters are characterized by good properties as elementary detecting devices [3]. But the spectrometric properties of the PPAC detectors may be evaluated basing upon only partial data on the detector energy resolution (see e.g. refs. [4-7]). At present, there is generally insufficient data available on the spectrometric properties of avalanche counters.

The determination of the energy resolution of an avalanche counter reduces to numerical formulation of the expression (FWHM/(dE/dx × d)) × 100 [%], where dE/dx is the specific particle energy loss (stopping power) and d refers to the electrode spacing. It should be noted that the expression is valid with the following assumptions:
- the particles pass the counter perpendicular to its electrodes,
- the charge density resulting from the primary ionization process (specific ionization) is constant within the entire interelectrode space of the counter.

In general, the properties of avalanche counters depend upon the electrical field intensity and gas pressure. It should be fully realized, however, that the counter's spectrometric properties depend upon not only the statistical fluctuations of the charge generated in the interelectrode space, which are affected by the basic ionization processes, but also upon the additional factors, viz:
- divergent source emission,
- fine energy structure in the emitted radiation, and
- particle energy loss straggling in the metallized electrode foil and the gas space.

The purpose of this investigation is to determine the energy resolution of PPAC detectors at moderate specific ionization (fig. 1). The investigation has been performed under measurement conditions being generally typical for the majority of physical experiments in which the detectors are used [9].

![Fig. 1 Mean effective energy E of alpha particles and its corresponding particle energy loss in the PPAC interelectrode gas space, determined for actual measurement conditions. See ref. [8] for data on the front electrodes of the PPAC.](image-url)
Fig. 2 shows empirical curve of the PPAC energy resolution at a pressure of 18 Torr of n-heptane vapour. The readings reached a value of 43 % at a voltage of \( U_{sc} \) (the \( U_{sc} \) voltage determines the beginning of space charge effect in PPAC, see ref. [10]). While the mean energy resolution value in the plateau range is slightly higher. In turn, the resolution variability as a function of the gas pressure is shown in figs. 3 and 4.

One can generally state that the energy resolution even equal to 30 %, at moderate specific ionization, is not good enough for a charged particle \( \Delta E \) detector.

![Fig. 2 PPAC energy resolution vs. detector supply voltage.](image)

![Fig. 3 Mean energy resolution in the plateau range (see fig. 2) vs. n-heptane pressure.](image)

![Fig. 4 Energy resolution at the \( U_{sc} \) voltage (see fig. 2) vs. n-heptane pressure.](image)


2.15 The Mosses as the Bioindicator of Air Pollution

by M.Matul, B.Mystek-Laurikainen, S.Mikołajewski, H.Trzaskowska

The mosses are considered to be useful monitors of atmosphere deposition because they have no root system and thus depend on nutrient supply predominantly from the atmosphere. The mosses are precise and sensitive bioindicators of heavy metal contamination of the natural environment. In general plants proved to be useful in assessing environmental pollution over large areas and long periods of exposure.

The pollution level can be monitored for different compartments of environment e.g. air, water, soil. The application of plants as bioindicators and biomonitors and useful criteria for their selection are presented. Contaminants of environment are determined in selected samples. The application of the most useful plants like algae, mosses, lichens, vegetable plants trees and their parts for evaluation of the pollution level of environment and their changes are discussed.
The radioactive contamination of mosses, proportional to the contamination of the ground level air shows the nonuniform concentration over the territory of the country and that the decrease of caesium radioactivity is much lower than one could expect on the life time basis.

Selected kind of mosses and their application in air monitoring are presented.

The mosses collected every second year since 1986 give the information about environmental pollution of 40 selected localities in Poland. Some comparison with situation in other countries is done and the results for lichens from Mongolia are presented. The air pollution in Poland is presented on the basis of regular air monitoring net-work.

The decrease of $^{137}$Cs content in air, in soil and in different kinds of mosses is discussed in terms of environmental conditions.

2.16 The Influence of Stressing Factors on Concentration of Radionuclides in Medicinal Plants

by B. Myslek-Laurikainen, M. Matul, K. Wierzchowska-Renke

Due to more and more common use of radionuclides and ionizing radiation for peaceful applications a continuous increase in radioactive contamination of environment is being observed. Reactors and nuclear bombs release the products of nuclear fission that form a sediment on overground parts of plants and on the surface of soil, penetrating afterwards inside the plants together with other mineral substances [1-4]. Contaminated plants may be used not only for alimentary purposes, but in medicine as well.

The study followed the influence of stressing road closeness and Aphids-infestation on cumulation of radionuclides in medicinal plants. The evaluation of radionuclides concentration was carried out in samples collected from sites localized closely to roads Achillea millefolium L., Tanacetum vulgare L., Helichrysum arenarium Moench ($^{134}$Cs, $^{226}$Ra, $^{40}$K) and in Aphids-infested Pastinaca sativa L. from the Garden of Medical University of Gdańsk ($^{137}$Cs, $^{226}$Ra, $^{40}$K, $^{226}$Ac).

The studies of radioactivity have shown that analysed samples of Achillea millefolium, Tanacetum vulgare, Helichrysum arenarium contain radionuclides of caesium, radium and potassium. Radioactive isotope $^{137}$Cs was found in insignificant amounts only; its content was at the background level.

The content of radium (its isotope $^{226}$Ra being one of the products of natural nuclear decay of radioactive series) was – as in the case of caesium – low in majority of samples.

The analysis of samples revealed also important quantities of radioactive $^{40}$K.

A different cumulation of evaluated elements was found in samples of particular organs of Pastinaca sativa. In parsnip samples only small amounts of $^{137}$Cs, $^{226}$Ra and $^{226}$Ac were found, while the amounts of $^{40}$K were important. Control plants cumulated more $^{40}$K than Aphids-infested ones. The results obtained prove that radioactive contaminations present no direct threat to people from the outside because they are caused by small amounts of radioactive substances. They penetrate to human body by respiratory or digestive system.


1) Medical Univ. Dept. of Biol. and Pharm. Botany, ul. J. Hallera 107, 08-416 Gdańsk, Poland
Table 1 Radionuclides concentration *pastinaca sativa* L. samples.

<table>
<thead>
<tr>
<th>Nr</th>
<th>Samples</th>
<th>$^{137}$Cs Bq/kg</th>
<th>$^{226}$Ra Bq/kg</th>
<th>$^{226}$Ra eU ppm</th>
<th>$^{228}$Ra Bq/kg</th>
<th>$^{238}$Ac eU ppm</th>
<th>$^{228}$Ac eTh ppm</th>
<th>$^{210}$Pb Bq/kg</th>
<th>$^{40}$K Bq/kg</th>
<th>%K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LEAVES Control sample</td>
<td>2.2 ± 0.3</td>
<td>3.0 ± 0.6</td>
<td>0.2 ± 0.0</td>
<td>4.5 ± 0.5</td>
<td>1.1 ± 0.0</td>
<td>45.0 ± 6</td>
<td>525 ± 10</td>
<td>10 ± 1.7</td>
<td></td>
</tr>
<tr>
<td>1a</td>
<td>LEAVES Plant louses defeated</td>
<td>1.9 ± 0.6</td>
<td>17.0 ± 1.2</td>
<td>1.4 ± 0.0</td>
<td>6.6 ± 0.9</td>
<td>1.6 ± 0.0</td>
<td>17.0 ± 1.2</td>
<td>835 ± 18</td>
<td>18 ± 2.7</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>FRUITS Control sample</td>
<td>0.8 ± 0.2</td>
<td>14.3 ± 0.6</td>
<td>1.2 ± 0.0</td>
<td>2.9 ± 0.6</td>
<td>0.7 ± 0.0</td>
<td>9.3 ± 5.5</td>
<td>741 ± 11</td>
<td>11 ± 2.4</td>
<td></td>
</tr>
<tr>
<td>2a</td>
<td>FRUITS Plant louses defeated</td>
<td>1.5 ± 0.4</td>
<td>13.3 ± 0.7</td>
<td>1.1 ± 0.0</td>
<td>4.7 ± 0.9</td>
<td>1.2 ± 0.0</td>
<td>17.2 ± 7.2</td>
<td>808 ± 14</td>
<td>14 ± 2.7</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Fruit STALKS</td>
<td>≤ 1.5 ± 0.5</td>
<td>- ± 0.0</td>
<td>- ± 0.0</td>
<td>- ± 0.0</td>
<td>- ± 0.0</td>
<td>- ± 0.0</td>
<td>- ± 0.0</td>
<td>- ± 0.0</td>
<td></td>
</tr>
<tr>
<td>3a</td>
<td>Leaves STALKS</td>
<td>1.3 ± 0.6</td>
<td>22.8 ± 1.1</td>
<td>1.0 ± 0.0</td>
<td>5.9 ± 0.4</td>
<td>1.5 ± 0.0</td>
<td>17.0 ± 9.7</td>
<td>938 ± 19</td>
<td>19 ± 3.1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>ROOTS Control sample</td>
<td>3.1 ± 0.6</td>
<td>48.0 ± 0.8</td>
<td>3.9 ± 0.0</td>
<td>7.3 ± 0.6</td>
<td>1.8 ± 0.0</td>
<td>19.0 ± 7.3</td>
<td>884 ± 11</td>
<td>11 ± 2.9</td>
<td></td>
</tr>
<tr>
<td>4a</td>
<td>ROOTS Plant louses defeated</td>
<td>3.8 ± 0.3</td>
<td>17.0 ± 1.2</td>
<td>1.4 ± 0.0</td>
<td>6.6 ± 0.9</td>
<td>1.6 ± 0.0</td>
<td>17.0 ± 1.2</td>
<td>835 ± 18</td>
<td>18 ± 2.7</td>
<td></td>
</tr>
</tbody>
</table>

2.17 Intelligent Systems for Environment Monitoring and Management

by M. Sowiński, Z. Moroz, M. Kowalski

Recent progress in biologically inspired computational methods has stimulated wide application of artificial neural networks and genetic algorithms to science and technology. Neural networks are based on principles similar to those functioning in neural cells. The genetic algorithms are kinds of optimisation procedures, which follow evolution mechanisms – they contain special operators of mutating and crossing, analogous to that observed in the Nature.

In particular we should expect similar progress in the field of ENVIRONMENT MANAGEMENT AND PRESERVATION. These tendencies are confirmed by great interest of EU in the problem, which included in the 5-th Programme of Research and Progress for 1999 - 2002 the theme: „ Intelligent Environmental Monitoring and Management Systems”.

Main advantages of the neural networks are:

1. Possibility of reliable predicting of correlations between input and output parameters, without necessity to work out sometimes very complicated experimental model.

2. Ability to learn and adapt to variable environment conditions.

It gives an opportunity to use neural networks for example to prognostication of behaviour of complicated, multiparametric systems in nearer or further time sequence on the ground of the knowledge collected in the past.

Main advantage of genetic algorithms is the ability to find optimal solutions of complicated multiparametric tasks very quickly.
Simultaneous application of artificial neural networks and a model of genetic algorithms gives an unique possibility to optimise the functioning of technical devices which serve to limit the emission of air pollutants with taking in account ecological and economical factors.

A system as that described above (artificial neural networks + genetic algorithms) has been developed in the Soltan Institute for Nuclear Studies with co-operation of the Institute of Nuclear Chemistry and Technology and the Polytechnic Institute of Bialystok. It was applied for operation optimisation of installation of simultaneous SO$_2$ and NO$_x$ removal from flue gas by electron beam method.

The models developed by us may be applied not only to pollutants (SO$_2$/NO$_x$/CO/dust) removal but also to optimisation of dry, semidry, and wet installations of desulphurization operation and the burning process itself.

It is expected that at the beginning of 2001 a unique opportunity in the field of environment monitoring and management (including prognostication) will arise. It comes from necessity to follow the bill of Ministry of Environment, Natural Resources, and Forestry from 1998-09-08 on emission to the atmospheric air of polluting substances from technological processes.

According to the bill, units burning organic fuels with power over 300 MW$_t$ (and in close perspective over 50 MW$_t$), are obliged to carry out continuous measurements of polluting substances (SO$_2$/NO$_x$/CO/dust) concentrations. It means that over 50% of pollutants originating from energy production will be subjected to control on the base of reliable data obtained in real time. It gives an opportunity to create environment management systems on the levels of the unit, parish/municipality, district, county, and the whole country, which are compatible with the systems of EU (Fig. 1).
## LIST OF PUBLICATIONS

**LIFETIME MEASUREMENTS AND THE NONAXIAL DEFORMATION IN $^{119}$In**  
J.Srebny,..., A.A.Wasilewski  

**A TUBULAR IONIZER AS AN EFFICIENT NEGATIVE FLUORINE ION SOURCE**  
A.Piotrowski and T.Kozlowski  
*Acta Physica Polonica B31(2000)899*

**STUDY OF MEDIUM MODIFICATIONS WITH THE NEW SPECTROMETER ANKE AT COSY-JULICH**  
S.Barsov,..., I.Zychor et al.  
*Acta Physica Polonica B31(2000)357*

**MEASUREMENT OF THE A HYPERON LIFETIME IN HEAVY HYPERNUCLEI AT COSY-JULICH**  
I.Zychor et al.  
*Acta Physica Polonica B31(2000)405*

**DOUBLE K-SHELL IONIZATION IN COLLISIONS OF FAST IONS WITH MID-Z ATOMS**  
J.Rzdziewicz, D.Chmielewska, T.Ludziejewski, P.Rymuza, Z.Sujkowski et al.  
*Acta Physica Polonica B31(2000)2159*

**LOCAL SPACE CHARGE EFFECT IN CONVENTIONAL AVALANCHE COUNTERS AT MODERATE SPECIFIC IONIZATION**  
J.Sernicki  
*Nukleonika 45(2000)125*

**RECOIL-DISTANCE LIFETIME MEASUREMENTS IN $^{196,197,198}$Ru: SEARCH FOR POSSIBLE ONSET OF COLLECTIVITY AT N=52**  

**LEVEL STRUCTURE OF $^{94}$Tc AT HIGH-SPINS AND SHELL MODEL CALCULATIONS**  
S.S.Ghugre,..., R.Kaczarowski  

**SIMULTANEOUS EXCITATION AND IONIZATION OF He-LIKE URANIUM IONS IN RELATIVISTIC COLLISIONS WITH GASEOUS TARGETS**  
T.Ludziejewski, P.Rymuza et al.  

**IS LAMB SHIFT IN HYDROGENLIKE URANIUM MEASURED ON COOLED, DECELERATED ION BEAMS**  
Th.Stoehlker,..., T.Ludziejewski,..., P.Rymuza et al.  

**QUADRUPOLE INTERACTION OF $^{172}$Yb AND $^{182}$Er NUCLEI IN THE FIRST EXCITED 2$^+$ STATE**  
K.Krolas, M.Rams and J.Wojtkowska  
*Z. Naturforchang. 55a(2000)45*

**DECAY OF HIGH SPIN ISOMERS IN $^{152}$Os**  
E.Ruchowska, R.Kaczarowski et al.  
*Acta Phys. Pol. (in press)*

**TOTAL ROOTHIAN SURFACE CALCULATION FOR NEUTRON-RICH $^{148}$Ce**  
R.Kaczarowski, W.A.Płosierński et al.  
*Acta Phys. Pol. (in press)*

**EXACTLY SOLVABLE MODEL ILLUSTRATING FAR-FROM-EQUILIBRIUM PREDICTIONS**  
O.Mazonka and C.Jarzynski  
*J. Stat.Phys. (in press)*
PARTICIPATION IN CONFERENCES AND WORKSHOPS

INVERSE PHOTOIONIZATION STUDIED VIA RADIATIVE ELECTRON CAPTURE INTO HIGHLY CHARGED IONS
T.Stoehler,...., T.Ludziejewski et. al.

FUSION ENERGY THRESHOLDS PREDICTED WITH AN ADIABATIC NUCLEUS-NUCLEUS POTENTIAL
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E.Genici,..., J. Wilczyński et al.

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F. Hanappe,..., J. Wilczyński et al.
HELLEUM-LIKE HOLE STATE ATOMS OF HIGH Z  
Z. Sujkowski (oral)  
Proc. XXXVIII Intern. Winter Meeting on Nuclear Physics, Bormio, Italy, 24-29 Jan. 2000, p. 84

RADIATIVE ELECTRON CAPTURE BY FAST ³⁷He⁺ IONS  
Proc. XXXVIII Intern. Winter Meeting on Nuclear Physics, Bormio, Italy, 24-29 Jan. 2000, p. 90

ELECTRON TRANSFER PROCESSES IN COLLISIONS OF RELATIVISTIC IONS WITH ATOMS  
Z. Sujkowski  
Proc. 7th Conf. on the Intersections of Particle and Nuclear Physics (CIPANP 2000), May 22-28, 2000, Quebec, Canada

THE INFLUENCE OF STRESSING FACTORS ON CONCENTRATION OF RADIONUCLIDES IN MEDICAL PLANTS  
B. Myslek-Laurikainen, K. Wierzchowska-Renke and M. Matul  
2nd International Symposium on Chromatography of Natural Product, Labinon-Kazimierz Dolny June 14-16 2000

THE MOSSES AS THE BIOINDICATOR OF AIR POLLUTION  
B. Myslek-Laurikainen, M. Matul, S. Mikolajewski, H. Trzaskowska and M. Kubicki  
The third International Meeting on Low-Level Air Radioactivity Monitoring, Dąbrówka near Nidzica 25-29 Sept 2000

THE AIR BORNE RADIOACTIVITY AND ELECTRICAL PROPERTIES OF GROUND LEVEL AIR  
M. Matul, S. Mikolajewski, B. Myslek-Laurikainen and H. Trzaskowska  
The third International Meeting on Low-Level Air Radioactivity Monitoring, Dąbrówka near Nidzica 25-29 Sept 2000

VALENCY CHANGE OF ACTIVE AND NON-ACTIVE IONS INSIDE OXIDE SINGLE CRYSTALS APPLIED IN OPTOELECTRONIC DEVICES  
S. M. Kaczmarek, J. Wojtkowska  

FUSION ENERGY THRESHOLDS PREDICTED WITH AN ADIABATIC NUCLEUS-NUCLEUS POTENTIAL  
J. Wilczyński  
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T. Morek, T. Kaczerowski, E. Rutowska, M. Kisielński et al.  
IFD2000 Conf. Warsaw University, 8-9 Dec. 2000

OCTUPOLE DEFORMATION LIMITS IN LANTHANIDE AND ACTINIDE REGIONS  
A. Syntfeld, W. Kureczewicz, R. Kaczerowski and J. Miernicka  
IFD2000 Conf. Warsaw University, 8-9 Dec. 2000

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SEARCH FOR A FLAVOR NONCONSERVATION IN DECAYS AND INTERACTIONS OF MUONS ³⁰  
T. Kozlowski  
RADIOMETRY AND RADIOECOLOGY
B. Myslek-Laurikainen

PHYSICAL METHODS OF ENVIRONMENTAL STUDIES - RADIOECOLOGY
B. Myslek-Laurikainen
Warsaw University, Warsaw, Summer Semester Course for Medical Physics students, 15 Feb. – 30 May. 2000

SELECTED TRENDS AND METHODS OF NUCLEAR STRUCTURE STUDIES
A.A. Wasilewski
PhD Seminar, Warsaw, 8 Feb. 2000

STUDY OF THE ELECTROMAGNETIC TRANSITIONS IN $^{193,198}$Ir NUCLEI
A.A. Wasilewski
PhD Seminar, Warsaw, 12 Dec. 2000

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Research scientists
Jan Blocki, Professor
Danuta Chmielewska, Dr.
- Scientific Secretary of the Institute
Rościśław Kaczarowski, Assoc. Professor
Tadeusz Kozlowski, Dr.
Tomasz Ludziejewski, Dr., till 30 Sept.
Bogumila Myslek-Laurikainen, Dr.
Zbigniew Moroz, Contract Professor 3/5
Antoni Piotrowski, Assoc. Professor 3/5
Weronika Płociennik, Dr.
Zygmunt Preibisz, Dr. 1/2

Wojciech Ratyński, Professor
Ewa Ruchowska, Dr
Edward Rurarz, Dr.
Mieczysław Słapa, Assoc. Professor 1/2
Mieczysław Sowiński, Assoc. Professor 4/5
Ziemowit Sujkowski, Professor
- Director of the Institute
Janusz Wilczyński, Professor
Jolanta Wojtkowska, Dr. 3/4
Izabela Zychor, Dr.

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Jacek Rzadkiewicz, MSc.
Alexander Undynko, MSc., till May, 29
Adam Wasilewski, MSc

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3 DEPARTMENT OF DETECTORS AND NUCLEAR ELECTRONICS

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phone: (22) 718-05-49
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Overview

The basic activities of the Department of Nuclear Electronics were concentrated in following areas:

- studies of new scintillation techniques,
- contribution to the EUROBALL project,
- electronics for experiments in High Energy Physics,
- development, investigation and production of silicon detectors,
- development of γ-ray spectrometry apparatus,
- development of new generation State of the Art PC based multichannel analyser,
- technical support for the Institute as the whole with special emphasis on networking,
- normalisation activities.

Most of the scientific achievements concerning the Department were summarised in 22 publications (released or being in press). The papers were published mainly in IEEE Trans. on Nucl. Sci. and Nucl. Instr. and Methods. Besides that, our scientists presented 9 contributions at international conferences (such as IEEE Nuclear Science Symposium 2000 in Lyon, France).

The Department was involved in scientific collaborations with a number of international centres, such as CERN, Royal Institute of Technology in Stockholm, FZR Rossendorf, GSI Darmstadt and companies as Advanced Photonix, Inc in California and Photonis in France. The collaboration with High Energy Physics Department of our Institute was focused on experiments at CERN (LHCb and NA48 experiments).

Studies of new scintillation techniques have brought important results in understanding of nonproportionality scintillator response to energy and their intrinsic resolution. Particularly, an intrinsic resolution of small (Ø 10 mm x 10 mm) and large (Ø 75 mm x 75 mm) NaI(Tl) crystals were measured and compared to the prediction of calculations. Papers on new scintillators such as LGSO, LSO, YSO and ZnSe(Te) were submitted to NIM. The comparative study of avalanche photodiodes of different internal structure in scintillation detection allows better understanding of the properties of avalanche photodiodes.

During 2000 preparations for a new HEP LHCb experiment at CERN were started. Contribution of our department to LHCb is to design, fabricate and test three kinds of modules - TFC Switch, Throttle Switch and Readout Supervisor. These modules are basic elements of Data Acquisition System of the experiment. Also the acquisition system for the NA48 experiment at CERN, which contained more than 140 large electronic modules (mainly FASTBUS), designed by us, was under our permanent supervision and maintenance.

In last year the Group of Semiconductor Detectors was incorporated into our Department. In the consequence area of our interests were extended over new significant subjects. In this area was established valuable collaboration with Institute of Physics (Warsaw University). The interesting study of an internal gain of Si-detectors for fission fragments was carried out.

The technical support for the Institute covers a lot of different types of activities, among them, a design and installation of new internal fibre optics local area network should be emphasised.

The main results of our activities are:

- better understanding of different processes in scintillators affecting nonproportionality of the response and intrinsic energy resolution,
- evaluation of properties of avalanche photodiodes of different internal structure in scintillation detection and discussion of the limitation of achievable energy resolution,
- development studies and designing works on electronics for new HEP LHCb experiments in CERN,
- advanced studies and preparation of a technical project for the new generation PC based or stand alone multichannel analyser.
3.1 Comparative Study of Avalanche Photodiodes with Different Structures in Scintillation Detection

by M. Moszyński, M. Kapusta, M. Balcerzyk, M. Szawlowski, D. Wolski, I. Węgrzecka, M. Węgrzecki

The performance of beveled-edge Large Area Avalanche Photodiodes (LAAPD) produced by Advanced Photonix, Inc. (API), Hamamatsu SPL 2560 APDs and APDs from the Institute of Electron Technology (ITE) was studied in scintillation detection using CsI(Tl), BGO, LSO and YAP scintillators. Measurements covered DC gain characteristics, relative response to X-rays and light, and energy resolution for 5.9 keV X-rays from $^{55}$Fe source. We also determined the electron-hole (e-h) pair numbers for the studied scintillators and the detector energy resolution for 662 keV γ-rays from a $^{137}$Cs source.

Table 1 presents the number of e-h pairs measured for all tested scintillators using different APDs operated at a goin of 50. A shaping time constant of 3 μs was used in all the tests.

<table>
<thead>
<tr>
<th>Crystal</th>
<th>LAAPD</th>
<th>SPL 2560</th>
<th>ITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CsI(Tl)</td>
<td>33800±1700</td>
<td>30900±1400</td>
<td>16500±800</td>
</tr>
<tr>
<td>BGO</td>
<td>5200±250</td>
<td>4200±200</td>
<td>-</td>
</tr>
<tr>
<td>LSO</td>
<td>19000±1000</td>
<td>8900±450</td>
<td>-</td>
</tr>
<tr>
<td>YAP</td>
<td>10200±500</td>
<td>4700±200</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1 Number of e-h pairs measured for different scintillators

Note systematically higher numbers of e-h pairs measured with the LAAPD than those for the SPL 2560 APD. The 10% difference observed for CsI(Tl) can be partially explained by the light attenuation introduced by the Hamamatsu device window. Results obtained with other crystals indicate superior quantum efficiency of the LAAPD structure.

Fig. 1 presents a comparison of energy spectra of 662 keV γ-rays from a $^{137}$Cs source measured with 5x5x5 mm$^3$ CsI(Tl) crystal coupled to LAAPD, and SPL 2560 and ITE APDs. Table 2 collects the energy resolution measured for all crystals.

<table>
<thead>
<tr>
<th>Crystal</th>
<th>LAAPD</th>
<th>SPL 2560</th>
<th>ITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CsI(Tl)</td>
<td>4.9±0.2%</td>
<td>5.8±0.3%</td>
<td>9.8±0.4%</td>
</tr>
<tr>
<td>BGO</td>
<td>8.5±0.3%</td>
<td>10.4±0.4%</td>
<td>-</td>
</tr>
<tr>
<td>LSO</td>
<td>9.3±0.4%</td>
<td>12.3±0.5%</td>
<td>-</td>
</tr>
<tr>
<td>YAP</td>
<td>5.7±0.3%</td>
<td>9.3±0.4%</td>
<td>-</td>
</tr>
</tbody>
</table>

Fig. 1 Energy spectra of 662 keV γ-rays from a $^{137}$Cs source measured with 5x5x5 mm$^3$ CsI(Tl) crystal coupled to LAAPD, and SPL 2560 and ITE APDs.

Table 2 Energy resolution for 662 keV γ-rays from a $^{137}$Cs source measured with different crystals and APDs

1) Advanced Photonix, Inc. 1240 Avenida Acaso, Camarillo, CA 93012, USA
2) Institute of Electron Technology, Al. Lotników 32/46, PL 02-668 Warsaw, Poland
3) Support for this work was provided by the Polish Committee for Scientific Research, Grants Nos. 8T 10C 005 15 and 8T 11B 037 13
3.2 Timing properties of LuAP:Ce studied with Large Area Avalanche Photodiodes

by M. Balcerzyk, M. Moszynski, M. Kapusta and M. Szawlowski

Prompted by recent interest in PET scanners equipped with LuAP:Ce (LuAlO₃:Ce) scintillators read by avalanche photodiodes we have measured timing properties of this scintillating material with Large Area Avalanche Photodiodes (LAAPD) from Advanced Photonix, Inc. (API). We have obtained time resolution of 1.16 ± 0.06 ns for 511 keV peak from a $^{22}$Na source with energy threshold set at 400 keV, and 680 ± 35 ps for $^{60}$Co source with energy threshold set at 1 MeV. The obtained e-h pair number of 6600±320 e-h pairs per MeV is comparable to that reported in [1] for the same crystal.

Fig. 1 shows the dependence of the LuAP:Ce time resolution on the LAAPD gain. For gains over 200, time resolution is slightly improved, but at the cost of higher excess noise factor of 2.6 [2]. For gains below 200, time resolution rapidly deteriorates to almost 5 ns at gain 50.

Very good time resolutions obtained with the LuAP:Ce coupled to the LAAPD are comparable to those of 1.02±0.03 ns and 570±30 ps, reported previously for LSO and measured in the same conditions [3] LSO crystal with its decay time of 46 ns yielded light output of 19600 e-h pairs per MeV measured with LAAPD [3]. For LuAP:Ce with its decay time of 16 ns we measured light output of 6600 e-h pairs per MeV. Note that the number of e-h pairs produced by LuAP:Ce in LAAPD is almost 3 times lower than that of LSO. The results obtained point to the scintillator decay time parameter as an important factor influencing the time resolution of the system.

The main contribution to the observed time spread with avalanche photodiodes comes from the noise level and the slope of the rising edge of the pulse at the input of the fast discriminator, which can be expressed as follows:

$$\sigma_{\text{time}} = \sigma_{\text{noise}} / (dV/dt)$$

where $\sigma_{\text{time}}$ is the standard deviation of the time distribution, and $\sigma_{\text{noise}}$ is the rms voltage noise at the output of the filter amplifier, while $dV/dt$ is the slope of the pulse leading edge at the discriminator threshold level [4].

For the fully integrated pulse from a fast charge sensitive preamplifier, $dV/dt$ is proportional to the number of the primary e-h pairs and inversely proportional to the decay time of the scintillator:

$$dV/dt = N_{\text{e-h}}/\tau$$

where $N_{\text{e-h}}$ is the number of primary e-h pairs and $\tau$ is the decay time constant of the crystal.

Using the numbers of e-h pairs and the decay time constants for both crystals one can calculate $N_{\text{e-h}}/\tau$ quantity equal to 420±20 e-h pairs per ns for LSO and 400±20 e-h pairs per ns for LuAP:Ce. Both quantities are very close, explaining thus comparable time resolution measured with LSO and LuAP:Ce at similar LAAPD gain values. This very simple consideration does not take into account a finite rise time of APD and preamplifier (10 ns for the timing output). This fact seems to be reflected in somewhat better time resolution of LSO due to its higher number of the e-h pairs.


*1) Advanced Photonix, Inc. 1240 Avenida Acaso, Camarillo, CA 93012, USA

*2) This work was supported in part by the Polish Committee for Scientific Research, Grant No 8T 11E 025 15 and 8T 10C 005 15
3.3 Intrinsic Energy Resolution of NaI(Tl) Scintillator

by M. Balcerzyk, J. Zalipska, M. Moszyński, W. Mengesha, J.D. Valentine, W. Klamra and M. Kapusta

It is known that an energy resolution of a scintillation detector is seriously affected by properties of a scintillator. Their contribution called an intrinsic resolution is connected with many effects such as inhomogeneities in the scintillator causing local variations of the light output, non-uniform reflectivity of the reflecting covering of the crystal, as well as the non-proportional response of the scintillator. The non-proportional light output is particularly important for the energy resolution of NaI(Tl) crystal. In the case of large volume crystals, an important contribution of multi-Compton interaction in the crystal, building up a full energy peak is expected. In the course of this work, two NaI(Tl) crystals with dimensions of 1 cm in diameter and 1 cm high, and 7.5 cm in diameter and 7.5 cm in height were studied. The light output was detected by photomultipliers.

In the study, the light output of the crystals, expressed in the photoelectron numbers, and their energy resolution for γ-rays in the energy range between 16 keV and 1333 keV were measured. The intrinsic resolution was compared with that calculated by Monte Carlo method for both sizes of the crystals using MCNP4B code [1].

Fig. 1 presents the energy spectrum of 662 keV γ-rays from a $^{137}$Cs source measured with the 7.5 x 7.5 cm NaI(Tl). Note an excellent energy resolution of 6.5%, fully comparable to that measured with the small crystal. Fig. 2 shows the measured and calculated intrinsic resolutions for both the crystals, expressed in the standard deviation of the full energy peaks. The experimental curves for both the crystals present a common dependence within the error bars.

![Fig. 1](image1.png)

**Fig. 1** Energy spectrum of 662 keV γ-rays from a $^{137}$Cs source measured with the 7.5 cm x 7.5 cm NaI(Tl) scintillator.

![Fig. 2](image2.png)

**Fig. 2** Intrinsic energy resolution of NaI(Tl) expressed in the standard deviation of the full energy peaks.

The calculated curve is based on the model, which takes into account multiple Compton scattering and cascade of K, L, and M X-rays of iodine, as well as, Auger electrons produced in the process of γ-absorption by photoeffect [1].

Fig. 2 shows that the calculations reflect the shape of the experimental curve for energies above 80 keV; however, the absolute values are about 30-50% lower. It is probably associated with the fact that the model considers all the processes in γ-ray detection before creating the secondary electrons. Thus the process of stopping of electrons in matter has to be also taken into account. The most probably is scattering of electrons on valance electrons, similar to that of Compton scattering for γ-rays. It seems to be confirmed by a lack of a difference between measured intrinsic resolution for Ø 1 x 1 cm and Ø 7.5 x 7.5 cm crystals.

For the low energy region, below 50 keV, there is a basic discrepancy showing that model used does not consider a further, important source of signal spread. The most probably is production of a large number of δ-rays, secondary electrons of few keV energies [2].


1) Georgia Institute of Technology, Atlanta, GA 30332-0405, USA.

2) Royal Institute of Technology, Dept. of Physics, S-104 05 Stockholm, Sweden.
3.4 Silicon ΔE-E Detectors for Identification of High Energy Protons and Alpha Particles

by W. Czarnacki, E. Belcarz, A. Kotlarski, T. Sworobowicz

Two ΔE-E silicon telescopes have been manufactured for identification of protons and alpha particles with high energies (around 50 MeV). Each telescope consists of two silicon detectors: a thin transmission ΔE detector, and a thick (total energy absorption) E detector. Since the range of the high-energy protons in silicon may amount to 1 mm, each of the E detectors has been manufactured as two stacked Si(Li) devices.

The transmission ΔE detectors have been manufactured of n-type silicon of specific resistivity of around 4000 [Ωcm]; they are approximately 130 μm thick. Surface of each of the ΔE detector amounts to around 1 cm². At the bias voltage U=50 V the detectors exhibited energy resolution of 28-32 keV FWHM for alpha particles of energy 5.8 MeV.

The method of drifting lithium ions into p-type silicon has been employed to produce the two devices for the E detector. The devices of thickness around 3.6 mm and around 7.6 mm have been stacked one behind the other, with a layer of dead silicon between them about 300 μm thick. Surface of each of the devices is over 1 cm². The stack bias voltage may be varied from 300 to 800 V.

To produce a telescope, both the ΔE and the E detector have been mounted in a special holder at a distance of about 1 mm. The telescopes are to be used for identification of high-energy protons and alpha particles in experiments on the Warsaw University U-200 cyclotron. The present work has been done in cooperation with Heavy Ion Laboratory of the Warsaw University.

3.5 Spectrometric X-ray HR-Si Detector Cooled with a Three-stage Peltier Cooler

by W. Czarnacki, A. Kotlarski, T. Sworobowicz, K. Kostrzewa

New model of an X-ray spectrometric detector with detecting device made of high-resistivity silicon (HR-Si) and optical feedback pre-amplifier has been designed. The detector is electrically cooled with a three-stage Peltier thermo-element. The HR-Si detector consists of:

1. vacuum cryostat with Beryllium window (20 μm thick)
2. three-stage Peltier thermo-element and a water-cooled radiator
3. miniature holder, in which a HR-Si detecting device, a 2N4416 Field Effect Transistor, and a temperature-controlling thermistor are mounted
4. optical feedback pulse pre-amplifier.

Active surface of the HR-Si detecting device amounted to about 10 mm², its active thickness ~ to 2.5 mm. Holder with the device was cooled down to T= - 84°C. The obtained energy resolution of the detector amounted to 340 eV FWHM. Work in progress.

3.6 Internal Charge Amplification at High Ionization Densities in Silicon Detectors

by E. Belcarz, W. Czarnacki, A. Kotlarski, T. Sworobowicz, K. Kostrzewa

Studies of time evolution of Cf-252 fission fragment spectra and their dependence on details of manufacturing technology of surface barrier silicon detectors have been undertaken. Up to now a laboratory stand for measuring Cf-252 fission fragment spectra has been set-up. It consists of (i) vacuum chamber, (ii) vacuum system (rotary pump, vacuum gauge, system of vacuum valve, and (iii) electronic circuits. 21 surface barrier detectors have been manufactured on n-type silicon; 12 of them have been tested for a period of 7 months. Pulse amplitudes and distortion of the high-energy tails of peaks in Cf-252 fission fragment spectra recorded with the tested detectors were measured each other week during the test period. Both time evolution and dependence on details of surface barrier manufacturing technology have been observed. Work in progress.
3.7 Multichannel Analyzer PC Card by S. Borsuk, Z. Guzik, A. Chlopik

A new version of Multichannel Analyzer (MCA) PC Card is being designed. The MCA Card is a computer based gamma measurement module including all the functions of a gamma measurement apparatus in a single ISA compatible PC Card. Prototype card and test module is shown in Fig. 1.

The MCA Card has a form of the PC plug-in mother board equipped with seven mezzanine subboards containing spectroscopy amplifier, spectroscopy A/D converter, HV control logic, microcontroller assembly, FPGA with histo memory and opto coupling logic. Beside that the main carrier board includes DC/DC converters, HV generation module and PC Bus connector and interface. DC/DC converters give the isolated supply voltages for analog circuits of the MCA Card and for external detector-preamplifier. The card is intended for direct connection to a preamplifier, providing on-board programmable high voltage bias supply. Entire analog part of the module is galvanically isolated by optocouplers.

All the system settings can be controlled externally by data acquisition software. A versatile interactive menu shows accumulated spectra in various modes as well as current progress of the data acquisition and actual parameters settings – all presentations are performed in real-time.

The interface between the ISA Bus and the module is based on ALTERA Flex 10K FPGA which also provides data router between histograming memory, microcontroller and the A/D converter. Also an incrementer is included in the same 144 pin chip. The heart of the system is a microcontroller mezzanine based on Philips P08C592 IC. The role of this unit is global supervising of the entire system behaviour, nonvolatile saving of operational parameters, performing several system algorithms as HV setting and so on.

Additional feature of the MCA card is a possibility of working in remote mode without need to plug-in the module into IBM PC slot. This mode of operation is useful in environment of high level of radiation or special field conditions and is realized by means of local CAN fieldbus network.

3.8 Set-up for Spectroscopy Measurements by A. Dziedzic, C. Gorny, W. Karnicki, J. Kucharski, M. Moszynski, A. Nawrot, D. Wolski

The spectroscopy equipment for environmental measurement has been developed. Prototypes of detector, high voltage power supply and spectroscopy amplifier were designed and constructed.

Detector with 2 x 2" NaI (TI) and XP 3212 photomultiplier has the energy resolution of 6.8 % for the 662keV γ-rays from a Cs-137 source.

High voltage supply provides positive voltage from 0 to 3 kV with output current up to 2mA.

The main spectroscopy amplifier specifications:
- Shaping time constant 0.5, 1, 2, 4 μs
- Gain 5 – 1500 V/V
- P/Z cancellation adjustment
- Gated Baseline Restorer with automatic noise discrimination threshold

Both HV Supply and Amplifier are built on 3Ux 220 mm boards which may be plugged into EURO standard cassettes (see Fig. 1)
3.9 Program Tukan 2000 for Multichannel Analyzer* by M. Plomiński, K. Traczyk, R. Marcinkowski, I. Obstoj

Tukan 2000 is a program containing comprehensive set of capabilities for acquiring and analyzing spectra from Multichannel Pulse Amplitude Analyzer PC Card. General description of the Tukan 2000 program was already placed in Annual Report INS 1999. This work has been continued.

Versatile, powerful spectra display system was prepared, containing: left and right marker concept, zoom mechanism, possibility of selecting any spectrum part to be displayed, logarithmic and linear scale, possibility of simultaneous visualization of different spectra, ROI (Region of Interest) displaying in distinguished forms. The left and right markers are used to define temporary or permanent ROIs. Spectrum being displayed can be controlled by mouse, menu or shortcut keys. Comfortable mechanism for searching disk spectra applying dialog window concept was developed. It performs preview of a spectrum being selected from a list together with its base parameters.

The following math libraries were prepared and added to the program: R_FitCalib.Dll including energy and shape calibration and efficiency calibration, R_PeakSearch.Dll including peak locate calculation algorithms and R_FitGauss.Dll containing peak fitting algorithms for singlets and multiplets. Last mentioned library applies Gauss and Polynomial or Gauss and Fermi or Gauss and Fixed Fermi functions.

32-bit DLL library containing card control commands was prepared. A special module to achieve versatile, visual control of the card and the acquisition process was designed.

3.10 Timing and Fast Control of the LHCb experiment at CERN by Z. Guzik and A. Chłopiński

LHCb is a hadron collider experiment planned for running on LHC machine at CERN. The main purpose of this experiment is to search for new physics through precise tests of the heavy flavor sector of the Standard Model.

The P-3 Department has been involved in the project since spring 1999 and participates in designing several vital elements of the Data Acquisition System in particular of the Timing and Fast Control (TFC) of the experiment.

The overall structure of the TFC system is depicted in fig. 1. The key element of this system is so called "Readout Supervisor", which will be single design, multipurpose module. It will act as an interface between the DAC system, the trigger system and the Front-End drives of the TTC subsystems located at the detectors – it will be responsible for all readout and triggering processes of the entire experiment.

The Readout Supervisor (RS) is the active main component in the LHCb Timing and Fast Control (TFC) system and is thus the heart of the synchronous readout. The Readout Supervisor receives the LHC bunch clock via the LHC machine interface and the level 0 and 1 trigger decisions from the central L0 and L1 decision units. It distributes these as well as internally generated triggers and various synchronous control commands to the Front-End (FE) electronics using a programmable patch panel (TFC Switch) and the CERN Trigger, Timing and Control (TTC) system developed by RD12. The TFC Switch allows running a sub-detector stand-alone or with any combination of sub-detector components (partitions). Different sub-systems can also run in parallel by using different Readout Supervisors.

The Readout Supervisor will also act as trigger rate controller. It will receive trigger throttle signals from any system that can have data congestion. The throttle signals will be ORed to make a single L0 and a single L1 throttle, which are fed back to the appropriate Readout Supervisors via the Throttle Switches.

The LHCb standard Experiment Controls System (ECS) Interface to board level electronics will be used to configure and monitor the activity of the Readout Supervisor. The ESC interface is based on so-called Credit Card PC (entire IBM PC with size less than usual credit card).

Our task is to design, test and fabricate these three basic modules of Timing and Fast Control, i.e. "Readout Supervisor", "TFC Switch" and "Throttle Switch". The modules will be finally designed in 6U VME standard and their first prototypes should appear at the end of this year.
3.11 Network, Internet and Intranet at INS-Świerk
by C. Górny, M. Kapusta, K. Leśniewski, A. Dziedzic, I. Zawrocka

Year 2000 was particularly rich in new initiatives concerning the development of the local network dedicated for IPJ. The main purpose of all activities was to perform modernization of the existing network topology to achieve a 100Mb/s speed network. First of all the network headquarter was reorganized and completely rebuilt including the renovation of the headquarter office. In the building of Technical Support and Administration, in Department P-II, and in Dosimetry Department the local network was extended and 8 new computers were connected to the LAN. Because building 67 housing Department of Training and Consulting was renewed, new topology for this building was developed and the whole building was cabled and connected to LAN. About 40 new computers were bought and the old 10Mb/s network cards were replaced in greater part by 100Mb/s cards. Besides the improvement of the LAN the network team advises buys of new computers. We help installing a new software and repair every malfunctioning network device, computers and printers. At the moment the network in Świerk area connects 5 buildings and provides the services for about 150 computers and 200 people. To fulfill all those requirements the Windows 2000 servers were upgraded for faster processors and amount of RAM was raised up to 512 MB.
LIST OF PUBLICATIONS

LARGE AREA AVALANCHE PHOTODIODES IN X-RAYS AND SCINTILLATION DETECTION
M. Moszyński, M. Kapusta, M. Balcerzyk, M. Szawlowski, D. Wolski

COMPARISON OF THE SCINTILLATION PROPERTIES OF LSO:Ce AND YSO:Ce AS THE DETECTORS FOR HIGH RESOLUTION PET
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C. Fahlander, ... M. Moszyński, ...

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M. Palacz, ... M. Moszyński, ...
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M.Moszyński, M.Kapusta, M.Balcerzyk, M.Szawlowski, D.Wolski, I.Węgrzecka, M. Węgrzecki
IEEE Transactions on Nuclear Science (in press)

INTRINSIC ENERGY RESOLUTION OF NAI:TL
M.Balcerzyk, M.Moszyński, W.Mengesha, J.D.Valentine, W.Klamra and M.Kapusta
accepted for publication in Proceedings of International Workshop Medical Applications of Scintillators Irkuck, Russia, July 11-15, 2000,

SCINTILLATION PROPERTIES OF LSO:CE, LGSO:CE, AND YSO:CE AND THEIR APPLICATIONS AS THE DETECTORS FOR HIGH RESOLUTION PET
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PARTICIPATION IN CONFERENCES AND WORKSHOPS

COMPARATIVE STUDY OF AVALANCHE PHOTODIODES WITH DIFFERENT STRUCTURE IN SCINTILLATION DETECTION
M.Moszyński, M.Kapusta, M.Balcerzyk, M.Szawlowski, D.Wolski, I.Węgrzecka, M. Węgrzecki - presented by M.Moszyński

INTRINSIC ENERGY RESOLUTION OF NAI:TL
M.Balcerzyk, M.Moszyński, W.Mengesha, J.D.Valentine, M.Kapusta - presented by M.Balcerzyk
Workshop on Medical Application of Scintillators, Baskai Lake, Rosja, July 11-15, 2000

TIMING PROPERTIES OF LUAP:CE STUDIED WITH LARGE AREA AVALANCHE PHOTODIODES
M.Balcerzyk, M.Moszyński, M.Kapusta - presented by M.Balcerzyk
31-st Crystal Clear Meeting, Gandawa, Belgia, 23-24.03.2000
SEARCH FOR INDIUM AND THALLIUM BASED HIGH DENSITY SCINTILLATORS

PROTON-ALPHA DISCRIMINATION IN ROSIB -4PI SI BALL FOR EUROBALL
M.Moszyński - oral presentation
EXOTAG working group meeting on Particle Identification Techniques, CERN, Geneva, 28-29.09.2000

NEW APPROACH TO DATA ACQUISITION AND CONTROL IN HEP EXPERIMENTS, INTERNATIONAL WORKSHOP - RELATIVISTIC NUCLEAR PHYSICS FROM HUNDREDS MEV TO TEV
Z.Guzik - oral presentation
Stara Lesna, Slovak Republic 26.06-1.07.2000

PROPOSITION OF INTERNATIONAL STANDARD: VME64 EXTENSIONS FOR PHYSICS AND OTHER APPLICATIONS (VME64XP)
J.Charuba - oral presentation
International Workshop „Relativistic Nuclear Physics: from Hundreds MeV to TeV”, Stara Lesna, Slovak Republic, June 26 – July 1, 2000

COMPACT-PCI - NEW STANDARD OF CONTROL AND MEASUREMENT SYSTEMS
J.Charuba - oral presentation
XII CONFERENCE „Application of Microprocessors in Automatic Control and Measurements”, Warsaw, October 9-10, 2000

PARTICIPATION IN ADVISORY EDITORIAL BOARDS, STANDARIZATION ORGANIZATIONS AND CONFERENCES

M.Moszyński – Member of Advisory Editorial Board of Nucl. Instr. And Meth. A.
Z.Guzik – Permanent reviewer of IEEE Tran. Of Nucl. Science
Z.Guzik – Member of Working Group No 173 for Microprocessor Systems of Polish Standard Committee
J.Charuba - Member of Working Group No 173 for Microprocessor Systems of Polish Standard Committee
J. Charuba - Member of Working Group No 266 for Nuclear Apparatus of Polish Standard Committee

J. Charuba - Member of Polish CAMAC Committee

J. Charuba – Member of Technical Coordination Committee of ESONE (European Studies on Norms for Electronics)


M. Balcerzyk – Chairman of session during 2000 IEEE Nuclear Science Symposium, Lyon, France, 15 - 20 October 2000

EDUCATION

M. Moszyński – supervisor of PhD students: M. Kapusta MSc and J. Zalipska M.Sc.

M. Balcerzyk - supervisor of student S. Bloński

SCIENCE POPULARIZATION TALKS AND ARTICLES

M. Moszyński

Oscar in electronics

Interview in Polish Radio, 8 Nov. 2000

AWARDS AND DISTINCTION

M. Moszyński

Merit Award 2000 – IEEE/Nuclear and Plasma Science Society

For outstanding contribution to the modern scintillation detector and its application in physics experiments, nuclear medicine and other fields

PERSONNEL

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Marek Moszyński, Professor, Deputy Director of the Institute
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Jerzy Kucharski, Eng.
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Michał Płomiński, Eng.
Tadeusz Sworobowicz 1/2
Krystyna Traczyk, MSc.
Marek Uzdowski, Eng.
Iwona Żawrocka, MSc.
Overview

The research activities of the Department in 2000, similarly to previous year were concentrated on the following problems:

- Ionization pattern at the nanometre level;
- Dosimetry for medical purposes;
- Numerical modelling of interaction of radiation with matter.

The following activities could be underline:

- Ionization pattern at nanometre level: The ion clusters spectra created along the nanometre section of track in Nitrogen, ranging from 0.15 to 13 nm (at unit density) irradiated by alpha particles with energy of 4.6 MeV were experimentally determined with the Jet Counter set up and compared with Monte Carlo calculations. Both methods confirmed that primary ionization along a "nanometric" alpha-particle track segment follows a Poisson distribution. The present ionization cluster probabilities produced in "nanometric" volumes, 2 nm to 10 nm in diameter, are the first ever determined experimentally and confirmed by Monte Carlo simulation. An extended collaboration with LNL Legnaro (under EC large scale facility program) as well as with Physikalisch-Technische Bundesanstalt (Braunschweig) has been continued.

- Dosimetry for medical purposes: The new method for standardising of absorbed doses from the beta-gamma radioactive sources used for endovascular brachytherapy has been devised. The method is based on the use of the new type of an ionisation chamber, called Ring Ionisation Chamber, RIC. The GAF Chromic detector MD55, TLD detector and specially designed "end window" ionization chamber have been applied for depth dose measurements from Y-90 wire. This activity is supported by Grant KBN Nr 4P05C01417.

- Numerical Modeling: A catheter-based beta emitter system with 32P has been modeled using MCNP4C Monte Carlo code. The absolute radial and axial absorbed dose distribution in water and PMMA has been calculated. The numerical calculations for the project of an experimental setup for study of the electronuclear method of energy generation based on use of a subcritical fast plutonium reactor and 650 MeV proton accelerator have been continued.
4.1 The Spectra of Ionization Clusters by Alpha-particles in "Nanometric" Volumes of Nitrogen: Experiment and Calculation
by S.Pszona, J.Kula and B.Grosswendt

Probability distributions of the size of ion clusters (number of ions in a specified target) created in "nanometric" volumes of nitrogen by single alpha-particles emitted by a gold-plated $^{241}$Am source were measured and calculated by a Monte Carlo simulation. The diameters of the cluster volumes had a mass per area of between 0.015 $\mu$g/cm$^2$ and 1.3 $\mu$g/cm$^2$, which corresponds to a nanometric size of between 0.15 nm and 13 nm if a material of unit density is assumed. To perform the measurements, a so-called Jet Counter was used. It consists of a pulse operated valve which injects into an interaction chamber an expansion jet of molecular nitrogen gas, which is crossed by a narrow alpha-particle beam. The ions created by single primary particles and by their secondary electrons within the interaction chamber were counted and analysed with respect to cluster size. In addition to the measurements, the probabilities of cluster size formation were also calculated by Monte Carlo methods in the same geometry as used experimentally. Both methods confirmed that primary ionization along a "nanometric" alpha-particle track segment follows a Poisson distribution. The present ionization cluster probabilities produced in "nanometric" volumes, 2 nm to 10 nm in diameter, are the first ever determined experimentally and confirmed by Monte Carlo simulation.

1) Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany

4.2 A New Method for Standardizing the Absorbed Dose from the $\beta/\gamma$ Radioactive Sources Used for Endovascular Brachytherapy
by S.Pszona and B.Kocik

The new method for absolute absorbed dose measurements from the radioactive beta/gamma sources in the form of wires or seeds used in endovascular brachytherapy of coronary disease is presented.

The method is based on the use of a new type of ionization chamber, called a Ring Ionisation Chamber, RIC. The RIC is a design which encompasses both a phantom and an ionization chamber. It has cylindrical shape and a catheter housing the source (wire or seeds) passes through it along its axis. Due to its similarity to a cylindrical ionisation chamber the well-established dosimetric protocol can be applied. Sensitive volume is derived upon calibration in terms of Kerma in air in $^{60}$Co beam at SSDL (traceable to a national standard). The combined uncertainties are of 3.5% and are much better than for an extrapolation chamber.

A (RIC), has an air-vented sensitive volume in the form of a 10 mm (a version with 3mm is also tested) long double wall cylinder, with a distance of 0.3 mm between the walls-electrodes. The inner diameter of sensitive volume is of 4 mm and therefore the measurements are done close to 2 mm radial distance from the chamber symmetry axis. The RIC's are made of PMMA. The new method was applied for absorbed dose measurements for $^{90}$Y catheter based sources at reference distance form the sources. This method has also been applied for measuring the axial uniformity of the investigated sources. The comparison with calculated dose depth doses have shown good agreement. One of the advantages of the new method (over the up to date in use) is very good geometrical reproducibility source-detector which in turn gives the excellent reproducibility of the dose readings. These are confirmed by the measuring results.

Conclusions: The new method of absorbed dose determination from catheter based beta-gamma sources used for endovascular brachytherapy has been elaborated. The method opens the new ways for improving the quality of cardiovascular brachytherapy procedures with respect to dose estimation.

4.3 Monte Carlo Calculation of Dose Distribution for $^{32}$P Brachytherapy Wire Source
by K.Wincel and B.Zareba

The absolute absorbed dose distribution in water and polymethylmethacrylate (PMMA) which are tissue substitutes has been calculated for $^{32}$P brachytherapy wire source. The cylindrical source $^{32}$P has dimensions of 27 mm in length and 0.24 mm in diameter and is encapsulated in NiTi tube. Beta-ray spectra was assuming according to [1]. MCNP4C – A General Monte Carlo N-Particle Transport Code with MCNPDAT cross-sections library was used. Option *F8 in MCNP4C code was applied to obtain
Fig. 1 Calculated values of dose rate per unit activity as a function of depth in water and PMMA, $^{32}$P source, MCNP4C code.

Energy deposition within cylindrical annuli with length varied from 2 mm to 20 mm in the source axial direction and with the thickness from 0.05 mm to 0.1 mm in the radial direction. Doses were calculated up to 6 mm from the source in the radial and axial directions. The number of histories was changing from 1000000 to 10000000 depending on the position and volume of detector. Electron and gamma history was terminated when particle richness energy were below 50 keV.

Fig. 2 Comparison of Monte Carlo dose calculations: MCNP4C (K. Wincel, B. Zareba) and MCNP4B2 [2] (F. Mourtada).

The largest relative statistical error observed is less then 5%. Calculated radial absorbed dose rate distribution in water and PMMA are presented on Fig. 1. Obtained radial dose distribution in water compared to results from MCNP4B2 [2] are plotted in Fig. 2.


4.4 Computational Physics

by A. Polański

Development of nuclear-nuclear interaction model.

The well known internuclear cascade model and Dubna Cascade program complex was developed [1], [2]. The intranuclear cascade model describes hadron-nucleus interactions quite exactly, but overestimates the multiplicity of mesons produced in nucleus-nucleus interactions without taking into account the meson and baryon resonance production. Inclusion of the resonance's leads to decreasing multiplicity of mesons, neutrons and protons. In order to overcome the problem, it is proposed to modify the FRITIOF code to low energies [3], [4]. For these purpose we choose:

\[
\frac{dW}{dM} \sim \frac{1}{M} \quad \text{Mmin}=1.1 \text{ GeV}
\]

Isotropic decay of quark strings with masses less than 1.7 GeV

Charge exchange of nucleons during the interactions

The Reggeon theory model of nuclear destruction.

As seen, the model predictions are close to each other. The FRITIOF model calculations are close to the experimental data. For the calculation we use the following values of the parameters: $C_{nd}=0.2$, $r_{nd}^{2n}=1.1$ fm$^2$ to reproduce the Ta nuclei destruction.
Fig. 1 Proton momentum distributions in n-Ta interactions. Points are the experimental data. The solid and dashed curves are the modified FRITIOF and CEM calculations, respectively.

Summing up, we can conclude that we have reached a satisfactory description of the meson and nucleon production in the nucleus-nucleus interactions at the energy of 3 GeV/nucleon in the framework of the sufficiently simple FRITIOF model. The model can be applied to a practical calculation of the nucleus-nucleus interaction characteristics at high energies.

4.5 Calculations of Subcritical Assembly in Dubna

by A. Poński

The properties of the experimental facility - a subcritical assembly in Dubna (SAD) - driven with the existing 660 MeV JINR protons accelerator have been investigated [5] - [17]. The assembly consists of a central cylindrical lead target surrounded by a mixed-oxide (MOX) fuel (PuO$_2$ + UO$_2$) and a leader reflector (Fig. 1).

Fig. 1 Geometry of subcritical assembly.

The calculated quantities were: a neutron multiplication coefficient, a neutron energy distribution for different places inside the subcritical assembly and the dependence of the energetic gain G on the proton energy. The fuel has been considered with a composition of plutonium dioxide PuO$_2$ and uranium dioxide UO$_2$. The content of plutonium isotopes in plutonium was as follows: 95% $^{239}$Pu, 5% $^{240}$Pu. Uranium was natural. Taking into account the split between the fuel element wall and the tablet, the effective density of the fuel is in the range from 9 to 9.5 g/cm$^3$. Calculations have been done in the MCNP4B code for different percentage of PuO$_2$ in the MOX fuel and for various density of the fuel fabricated in the Research Institute of Atomic Reactors in Dimitrovgrad in Russia.

According to Fig. 2, we found that for $k_{eff} = 0.945$ the percentage of PuO$_2$ in MOX fuel is about 29 for effective density: 9.0 g/cm$^3$. Fig. 3 presents neutron spectra averaged over the small volumes calculated along the radius ($r = 8.5$ cm, 15 cm, 30 cm and 38 cm) of the subcritical assembly with $k_{eff} = 0.947$.

Neutron flux: 1.54*10$^{12}$ cm$^{-2}$s$^{-1}$, 1.35*10$^{12}$ cm$^{-2}$s$^{-1}$, 0.74*10$^{12}$ cm$^{-2}$s$^{-1}$, and 0.52*10$^{12}$ cm$^{-2}$s$^{-1}$, respectively, was obtained inside the core.
Fig. 3 The neutron spectrum calculated along the radius (r=8.5 cm, 15 cm, 30 cm and 38 cm) of the subcritical assembly with $k_{\text{eff}}=0.947$.

Calculations were performed for the 660 MeV protons and 1 μA current. A LCS computer code was used. Several conclusions can be made from the presented results: (i) different neutron spectra can be formed inside the assembly - from hard up in the blanket to epithermal ones in the lead reflector; (ii) the fast neutron flux is about $10^{12}$ cm$^{-2}$s$^{-1}$. The calculations show that for the subcritical assembly with a mixed-oxide (MOX) BOR-60 fuel (29%PuO$_2$+71%UO$_2$) the multiplication coefficient $k_{\text{eff}}$ is equal to 0.947, the energetic gain is equal to 30, the fission power is 20 kW and the neutron flux density is $10^{12}$ cm$^{-2}$s$^{-1}$.

LIST OF PUBLICATIONS

MONTE CARLO MODELING OF ELECTRONUCLEAR PROCESSES IN EXPERIMENTAL ACCELERATOR DRIVEN SYSTEM
A. Polański,

A NEW METHOD FOR MEASURING ION CLUSTERS PRODUCED BY CHARGED PARTICLES IN NANOMETRE TRACK SECTION OF DNA SIZE
S. Pszona, M. Mariańska and J. Kula

PARTICIPATION IN CONFERENCES AND WORKSHOPS

RESEARCH PROGRAM FOR THE 660 MEV PROTON ACCELERATOR DRIVEN MOX-PLUTONIUM SUBCRITICAL ASSEMBLY
Proc. Topical Conference on Plutonium and Actinides, Santa Fe New Mexico, USA, 10-13 July 2000, ed American Inst. of Physics, 2000, p. 194

MONTE CARLO MODELLING OF FAST SUB-CRITICAL ASSEMBLY WITH MOX FUEL FOR RESEARCH OF ACCELERATOR DRIVEN SYSTEMS
A. Polański, V. Barashenkov, I. Puzynin, I. Rakhan, and A. Sissakian
Intern. Conf. on Advanced Monte Carlo on Radiation Physics, Particle Transport Simulation and Applications, Lisbon, Portugal, 23-26 Oct. 2000, p. 253

INTEGRAL NUCLEON- AND PION-NUCLEUS CROSS-SECTIONS FOR THE MONTE CARLO TRANSPORT CODES
V.S. Barashenkov, A. Polański
International Conference on Advanced Monte Carlo on Radiation Physics, Particle Transport Simulation and Applications, Lisbon, Portugal, 23-26 October 2000, p. 313

SIMULATION OF NUCLEUS-NUCLEUS INTERACTIONS IN THE FRAMEWORK OF THE FRITIOF MODEL
A. Polański, A. Galoyan, V. V. Uzhinski
International Conference on Advanced Monte Carlo on Radiation Physics, Particle Transport Simulation and Applications, Lisbon, Portugal, 23-26 October 2000, p. 382

EXPERIMENTAL STUDIES OF ELECTRONUCLEAR METHOD OF ENERGY PRODUCTION AND TRANSMUTATION OF RADIOACTIVE WASTES USING RELATIVISTIC BEAMS FROM JINR SYNCHROPHASOTRON/NUCLOTRON
XV International Seminar on High Energy Physics Problems, Relativistic Nuclear Physics and Quantum Chromodynamics, Dubna, Russia, September 25-29, 2000, p. 48

APPLICATION OF RQMD AND FRITIOF MODELS FOR DESCRIPTION OF NUCLEUS-NUCLEUS INTERACTIONS AT ENERGY OF 3.56 GEV/NUCLEON
A.S. Galoyan, E.N. Kladnitskaya, A. Polański, O.V. Rogachevski, V. V. Uzhinski

ADS'S BASED ON THE 660 MEV PROTONPHASOTRON OF JINR FOR RESEARCH ON UTILIZATION OF PLUTONIUM
V.S. Barashenkov, I.V. Puzynin, and A. Polański

MONTE CARLO EXPERIMENTS WITH ELECTRONUCLEAR SYSTEMS
V.S. Barashenkov, A. Polański, I.V. Puzynin
Second Intern. Conf. Modern Trends in Computational Physics, Dubna, Russia, July 24-29, 2000, p. 39

RESEARCH PROGRAM FOR THE 660 MEV PROTON ACCELERATOR DRIVEN MOX-PLUTONIUM SUBCRITICAL ASSEMBLY
Proc. Topical Conference on Plutonium and Actinides, Santa Fe New Mexico, USA, 10-13 July 2000, ed American Institute of Physics, 2000, p. 194

MONTE CARLO MODELLING OF FAST SUB-CRITICAL ASSEMBLY WITH MOX FUEL FOR RESEARCH OF ACCELERATOR DRIVEN SYSTEMS
A. Polański, V. Barashenkov, I. Puzynin, I. Rakhan, and A. Sissakian
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LECTURES COURSES AND EXTERNAL SEMINARS

Dosimetry with GAF Chromic foils
S.Pszona, Institute of Oncology, Warsaw, 18 April 2000

Performances of GAF Chromic Detectors
S.Pszona, Institute of Atomic Energy, Świerk, 05 April 2000

OTHER PAPERS

IONISATION CLUSTERS AT DNA LEVEL- PHYSICAL MODELING
S.Pszona
Report IPJ 28/IV/2000

NANODOSIMETRIC GAS COUNTERS
I.Y.Tamboul, I.C.McDougal, D.E.Watt, S.Pszona, J.Kula and S.Mariąnska
Chapter 3 In Radiation Quality Assessment Based on Physical Radiation Interaction at Nanometre Level, LNL-INFN (REP) 161/200
Edited by P.Colautti

ADS's BASED ON THE 660 MeV PROTON PHASotron of JINR FOR RESEARCH ON UTILIZATION OF PLUTONIUM
V.S.Barashenkov, A.Polański, I.V.Puzynin
Preprint JINR E2-2000-128

MONTE CARLO MODELING OF BIREACTOR ELECTRONUCLEAR SYSTEM
V.S.Barashenkov, S.A.Bznuni, A.H.Khudaverdean, A.Polański, A.N.Sosnin, V.M.Zhamkuchyan
Preprint JINR P2-2000-137

SPOsób pomiaru przestrzennego równowaznika dawki
S.Pszona
Patent awarded 05.2000

PERSONNEL

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Bogdan Kocik
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Overview

In 2000 the research activity in the Dept. P-V was concentrated upon studies in the field of high-temperature plasma physics, nuclear fusion, and plasma technology. The main topics were as follows:

1. Analysis of selected problems of plasma theory,
2. Investigation of phenomena in high-current pulse discharges of the Plasma-Focus (PF) and Z-Pinch type,
3. Development of the selected methods and equipment for plasma diagnostics,
4. Research on technology of experimental facilities for basic studies and applications,
5. Studies of the modification of material surfaces by means of pulse plasma-ion streams.

In a frame of theoretical studies the numerical modeling was continued for discharges in coaxial plasma accelerators. The second theoretical aim was the description of some elementary atomic processes in the quasi-classical approach. A paper on the electron scattering on the atoms and molecules was published. In the quasi-classical model, the electron spin was taken into account and trajectories of 2 electrons in the helium atom were analyzed.

In the frame of experimental studies, various phenomena were investigated in PF and Z-Pinch systems. The emission of pulse electron beams and ions as well as polarized X-rays were investigated in the MAFA-PF facility. New data about polarization of selected X-ray lines were obtained (2 papers at conferences and 2 publications). Ion emission measurements performed in small-scale PF-devices at INFIP and IFAS (Argentina), and in the Micro-Capillary device at Ecole Politechnique (France), were elaborated (5 papers at conferences and 2 publications). New measurements were also performed in the Capillary Z-Pinch device at IPP in Prague.

With partial support of a US research contract, studies of the optimization of a neutron yield were performed in the PF-360 facility with special cryogenic targets (made of “heavy ice” layers) or deuterium-gas targets (10 presentations at conferences, 2 reports for EOARD, and 7 papers submitted for publication). In collaboration with IFPiLM in Warsaw, the P-V Dept. participated in experiments with PF-150 and PF-1000 facilities, which concerned plasma dynamics and the emission of X-rays and charged particles. For the first time the PF-1000 facility was operated at 1 MJ (9 joint presentations at conferences and 3 publications).

Within a frame of a European Research Grant, the characterization of coatings deposited by means of plasma techniques was performed in the collaboration with IPP in Prague (1 talk at an international symposium and 2 publications). To develop plasma diagnostics, new calibration measurements were carried out for selected nuclear track detectors applicable to plasma experiments. The results, obtained in collaboration with Dept. P-I, were presented at the topical conference and in 2 publications. In cooperation with the Kurchatov Institute in Moscow, a new X-ray spectrometer was developed and equipped with a spherical crystal ensuring very good spectral and spatial resolution. In collaboration with KIPT in Kharkov, new optical and corpuscular measurements were performed within the IBISEK device, and a new method of their interpretation was developed (2 talks at international conferences and 2 papers submitted for publication).

To optimize pulsed plasma devices for research and technological purposes, the modernization of the PF-360 facility was performed. Studies of the interaction of pulsed plasma streams with surfaces of selected materials were carried out in collaboration with KIPT in Kharkov. Influence of micro-droplets in arc-discharges, and self-oscillatory regime in magnetron discharges, were studied in cooperation with HCEI in Tomsk. In collaboration with an Italian team, research on the deposition of super-conducting (Nb) layers was continued with the use of a modified cylindrical magnetron. The technological results were summarized in 7 publications and 7 papers presented at international conferences. Other studies of plasma-ion techniques applicable for the material engineering were carried out in collaboration with the Dept. P-IX (see another chapter of this issue).

The most important achievements of the Dept. P-V in 2000 were as follows:
- Enhancement of the neutron emission from PF-360 facility by means of the cryogenic targets,
- New results from the PF-1000 facility at 1 MJ energy (obtained in collaboration with the IPPM in Warsaw),
- Development of X-ray and corpuscular diagnostics in different pulsed plasma devices (in collaboration with Dept. P-I and several research centers abroad),
- New results in the field of applications of plasma discharges to material technology (in collaboration with Dept. P-IX, IPP in Prague, KIPT in Charkov, HCEI in Tomsk, and Universita Tor Vergata in Rome).

The results listed above have been described in 32 (including 6 accepted) publications in various scientific journals, and 52 (including 15 invited) papers presented at different international conferences.
5.1 Verification of Plasma Dynamics Model for IPD Accelerator
by M.Rabiriski, K.Zdunek

In surface engineering, a pulse plasma is often used in the synthesis and deposition of various materials in the form of layers. Within the IPD (Impulse Plasma Deposition) coaxial accelerator the plasma is generated in the working gas due to a high-voltage high-current pulse discharge. During the IPD surface engineering process the plasma discharge is used for synthesizing amorphous- and nano-structured high-melting materials in the form of coatings deposited upon different substrates. Coatings made of diamond, titanium nitride, multi-component metallic alloys, and alumina oxide, have been obtained while implementing this technique.

The two-dimensional snowplow model has been proposed as a relatively simple but accurate for the simulation of the current sheath, driven by the Lorenz force throughout the IPD discharge [1]. This self-consistent model combines the description of the electric circuit with the plasma resistance and inductance, as well as the balance of magnetic and fluid pressures at the contact interface, depending on the condenser bank parameters and the plasma outflow along the sheath. There is also a continually growing demand for the validation of plasma dynamics codes by comparison with experimental observations.

In the present study, the real shape of the current sheath, as well as its dynamics, were examined experimentally with the high-speed CCD framing-cameras [2].

We observed characteristic features of the discharge region [3]: the paraboloid current sheath moving within the inter-electrode region (see Fig. 1), and dense plasmoids produced as the result of plasma sweeping in the region of the Rayleigh-Taylor instability at the electrode end (see Fig. 2).

![Fig. 1 High-speed images of plasma in visible spectrum registered for the IPD accelerator, operated at C = 100 μF, U = 6 kV, p = 60 Pa N2. The images show the inter-electrode region, cathode on the top, anode on the bottom, a ceramic insulator on the left, and the accelerator outlet on the right.](image1)

![Fig. 2 High-speed image of plasma observed in the region at the accelerator outlet. The electrode end was on the left, and the discharge conditions were the same as in Fig. 1.](image2)

This specific deformation of the current sheath in the z-pinch region seems to be very important for the phase composition and morphology of the material deposited upon the substrate.

The preliminary results prove that a qualitative or even semi-quantitative correlation exists between the previously worked-out model and recent experimental observations.

The described experimental studies were supported by the KBN Research Grant No. 7 T08C 04517.


1) Faculty of Materials Science, Warsaw University of Technology, 02-524 Warsaw, Poland.
5.2 A New Step in the Classical Description of Elementary Atomic Process
by M.Gryzinski

Basic principles of a quantum collision theory have been critically examined. In particular, it has been shown that the rigorously formulated binary-encounter classical collision theory has no equivalent in quantum mechanics [1]. In quantum mechanics, the fundamental problem of atomic collision physics, i.e. the collision of an electron (or proton) with an hydrogen atom, still has no satisfactory solution. On the contrary, within classical dynamics there exists a rigorously formulated algorithm for numerical calculations, which yields results in perfect agreement with experiments.

In the quantum theory there exist many prescriptions for solving the trivial (in fact) problem of atomic collision physics. Many theoretical papers have already been published, and all these prescriptions give quite different results. There were, however, presented arguments that the Born collision theory is a formal fitting procedure, without any physical meaning; amplitudes and phase shifts of the wave function used in this theory play the same role as amplitudes and phase shifts in the Fourier expansion. There were also shown: the fundamental error in quantum theory of low energy scattering (so-called Ramsauer effect), and an error in the description of the Stark effect.

These and other arguments, showing that our theoretical physics is going the wrong way, were presented at the conference on "Mathematical problems of time and space “, which was held in Novosibirsk, on 22-24 June, 2000 [2-3]. All presented papers will be published in proceedings of this conference.


5.3 Studies of X-ray Spectra and Charged Particle Beams Emitted by Hot Spots within a Plasma-Focus System
by L.Jakubowski, M.Sadowski, J.Zebrowski, and E.O.Baronova

The main aim of these studies was to investigate a correlation between the appearance of hot spots and the emission of intense X-rays, REB pulses, and pulsed ion beams. In order to register spectra of the X-ray emission from individual hot spots distributed along the z-axis (see Fig. 1), an additional slit (600 μm in width) was applied in front of the X-ray crystal spectrometer. It was perpendicular to the dispersion axis of the crystal.

The most important results of the studies described in paper [1] can be summarized as follows:
1. Different parts of the registered X-ray spectral lines can be correlated with time-integrated X-ray pinhole images of individual hot spots. This makes possible the exact determination of the hot-spot position along the z-axis, as a function of distance from the anode end, as well as some estimation of the plasma concentration and electron temperature values within individual hot spots.
2. Relative intensities of the resonance and intercombination X-ray lines, as registered by means of two crystal spectrometers with mutually perpendicular dispersion planes, appeared to be different. This effect can be explained by different polarization of the spectral lines considered.
3. Values of the electron concentration and temperature, as estimated for individual hot spots, do not change monotonically. This suggests that such hot spots are formed independently, and local plasma parameters (n_e and T_e values) have a stochastic character.

Fig. 1 X-ray spectra obtained for the individual hot spots.
For the time-integrated and space-resolved measurements of pulsed ion streams, a small pinhole camera equipped with solid-state nuclear track detectors was applied. It made it possible to determine a spatial distribution of the investigated ions, and to estimate absolute values of the ion flux (Fig. 2).

Simultaneously with the ion studies, we also performed space- and time-resolved measurements of the pulsed REBs [2]. Those measurements enabled, in many cases, individual ion pulses to be assigned to electron-induced peaks, which were originated from the determined hot spots. Using the time-of-flight (TOF) technique, an energy spectrum of the investigated ions was also estimated.

The most important results of the recent experimental studies can be summarized as follows:

1. PF discharges emit pulsed collimated ion beams, which can produce images within an ion pinhole camera. Such ion images can supply information about local micro-sources (hot spots) inside the dense plasma column, which emit the fast ions.

2. The observed ion beams of energy higher than 1.3 MeV, are usually emitted within a narrow cone oriented along the axis of the PF discharge. The ion current density upon the measuring diaphragm reaches several mA, and the particle flux density amounts to $2.5 \times 10^{12}$ deuterons/sr.

3. The FWHM value of the ion pulse (upon the registration plane) amounts to about 20 ns. The energy spectrum of the accelerated deuterons extends up to about 1 MeV, and its maximum appears within the energy range of 400-450 keV.

Based on the experimental results described above, one can suspect that the fast ion beams emitted along the PF discharge axis, as well as the pulsed REBs emitted in the upstream direction, are generated within the micro-sources (hot spots). Such hot spots, constituting miniature short-living pinches, are formed successively (starting from the electrode ends), when the current-sheath collapse region moves along the PF pinch axis.


5.4 Investigation of the Emission of Pulsed Ion Beams from a Small-Scale PF-type Device and from a Micro-Pinch System

by E.Skladnik-Sadowska, J.Baranowski, K.Czaus, M.Sadowski, J.Zebrowski, M.M.Milanese

Within a frame of the described theme, we carried out a detailed analysis of the experimental results, which were obtained during previous joint experiments performed at IFAS in Tandil, Argentina. Those studies embraced an investigation of the structure of the emitted ion beams in dependence on their energies (see Fig. 1), and detailed measurements of the angular distribution of the ions studied.

The results of the described measurements were elaborated in details during the first quarter of 2000. They were presented at the 20th International Conference on Nuclear Tracks in Solids, which was held in Portorož, Slovenia, in August 2000 [1].

Within the same theme, we also realized the 3rd phase of the European research grant realized under the official contract with the Ecole Politechnique in Palaisseau, France. Also performed were basic plasma studies included in the statute activity of IPJ in...
Świerk. During the first half-year, results of the time-integrated measurements of the ion beams emitted from the Micro-Pinch system were elaborated. The applied system for the additional acceleration of ions enabled the ion images on the CN-LR115 nuclear track detector to be obtained, in spite of the fact that their energies were lower than the energy threshold of this detector (about 20 keV). The analysis of the registered ion images, as performed for different experimental conditions, made possible an assessment of the maximum ion flux density equal to about $6 \times 10^8$ ions/cm$^2$. This value remains in a good agreement with results of the time-resolved ion measurements, which were used as the basis for the assessment of an average ion energy value (equal to 15-30 keV) and the ion flux density (equal to $10^7-10^8$ ions/cm$^2$). It was shown that the Micro-Pinch discharges are point-like sources of ions with different ionization values and energies of 5-30 keV. The results of the described ion measurements were presented at the 19th Symposium on Plasma Physics and Technology, which was held in Prague, the Czech Republic, in June 2000 [2].

Within a frame of the scientific collaboration with the Institute of Plasma Physics in Prague, we prepared new equipment for time-integrated and time-resolved measurements of ions and electrons, which are emitted from plasma discharges in the Capillary-Pinch device. Also performed were preliminary series of the ion measurements. The obtained results are now under elaboration and they should be published in 2001.

In addition, within a frame of the research program we prepared four review papers, which summarized the experimental studies performed so far with the experimental facilities of the RPI-IONOTRON and PF types. Those papers were presented at different international conferences [3-6].

5.5 Studies of Plasma Focus Discharges within the PF-360 Facility Equipped with Additional Cryogenic and Gas-puffed Targets

by J.Żebrowski, J. Baranowski, K. Czaus, L. Jakubowski, M. Sadowski, E. Składnik-Sadowska, and J. Stanisławski

Experimental investigations of dense magnetized plasmas produced in the modernized PF-360 facility, operated with additional cryogenic and gas-puffed targets, were performed. These investigations were partially supported the US-AF EOARD contract No. SPC99-4088.

In the framework of these studies, neutron emission, especially the total neutron fluence, and neutron emission anisotropy, were measured for different types of cryogenic targets covered with D$_2$O-ice layers, and for an additional D$_2$-gas target produced by a special fast-acting gas valve. The main aim of these experiments was to overcome the neutron saturation effect and to increase the maximum neutron yield from PF discharges by using fast deuteron beams, which are emitted from a pinch column, and which can interact with additional nuclear targets.

The results obtained indicate that the additional cryogenic target of the "planar" type seems to be the most promising. The neutron emission, obtained with the application of such a target, demonstrated a considerable increase in the average neutron yield (from $2.4 \times 10^{10}$ to $3.8 \times 10^{10}$ neutrons/shot) at the determined experimental conditions, as shown in Fig. 1.

The measurements of the spatial characteristics of the neutron emission showed that the neutron anisotropy achieved the value of 1.7-2.0 for the PF-
360 facility. These values did not change considerably when the cryogenic target of the "planar" type was applied, but the neutron emission angular distribution for angles close to the z-axis ($\Phi = 0^\circ - 60^\circ$) was strongly disturbed in that case.

![PF-360](image)

**Fig. 1** Average neutron yields versus the initial $D_2$-filling pressure, as measured for PF-360 discharges performed with the $D_2$-ice-planar target placed at different axial positions. The initial conditions were $U_0 = 30$ kV and $W_0 = 130$ kJ.


5.6 Experimental Investigations of Plasma Sheath Dynamics, X-ray and Fast Ion Beam Emission in the PF-150 and PF-1000 Facilities Operated in Different Regimes

by A. Szydlowski, M. Scholz, L. Karpinski, M. Sadowski, K. Tomaszewski, and M. Paduch

The PF-1000 facility, constructed and operated at the Institute of Plasma Physics and Laser Microfusion (IPPLM) in Warsaw in collaboration with the Dept. P-V at IPJ-Swierk, has recently been modernized and optimized. The new outer and inner electrodes are 400 mm and 230 mm in diameter, respectively. The electrodes are about 600 mm in length. The replacement was motivated by theoretical calculations which indicated that the larger electrodes may better transmit electrical energy (up to 1 MJ) from the condenser bank to plasma discharges. The main objective of the experiments with the PF-1000 facility was to determine the total neutron yield as a function of the discharge energy and voltage, for different $D_2$ filling pressures.

The total neutron yield (in every shot), and the neutron angular distribution were measured with four silver-activation counters placed around the main PF-1000 chamber. Before the experiments, the counters were calibrated with an Am-Be neutron source of the known activity equal to $1.5 \times 10^7$ neutrons/4πsec. During the calibration measurements the neutron source was inserted into the main discharge chamber (on the electrode axis), where the plasma column is formed.

![PF-1000](image)

**Fig. 1** Average neutron yield versus the initial energy stored in the condenser bank of the PF-1000 facility. The initial pressure was $p_0 = 2$-5 torr $D_2$. 
In 2000, only one series of discharges was performed with the modernized PF-1000 facility. The neutron emission was investigated as a function of the initial charging voltage for several values of the D$_2$ filling pressure. The largest neutron yield, equal to about $2 \times 10^{11}$ neutrons/shot, was registered at $U_0 = 40$ kV and $W_{bat} = 1040$ kJ, as shown in Fig. 1.

An averaged coefficient of the neutron emission anisotropy decreased monotonically with an increase in the initial filling pressure, as shown in Fig. 2. In general, the neutron angular distribution seems to be more isotropic in the PF-1000 facility than that observed in other PF experiments. The emission of fast ions was measured by means of a miniature ion pinhole camera, which was placed on the electrode axis, at a distance of 40 cm from the inner electrode outlet. This camera was equipped with solid-state nuclear track detectors of the CR-39 type. Ion beams were registered only in PF shots performed at lower D$_2$ filling pressures. The ion pinhole pictures, which were scanned with an optical microscope, showed ion crater densities of the order of $1-6 \times 10^6$ craters/cm$^2$ (up to the saturation level).

Three different high-speed cameras (two streak cameras and one framing camera) were used to study the dynamics of the plasma current sheath, especially during the collapse phase. The plasma column was also observed by means of an X-ray pinhole camera equipped with three pinholes covered by metal filters of different thickness (10-µm Be, 25-µm Be, and 50-µm Al foils, respectively). It made it possible to observe the plasma-focus in the X-radiation of different hardness. The results of the observations are now under consideration. Some selected results have already been presented at the international workshop in Kudowa [6-7].

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1) Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland.
5.7 Measurements of Voltage and Current Pulses and Emission of Ions in the RPI-type Plasma Gun with Modified Electrodes
by J. Baranowski, E. Składnik-Sadowska, K. Czaus, M. Sadowski, and A. Tsarenko

In the framework of the European Research Grant, which was realized in the collaboration with the Ecole Polytechnique in Palaiseau, France, experimental studies of the influence of the electrode ends on the emission of ions (protons) were performed. The studies concentrated mainly on measurements of the ion beams, and particularly of energy and density of ion currents for the standard and modified electrode configurations (Fig. 1).

It was found that the so-called energy-density coefficient (defined as $\eta = \sum E(n)_\text{axis} / \sum E(n)_\text{angle}$) is better for the standard coaxial electrodes. Those results were presented at the Symposium on Plasma Physics and Technology in Prague [1].

Within the frame of the statute research program run at IPJ in 2000, several series of experiments with a modified IBISEK-RPI device were carried out. Measurements of the pulse ion beams were performed by means of Faraday-type collectors.

In cooperation with the KIPT in Kharkov, some basic equipment for spectroscopic measurements within the IBISEK device was prepared, and preliminary series of time-integrated and time-resolved measurements of the visible radiation from nitrogen plasma have been performed. The results of these studies were presented at the European conference in Budapest [2].

In cooperation with the KIPT plasma diagnostic group, we also performed several series of time-integrated and time-resolved spectroscopic measurements of the visible radiation from hydrogen plasma produced in the IBISEK facility. The emission lines $\text{H}_\alpha$ ($\lambda=4861,332$ Å) and $\text{H}_\beta$ ($\lambda=6562,793$ Å) were studied. The time-resolved measurements of the chosen spectral lines, which were performed through two side-on windows located at a distance of 10 cm, gave a possibility to estimate the velocity of hydrogen-ions as a function of operational parameters, e.g., a time delay $\tau$ (between the gas puffing and the application of high-voltage pulse).


5.8 Widening of Calibration Measurements of Solid-state Nuclear Track Detectors and Their Application in High-temperature Plasma Experiments
by A. Szydłowski, M. Sadowski, A. Banaszak, M. Jaskóla, T. Czyżewski, A. Korman, and J. Fijal

Solid-state nuclear track detectors (SSNTDs) have become a very useful diagnostic tool for quantitative measurements of fast ions emitted from high-temperature plasmas. However, in order to use such detectors in the optimal way, it is necessary to have a well-founded knowledge of this detection technique. In order to determine detection properties, especially those essential for corpuscular diagnostics of high-temperature plasmas, detailed studies of modern SSNTDs (of the CR-39, PM-355, PM-500, and PM-600 types) were undertaken at the IPJ several years ago. Up to now we gathered a collection of the data on diameters of tracks formed by different ion species in the investigated detectors. Track diameters, which were investigated as a function of particle energy and etching time, initially were studied for ions of energy ranging from 0.3 to 4.5 MeV.

Recently, we investigated the track diameters also for H- and He-ions of low energies (0.07-0.3 MeV),
and these for more energetic C-ions (of energy within the range of 1-44 MeV), as shown in Fig. 1.

![Fig. 1 Characteristics of the PM-355 track detectors applicable for the detection of carbon ions.](image)

The results obtained were presented at several international conferences, and a dozen or so papers were published (or submitted for publication, mainly in the NIM and Radiation Measurements). Besides the aforementioned objectives, the data collected in our laboratory shed some new light on mechanisms of the track formation in solid-state track detectors, and they even indicated a possibility of ion identification on the basis of track diameter evolutions (expressed as a function of the etching time). These questions were the subject of two recent papers in 2000 [1-2].

The paper [1] was devoted to characteristics of the PM-355 SSNTD for normal-incident light ions of MeV energies. The paper [2] concerned advantages of the PM-355 detectors for the registration of light ions and diagnostics of high-temperature plasmas. In 2000 we also irradiated samples of the PM-355 detectors (earlier recognized as the best one), using C-ions of energies ranging up to 44 MeV, and the corresponding detection characteristics (i.e. track diameters vs. ion energy and etching time for these ions) were determined.


5.9 Design of an X-ray Spectrometer with a Spherical Crystal, and Equipment for Registration of Plasma Ions

by L.Jakubowski, E.O.Baronova

To investigate X-ray spectra, and in particular to study the polarization of the selected X-ray lines in the MAJA-PF facility, we used two similar crystal spectrometers, with their dispersion axes mutually perpendicular. Those spectrometers had somewhat different values of the crystal constant. The first spectrometer (denoted A) was parallel to the z-axis and it had the constant 2d = 0.851 nm, while the second spectrometer (denoted B) was perpendicular to the same axis and it had the constant 2d = 0.667 nm. Therefore, those spectro-meters differed in their spectral characteristics.

In 2000 we replaced the crystal in the first (A) spectrometer by a spherical crystal with the constant 2d = 0.667 nm. After that, we performed some modification of this spectrometer and we performed an accurate adjustment of it at the MAJA-PF experimental facility. As a result, it was possible to register the X-ray spectra of very high quality, which enabled even the ArXII lines to be identified. The sensitivity and spectral resolution of the spectrometer was also considerably improved.

In 2000 we also developed a prototype of the diagnostic equipment for time-integrated registration of ion beams with nuclear track detectors, and simultaneous time-resolved measurements of ions by means of scintillation detectors and a fast oscilloscope.

1) Russian Scientific Center "Kurchatov Institute", Moscow, Russia.
5.10 Design and Testing of Special Pulse Generators Used in Laboratory and Industrial Investigations

by J. Witkowski, K. Kociecka, A. Jerzykiewicz, R. Mirowski, B. Kolakowski, and M. Kuk

The design and testing of special current- and voltage-pulse generators, which are used in scientific and industrial laboratories for electromagnetic (EMC) compatibility investigations of the electric and electronic equipment, was continued [1-3]. Different schemes of the generators producing pulses for testing of road vehicles, according to the standards PN-ISO-7637-1 and PN-ISO-7637-2, were calculated and tested. Such generators can produce pulses with parameters as follows: 1/2000 µs, 1/50 µs, 60/300 µs, 5/100 ns, 5/100 ms, as well as 5-10/40-400 ms. They can operate at various values of the internal resistance and within the voltage range up to 1100V.

Preliminary measurements of magnetic field strength were performed for different antennas, which were supplied from:
- a continuous current source, operated at 50 Hz;
- a pulse current source, operated in the 8/20-µs mode.

The results of activities in the field of the EMC investigations were presented at international conferences in Prague and Brno [1-3].


5.11 Modernization of High Current Pulse Generators and Contracts with Industry

by J. Witkowski, K. Kociecka, A. Jerzykiewicz, R. Mirowski, B. Kolakowski, and M. Kuk

In the framework of the modernization of current pulse generators, which are used to supply plasma experiments, the renovation of the PF-360 current-pulse generator was performed. The Rogowski coil circuit was adapted to demands of the modern digital oscilloscopes with low input voltages. The current measurement coefficient was determined [1]. The voltage divider, which is used for measurements of voltages between the PF-360 electrodes, was tested, and its response time to the rectangular voltage pulse was evaluated to be below 4 ns. The divider ratio value was compared with that of the calibrated divider, as a function of voltage. The differences were within the range of 0.7%. The dry-air distribution system for pressurized spark gaps was also modernized. In 2000 we have realized several contracts for industrial laboratories. The most important were as follows:

1. The construction and testing of the voltage- and current-surge generator of the GU-25/2s type. The generator was designed for testing of electric appliances according to the known standards: PN-88/E-88605, PN-90/E-06150/10, PN-IEC 1008-1+A#1996. After laboratory tests, that generator was put in operation. It can produce voltage surges of the shape 1.2/50 µs, with the crest value up to 20 kV. It can also generate damped oscillatory current-pulses with the first amplitude equal to 200 A. Tests and measurements, run with this generator, can be controlled by means of a personal computer [2-3]. The front panel of the generator is shown in Fig. 1.

Fig. 1. General view of the GU-25/2s generator.

2. Design and construction of the EM20-1 system. That system was designed for testing of electromagnetic compatibility of road vehicles according to the requirements of the standards PN-ISO 7637-1 and PN-ISO 7637-2. The EM20-1 system was built and tested [4].

The results of the above-mentioned technological activities were presented on the topical symposium on high-voltage engineering, which was held in Poznań [5-6].

5.12 Some Problems of Plasma Material Interaction in Fusion Devices


In 2000 the collaboration of IPJ with the Institute of Plasma Physics at the National Scientific Center KhIPT in Kharkov concentrated on selected problems of plasma-material interaction in fusion devices. The plasma-material interaction processes are of importance for nuclear fusion physics and technology. The main directions of those investigations were studies of various materials during and after the plasma irradiation, as well as studies on the behavior of hydrogen isotopes in plasma facing components of a fusion reactor. In our investigations, we focused on mechanisms of boron-carbide erosion, and behavior of TiN-coated stainless-steel surfaces, under irradiation with hydrogen plasma-ion fluxes [1-3].


5.13 Optimization of Plasma Devices for Plasma Technology

by J.Langner M.Sadowski, P.M.Schanin, S.V.Grigoriev, I.V.Lopatin, V.S.Tolkachev

The main aim of the scientific collaboration with the Institute of High-Current Electronics (HCEI), Russian Academy of Sciences in Tomsk, which was begun in 2000, was the optimization of various plasma devices applied in plasma technology.

The first problem was the reduction of the formation of micro-droplets in vacuum-arc discharges, used for the deposition of thin metal or metal-oxide layers. It was known that micro-particles could be removed from the active area by an appropriate filtering. Such technologies have just been introduced for EMC tests of road vehicles, Technical Design IPJ, PV, Swierk, March, 2000 - in Polish.


ionic component population of the arc-evaporated material. Depending on the polarization voltage applied to the treated sample, and the temperature of the reactive gas plasma, a fourfold or fivefold decrease in the number of micro-droplets has been achieved [1].

Within the framework of the described collaboration the self-oscillatory operation of a sputtering magnetron system has also been investigated experimentally [2].


5.14 Application of Arc Plasma Discharges to Coating of Material Surfaces
by J.Langner, M.Sadowski, B.Kolman1, P.Chraska2, J.Matejicek3, J.Pisacka3, E.Langner3, E.Maslanko3

Within the framework of a collaboration with the Institute of Plasma Physics (IPP), Czech Academy of Sciences in Prague, research on surface morphology of the arc-produced coatings has been carried out. In particular, characteristics of arc-deposited coatings, the samples was studied by means of a scanning electron microscope (SEM) technique in Prague. It was shown that the originally matted surfaces of the ceramic layers were changed into shining ones. The thickness of this modified layer did not exceed 1 μm (see Fig. 1).

Another joint work was devoted to technological research on the coating of the standard screw taps, which were coated with TiN layers deposited by means of the arc-plasma discharges [2]. It was found that the TiN-coated tools demonstrate the wear resistance improved by a factor of about 2.

These joint studies were partially supported by the INCO-COPERNICUS Contract no ERB 1C1SCT97-0705, which was coordinated by Ecole Politechnique, Palaiseau, France.


1) Institute for Plasma Physics (IPP), Czech Academy of Sciences, Prague, Czech Republic.
2) ARC-Tech S.C. Plasma Technology Entertainment, 05-400 Swierk by Warsaw, Poland

![Fig. 1 Surface of the alumina sample treated with Ti- and N-ions. Cracks with the rounded edges can be observed.](image-url)
5.15 Formation of Thin Superconducting Films for RF Cavities

For future large superconducting RF accelerators, technology of Nb-coated copper cavities seems to be a very interesting alternative to the cavities made of bulk Nb, for the sake of costs. The technology of thin niobium film coating was successfully used for the production of the 350 MHz LEP accelerating cavities. For high-Q, high gradient 1.3 GHz cavities (TESLA, TTF-FEL), a further progress in this technology is still needed.

For the coating of such cavities it was proposed at the University of Rome “Tor Vergata” to use a cylindrical magnetron sputtering system with magnetic coils placed externally. This set-up was realized in the early 90s and was put into operation in the mid 90s.

Since 1997, within the collaboration with IPJ more systematic studies of the deposition of Nb films have been undertaken. Since 1997, about 50 glass- and sapphire-samples with Nb films have been produced and analyzed. A very good quality of the films was obtained, with a critical temperature of about 9.5 K, and RRR values ranging up to 30 [1-2] (see Table I).

Table I Data of the investigated samples.

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Although the magnetron sputtering method, used up to now exclusively for producing Nb-Cu resonators, seems to now be a mature technology (see the 350-MHz LEP cavities), it has however some drawbacks. One of them is the relative low impact energy of the Nb atoms (1-10 eV) and the need of a carrier gas.

An interesting alternative to the magnetron sputtering technique might be the vacuum-arc deposition. In this method the energy of metal ions is within the range of (10-100) eV, and it allows for creating a denser superconducting film. Therefore, investigation of the applicability of this method became a topic for the collaboration between the INS and the University of Rome “Tor Vergata”. Also DESY representatives declared some interest in the collaboration to master this method in practice.

On July 10, 2000, a special workshop on thin film coating methods for superconducting cavities was organized at DESY headquarters. Dr. J. Langner was invited to give an important overview talk on arc-deposition methods [3]. As a result of this workshop, there appeared a DESY proposition to join the existing collaboration INS - “Tor Vergata”. This proposition was discussed during the working meeting DESY-IPJ, which was held in Świerk on October 4-5, 2000. As a result of this meeting, it was decided to supplement the DESY-IPJ collaboration by some studies in the field of physics and technology of superconducting accelerating structures.

A very important aim of the described collaboration is the construction of a new technological system with high and clean vacuum conditions in the Dept. P-V IPJ in Świerk, with the help of DESY. In such a system it should be possible to deposit thin film Nb-coatings upon copper cavities.


1) The University of Rome “Tor Vergata”, Via della Ricerca Scientifica 1, 00133 Rome, Italy.
2) INFN, LNF, 0044 Frascati, Italy.
LIST OF PUBLICATIONS

PLASMA CHARACTERISTICS OF THE PROTO-1Z PULSED ARC
D.Grondona, H.Kelly, A.Marquez, F.Minoti and J.Zebrowski

DETECTION OF MICROSECOND PLASMA PULSES IN MW RANGE
Z.Werner, J.Langner, J.Stanislawski and J.Bialoskorski

SURFACE MODIFICATION OF CONSTRUCTIONAL STEELS BY IRRADIATION WITH HIGH INTENSITY PULSED NITROGEN PLASMA BEAMS

KINETICS OF PULSED EROSION DEPOSITION PROCESS INDUCED BY HIGH INTENSITY PLASMA BEAMS

DETECTION CHARACTERISTICS OF PM-355 SOLID-STATE NUCLEAR TRACK DETECTOR FOR NORMAL INCIDENT LIGHT IONS WITHIN MeV ENERGIES

DIELECTRONIC STRUCTURE OF 21-1s TRANSITIONS OF MULTICHARGED IONS OF ARGON WITH NUCLEAR CHARGES Z=10-17

DIFFERENTIAL SCATTERING OF ELECTRONS FROM ATOMS AND MOLECULES: 1. GENERAL AND EXACT BINARY-ENCOUNTER APPROXIMATION CROSS SECTIONS FOR THREE-DIMENSIONAL TRANSFER OF ENERGY AND LINEAR MOMENTUM FROM THE INCIDENT ELECTRON TO THE ELECTRONS OF THE TARGET
M.Gryzinski and A.Kunc

STUDIES OF HYDROGEN DISCHARGES IN RPI-TYPE DEVICES WITH DIFFERENT ELECTRODE CONFIGURATIONS
J.Baranowski, K.Czaus, M.Sadowski and E.Skladnik-Sadowska

„HOT ELECTRONS" INFLUENCE ON ARGON K-SPECTRUM EMITTED FROM PLASMA FOCUS DISCHARGES
L.Karpinski, A.Szydlowski, et al.

EXPERIMENTAL STUDIES OF AL. CORONA PLASMA CREATED WITHIN THE PF-1000 PLASMA FOCUS FACILITY
M.Scholz, L.Karpinski, K.Tomaszewski and M.Paduch, J.Kravarik, P.Kubes, A.Szydlowski, V.Romanova, and S.Pliske

3-D MODELING OF ION MOTION WITHIN DYNAMIC FILAMENTARY PF-PINCH COLUMN
A.Pasternak, M.Sadowski and A.Galkowski

TIME-INTEGRATED AND TIME-RESOLVED STUDIES OF PULSED ION BEAMS FROM FAST MICRO-CAPILLARY DISCHARGES
E.Skladnik-Sadowska, M.Sadowski, A.Engel, J.Laure, P.Choi, C.Dumitrescu, A.Guilbert and J.Rous

APPLICATION OF THE EMC PRINCIPLES TO THE PLASMA RESEARCH LABORATORIES
K.Kociecka and J.Witkowski

SPACE-RESOLVED STUDIES OF X-RAY SPECTRA WITHIN PLASMA-FOCUS SYSTEM
L.Jakubowski, M.Sadowski and E.O.Baronova

RESULTS OF RECENT EXPERIMENTS WITH PF-1000 FACILITY EQUIPPED WITH NEW LARGE ELECTRODES
M.Scholz, L.Karpinski, M.Paduch, K.Tomaszewski, R.Miklaszewski, T.Pierczyk, M.Sadowski and A.Szydlowski

XUV EMISSION FROM A WIRE-PLASMA FOCUS DISCHARGE
P.Kubes, J. Kravarik, D.Kir, M. Paduch, K. Tomaszewski, E. Skladnik-Sadowska, and M.Sadowski
APPLICATION OF ARC-PLASMA DISCHARGES TO COATING OF SCREW TAPS
J. Langner, M. Sadowski, E. Maslanko, E. Langner, P. Chraska, B. Kolman, J. Matejicek and J. Pitsocka

INTENSE PULSED PLASMA BEAMS IN CERAMICS/METAL BRAZING

COMPARISON OF CHARACTERISTICS OF PULSED ION BEAMS EMITTED FROM DIFFERENT SMALL PF DEVICES

SURFACE MODIFICATION OF PLASMA-SPRAYED ALUMINA DEPOSITS BY HIGH-ENERGY ION BEAMS
M. Sadowski, J. Langner, J. Stanislawski, J. Matejicek, B. Kolman and P. Chraska

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THIN NI OBIUM SUPERCONDUCTING FILM PREPARED BY MODIFIED CYLINDRICAL MAGNETRON

STUDY OF FUSION NEUTRON YIELD FROM PF-360 FACILITY EQUIPPED WITH SOLID-STATE OR GAS-PUFFED TARGETS
J. Żebrowski, J. Baranowski, I. Jakubowski, M.J. Sadowski and J. Stanislawski

EROSION, PERMEATION AND OUTGASSING PERFORMANCES OF TIN COATING UNDER/AFTER HYDROGEN PLASMA IRRADIATION
G.P. Glazunov, J. Langner, M. Sadowski, J. Stanislawski, V.I. Tereškin et al.,

STUDIES AND APPLICATIONS OF DENSE MAGNETIZED PLASMAS
M. Sadowski

STATUS OF RESEARCH ON MODIFICATION OF SURFACE PROPERTIES BY PULSED PLASMA STREAMS AT SINS-SWIERK
J. Langner, J. Piechoszewski, J. Stanislawski and Z. Werner
Nukleonika 45, No.3 (2000) 193-197

PROGRESS IN DENSE MAGNETIZED PLASMA RESEARCH IN POLAND; A REVIEW
M. Sadowski

INVESTIGATION OF CURRENT SHEET DYNAMICS IN IPD ACCELERATOR
M. Rabinski and K. Zdunek

SPATIAL STRUCTURE AND ENERGY SPECTRUM OF ION BEAMS STUDIED WITH CN-DETECTORS WITHIN A SMALL PF-DEVICE
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STUDY OF DEUTERON MOTION IN A FILAMENTARY PF PINCH COLUMN FOR DIFFERENT CONFIGURATIONS OF FILAMENTS  
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Nukleonika (in press)

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Nukleonika (in press)

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CLASSIFICATION AND OVERVIEW OF VARIOUS DEPOSITION TECHNOLOGIES
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SPATIAL STRUCTURE AND ENERGY SPECTRUM OF ION BEAMS STUDIED WITH CN-DETECTORS WITHIN A SMALL PF-DEVICE
Abstracts 29th International Conference on Nuclear Tracks In Solids, Portoroz, Slovenia, August 2000, p. 60.
ADVANTAGE OF PM-355 NUCLEAR TRACK DETECTORS IN LIGHT-ION REGISTRATION AND HIGH-TEMPERATURE PLASMA DIAGNOSTICS
Abstracts 20th International Conference on Nuclear Tracks In Solids, Portoroz, Slovenia, August 2000, pp.61-62.

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J.Langner, L.Catani, M.Cirillo, R.Russo, S.Tazzari, and R.Sorchetti, (invited talk)

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EFFECTS OF NON-LINEAR PLASMA PROCESSES IN HIGH-CURRENT PINCH-TYPE DISCHARGES
M.Sadowski, (invited talk)
Proc. 12th Symposium on High Current Electronics, Tomsk, Russia, September 24-29, 2000, pp. 185-190.

OUTGASSING FROM TiN-COATED PLASMA FACING COMPONENTS OF URAGAN-3M TORSATRON
Proc. 5th Conf. on Modification of Materials with Particle Beams and Plasma Flows, Tomsk, Russia, Sept 24-29, 2000, pp. 104-106.

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VERIFICATION OF PLASMA DYNAMICS MODEL FOR IPD ACCELERATOR
M. Radziszewski, M. Radziszewski, K. Tomaszewski, and M. Sadowski, (oral)

A METHOD OF IMPURITY DIAGNOSTICS IN DENSE PLASMA SYSTEMS
A. V. Tsarevsk, V. V. Chetotov, M. Sadowski, and V. I. Tereshin, (oral)

INFLUENCE OF DIAPHRAGMS ON MEASUREMENTS OF IONS Emitted FROM DENSE MAGNETIZED PLASMAS
E. Skladnik-Sadowska, and M. Sadowski, (oral)

NEUTRON AND FAST ION EMISSION FROM PF-1000 PLASMA FOCUS FACILITY EQUIPPED WITH NEW LARGE ELECTRODES
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STUDIES OF PLASMA-FOCUS DISCHARGES WITHIN THE PF-360 FACILITY EQUIPPED WITH PLANAR D2-O-ICE TARGETS
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INVESTIGATION OF PLASMA-FOCUS DISCHARGES IN THE PF-360 FACILITY WITH ADDITIONAL D2-GAS-PUFFED TARGETS
J. Stanislawski, J. Baranowski, L. Jakubowski, M. Sadowski, and J. Zebrowski, (oral)

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EXPERIMENTAL STUDY OF A POWERFUL ENERGY FLOW EFFECT ON MATERIALS ON PF-1000 INSTALLATION
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THE MAIN ISSUES OF DENSE MAGNETIZED PLASMA IN POLAND
M. J. Sadowski and M. Scholz, (poster)

PROTECTION AGAINST EMC DISTURBANCES GENERATED IN HV PLASMA LABORATORIES
A. Jerzykiewicz and K. Kociecka, (oral)

EMC SIMULATORS FOR TESTING OF ELECTRICAL LABORATORY EQUIPMENT
K. Kociecka and A. Jerzykiewicz, (oral)

ALLOYING OF SILICON ON Ti6Al4V USING HIGH-INTENSITY PULSED PLASMA BEAMS

ALLOYING OF Pd INTO Ti BY PULSED PLASMA BEAMS
LECTURES, COURSES, AND EXTERNAL SEMINARS

Formation of Thin Super-Conducting Layers by Means of Magnetron Discharges
J. Langner

New Achievements and Trends in Research on High-Power Plasma Discharges
M. Sadowski
Physical Seminar at the Institute of Physics, Nicolaus Copernicus University, Torun, Poland, 27 Jun., 2000.

The March Towards Sun
M. Rabinski
IV Festival of Science, Warsaw, Poland, 16 Sept., 2000.

Plasma – the Fourth State of Matter
J. Baranowski
IV Festival of Science, Warsaw, Poland, 23 Sept., 2000.

Development of Plasma-Focus Research in Poland
M. Sadowski
Plasma Seminar at the Institute of Nuclear Fusion, RRC Kurchatov Institute, Moscow, Russia, 21 Sept., 2000.

Experimental Assessment of Ion Beams Obtained from PF-1000 Facility
A. Szymkowiak
Meeting of the Committee of Medical Physics and Radiobiology, Polish Academy of Sciences, Warsaw, Poland, 18 Oct., 2000.

PARTICIPATION IN PROGRAM AND ORGANIZING COMMITtees OF CONFERENCES;

M. Sadowski - Member of the International Program Committee
27th EPS Conference on Controlled Fusion and Plasma Physics, Budapest, Hungary, June 12-16, 2000

M. Sadowski - Member of the International Program Committee
1st Int. Congress on Radiation Phys., High Current Electronics, and Modifications of Materials, Tomsk, Russia, 24-29 Sept., 2000

J. Langner - Member of the International Program Committee
1st Int. Congress on Radiation Phys., High Current Electronics, and Modifications of Materials, Tomsk, Russia, 24-29 Sept., 2000

M. Sadowski - Chairman of the International Program Committee

M. Sadowski - Member of the International Scientific Committee
Troisieme Seminaire Franco-Polonais sur les Plasmas Thermiques dans l’Espace et en Laboratoire, Poznan, Poland, 23-26 Apr., 2001 - under organization.

M. Sadowski - Chairman of International Scientific Program Committee

M. Rabinski - Member of the Organizing Committee

M. Rabinski - Member of the Organizing Committee

DIDACTIC ACTIVITY

M. Sadowski - Supervisor of Ph.D. thesis of Mr. A. Pasternak (IPJ)
Ph.D. thesis under preparation

M. Sadowski - Supervisor of Ph.D. thesis of Mr. J. Zebrowski (IPJ)
Ph.D. thesis under preparation

M. Sadowski - Supervisor of Ph.D. studies of Mrs. A. Banaszak (IPJ)
II year of Ph.D. courses
PERSONNEL

Research scientists

Jarosław Baranowski, Dr.                           Marek Rabinski, Dr.
M. Gryziński, Assoc. Prof.                     Marek Sadowski, Professor
Lech Jakubowski, Dr.                            Elżbieta Składnik-Sadowska, Dr. (3/5)
Krzystyna Kocięćka, Dr.                           Adam Szydlowski, Dr.
Marian Kowalski, Dr. (on leave of absence)       Jarosław Żebrowski, MSc.
Jerzy Langner, Dr.

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Aneta Banaszak, MSc.
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Technical and administrative staff

Krzysztof Czaus, B.Sc.E.E.                     Józef Kloch
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Krzysztof Gątarczyk                        Krzysztof Michalik
Alicja Gawrońska                             Robert Mirowski, M.Sc.E.E.
Krzysztof Gniadek                             Wojciech Pijanowski
Andrzej Jerzykiewicz, Dr.                     Ryszard Rybicki
Marek Jerzejczyk                                Jacek Stanisławski, M.Sc.E.E.
Paweł Karpiński                               Andrzej Trembički
Krzysztof Kasperski                            Andrzej Wiraszka
Bernard Kołakowski                           Jan Witkowski, B.Sc.E.E.
Overview

The activities of the Department of High Energy Physics are centered around experiments performed at accelerators in the following laboratories:

- **At CERN, the European Laboratory for Particle Physics in Geneva, Switzerland:**
  - DELPHI at LEP e⁺e⁻ storage ring is concerned mainly with the tests of the Standard Model, b-quark physics, gamma-gamma interactions and search for Higgs boson and supersymmetric particles
  - NA48 - studies of the CP-violation and rare K⁰ decays
  - SMC - Spin Muon Collaboration is investigating the spin dependent nucleon structure functions and the gluon role in the nucleon spin
  - NA49 and WA98 deal with heavy ion physics looking for possible effects of the phase transition to the quark-gluon plasma state

- **At CELSIUS Storage Ring in Uppsala, Sweden:**
  - WASA - a precise study of near threshold production of light mesons, and their decays.

- **At DESY in Hamburg, Germany:**
  - ZEUS - deep inelastic scattering of electrons and protons, proton structure functions, diffractive photon-proton interactions.

The groups of our Department participated in the construction phase of the experiments, both in hardware and in development of the software used in data analysis. Presently they take part in the data collection, detector performance supervision and data analysis.

The Department is also actively involved in the preparation of new experiments:

- CMS (Compact Muon Solenoid) and LHCb (b-quark production and CP-violation) at the LHC (Large Hadron Collider) at CERN,
- ALICE - experiment to study the heavy ion interactions at the LHC,
- COMPASS (Compact Muon and Proton Apparatus for Structure and Spectroscopy) at the SPS at CERN.
- WASA- 4π - commissioning of a new version of the WASA detector at CELSIUS in Uppsala,
- study of charge exchange processes in d-p collisions at Nuclotron in Dubna.

A small mechanical workshop is attached to our Department. It is involved in the preparation of the COMPASS experiment and participated in the construction of the prototypes for the alignment monitoring system for the Outer Tracker detector in the LHCb experiment.

Two of our colleagues work on the phenomenology of the quark-gluon plasma formation and of the low energy hadron-hadron reactions.

Several physicists from our Department are actively involved in science popularization by contributing articles to newspapers and preparing www pages with information about our activities.

We collaborate closely with the Institute of Experimental Physics of the Warsaw University in most of our experiments as well as take part in teaching and supervising diploma works. There is also a group of 10 PhD students.
6.1 DELPHI Experiment in 2000

The year 2000 was the last year of the LEP operation. Originally LEP was supposed to be closed in June. However indications, coming mainly from the ALEPH experiment that the Higgs boson production might be observed, were taken seriously enough to delay twice the closure of LEP. Its energy has been pushed up beyond the value considered previously as unreachable, up to 209 GeV. In spite of that no convincing evidence of the standard Higgs boson production has been obtained. The lower limit for its mass was established to be 113.5 GeV/c². This is definitely above the value obtained from the best fit of the Standard Model to a very rich set of experimental data (Fig. 1). Similarly no other new physical object suggested by theory has been found.

This situation suggests that the Higgs boson may not be the one of the Standard Model. Its mass may be below the lower limit quoted above and therefore it still can be produced at LEP energies. Such a consideration strongly justifies the Higgs search programme that started in Warsaw few years ago. This programme has been carried on in 2000. The analysis being performed within the framework of the Two Higgs Doublets Model aims to establish which values of Higgs bosons masses are excluded by experimental data.

It is possible that some of the predicted particles have their masses exceeding not very substantially LEP collision energies. They can not be produced and observed directly but their presence should be felt as an additional virtual particle exchange in the decays of known particles. It may occur, therefore, that the decay rate of a b-quark into a s-quark and a gluon is modified by the existence of a new, not yet observed particle(s). The precise measurement of this decay rate can give an indication of its (their) reality. The analysis of the b → s + g decay was continued in 2000.

![Fig. 1](image)

Fig. 1 $\Delta \chi^2$ dependence on the Standard Higgs boson mass. The minimum of $\Delta \chi^2$ corresponds to the most probable value of the boson mass: 70-85 GeV/c². The grey region is excluded experimentally for the standard Higgs boson.

6.2 ZEUS Experiment in 2000
by M.Adamus and T.Gadaj

During HERA accelerator operation in 2000 year ZEUS experiment continued data acquisition from collisions of 920 GeV protons with 27.6 GeV positrons. Warsaw group was responsible for smooth running of VETO WALL (VW) component (see Annual Report 1999). In the scope of silicon microvertex detector installation VW HV system is to be moved to the electronic hut (Rucksack) during 2000/2001 shutdown. This task requires wide hardware activity. In the period between October and December some preliminary works were done. The most important were:

- tests of 70 m HV extender cables
- test of 70 m auxiliary cables
- production and check of the cables for the driving of the VW HV system and readout of the individual channel HV value
- de-assembling of the VW front-end electronics and HV system
- preparing of the new racks in the Rucksack for the HV suppliers and dividers.

The further activity i.e. assembling of the VW front-end electronics and HV system as well as secondary start-up of the system are to be done until end of the 2000/2001 shutdown. Warsaw group is also involved in physics analysis which concerns study of multiplicity moments in deep inelastic scattering (DIS) [1]. Some results were presented at Osaka 2000 conference. Short description of the topic can be found below.

Multiplicity moments of charged particles in deep inelastic $e^+p$ scattering have been studied in the current region of the Breit frame with the ZEUS detector at HERA using an integrated luminosity of 38.4 pb⁻¹. The evolution of the moments for $Q^2>$1000 GeV² is studied as a function of restricted regions in the transverse momentum, total momentum and polar angle of final-state particles. Analytic perturbative QCD predictions for partons show
considerable deviations from the measurements, while Monte Carlo models give better agreement with the data, although some discrepancies are observed. The results indicate a large influence of the hadronization stage on the multiplicity distributions in the limited phase-space regions studied here, which is inconsistent with the expectations of the Local Parton-Hadron Duality.

[1] M.Adamus, S.Chekanov, L.Zawiejski, ZEUS - Note 00-031

Fig. 1 Factorial moments for charged particles in the current Breit hemisphere as a function of $p_t^w$ compared to Monte Carlo models. The inner error bars are statistical uncertainties, the outer are statistical and systematic uncertainties added in quadrature.

6.3 SMC Experiment at CERN


The SMC experiment finalizes the analysis of the data taken in year 1996. It was working with polarized target (proton or deuteron) and polarized muon beam. Most of the SMC results have been presented in a series of papers. Recently the description of measurement of beam polarization using the asymmetry in the elastic scattering of polarized electrons was published [1].

The analysis still in progress concerns the determination of gluon polarization for which the selection of photon-gluon fusion (PGF) process is needed. The most popular way of searching for such process is a production of charm particles $D^0$ or $D^*$. Since the identification of the decay products of $D^0$ or $D^*$ was not possible in SMC the selection of events with two hadrons with large $p_t$ was proposed [2]. Since mainly light quarks are produced in PGF the statistics in high $p_t$ analysis is supposed to be larger than for events with production of $D^0$ or $D^*$. The requirement of two hadrons with large $p_t$ brings significant reduction of the leading order process in DIS - virtual photo-absorption contribution. The second source of background, the Compton process contribution, remains comparable with the PGF contribution.

The high $p_t$ analysis using cuts method as well as the neural network selection method is used to choose PGF process. The algorithm for the neural network has been prepared in collaboration with Warsaw University of Technology.

As the criteria for the comparison of the methods two variables are calculated: purity which describes the fraction of PGF events in the finally selected sample (in percent) and efficiency which is the fraction of PGF events which survived selection (also given in percent).
The results are compared in Fig. 1. The solid line shows the neural network results. The points correspond to different values of cut on \((p_T^1 + p_T^2)/p_{\text{min}}\), where \(p_{\text{min}}\) is within range \((1.3-3.2)\). The purity obtained by neural network at the given efficiency is about few percent better than the one for cuts method. The criteria for finding optimum selection for the further analysis are related to the precision in gluon polarization determination. The best result is obtained for efficiency 20% and purity 47%. In near future the methods described here can be also used in the analysis of COMPASS experiment.


6.4 Results from the NA48 Experiment


NA48 direct CP-violation experiment at CERN SPS has presented a new preliminary measurement of Re \(\varepsilon'/\varepsilon\). Based on the 1998 data sample Re \(\varepsilon'/\varepsilon = (12.2 \pm 2.9 \text{ (stat.)} \pm 4.0 \text{ (syst.)}) \times 10^{-4}\) was obtained [1]. Combining this result with the NA48 published data (based on 1997 data sample) and taking into account the correlated systematic errors one gets Re \(\varepsilon'/\varepsilon = (12.2 \pm 4.3) \times 10^{-4}\). The first observation of the decay \(K_S \rightarrow \pi^+ \pi^- e^+ e^-\) based on the data collected in 1998 has been presented [2]. Clean sample of 56 events with negligible background contamination was identified. Using \(K_L \rightarrow \pi^+ \pi^- \pi^0\) decays as normalization sample, the branching ratio is measured to be \(\text{BR (}K_L \rightarrow \pi^+ \pi^- e^+ e^-\) - (4.5 \pm 0.7 \text{ (stat.)}) \pm 0.3 \text{ (syst.)}) \times 10^{-5}\). This result is in good agreement with the theoretical expectations from the mechanism of inner bremsstrahlung.

The measurement of the branching ratio of \(K_S \rightarrow \gamma\gamma\) was performed using the NA48 spectrometer [3]. Trigger decisions for \(\gamma\gamma\) decays and the reconstructed longitudinal vertex position were based on signals from the electromagnetic liquid crypton calorimeter. For the event selection, additional informations from the hadron calorimeter and veto counters on the \(K_L\) and \(K_S\) beams were used. In order to determine the \(K_S\) and \(K_L\) fluxes in the beam, the decay \(K_S \rightarrow \pi^0 \pi^0\) was selected with the similar conditions as for the \(K_S \rightarrow \gamma\gamma\) channel. After fiducial cuts and background reducing cuts the total sample of 149 \pm 21 \(K_S \rightarrow \gamma\gamma\) events was selected and the branching ratio of \([2.58 \pm 0.36 \text{ (stat.)} 
\pm 0.22 \text{ (syst.)}) \times 10^{-5}\) was determined. This number is in good agreement with the theoretical prediction of chiral perturbation theory. From this new measurement the ratio of the relative widths of \(K_S \rightarrow \gamma\gamma\) to \(K_L \rightarrow \gamma\gamma\) was determined to be \(2.53 \pm 0.35 \text{ (stat.)} \pm 0.22 \text{ (syst.)}\).

As a side activity at NA48, the large number of hyperons produced at the \(K_S\) target enables precise measurements of hyperon masses and decay channels. In 2000 the NA48 collaboration published a new measurement of the \(M_{\Xi^0} = 1314.82\pm0.6 \text{ (stat.)} \pm 0.20 \text{ (syst.)} \text{ MeV}\), a factor 3 more precise that the present PDG value. Also, branching fractions to some rare decay channels have been determined. The values were \(\text{BR (}\Xi^0 \rightarrow \Lambda \gamma\) = (1.90 \pm 0.34 \text{ (stat.)} \pm 0.19 \text{ (syst.)}) \times 10^{-3}\) and \(\text{BR (}\Xi^0 \rightarrow \Sigma^0 \gamma\) = (3.14 \pm 0.76 \text{ (stat.)} \pm 0.32 \text{ (syst.)}) \times 10^{-3}\).

[2] A. Lai et al., Observation of the decay \(K_S \rightarrow \pi^+ \pi^- e^+ e^-\) to be published on Phys.Lett.B

6.5 Hadron Production in Nuclear Collisions at 158 GeV/c

by H. Bialkowska, B. Boimmska

The NA49 experiment studies hadron production in nuclear collisions in a wide acceptance spectrometer with particle identification. In the year 2000 the main effort concentrated on the study of energy dependence of the \(K/\pi\) ratio, with possible implications for quark gluon plasma formation. On the other hand, an extended study of strangeness production in proton-gluon plasma collisions gave an
indication of multiply strange hyperon enhancement. Both results, in a preliminary stage, were submitted to the Quark Matter Conference. The results published in 2000 concern 2 topics:

1. $\Phi$ meson production in pp, pPb and central PbPb collisions [1]. Fig. 1 shows the observed increase of $\Phi/\pi$ ratio in pPb collisions as a function of the number of slow protons (characterizing the event centrality), and an increase of $\Phi/\pi$ in pp collisions, as a function of charged multiplicity. This result was studied more extensively in [2], where the strange particle increase was observed to scale with the participant density in nuclear collisions.

2. Deuteron production in central Pb – Pb collisions [3]. A coalescence factor B was determined and its transverse mass dependence studied, and discussed in terms of a model with collective expansion of the source created in nuclear collisions [3].


![Graph showing $\Phi/\pi$ ratio as a function of multiplicity for p–p and as a function of centrality measured by the number of slow protons for p–Pb.]

**6.6 Central Pb+Pb Collisions at 158 A GeV/c Studied by $\pi^+\pi^-$ Interferometry**

by K.Karpio and T.Siemiaczuk for WA98 Collaboration

Two-particle correlations have been measured for identified $\pi^+$ from central 158 A GeV Pb+Pb collisions and fitted radii of 7 fm in all dimensions have been obtained [1]. A multi-dimensional study of the radii as a function of $k_T$ is presented, including a full correction for the resolution effects of the apparatus. The cross term $R_{\text{out-long}}$ of the standard fit in the Longitudinally CoMoving System (LCMS) and the $\nu$ parameter of the generalised Yano-Koonin fit are compatible with 0, suggesting that the source undergoes a boost expansion.

The shapes of the correlation functions in $Q_{xy}$ and $Q_z = \sqrt{Q^2_x + Q^2_y + Q^2_z}$ have been analyzed in detail. They are not Gaussian but better represented by exponentials. As a consequence, fitting Gaussians to these correlation functions may produce different radii depending on the acceptance of the experimental setup used for the measurement.


**6.7 Estimate of the Spin-Flip Contribution to the $np \rightarrow pn$ Proces from the Charge Exchange Reaction on the Deuteron**

by T.Siemiaczuk for Dubna-Kosice-Warsaw Collaboration

An estimate of the spin-dependent part of the $np \rightarrow pn$ exchange amplitude has been made on the basis of the $dp \rightarrow p(p)p\pi_n$ data, taken by the 1m hydrogen bubble chamber in a full solid angle arrangement [1]. At the momentum of 1.67 GeV/c per nucleon, as it has been shown, the $np \rightarrow pn$ amplitude is entirely spin-dependent. This result opens up new possibilities for the experiments with polarized deuteron beams and polarized proton target.

6.8 New ALICE TDR Reports
by A.Deloff, K.Karpio, T.Siemiarczuk and G.Wilk for ALICE Collaboration

Two ALICE TDR Reports have been published [1,2], submitted to and accepted by the Large Hadron Collider Committee at CERN.

Time Projection Chamber (TPC) TDR summarizes the design considerations and the specifications for the TPC and outlines the proposed technical solutions. A traditional focus of physics with the TPC will be hadronic physics, where in addition to efficient track reconstruction in the expected high-multiplicity background the emphasis will be on energy-loss resolution and two-track separation.

Time of Flight (TOF) TDR answers to demand of the system with outstanding intrinsic characteristics dictated by the large number of particles produced in the collisions of lead ions.


6.9 Observation of Direct Photons in Central 158 A GeV $^{208}$ Pb-$^{208}$ Pb Collisions
by K.Karpio and T.Siemiarczuk for WA98 Collaboration

A measurement of direct photon production in $^{208}$Pb + $^{208}$Pb collisions at 158 A GeV has been carried out in the CERN-WA98 experiment [1]. The invariant yield of direct photons in central collisions is extracted as a function of transverse momentum in the interval 1.5 < p_T < 4 GeV/c. The results constitute the first observation of direct photons in ultrarelativistic heavy ion collisions.


6.10 $\Delta^+$ Production in 158 A GeV $^{208}$ Pb + $^{208}$ Pb Interactions at the CERN SPS
by K.Karpio and T.Siemiarczuk for WA98 Collaboration

The $\Delta^+$ - resonance production in central 158 AGeV $^{208}$Pb + $^{208}$Pb collisions at the CERN SPS has been studied [1]. The $\Delta^+$ production was estimated from the invariant mass spectrum of $p\pi^+$ - pairs by subtracting a mixed event background. The measured $\Delta^+$ abundance is compared with the results from other experiments at lower energies, and with a model calculation assuming thermal and chemical equilibrium.


6.11 Proton-Proton Data Measured by the Nucleon-Nucleon Collaboration at Saturne II
by T.Siemiarczuk for the Nucleon-Nucleon Collaboration

This report [1] contains pp results obtained during the period 1980-1995 within the Nucleon-Nucleon (NN) program at SATURNE II. The spin-dependent total cross section differences and the pp elastic and quasi-elastic scattering observables were measured up to the 2.8 GeV beam kinetic energy over a large angular range. The measurements were performed with a polarized and unpolarized beams of protons and deuterons and/or with the polarized and unpolarized proton and deuteron targets.

Observables depending on the initial and the recoil particle polarizations were measured for different combinations of polarization directions. The present data allowed to perform the direct reconstruction of pp elastic scattering matrix up to 2.70 GeV and considerably extend the region of unambiguous phase shift analyses. It must be noted that independent pp elastic scattering data, not listed here, were also obtained at SATURNE II by other experiments.

6.12 Three-Pion Interferometry Results from Central Pb+Pb Collisions at 158 A GeV/c
by K.Karpio and T.Siemiarczuk for WA98 Collaboration

Three-particle correlations have been measured for identified π from central 158 A GeV/ Pb+Pb collisions by the WA98 experiment at CERN [1]. A substantial contribution of the genuine three-body correlation has been found as expected for a mainly chaotic and symmetric source.


6.13 The CELSIUS/WASA Experiment
by A.Kupš, P.Marciniewski, A.Nawrot, J.Stepaniak

The WASA (Wide Angle Shower Apparatus) is a detector set-up built by the international collaboration around the internal pellet target at the CELSIUS Storage Ring in Uppsala. The detector was designed to measure both photons and charged particles with a detection coverage close to 4π sr. The momenta of the charged particles are measured in a strong magnetic field provided by the extremely thin-walled superconducting solenoid.

In the year 2000 the whole electromagnetic calorimeter consisted of 1012 CsI(Na) crystals entered into operation, as well as part of Mini Drift Chamber surrounding the target.

The performance of the trigger system was tested, especially the part based on hit cluster multiplicity in the electromagnetic calorimeter. At the end of the year the runs with the hydrogen target and proton beams of energy 400 and 1360 MeV have been performed.

The proposals were prepared for the multiple pion production studies in proton-proton and proton-deuteron collisions. The proposed experiment (C62) has been accepted by the International Program Advisory Committee.

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Fig. 1 Installation of the central part of the WASA set-up.
6.14 Effective Range Function Below Threshold
by A. Deloff

We demonstrate that the kernel of the Lippmann-Schwinger equation, associated with interactions consisting of a sum of the Coulomb plus a short-range nuclear potential, becomes degenerate below threshold. Taking advantage of this fact, we present a simple method of calculating the effective range function for negative energies. This may be useful in practice since the effective range expansion extrapolated to threshold allows us to extract the low-energy scattering parameters: the Coulomb modified scattering length and the effective range.

6.15 Color Instabilities at Ultrarelativistic Heavy-Ion Collisions
by S. Mrówczyński

Partons, mostly gluons, are expected to be copiously produced at the early stage of ultrarelativistic heavy-ion collisions at RHIC and LHC. The parton momentum distribution is strongly anisotropic being elongated along the beam direction. The stability of such a system with respect to the color plasma modes has been discussed in the series of our papers [1-5]. The gluon polarization tensor which enters the dispersion equation has been computed within the semiclassical kinetic [1-3] and Hard Loop diagrammatic [5] theories. The two approaches are shown to provide exactly the same result. The dispersion equation has been solved and the existence of the unstable mode, which exponentially grows in time, has been demonstrated. The mode is known in the plasma physics as the Weibel or filamentation instability. The characteristic time of the instability development has been estimated and the possible role of the phenomenon in the dynamics of heavy-ion collisions at RHIC and LHC has been discussed. It has been shown that the instability development leads, in particular, to the collective transverse flow. A method of the instability detection [6] has been proposed. The method demands the azimuthal fluctuation analysis on the event-by-event basis.


6.16 Participation in the CMS Experiment at the LHC Accelerator at CERN
by R. Gokieli, M. Górski, G. Wrochna, P. Zalewski

The activity in the preparation of the CMS experiment is a continuation of the studies in which we took part in previous years.

We continued the research on the behavior of the prototypes of the Resistive Plate Chambers, which are used in the muon trigger. A prototype was tested at CERN at the Gamma Irradiation Facility (GIF) with the muon beam in the presence of high radiation flux from a cesium gamma source. One of the interesting properties of the chamber is its ability to respond with low number of strips being fired. The percentage of high strips multiplicity events together with the chamber efficiency is shown in the figure. It may be seen that there is a region of about 1 kV width where the chamber is already fully efficient, while the percentage of the streamer discharges remains low.

The results from the irradiation are currently being analyzed and will be reported.

One of the main efforts during the year 2000 was the preparation of the Technical Design Report of the CMS trigger and Data Acquisition System which was published early in year 2001. The Warsaw group participated in the sections concerned with the muon part of the triggering system. We dealt mostly with the questions of the trigger performance and the system of transmitting the data from the RPCs to the electronics.

![Fig. 1. The efficiency and streamers fraction for the RPC prototype as a function of the voltage.](image)
The questions concerning the influence of the chamber noise on the trigger efficiency and rate were addressed. During this year a second prototype of the integrated circuit serving as the main building block of the muon trigger was produced in collaboration with Warsaw Technical University. It is being currently tested.

We continued the studies on the visibility of a possible signals of new physics including supersymmetry and hypothetical higher spatial dimensions. Our results on Gauge Mediated Supersymmetry Breaking were presented by several CMS speakers since last year. We initiated work on the implementation of the high level triggers permitting the selection of interesting events (M.Sc. thesis by L.Go Giles under G.Wrochna supervision).

The participation in the future large experiments in the high energy physics domain requires a new approach to the problems of the data analysis. The data processing will be organized in a hierarchical way, with large regional centers and smaller ones spread all over the world. Our lab starts to participate in the DataGrid project, coordinated by the CERN laboratory. We plan, together with computing centers from Cracow and other cities to form a distributed high-performance computing network with high speed data transmission and capabilities.

6.17 The LHC-b Experiment at CERN
by M.Adamus, A.Nawrot and M.Szczekowski

LHC-b is a hadron collider experiment in preparation at CERN, which plans to start taking data as soon as the LHC machine becomes operational. The main goal of the LHC-b experiment is to search for new physics through precise tests of the heavy-flavour sector of the Standard Model. The most stringent test is expected to be provided by a combination of precise measurements of CP violation in the B meson system. The unitarity of the Cabibbo-Kobayashi-Maskawa matrix implies relations between matrix elements that can be graphically represented as so-called unitarity triangles. The LHC-b experiment intends to measure all the parameters of the two triangles relevant for the B-meson system with a very good precision.

![Fig. 1 The LHCb detector seen from above (cut in the bending plane). The tracking chambers are labeled T1 - T11, the muon chambers are labeled M1 - M5.](image)

To fully exploit the high forward $b\bar{b}$ production cross-section at LHC energies, the LHC-b experiment has been designed as a single-arm, forward spectrometer running in collider mode (Fig.1). Important characteristics of the experiment are:

- An excellent hadronic particle identification over a large momentum range (from 1 to 150 GeV/c) provided by three Ring Imaging Cherenkov (RICH) detectors. This is essential both for the exclusive reconstruction of hadronic $B$ decay modes and to tag the neutral $B$ hadrons' initial flavour.
- In addition to high-$p_t$ lepton triggers, there will be a high-$p_t$ hadron trigger. This trigger, as well as the low thresholds for the lepton triggers, ensure a high trigger efficiency also for purely hadronic $B$ decays.
- A good proper time resolution, necessary to resolve the fast $B_s^0 \rightarrow B^0 \bar{B}^0$ oscillations, is provided...
by the vertex detector. This device will provide a 40 μm resolution on the interaction point along the beam axis.

- A good mass resolution provided by the tracking system. Because of the high particle density close to the beam axis, the tracking system is split into outer and inner subsystems at a radius of approximately 0.5 m. The Outer Tracker will consist of about 130 000 drift chambers with straw-tube geometry.

Starting from spring 1999, the Warsaw group is involved in the construction of the Outer Tracker system, in particular in the design, tests and construction of the alignment system for these huge (7m x 6m) drift chambers.

One of the possible solutions for the alignment system is the CCD/RASNIK - a precise three-point alignment monitor developed at NIKHEF (Fig. 2). This system consists of three components: an illuminated coded mask, a lens and a CCD camera with readout electronics. The lens projects a part of the mask onto the CCD. Commercial video electronics captures the CCD video frame and stores the digitized CCD image as a binary file. This file is used to determine the location of the lens center with respect to the optical axis as defined by the centers of the CCD and the mask.

In Warsaw laboratory the three components (CCD camera, lens and mask) are mounted on a common optical bench via mechanisms which allow automatic settings of the position of the lens, the camera and the mask. The results of the tests on the stability, resolution and linearity of the system are presented in ref. [1]. A precision of 2 – 3 μm is obtained for X and Y coordinates, perpendicular to the test bench, over a distance of 5.6 m (Fig. 3 and 4). The effects of temperature gradients were also investigated. All the results show that the system is well adapted to the LHCb Outer Tracker needs [1].

![Fig. 2 Principle of operation of the RASNIK alignment monitoring system.](image)

![Fig. 3 Distribution of the X coordinate measured by the RASNIK system with no mechanical changes of the set-up. The stable period of the test bench operation was chosen with appropriate time cut. The r.m.s. value of the distribution is about 3 μm.](image)
A design of an optical alignment monitoring system for the Outer Tracker stations in LHCb experiment was analysed using the error propagation and geometrical reconstruction software SIMULGEO. The optimum solution for the monitoring system was chosen by comparing results obtained for various configurations of the system [2]. The proposed configuration of the full alignment monitoring system for the Outer Tracker detector is shown in Fig. 5 [3].

Two electronics engineers from the 3rd department of the Institute are involved in the design and tests of the Readout Supervisor, the main control unit for the Data Acquisition system of the LHC-b experiment [4].

Fig. 4 The same as in Fig. 3 but for the Y coordinate. The r.m.s value of the distribution is about 2 μm.

Fig. 5 The design of the alignment system for the Outer Tracker stations of chambers (T3 - T10) with 58 RASNIK monitor lines. The thick squares represent the frames of the stations. All the cameras are placed on the T6 station frame. The masks are placed on the T3 and T10 stations frames. The lenses are placed on all the other stations frames. Each thin line connecting the masks and the cameras represent two (for lenses on T4 and T5) or three (for lenses on T7, T8 and T9) RASNIK monitors.

6.18 The COMPASS Experiment at CERN

COMPASS (Common Muon and Proton Apparatus for Structure and Spectroscopy) [1] is the new fixed-target experiment planned to run on the SPS accelerator at CERN. It will be located in the North Area of SPS, in a hall inherited from the SMC Experiment. COMPASS is the state-of-the-art spectrometer with excellent particle identification and calorimetry, capable of standing beam intensities of up to $2 \times 10^8$ projectiles/spill. These very large intensities do require completely new fast readout electronics, that has been designed and successfully tested. One of the most distinguishing elements of the COMPASS setup is a polarized target, consisting of two cylindrical cells, each 60 cm long and with a diameter of 3 cm. It is the biggest polarized target ever used. Both target's cells will be filled with ammonia (as a proton target) or $^6\text{LiD}$ (as a deuteron one), and at the same time will be polarized in opposite directions [1].

Two physical programs are foreseen for COMPASS, with a muon beam and with hadron beams [1]. The main goal of the muon program is to determine $\Delta G/G$ – ratio of polarized and unpolarised gluon distribution functions of the nucleon; the former one parametrizes contribution of the gluons to the spin of the nucleon. $\Delta G/G$ will be determined from the measurements of spin asymmetries of the cross sections for: (1) production of open charm mesons, (2) production of pairs of oppositely charged hadrons with high $p_T$, (3) diffractive production of $p \otimes$ mesons. Expected accuracies for $\Delta G/G$ extracted from the mentioned measurements are in a range 0.05 – 0.10. Other goals of the muon program are to investigate quark spin distributions for different flavours, and to determine $g_1$ and $h_1$ – spin-dependent structure functions of the nucleon.

As to the hadron program, its three main issues are: (1) studies of charmed baryons (large statistics of which will be available with COMPASS), (2) spectroscopy of light-quark systems, with searches for QCD exotic states (i.e. glueballs) and (3) Primakoff reactions.

During year 2000 large efforts were done concerning hardware part of the setup. Substantial amount of detectors of the initial setup were positioned inside experimental hall and equipped (fully or partially) with electronics. Installations of other detectors also started. However, the most important that happened was the test run with the muon beam.

Our Warsaw Team of COMPASS consists of two groups: one from SINS and another from Warsaw University of Technology. The SINS's group is mainly engaged in activities concerning preparations, upgrades and tests of the off-line software for the charged tracks reconstruction. The main outcome of the group in year 2000 was completion of preparation and tests of RECON – one of two main algorithms for track reconstruction prepared for COMPASS. We also pursued Monte Carlo Studies. Reports on these activities have been presented at the off-line group meetings at CERN, at the main COMPASS meetings, and results have appeared as COMPASS notes [2,3]. It is worthwhile to mention that our SINS's workshop has accomplished a project of producing all active components for scintillating hodoscopes for the muon trigger. The group from WUT (engaged in hardware as well as in software) has designed new prototypes and has been building working modules of front-end electronics for large positioning detectors, the straw chambers.

At the moment the completion of the initial COMPASS setup is progressing. First physical run taking data is expected to start in summer of 2001.

[1] G.Baum et al., CERN/SPSLC/96-14,
SPSLC/P297, 1 March 1996
[2] R.Windmolders, K.Kowalik, K.Kurek,
A.Mielech, E.Rondio, COMPASS Note 2000-11

6.19 Experiment PP2PP at RHIC
by A.Sandacz

The Relativistic Heavy Ion Collider RHIC at Brookhaven, operating with polarized proton beams and luminosity up to $10^{34} \text{cm}^{-2}\text{s}^{-1}$, opens up an entirely new energy range for the study of $pp$ collisions as a part of the RHIC Spin program [1]. The experiment PP2PP [2] at RHIC will study elastic proton-proton scattering. Having polarized proton beams offers the exciting opportunity for comprehensive, high-luminosity $pp$ elastic scattering experiment covering a wide, mostly unexplored domain in energy and momentum transfer:

$50 < \sqrt{s} < 500$ GeV and $4 \cdot 10^4 < l < 1.3$ GeV$^2$, within a single experiment.

The accurate measurement of the elastic differential cross section at small $l$, the total cross section, the ratio of the real to imaginary parts of the forward scattering amplitude, and the slope of the forward diffraction peak as a function of energy will elucidate features of the pomeron, which remains a mystery forty years after it was proposed. The accurate data in the region of the interference dip at
|l| \equiv 1 \text{ GeV}^2 \) will provide the opportunity for a direct comparison with existing data from \( pp \) colliders, which cover some of the same energies, thus probing the interference of the three-gluon exchange with several other exchange contributions, thought to be responsible for the observed dip. The emerging picture of diffraction in the framework of QCD should account for the spin phenomena, which do not appear to vanish at the largest energies where the data exist. This demands the studies of the spin effects in elastic \( pp \) scattering at the highest available energies.

Our group together with a group from IFJ Kraków have joined the PP2PP collaboration in August 2000. Presently the main responsibilities of the Polish members of PP2PP are in the offline software: development of algorithms for the simulation of the propagation of scattered protons in the accelerator rings, simulation of the response of the Roman pot detectors, development of the algorithms for the track and event reconstruction, simulation of events, and studies of the apparatus effects, the reconstruction efficiency and of the purity of the sample of elastic events.

The experiment PP2PP is scheduled for a technical run in late summer of 2001. The first data taking is expected in 2002.


6.20 Preparation for Long Base Line Neutrino Experiments
by E. Rondio, J. Stepiäñik, M. Szeptycka, M. Szleper

Secrets of the mysterious neutrinos are one of the most exciting questions recently appearing in physics. The interpretation of the observations from Super Kamiokande experiment [1] as neutrino oscillations requires massive neutrinos. The fact that neutrinos acquire mass is of great importance for the theory of fundamental interactions between basic constituents of matter. More detailed studies of this phenomenon and a precise determination of the neutrino mixing parameters are planned with neutrino beams pointing to far away detectors (Long Base Line experiments). In 1999 several groups in Poland started to prepare for the active participation in one of the European projects on the neutrino beam [2] from CERN to Gran Sasso, which is scheduled to start in 2005. One of the experiments planned there, ICARUS/ICANOE [3], will use very large Time Projection Chambers (TPCs) filled with liquid argon. The development of this techinc started several years ago in Italy [4]. Groups from Poland (Katowice, Krakow, Warsaw, Wroclaw) decided to form single unified group and join this project. From our Institute participants from Departments of Nuclear Spectroscopy and Technique and Nuclear Electronics are also involved. The request of Polish group for joining the ICARUS collaboration was accepted in summer 2000.

ICARUS is the largest TPC filled with liquid argon ever built. Therefore it should be carefully and systematically tested before it is put in operation in the experimental underground environment (Gran Sasso). Tests with cosmic muons have two aims - first to show that ICARUS sees and is able to reconstruct the very long tracks (of the order of 15-20m), second to check whether the efficiency of track registration is uniform over all ICARUS volume. By the end of year 2000 the first 300 ton TPC was mounted in Pavia.

The main field of activity in Warsaw was connected with work on the external trigger on cosmic muons in collaboration with the Italian group from l'Aquila University and the INFN Gran Sasso Laboratory. Any detectors of charged particles can be used to build a cosmic muons trigger. The scintillators were selected due to high efficiency and simplicity. The geometry of the triggering counters was studied with a simple simulation. Two trigger configurations were defined: for horizontal muons scintillator planes will be placed on short vertical walls of the detector (as for the 10m\(^2\) module) and the other configuration will consist of two pairs of (0.3 x 2.0)m\(^2\) counters, where two are used in coincidence and other two are used as veto. The second configuration was studied, prepared and mounted by the Warsaw group. Counters were assembled and tested in Gran Sasso. The results of this work is presented as an internal note of ICARUS collaboration [5]. Trigger rate of about 0.9 Hz obtained in this test was acceptable and consistent with simulation. The installation of triggering counters on a support above ICARUS was done at the end of year 2000.

After installation of the trigger the Polish group will take part in the test data taking to get familiar with the TPC operation and gain experience with online software. With such experience analysis would then be continued at the home institutions. This is very important for efficient participation in the preparation for the full size experiment, where the Polish group would like to contribute to the development of the simulation and reconstruction software as well as to the detector construction and tests.


LIST OF PUBLICATIONS

SEARCH FOR HEAVY STABLE AND LONG-LIVED PARTICLES IN $e^+e^-$ COLLISIONS AT $\sqrt{s} = 189$ GeV

HADRONIZATION PROPERTIES OF $b$ QUARKS COMPARED TO LIGHT QUARKS IN $e^+e^-$ TO $q\bar{q}$ ANTI-$q$ FROM 183 GeV TO 200 GeV

DETERMINATION OF $V_{ub}/V_{cb}$ WITH DELPHI AT LEP

$W$ PAIR PRODUCTION CROSS-SECTION AND $W$ BRANCHING FRACTIONS IN $e^+e^-$ INTERACTIONS AT 189 GeV

INCLUSIVE $\Sigma$ AND $\Lambda^{(1600)}$ PRODUCTION IN HADRONS AT 189 GeV

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$\Delta^+\bar{\Delta}^+$ PRODUCTION IN 158 AGeV $^{208}$Pb + $^{208}$Pb INTERACTIONS AT THE CERN SPS
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MEASUREMENT OF INCLUSIVE D*+ PHOTOPRODUCTION AT HERA
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MEASUREMENT OF THE $E_2$, JETQ2 DEPENDENCE OF FORWARD JET PRODUCTION AT HERA
J. Breitweg, M. Adamus, et al.

MEASUREMENT OF INCLUSIVE PROMPT PHOTON PHOTOPRODUCTION AT HERA
J. Breitweg, M. Adamus, et al.

MEASUREMENT OF THE PROTON STRUCTURE FUNCTION F2 AT VERY LOW Q2 AT HERA
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SEARCH FOR THE SGOLDSTINO AT $\sqrt{s}$ FROM 189 TO 202 GeV
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LIMITS ON THE MASSES OF SUPERSYMMETRIC PARTICLES AT $\sqrt{s} = 189$ GeV

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SEARCH FOR SUSY WITH R-PARITY VIOLATING LL' COUPLINGS AT $\sqrt{s} = 189$ GeV

MEASUREMENT AND INTERPRETATION OF FERMION-PAIR PRODUCTION AT LEP ENERGIES OF 183 AND 189 GeV

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UPDATE OF THE SEARCH FOR CHARGINOS NEARLY MASS-DEGENERATE WITH THE LIGHTEST NEUTRALINO

A NEW MEASUREMENT OF THE BRANCHING RATIO OF $K_s \rightarrow \gamma\gamma$

DEUTERON PRODUCTION IN CENTRAL Pb+Pb COLLISIONS AT 158 AGeV
S. Afanasiev, B. Boimska, H. Bialkowska, et al.

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S. Afanasiev, B. Boimska, H. Bialkowska, et al.

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PHOTON EVENTS WITH MISSING ENERGY AT V₁ = 183 TO 189 GeV

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CENTRAL Pb + Pb COLLISIONS AT 158 AGeV STUDIED BY \pi\pi INTERFEROMETRY
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SCALING OF PARTICLE AND TRANSVERSE ENERGY PRODUCTION IN Pb + Pb COLLISIONS AT 158 AGeV
M. M. Aggarwal, K. Karpio, T. Siemiarczuk, et al.

CHARGED AND IDENTIFIED PARTICLES IN THE HADRONIC DECAYS OF W BOSONS AND IN e⁺e⁻ \rightarrow q \text{ anti} q FROM 130 GeV TO 200 GeV

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SEARCH FOR RESONANCES DECAYING TO e⁺ jet IN e⁺p INTERACTIONS AT HERA
J. Breitweg, M. Adamus, et al.

MEASUREMENT OF DIFFRACTIVE PHOTOPRODUCTION OF VECTOR MESONS AT LARGE MOMENTUM TRANSFER AT HERA
J. Breitweg, M. Adamus, et al.
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MESONS AT HERA
J.Breitweg, M.Adamus, et al.

MEASUREMENT OF $D^{*-}$ PRODUCTION AND THE CHARM CONTRIBUTION TO $F_2$ IN DEEP INELASTIC SCATTERING
AT HERA
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ANGULAR AND CURRENT-TARGET CORRELATIONS IN DEEP INELASTIC SCATTERING AT HERA
J.Breitweg, M.Adamus, et al.

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AT HERA
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SEARCH FOR CONTACT INTERACTIONS IN DEEP INELASTIC $e^+p \rightarrow e^+x$ SCATTERING AT HERA
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MEASUREMENT OF OPEN BEAUTY PRODUCTION IN PHOTOPRODUCTION AT HERA
J.Breitweg, M.Adamus, et al.

THREE-PION INTERFEROMETRY RESULTS FROM CENTRAL $Pb + Pb$ COLLISIONS AT 158 $A GeV/c$
M.M.Aggarwal, K.Karpio, T.Siemiarczuk, et al.

TIME EVOLUTION OF NEAR MEMBRANE LAYERS
K.Dworecki, S.Mrózwnyński, et al.,

OBSERVATION OF DIRECT PHOTONS IN CENTRAL 158 $A GeV$ $208Pb + 208Pb$ COLLISIONS
M.M.Aggarwal, K.Karpio, T.Siemiarczuk, et al.

$\eta^+$ AND $K^0_s$ ZERO-ENERGY SCATTERING: A FADDEEV APPROACH
A. Deloff

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HARD LOOP APPROACH TO ANISOTROPIC SYSTEMS
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A.Deloff

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S.Mrózwnyński

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H.Białońska

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T.Kosztołowicz and S.Mrózwnyński
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DIFFERENTIAL CROSS SECTIONS OF THE pp → ppπ REACTION FROM 310 to 425 MeV

THE WASA DETECTOR AT CELSIUS

Φ- MEASURE OF EVENT-BY-EVENT FLUCTUATIONS
S. Mrówecki

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INTERNAL NOTES AND REPORTS

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H. Białkowska
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A. Sandacz
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REMARKS ON VECTOR MESON PRODUCTION AT eRHIC
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SPIN ASYMMETRIES IN EXCLUSIVE VECTOR MESON PRODUCTION
A. Sandacz

STUDIES OF COLOUR TRANSPARENCY IN LEPTOPRODUCTION
A. Sandacz

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E. Rondio

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S. Mrówczyński
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S. Mrówczyński
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\( \phi \) - MEASURE OF EVENT-BY-EVENT FLUCTUATIONS
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J. Nassalski

EXCLUSIVE MEASUREMENT OF pp -> p\pipi^+\pi^- AT CELSIUS
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NEW MEASUREMENT OF e' / e BY NA48
W. Wislicki
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LECTURES, COURSES AND EXTERNAL SEMINARS

Rare decays at NA48: results and prospects
M. Szleper, Northwestern University, Nov. 27, 2000

Multiple charged pion production at energies 1100-1360 MeV using the WASA Detector
J. Stepniak
Open Session of the Program Advisory Committee Meeting, the Svedberg Laboratory, Uppsala, Sweden, May 5-6, 2000

Studies of η meson Dalitz decays
J. Stepniak
WASA Collaboration Meeting, Uppsala University, Sweden, March 13-14, 2000

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INTERNAL SEMINARS

Experiments in Relativistic Heavy Ion Physics
H. Białkowska, UW, Warsaw, May 18, 2000

Particle Production as a Function of Centrality in Relativistic Ion Collisions (Na49)
H. Białkowska, IFJ, Kraków, Jan. 18, 2000

Physics of Relativistic Heavy Ion Collisions
H. Białkowska, UW, Warsaw, March 10, 2000

Circumstantial Evidence for Quark Gluon Plasma
H. Białkowska, UW, Warsaw, March 7, 2000

Was a Quark Gluon Plasma Discovered?
H. Białkowska, UW, Warsaw, April 7, 2000

Physics at RIHC: Collisions of Ions-Hadrons-Electrons?
H. Białkowska, UW, May 12, 2000

Production of Multiple Strangeness in Heavy Ion Collisions
H. Białkowska, IFJ, Kraków, Oct. 25, 2000

Production of Multiple Strangeness in Heavy Ion Collisions
H. Białkowska, UW, Warsaw, Oct. 20, 2000

What is Higgs Mechanism Worth?
P. Zalewski, UW, Wilna, May 27, 2000

Direct CP violation in K^0 decays
W. Wiślicki, UW, Warsaw, March 24, 2000

Playing with Physics
P. Zalewski, UW, Warsaw, Science Festival, Sept. 16-24, 2000

Does LEP2 see Higgs?
P. Zalewski, UW, Warsaw, Oct. 6, 2000

What new Physics Will Discover LHC?
P. Zalewski, UW, Warsaw, Nov. 17, 2000

Study of the CP and T Symmetry Breaking in K^+ Decays (first part)

For what do we need the COMPASS?
J. Nassalski, UW, Warsaw, March 27, 2000
Study of the CP and T Symmetry Breaking in K^0 Decays (second part)
M. Szleper, UW, Warsaw, Jan. 21, 2000

Experimental Studies of Nucleon Structure
E. Rondio, Institute of Physics, Pedagogical University, March 15, 2000

Investigation of the Spin Effects in the Nucleon
E. Rondio, UG, Gdansk, June 2, 2000

Long Base Line Neutrino Experiments-Determination of Neutrino Oscillation Parameters
E. Rondio, UW, Warsaw, May 3, 2000

Physics at RHIC: Collisions of Ion-Hadrons-Electrons?
A. Sandacz, UW, Warsaw, May 12, 2000

Long Base Neutrino Experiments
M. Szeptycka, UW, Warsaw, Apr. 14, 2000

Neutrino Factories
M. Szeptycka, UW, Warsaw, Nov. 10, 2000

The RPC Chambers in the Muon Trigger of the CMS Experiment at LHC
M. Gorski, UW, Warsaw, Oct. 20, 2000

3 Nobels in 10 minutes-Collaboration of particle physicists with electronic engineers
G. Wrochna, Seminarium PERG/IEEE, UW, Warsaw, Jan. 2000

Event selection in CMS Experiment

CP violation in decays of beauty particles in LHCb experiment (first part)
M. Szczekowski, UW, Warsaw, Oct. 13, 2000

CP violation in decays of beauty particles in LHCb experiment (second part)
M. Szczekowski, UW, Warsaw, Oct. 20, 2000

CP violation in decays of beauty particles in LHCb experiment (third part)
M. Szczekowski, UW, Warsaw, Nov. 3, 2000

SCIENCE POPULARIZATION TALKS AND ARTICLES

How the Nucleon is Arranged
E. Rondio, Science Festival, Warsaw, Sept. 23-24, 2000

How Physicists Look Inside the Nucleon
E. Rondio, Exposition “How energy becomes matter”, Cracow, Nov. 9, 2000

S. Mróweczyński
12 articles in weekly „Polityka”

P. Zalewski
13 articles in „Delta”

G. Wrochna
1 article in „Delta”

Will LEP Discover Higgs?
P. Zalewski
Polsat 2, Sept. 2000

Events of the XX Century-the Atomic Bomb
P. Zalewski
Radio, Pr., I PR, Nov. 2000

New Results in the Elementary Particle Physics, Especially Last Results from LEP
M. Gorski
The POLSAT TV Network, Sept. 18, 2000

H. Bielikowska
1 article in „Świat Nauki”, May 2000

H. Bielikowska
1 article “Wiedza i Życie”, Apr. 2000
H. Białkowska
1 article „Postępy Techniki Jądrowej” 43, 34, 2000

R. Sosnowski
1 article „Gazeta Wyborcza”, Sept. 13, 2000

W. Wiślicki
1 article „Wszechświat” 101, (2000) 8

R. Sosnowski
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R. Sosnowski
Radio, Pr. III, Aug. 2, 2000

R. Sosnowski
Radio Szczecin, Nov. 28, 2000

J. Nassalski
TVP1, Nov. 28, 2000

H. Białkowska
TVP, Panorama, Feb. 2000

Compact Muon Solenoid-experiment challenge
G. Wrochna
Lecture for students at CERN, Geneva, May 2000

Detection of elementary particles
G. Wrochna
Summer course for high school teachers, UW, Warsaw, July 2000

Physics methods of dating in human prehistory research
G. Wrochna
Lecture for fellows of National Children Found, Świdnica, Poland, May 2000

How to discover new particle?
G. Wrochna
Science Festival, UW, Warsaw, Sept. 2000

Particle physics for everyone
G. Wrochna
WWW site: http://info.fuw.edu.pl/HEPcms/edu/edu.htm
PERSONNEL

Research scientists
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Helena Białkowska, Assoc.Prof. 
Andrzej Deloff, Assoc.Prof. 
Tomasz Gadaj, MSc. ¼ (on leave till June 30) 
Ryszard Gokieli, Dr. ¼ (on leave) 
Maciej Górski, Dr. 
Andrzej Filipkowski, Dr. † 
Krzysztof Karpio, MSc. 
Andrzej Kupść, Dr. ¼ (on leave) 
Pawel Marciniewski, MSc. ¼ (on leave till Dec. 31) 
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Overview

The Department of Cosmic Ray Physics in Łódź is involved in basic research in the area of high-energy physics and cosmic ray physics related to:

- Experimental and phenomenological studies of Extensive Air Showers induced by cosmic ray particles.
- Studies of ultra-high energy (above \(10^{19}\) eV) cosmic rays: determination of energy and primary particle mass composition.
- Studies of asymptotic properties of hadronic interactions based on the analysis of cosmic ray propagation through the atmosphere.
- Studies of mass composition of cosmic rays in the energy range \(10^{15} - 10^{17}\) eV.
- Registration of cosmic ray intensity variation correlated with solar activity.

Theoretical and experimental studies of Extensive Air Shower properties are performed mostly based on the results obtained by the Łódź Extensive Air Shower Array. We have noticed unexplainable delayed signals registered about 500-900 microseconds after the main EAS pulse. We prepared hardware for further experimental study of this effect.

In September we have started registration of 5GeV muon flux with the underground muon telescope. We registered 3 decreases of muon intensity correlated with Forbush decreases registered at lower energies. Variations of primary cosmic ray of energies up to about 100GeV were responsible for our registrations. These set the upper limits for geometrical size of geomagnetic disturbances in interplanetary space.

In construction and data interpretation of cosmic ray experiments, the Łódź group collaborates with many foreign institutes and laboratories: Forschungszentrum in Karlsruhe (Germany), Collège de France, Institute for Nuclear Studies of the Russian Academy of Sciences and Uppsala University (Sweden).

We have organised (together with the Physics Department of the University of Łódź) the 17th European Cosmic Ray Symposium (24-28 July 2000) in which about 150 physicists participated (about 100 from abroad).
7.1 Łódź Extensive Air Shower Array
by J.Gawin, J.Karczmarczyk, S.Pachała, J.Swarzynski, J.Szabelski

The Łódź hodoscopic array has been registering extensive air showers (EAS) for most of the year. We have continued registrations of signals delayed by several hundreds microseconds relative to the EAS front. Statistically important information has been obtained from the registering array in the CAMAC crate. The information concerns the signals from Geiger – Müller counters. We observe the effect of registrations of signals delayed by 500-800 microseconds after EAS front (maximum for around 600 microseconds) that significantly outnumber the predicted background. The effect occurs only for big showers (it is not observed in most of registered events). For one month we have also carried registrations of delayed signals from scintillation detectors. Digital oscilloscope TDS3032 steered from PC computer has been used for registration of signals from two scintillation counters for times between 600 µs before EAS and 1200 µs after EAS. We have found events of EAS registration with short series of signals occurring at 500 – 700 µs after the coincidence signal. Amplitudes of these signals are smaller than typical signals coming from single muons. We are not able to explain this effect. We plan further experimental work in this direction. Similar effects have been observed by other EAS arrays: Tien-Shan experiment, array Karpet at Baksan and EAS detector in Mexico. Three possible scenarios are discussed: a) an artificial effect connected with gas counters, b) registration of neutrons produced in the interactions of EAS hadrons, c) hypothetical generation of non-interacting EAS component.

Results of this work have been presented at the 26th Russian Conference on Cosmic Rays in Dubna and at the 17th European Cosmic Ray Symposium in Łódź. They will also be published in Izviestia of the Russian Academy of Sciences.

7.2 Investigation of the Extensive Air Showers – from KASCADE to KASCADE GRANDE
by J.Zabierowski

The Extensive Air Showers (EAS) of cosmic rays have been investigated by means of KASCADE detection facility, located in Forschungszentrum Karlsruhe in Germany, since 1996. Up to now over 370 millions of EAS events have been recorded and preprocessed and the data taking is going on at the rate of 4 events per second. The unique feature of KASCADE is that it can measure with high precision all three components of the air shower, and the muonic component even with four different thresholds. This allows for many multiparameter analyses of the data, with the main goal to establish the energy spectrum and the mass composition of primary cosmic particles in the energy range 5x10^{14} - 5x10^{16} eV. The variety of our methods of data interpretation together with the first results has been reported at many international conferences (recent see [1,2]. At the same time a thorough analysis of the experimental data based on large data samples takes place. Just recently the lateral distributions of electrons, muons and hadrons in the showers measured by KASCADE have been published [3].

During last year a new detecting facility, namely the Large Muon Tracking detector, using streamer tubes as detecting devices, was finally put into operation [4]. In addition to the possibility of having another tool for muon lateral distribution investigation at yet another threshold (0.8 GeV), it allows for determination of the mean muon production height - another primary mass sensitive parameter.

In 2000 the extension of KASCADE experiment by enlarging electron detection area to 0.5 km² has started. In collaboration with the EAS-TOP team from Italy the scintillator detectors from their experiment (which was closed in the spring last year) will allow extending the precise EAS measurements up to 5x10^{17} eV on the primary energy scale. Thus, the new experiment - named KASCADE GRANDE - will supply data on the primary mass composition and hadronic interaction parameters closer to the threshold of the future experiment investigating EAS of the highest energies (> 10^{19}) - Pierre Auger Observatory.

7.3 Energy Estimation for Giant Air Showers
by J. Gawin, I. Kurp, B. Szabelska, J. Szabelski and T. Wibig

We continued our collaboration with Prof. J. N. Capdevielle and his group from Collège de France on the problem of an energy estimation for the biggest registered showers (for energies greater than $10^{19}$ eV/particle). We have proposed a new function describing lateral distribution of different EAS components. The function gives much better fits to the simulated lateral distributions of particles in EAS of energies exceeding $10^{20}$ eV than functions currently used for experimental data interpretation.

New localisations and energy estimations of showers from published catalogues of the biggest registered events are often significantly different from the original ones. In many cases they give much lower values of estimated energy (shower sizes or charged particle densities at 600 m from the EAS core) than this obtained by the authors of experiment.

Our results are important for future experiments like AUGER.

Results of this work were presented during four conferences in 2000: the 26th Russian Cosmic Ray Conference in Dubna, the 17th European Cosmic Ray Symposium in Łódź, the 11th ISVHECRI in Brasil and the Chacaltaya meeting in Bolivia.

7.4 Cosmic Rays of the Highest Energies
by T. Wibig

Investigations of ultra-high energy cosmic rays have been continued in the collaboration with Prof. A. W. Wolfendale from the University of Durham, England. In particular the hypothesis of the existence of heavy nuclei at energies above $10^{19}$ eV has been examined.

Studies of the anisotropy of observed extensive air shower directions support rather substantially the idea of separating the Galactic and extra-Galactic component of cosmic ray flux. These results were presented by Prof. Wolfendale on XVII European Cosmic Ray Symposium in his invited lecture "Prospects for extra-Galactic particles from exotic processes", which will be published in the Journal of Physics. The work is continued and a following paper is submitted for publication in the same journal.

Following this general line, detailed calculations concerning particle transport in intergalactic space are in progress, what should effect next publication in the year 2001.

7.5 High Energy Interactions around the Knee
by I. Kurp and T. Wibig

Studies and modelling of strong interactions at very high energies resulted in the year 2000 the invited talk in XVII European Cosmic Ray Symposium "High Energy Interactions at the knee" given by T. Wibig which will be published in Journal of Physics. During the Łódź ECRS also another three poster contributions were presented: "KNO scaling violation in the geometrical model of high energy interactions", "Proton-proton cross section in the geometrical model of high energy interactions", and "FRITIOF in CORSIKA". In the first the new interpretation of breaking of the multiplicity distribution scaling seen at highest SPS and Tevatron energies has been given. In the second we have shown the simple geometrical parameterisation of data on cross sections at 1800 GeV measured by E-811 experiment at Fermilab. The achieved agreement with new data gives us a degree of certainty in an eventual extrapolation of accelerator results to the cosmic ray energy domain. A third contribution presented results of Monte Carlo extensive air shower simulations with the well known and of widely use high-energy interaction generator FRITIOF.

7.6 Mass Composition of Primary Cosmic Rays at the Knee Region: Muon Group Analysis
by J. Szabelski

Registered muon groups of energies above several tens of GeV are still very promising experimental material which can provide significant information about mass composition of primary cosmic rays at the so called knee in the EAS size spectrum. We have started joint work with the Russian physicists
concentrated on elaborating a more precise method of finding the number of muons registered in the Baksan telescope. The telescope is able to register muons of energies above 200 GeV. From some chosen directions energies of registered muons exceed 1000 GeV. Simulations of muon group registrations performed with the program GEANT will serve as a basis for the new approach.

### 7.7 CELSIUS/WASA Collaboration - Closer to Meson Rare Decays Investigation
by J.Zabierowski

The year 2000 was devoted to finishing the installations and intensive tests with the beam of different WASA detector components and pellet target system [1,2]. In particular, the Light Pulser Monitoring System, designed and built in Lodz, has been installed in Uppsala and preliminarily adjusted. It allows now to speed up final tests and adjustments of the scintillation counters in the experimental setup.

Collaboration got approved by TSL PAC as well as several proposals concerning production of pions in different reactions (pp, pd, dd) and energy ranges, meant, apart from interesting physics, as final tests of the apparatus. In parallel, the data obtained with the previous PROMICE/WASA experimental setup were analyzed and the results published in journals and on conferences [3-6].

### 7.8 16 Bits ADC Block
by J.Karczmarczyk

It often happens in EAS registrations that the same scintillation counter is hit by a single particle in one event and by 1000 particles in another event. The number of hitting particles in both cases is important for the interpretation of the physical event. Up to now we have used ADC block with the 1024 channels resolution. We have designed the block ADC with 65000 channels. The constructed prototype of CAMAC block enables “simultaneous” converting of 8 signals.

### 7.9 Cosmic Ray Muons Correlated with Solar Activity
by I.Kurp, J.Karczmarczyk, P.Plucinski, J.Swarynski, B.Szabelska and J.Szabelski

The underground muon telescope has started to register the flux of muons with energies above 5 GeV in September 2000. The aim of the device is to measure the muon flux from different directions and to detect changes of this flux correlated with solar flares. The Sun is now in a state of maximum activity. Unexpectedly, we have registered some decrease of the muon flux that can be correlated with the so-called Forbush decreases: falling of low energy cosmic ray intensity registered mainly by the neutron monitors. We have registered decreases of muon flux at the level of 1% at the time when neutron monitor in Apatity station registered the Forbush decreases of 5-7 % (on 17 September, 29 October and 26 November). The effects measured at the Apatity station are related to the changes of cosmic ray intensity at energies below 10 GeV. For 5 GeV muons registered in our telescope the median energy of primary cosmic rays is equal to around 20 GeV and to obtain 1% change in muon flux we need several % change of intensity of cosmic particles at energies up to about 50 GeV. Such a high energy is near to the upper limit of cosmic ray energies affected by Forbush decrease, and therefore sets the upper limit of the geometrical size of interplanetary disturbances. Updated information can be found on www.u.lodz.pl.

LIST OF PUBLICATIONS

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HIGH ENERGY COSMIC RAYS IN THE LOW STRATOSPHERE AND EXTRAPOLATION ABOVE LHC ENERGIES
J.N. Capdevielle, F. Cohen, L. Kurb, C. Le Gall, B. Szabelska, J. Szabelski
Il Nuovo Cimento (in press)

LATERAL DISTRIBUTIONS , LOCALIZATION METHODS, p(600), SIZE AND ENERGY DETERMINATION IN GIANT EAS
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Nuclear Physics B (in press)

REGISTRATION OF SIGNALS DELAYED BY 500-2000 μs RELATIVELY TO THE SHOWER FRONT
Izvestia of the Russian Academy of Sciences (in press)

MULTIPLECTITY SPECTRA IN MUON BUNDLES DEEP UNDERGROUND
[Note: Authors not present in the list, may need to be added if not listed]
Journal of Physics G (in press)

HIGH ENERGY INTERACTIONS AROUND THE ‘KNEE’
T. Wibig
Journal of Physics G (in press)

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T. Wibig
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PROSPECTS FOR EXTRAGALACTIC PARTICLES FROM EXOTIC PROCESSES
A. W. Wolfendale, T. Wibig
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C. Buettner et al. for the KASCADE Collaboration
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J. Zabierowski et al. for the KASCADE Collaboration.
17th European Cosmic Ray Symposium, HE 3.2, 24-28.07.2000, Lodz, Poland

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T. Wibig
17th European Cosmic Ray Symposium, HE 4.15, July 24–28, 2000, Lodz, Poland

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REGISTRATIONS OF SOLAR FLARES ON THE GROUND
REGISTRATIONS OF HIGH ENERGY COSMIC GAMMA RAYS
I. Szabelski
Olsztyn Planetarium, 13 October 2000.

THE FIFTH FORCE
T. Wibig
Olsztyn Planetarium, 6 October 2000.

COSMIC RAY REGISTRATIONS IN LODZ LABORATORY
OBSERVATIONS OF HIGH ENERGY GAMMA RAYS
I. Szabelski
Astronomical Observatory of the Ukrainian Academy of Sciences, Kiev 8 – 15 November 2000

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Fermi Model
I. Kurp, 6 March 2000.

Models of gamma ray production in pulsars

About the discovery of muon poor showers
T. Wibig, 3 April 2000.

Pulsars
M. Matraszek, 3 April 2000.

Gamma ray production in pulsars
M. Matraszek, 10 April 2000.

Gaseous detectors
M. Matraszek, 27 April 2000.

Uniform approach to classical analysis of small signals
M. Matraszek, 4 May 2000.

Gaseous detectors
Experimental works in the Lodz laboratory in 1968 – 1984¹⁰
Connections between elastic and non-elastic scattering of hadrons in geometrical model¹⁰

Semiconductor detectors⁹

Hadrons in extensive air showers¹¹

Calorimeters⁹
M.Matraszek, 2 June 2000.

Hadron registrations in muon detector¹¹

Breaking of KNO scaling⁹
T.Wibig, 10 July 2000.

Passing of muons through the ground³
M.Matraszek, 10 July 2000.

a) in Polish
b) in English
c) in Russian

PARTICIPATION IN PROGRAM AND ORGANISING COMMITTEES OF CONFERENCES

J.Szabelski – Co-chairman of the Local Organising Committee
17th European Cosmic Ray Symposium, July 24—28, 2000, Łódź, Poland

I.Kurp – Member of the Local Organising Committee
17th European Cosmic Ray Symposium, July 24—28, 2000, Łódź, Poland

M.Matraszek – Member of the Local Organising Committee
17th European Cosmic Ray Symposium, July 24—28, 2000, Łódź, Poland

B.Szabelska – Member of the Local Organising Committee
17th European Cosmic Ray Symposium, July 24—28, 2000, Łódź, Poland

T.Wibig – Member of the Local Organising Committee
17th European Cosmic Ray Symposium, July 24—28, 2000, Łódź, Poland

CHAIRING OF CONFERENCE SESSIONS

PERSONNEL

Research scientists

Jerzy Gawin, Professor
Barbara Szabelska, Dr.
Jacek Szabelski, Dr.
Tadeusz Wibig, DSc.,
Janusz Zabierowski, DSc.

PhD students

Izabela Kurp, MSc.
Michał Matraszek, MSc., till Sept. 30

Technical and administrative staff

Jadwiga Feder
Karol Jędrzęjczak
Jacek Karczmarczyk
Ryszard Lewandowski
Stefan Pachała
Zygmunt Piskor
Paweł Pluciński
Józef Swarzyński
Przemysław Tokarski
Overview

The Department of Nuclear Theory consists of 18 physicists and 3 PhD students working on different aspects of low energy, high energy, plasma and nonlinear physics as well as on general problems of quantization of particle dynamics. In addition to this activity, close collaboration with COMPASS, LEAR and ALICE Collaborations at CERN should also be emphasized. Results of our work in 2000 are presented in 20 published regular papers (plus some conference proceedings) and in over 23 papers already accepted for publication. The specific topics worthy of special emphasis are:

- A special theoretical method was proposed allowing evaluation of atomic masses measured at experiments at GSI, Darmstadt. It is now being successfully used by the GSI experimental group.
- Studies of so called deformed superheavy nuclei.
- Investigations of the most suitable mechanisms to obtain superheavy elements with emphasis on reproducing new experimental data in this field.
- Selfconsistent calculation of the exact Coulomb exchange effects in spherical nuclei has been presented and compared with the standard Slater approximation.
- Studies of strange nuclear matter with form on Σ hyperon and Σ atom.
- The recently proposed new model for calculating parton distributions has been extended to nuclei and successfully applied to deep inelastic collisions with nuclear targets.
- A general form of the multi-channel Bethe-Salpeter equation has been discussed with the aim to extract useful information for scattering amplitudes.
- The hadroproduction of vector mesons of different kinds in the frame of QCD has been pursued in a series of papers. The dominance at non spin-flip contributions has been established.
- The problem of the spin content of the proton has been studied and it was established that the total quark contribution to the proton spin is 0.3±0.07, whereas quark angular momentum contributes 0.17±0.06. The rest must be therefore due to the gluons.
- The possible fractal (both in phase-space and in space-time) structure at the hadronic sources producing finally observed particles has been investigated using the cascade model with Bose-Einstein correlations and introducing so called Tsallis statistics. A new interpretation of the nonextensivity parameter of Tsallis statistics has been proposed.
- The plasma group continued its investigation of nonlinear waves and solitons and their instabilities. They obtained new confirmation of the quasi-quantum character of a soliton. This was done by investigating their before and after collisional properties.

Other topics covered include studies of a power correction for $\gamma^*\gamma^* \rightarrow \pi\pi$ processes, the role of nonextensivity in multiparticle production, effective QCD-lagrangian, classical and quantum dynamics of relativistic particles in spacetimes with different topologies and the role of conformal invariance in the description of an expanding universe.

Collaborations with several universities have been maintained. These include the Universities of Warsaw, Polish Academy of Sciences, Kielce, Łódź, Muenchen, Liege, Siegen, Helsinki, São Paulo, Berkeley, Brussels, St. Petersburg, Tbilisi, Regensburg, Lipsk, London, Warwick and the Institutes at: CERN, GSI and JINR.
8.1 Mass Evaluation for Nuclei in the Pb Region
by Z. Patyk

The maximum likelihood method has been applied for the evaluation of atomic masses in the element range of 57 < Z < 84 measured at GSI Darmstadt in the storage ring ESR [1-3]. These mass values have been deduced from the revolution frequencies of the cooled ions and known mass and Qα values measured earlier. 104 mass values have been deduced with about 100 keV precision. The measured masses cover the neutron-deficient region in Pb vicinity close to the proton drip line. The mass evaluation has been done in close contact with the GSI group.


8.2 Properties of Heavy and Superheavy Nuclei
by I. Muntian, Z. Patyk and A. Sobiczewski

Analysis of the problem of “deformed” superheavy nuclei has been continued [1-3]. This is the problem of experimental confirmation of deformation of superheavy nuclei situated around the nucleus 270-Hs, predicted theoretically.

The sensitivity of calculated properties of superheavy nuclei to various changes has been also studied [4]. Ground-state properties of the heaviest nuclei have been recalculated within a macroscopic-microscopic approach. Both macroscopic and microscopic parts of the energy have been modified. Such properties as deformation, masses, neutron separation energies, alpha-decay energies and half-lives have been studied. A large region of even-even nuclei with proton, Z=82-128, and neutron, N=126-188, numbers has been considered.


8.3 Production Mechanism of Superheavy Elements
by R. Smoląfczuk

We investigated the formation of superheavy nuclei in cold fusion reactions with the emission of only one neutron [1-3]. In ref. [4], we refined our original reaction model [5] which prompted the Berkeley experiment [6] on the synthesis of a new superheavy element 118, its alpha-decay product element 116 and lighter even Z descendants. A cutoff Coulomb barrier was replaced by a smooth fusion barrier with the height and the curvature modeled phenomenologically. Moreover, the survival probability of the compound nucleus was calculated by using a simpler formula. The latter takes implicitly into account the influence of shell effects on the level density through different temperatures for the equilibrium and the saddle-point configurations. These changes lead to significantly lower fusion probabilities in comparison with those obtained in the original model. We reproduced measured formation cross sections of elements Z=102-112 [2,3,7,8] within a similar accuracy in both models. For nuclei with larger atomic and neutron numbers, the refined model [4] predicts smaller cross sections than those obtained in the original model [5]. In particular, for the reaction of krypton 86 with lead 208, we predicted the cross section only by a factor of 2.7 larger than that reported by the LBNL Heavy Element and Radiochemistry group [6].

For cold fusion reactions of heavy ions with lead-208 targets, which might lead to new superheavy elements 119, 120 and 121, we predicted the cross sections of the order of 1 picobarn. These relatively large cross sections are obtained because of the magicity of the reaction partners, which leads to larger Q value and, consequently, to larger fusion probability.
8.4 Selfconsistent Calculations of the Exact Coulomb Exchange Effects in Spherical Nuclei
by J. Skalski

Hartree-Fock binding and single-proton energies were calculated including the exact Coulomb exchange with the Skyrme SkP and SkM* forces for a number of spherical nuclei up to the expected superheavy species. Results are presented as corrections to the standard Slater approximation. The calculated corrections are nearly force-independent, at least for the realistic Skyrme-like effective nuclear forces. Corrections to the Slater approximation for proton energies constitute on average about 1/3 of the total Cex shift. The correction percentage for particular subshells ranges from about 50% (45%) for deeply bound levels to 20% (30%) for valence subshells in heavy (light) nuclei. These corrections have little effect on the bulk nuclear properties. Most direct consequences are expected for the predictions of the proton drip-line and for the understanding of the Coulomb displacement energies of individual s.p. levels. [1]


8.5 Single Particle Potential of a Σ Hyperon in Nuclear Matter
II. Rearrangement Effects
by J. Dąbrowski

The rearrangement contribution to the real part of the single particle potential of a Σ hyperon in nuclear matter, U_j, was investigated. The isospin and spin dependent parts of U_j were considered. Results obtained for four models of the Nijmegen baryon-baryon interaction were presented and discussed. [1]


8.6 Σ Atoms and the ΣN Interaction
by J. Dąbrowski, J. Rożynek, G.S. Anagnostatos

The strong interaction shifts ε and widths Γ of the lowest observed levels of Σ atoms were investigated with four models of the Nijmegen baryon-baryon interaction. Simple expressions for ε and Γ were applied in which proton and neutron density distributions obtained from the isomorphic shell model were used. Satisfying results obtained for model F favor this model as a realistic representation of the ΣN interaction. [1-2]


[1] National Center „Democritos”, Athens, Greece
8.7 The $\pi \Lambda \Sigma$ Coupling Extracted from Hyperonic Atoms

by B. Loiseau$^1$ and S. Wycech

The lifetime of a $\Sigma^-$ hyperon bound into an atomic orbit is determined by the reaction

$\Sigma^- p \rightarrow \Lambda n$. In high angular momentum states of the atom the orbital hyperon and nuclear proton are separated by a high centrifugal barrier. This barrier suppresses short range forces and the hyperon conversion process is dominated by the long range pion exchange. The most precise atomic level widths and intermediate energy scattering data are used to extract the strength of pion hyperon coupling.

One obtains $f_{\pi \Lambda \Sigma}^2 / A_{451} = 0.048 \pm 0.005$ (statistic) $\pm 0.004$ (systematic). The systematic errors are due to uncertain nuclear densities, unknown short range interactions and poor knowledge of the energy released in the reaction. [1]


8.8 Parton Distributions in Nuclei

by J. Rożynek, G. Wilk

Recently a simple model for parton distributions in hadrons has been presented in which they are derived from a spherically symmetric, Gaussian distribution, the width of which reflects, via the Heisenberg uncertainty relation, the hadronic size. Two distinct parts are distinguished in a hadron: a „bare“ hadron (identified with valence quarks and gluons) and hadronic fluctuations (identified with pions, which are later the source of sea partons). The parton density distributions were calculated numerically using a Monte Carlo technique, and good agreement with deep inelastic scattering data was reported. In [1] we have used the same method to calculate parton distributions in nuclei. Preserving the simplicity of the model and using the standard nuclear structure we were able to successfully describe the parton distribution function $F_2(x)$ in a nucleus over the whole range of $x$. The only changes introduced were dictated by the presence of other hadrons around the one under investigation in a similar fashion as in our previous work on this subject done many years ago. However, in the present case we were able to describe also the region of small $x$, which shows effects of shadowing and therefore is of particular interest to the physics of heavy ion collisions.


8.9 The Nuclear Scalar Potential and The EMC Effect

by J. Rożynek

Based on the relativistic mean field model of nuclear matter with scalar and vector components, a convolution model of deeply inelastic electron-nucleus scattering has been developed [1]. The influence of the scalar potential changes the nucleon structure function inside the nucleus and ensures agreement with the experiment in the Björken $x > 0.2$. The sum Rules are discussed. The role of the relativistic scalar and vector nuclear potential in the nucleus is shown.


8.10 Multi-Channel Bethe-Salpeter Equation

by J. Boguszyński$^1$, H. D. Dahmen$^2$, R. Kretschmer$^3$, L. Lukaszuk

A general form of the multi-channel B-S equation has been considered. In contradistinction to hitherto applied approaches, our coupled system of equations leads to the simultaneous solutions for all relativistic four-point Green functions (elastic and inelastic) appearing in a given theory. A set of relations, which may be helpful in approximate treatments, is given. An example of extracting useful information from the equations is discussed: we consider the most general trilinear coupling of $N$ different scalar fields and obtain - in the ladder approximation - closed expressions for the Regge trajectories and their couplings to different channels. Sum rules for relevant
scattering amplitudes in the diffractive region and an example containing non-obvious symmetry are discussed.


8.11 Direct J/Ψ Hadroproduction in $k_t$-factorization and the Color Octet Mechanism
by Ph.Hagler1, R.Kirschner2, A.Schäfer3, L.Szymanowski, O.V.Teryaev3,4

The hadroproduction of direct J/Ψ in the framework of the $k_t$-factorization approach is studied. The color-singlet contribution is essentially larger than in the collinear approach but is still an order of magnitude below the data. The deficit may be well described by the color octet contribution with the value of the matrix element $<0|O_{8}^{1/2}|S_{1}>$ substantially decreased in comparison with the fits in the collinear factorization. This should lead to a reduction of the large transverse polarization, predicted in the collinear approach. [1]


8.12 Towards a Solution of the Charmonium Production Controversy: $k_t$-factorization Versus Color Octet Mechanism
by Ph.Hagler1, R.Kirschner2, A.Schäfer3, L.Szymanowski, O.V.Teryaev3,4

The cross section of $\chi_c$, hadroproduction is calculated in the $k_t$-factorization approach. We find a significant contribution of the $\chi_c$ state due to non-applicability of the Landau-Yang theorem because of off-shell gluons. The results are in agreement with the data and leave no room for the a color octet contribution. Our results could therefore lead to a solution of the longstanding controversy between the color singlet model and the color octet mechanism [1].


8.13 Heavy Quark Production as Sensitive Test for an Improved Description of High Energy Hadron Collisions
by Ph.Hagler1, R.Kirschner2, A.Schäfer3, L.Szymanowski, O.V.Teryaev3,4

QCD dynamics at small quark and gluon momentum fractions or large total energy, which plays a major role for HERA, the Tevatron, RHIC and LHC physics, is still poorly understood. For one of the simplest processes, namely bottom-antibottom production, next-to-leading-order perturbation theory fails. We show that the combination of two recently developed theoretical concepts, the $k_t$-factorization and the next-to-leading-logarithmic-approximation BFKL vertex, gives perfect agreement with data. One can therefore hope that these concepts will provide a valuable foundation for the description of other high energy processes. [1]

8.14 Light Vector Meson Photoproduction at Large $t$

by Yu.Ivanov$^{(1,2)}$, R.Kirschner$^3$, A.Schäfer$^4$, L.Szymanowski

We have studied (in perturbative QCD) all independent helicity amplitudes describing the photoproduction of light vector mesons at large $t$. We found a new hard production mechanism which is related to the possibility for a real photon to fluctuate into a massless $qar{q}$ pair in a chiral-odd spin configuration. Each helicity amplitude is given as a sum of a usual chiral-even contribution (when the helicities of quark and antiquark are antiparallel) and this additional chiral-odd part (where the helicities of quark and antiquark are parallel). The chiral-odd contribution is large and it leads to a dominance of the non spin-flip amplitude in a very broad region of intermediately high $t$. All amplitudes are expressed in terms of short distance asymptotics of the light-cone wave functions of vector meson (photon). We demonstrate that for each helicity amplitude there exists a soft non-factorizable contribution. We give arguments that for dominant non spin-flip helicity amplitude the relative contribution of the soft non-factorizable interactions is not numerically large [1]


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2) Institute of Mathematics, Novosibirsk, Russia
3) Universität Leipzig, Germany

8.15 Quark Orbital Angular Momentum from Lattice QCD

by N.Mathur$^{(1,2)}$, S.J.Dong$^1$, K.F.Liu$^3$, L.Mankiewicz, N.C.Mukhopadhyay$^2$

The spin content of the proton remains a challenging problem in QCD both experimentally and theoretically. The surprisingly small contribution from the quark spin revealed by the polarized deep inelastic scattering experiments (world average: $\Sigma = 0.25 \pm 0.10$) has stimulated interest in the understanding of this proton spin problem. While the lattice QCD calculations confirmed the small quark spin content in agreement with experiments, there is little consensus on where the rest of the proton spin resides. There have been suggestions based on the Bjorken sum rule, the parton evolution, the chiral quark model and skyrmion that the quark orbital angular momentum in the nucleon can be substantial. It is further proposed that the off-forward parton distributions from the deeply virtual Compton scattering can be used to measure the quark orbital angular momentum distribution and thereby its moments.

We calculate the quark orbital angular momentum of the nucleon from the quark energy-momentum tensor form factors on the lattice with quenched approximation. The calculation is done on a quenched $16^3\times 24$ lattice at $\beta = 6.0$, with Wilson fermions and with $\kappa = 0.148$, 0.152, 0.154 and 0.155. The disconnected insertion is estimated stochastically which employs the $Z_2$ noise with an unbiased subtraction. This reduced the error by a factor of 3–4 with negligible overhead. The total quark contribution to the proton spin is found to be $0.30 \pm 0.07$. From this and the quark spin content we deduce the quark orbital angular momentum to be $0.17 \pm 0.06$ which is $-34\%$ of the proton spin. We further predict that the gluon angular momentum to be $0.20 \pm 0.07$, i.e. $-40\%$ of the proton spin is due to the glue. [1]


1) University of Kentucky, Lexington
2) Applied Physics and Astronomy, RPI, Troy, NY
3) SLAC, California

8.16 On the Possible Fractality of the Emitting Hadronic Source

by O.V.Utyuzh, G.Wilk, Z.Wlodarczyk$^1$

The multiparticle spectra of secondaries produced in high energy collision processes are the most abundant sources of our knowledge of the dynamics of such processes. Among others, two features emerging from the analysis of these spectra are of particular interest: (i) the so called intermittent behaviour observed in many experiments in the analysis of factorial moments of spectra of produced secondaries and (ii) the Bose-Einstein correlations (BEC) observed between identical particles. Whereas the former seems to indicate the existence of some (multi) fractal structure of the production process the latter are established as, by now, the most important source of our knowledge on the space-time aspects of the multiparticle production processes. Both effects are compatible with each other if the emitting source
fluctuates in size in a scale-invariant (i.e., power-like) way. This can be achieved in two ways: (i) either the shape of the interaction region is regular but its size fluctuates from event to event according to some power-like scaling law or (ii) the interaction region itself is a self-similar fractal extending over a very large volume. In [1,2] we have investigated this problem numerically by constructing a Monte Carlo event generator based on the self-similar cascade process, both in phase space and in space-time and by amending it with the simple prescription of numerical modelling BEC. We have found that BECs are, indeed, substantially influenced by the fact that the production process is of the cascade type (both in momentum and space-time), although not to the extent anticipated in the literature.


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8.17 Nonextensivity in the Multiparticle Production
by O.V.Utyuzh, G.Wilk, Z.Wlodarczyk

We have investigated the effect of nonextensive statistics as applied to the chemical fluctuations in high-energy nuclear collisions discussed recently using the event-by-event analysis of data [1]. It turns out that very small changes of the nonextensivity parameter \( q \) drastically changes the expected experimental output for the fluctuation measure. This result is in agreement with similar studies of nonextensity performed recently for transverse momentum fluctuations used in literature in the same reactions. We have also shown [2] that this nonextensivity parameter \( q \) occurring here (as well as in some other applications of Tsallis statistics and sometimes known as index of the corresponding Lévy distribution) is entirely given by the fluctuations of the parameters of the usual exponential distribution in the sense that, when ether one has a dependence of the form \( \exp(-x/\lambda) \), and the quantity \( 1/\lambda \) fluctuates with some normalized variance \( \omega \). This leads to the effective power-like distribution of the type \( [1-(1-q)x/\lambda]^{1/(1-q)} \) with \( q = 1 \pm \omega \). This effect can be studied experimentally in heavy ion collisions in an event-by-event type of analysis of experimental data and is therefore important for their proper understanding.


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8.18 Dynamics of Waves and Multidimensional Solitons of the Zakharov-Kuznetsov Equation
by E.Infeld, A.A.Skorupski and A.Senatorski

Nonlinear waves and one-dimensional solitons of the Zakharov-Kuznetsov equation are unstable in two dimensions. Although the wavevector \( K \) of a perturbation leading to an instability covers a whole region in \((K_x,K_y)\) parameter space, two classes are of particular interest. One corresponds to the perpendicular, Benjamin-Feir instability \((K_y = 0)\). The second is the wavelength-doubling instability. These two are the only purely growing modes. We concentrate on them. Both analytical and numerical methods for calculating growth rates are employed and results compared. Once a nonlinear wave or soliton breaks up owing to one of these instabilities, an array of cylindrical and/or spherical solitons can emerge. We investigate the interaction of these entities numerically [1, 2].

8.19 Instabilities an Oscillations of one- and two-Dimensional Kadomtsev-Petviashvili Waves and Solitons
II. Linear to Nonlinear Analysis
by E.Infeld, A.A.Skorupski and G.Rowlands

We further investigate the dynamics of nonlinear structures that arise from the Kadomtsev-Petviashvili equation. When the analysis is linear, assuming perturbations to grow exponentially in time, we find the growth rates of two important instabilities numerically. The wavelength doubling instability is seen to dominate its rival, that of Benjamin and Feir, at least when the amplitude of the wave is not too large. Approximate formulas, found in Part I, are checked against these numerically found values. The models are seen to be reasonable. For the dominant, wavelength doubling instability, our model extends beyond the assumed region of validity. Agreement is surprisingly good.

When we depart from linear stability analysis and include terms nonlinear in the perturbation, a simple analysis shows that the linear instability eventually drives a doubly space periodic, hyperbolic secans pulse in time. After a long time, initial conditions are reproduced. A proof that the maximum amplitude achieved by the perturbation is proportional to the linear growth rate is given. This fact was suspected from numerics. A second class of possible dynamic behaviour, not arising from initially linear growth of a perturbation, is found.

1) Warwick University, UK

8.20 Power Corrections to the Process $\gamma\gamma \rightarrow \pi\pi$ in the Light-Cone Sum Rules Approach
by N.Kivel, L.Mankiewicz,

Hadron production in the reaction $\gamma\gamma \rightarrow$ hadron(s) has been a subject of considerable interest for a long time, both from the experimental and theoretical points of view. The key role in QCD description of such processes is played by the QCD factorization theorem. For example, QCD factorization has been successfully applied to the reaction $\gamma\gamma \rightarrow nP$. The $F^\pi_m(Q^2)$ form-factor data obtained by the CELLO and CLEO collaborations are in a good agreement with the available QCD analysis.

Recently it has been proposed to investigate a similar process $\gamma\gamma \rightarrow \pi\pi$ when the two pion state has a small invariant mass. It has been argued that QCD factorization applies to this case as well. The resulting amplitude depends on new non-perturbative objects, the so-called two-pion distribution amplitudes (2π DA’s). They are given by matrix elements of twist-2 QCD string operators between vacuum and the two-pion state. Moreover, 2π DA’s can be related by the crossing symmetry to skewed parton distributions which recently have been subject of considerable interest.

The main result of this paper is a numerical estimate of power-suppressed correction to the leading-twist helicity-conserving amplitude of the process $\gamma\gamma \rightarrow \pi\pi$. Light-cone sum rules technique allows us to circumvent difficulties due to non-factorizability of the power-suppressed terms. Although formally our analysis is not complete, as we have neglected the contribution of higher twist operators to the amplitude of two-pion production in a collision of two virtual photons, we believe that the general picture is reliable, at least qualitatively. Power corrections are increasingly important with decreasing $Q^2$ for $Q^2 \leq 4 \text{ GeV}^2$, and become about 50% of the leading-twist amplitude at $Q^2 = 1 \text{ GeV}^2$ [1].


1) Petersburg Nuclear Physics Inst., Gatchina, Russia

8.21 Geometric Quantization of Field Theory
by K.Bragiel and W.Piechocki

We prove that the space of smooth initial data and that of smooth solutions to the Liouville equation are homeomorphic [1].


1) Institute of Physics, Białystok, Poland
8.22 Classical and Quantum Dynamics of a Relativistic Particle in Spacetimes with Different Topologies
by G. Jorjadze and W. Piechocki

Dynamical integrals constructed by the isometry groups of corresponding spacetimes are used for the gauge-invariant Hamiltonian reduction. The physical phase-spaces parametrize the set of classical trajectories in spacetimes. Canonical quantization leads to self-adjoint representations of the set of classical observables of the corresponding systems [1, 2, 3].


8.23 The QCD-Based Analysis of the Nonleptonic Kaon Decays
by J. Wrzecionko

Starting directly from the QCD-lagrangian, effective actions describing weak K-meson decays in different channels have been constructed. In the derivation of the corresponding effective lagrangians a method of bilocal bosonizations, which incorporates the chiral symmetry breaking mechanism, has been used. The nonleptonic decay rates of K-mesons based on the derived (by the proposed method) weak effective lagrangians has been calculated. $\Delta I = \frac{3}{2}$ transition rates are of the same order of magnitudes. The $\Delta I = \frac{1}{2}$ dominance role could not be explained if the strong interaction effects are not included. [1]


8.24 The $\eta N$ and $\eta NN$ States
by S. Wycech and A. M. Green

The $\eta N$ interaction is apparently strongly attractive. It may generate quasi-bound states in the $\eta NN$, $\eta NNN$ and heavier nuclear systems with $\eta$ mesons localized on a nuclear surface. On the other hand the final state $\eta - NN$ and $\eta NNN$ interactions indicate only weak enhancement at very low energies. We argue that this inconsistency is related to a mismatch of a very small $\eta$-meson formation region and a large region involving final state interactions.

The dynamic propagation of a $\eta NN$ system from small to large distances suppresses the final state interactions due to quasi-bound states [1].


8.25 Conformal and Reparametrization Invariance in Description of Expanding Universe
by M. Pawłowski, V. Pervushin

Classical and quantum universes are described in a conformal-invariant unified theory given in the space with the geometry of similarity where both the Planck mass and masses of elementary particles are formed by a scalar dilaton field. The reparameterization - invariant and conformal - invariant perturbation theory is formulated without introduction into the theory of any dimensional constant of the type of the Planck mass. We show that the definition of particle-like variables by the diagonalization of their Hamiltonian excludes the dilaton-matter vertices which can lead to the effective Coleman-Weinberg
potential breaking conformal symmetry in the spirit of the Higgs effect. We discuss the problems of the origin of the Hubble evolution, initial cosmic data, the arrow of time, dark matter, and the "supernova data" on the "accelerating universe". A generalization of the Faddeev-Popov unitary perturbation theory is presented, and a range of validity of conventional perturbation theory (that violates the conformal symmetry) is established. [1,2]

8.26 Solution to Teichmann's Model of Electrostatic Double Layers
by P.P.Goldstein

Teichmann's model [1] for high-frequency phenomena in unmagnetized double layers (DL) is approximately solved. The model describes electrons moving in a field of the DL, corresponding to a perturbed BGK equilibrium, dynamics of ions is neglected. The method relies on stationary phase integration of electron equations of motion over unperturbed orbits.

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E. Inzelt, A. Skorupski
Europhysics Letters 52 (2000) 545-550

THE NUCLEAR SCALAR POTENTIAL AND THE EMC EFFECT
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THE POSSIBLE SPACE-TIME FRACTALITY OF THE EMITTING SOURCE

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HEAVY QUARK PRODUCTION AS SENSITIVE TEST FOR AN IMPROVED DESCRIPTION OF HIGH-ENERGY HADRON COLLISIONS.

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E. Infeld, A.A. Skorupski and A. Senatorski

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G.Wilk and Z.Wlodarczyk
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- Kulpa Jarosław, M.Sc.
- Muntian Igor, M.Sc.
- Utyuzh Oleg, M.Sc.

### Technical and administrative staff

- Sidor Janina
Overview

The technology of modifying surfaces of industrially used materials by means of continuous and pulsed energy beams has been intensely studied for more than 20 years. In some fields it is presently utilized on a broad scale in industry. A significant role among various methods play continuous or pulsed ion and plasma beams. The P-IX Department jointly with the P-V Department utilizes some globally unique sources of intense plasma pulses, and jointly with Forschungszentrum Rossendorf (FZR, Dresden, Germany) conducts research on application of continuous ion beams using FZR and IPJ facilities. Main objectives of the Department are:

- searching for new ways of modifying surface properties of solid materials by means of pulsed plasma beams
- implementation in the Institute and in the country the ion implantation technique as a method of improving the quality of parts of machinery and tools applied in industry.

These objectives were in 2000 accomplished particularly by:

- research on technology of producing surface alloys by plasma pulses
- application of implantation techniques to improve materials used industrially
- structural analysis of Ti/Al$_2$O$_3$ metal-ceramics joints produced by plasma pulses
- purchase of a new high-current MEVVA-type TITAN implanter.

The research was conducted in cooperation with the P-V Department of IPJ, and with INCT (Warsaw), Warsaw University of Technology, ITME (Warsaw), Forschungszentrum Rossendorf FZR (Dresden, Germany), as well as with some industrial plants.

Significant refurnishing of laboratories took place in 2000. A new instrument for testing wearing and friction of surfaces of the treated samples in a controlled environment has been deployed in an air-conditioned room. An operational room for a new high-current MEVVA-type TITAN implanter (to be installed in 2001) and an adjacent room for washing/cleaning of the to-be-treated materials have been suitably overhauled and equipped.
9.1 ETLIT Computer Program in Simulations of Thermal Evolutions

by W.Szymczyk, J.Piekoszewski, Z.Werner

When energy is delivered to regions of lateral dimensions \((y,z)\) much larger than the depth of heat diffusion in sample bulk in the \(x\) direction (which is the case in our experiments), one-dimensional equation may be used to calculate thermal evolution:

\[
C_s \rho \frac{\partial T(x,t)}{\partial t} = \frac{\partial}{\partial x} \left[ K(T) \frac{\partial T(x,t)}{\partial x} \right] + G(x,t)
\]

where \(C_s\) is the sample material specific heat, \(\rho\) is the sample material density, \(T\) is the temperature in time \(t\) at \(x\) depth within the sample, and \(K(T)\) is the sample material heat conductivity (temperature-dependent). The \(G(x,t)\) term describes heat generated in the sample by a pulse (or pulses) of the supplied energy. In our experiments energy is always deposited on sample surfaces.

The ETLIT program takes into account phase transitions (melting and solidification of the sample material), as well as gives an opportunity to make temperature-dependent not only the heat conductivity \(K(T)\), but also the specific heat \(C_s\).

The \(G(t)\) pulse may have an arbitrary shape e.g. Gauss curve, rectangle, series of rectangles, series of triangles etc. However, description of its time dependence must be contained in a 150-element array, elements of which represent fixed time moments \(t_j\). The array must also include those time moments after the energy pulse has ceased, for which thermal evolution is to be calculated.

Sample may contain up to 7 different materials in any configuration. However, the whole description must be contained in a 150-element array, elements of which represent selected planes within the sample bulk (the so-called nodes). The \(x_0\) node represents sample surface i.e. the \(x=0\) plane. The last node \(x_{150}\) (backplane) should represent a plane distant enough to satisfy the boundary condition accepted in the program algorithm: for any time \(t\), the backplane temperature \(T_{150}\) is equal to the ambient temperature. In our practice it is enough to take \(x_{150}=1000\) \(\mu m\), since the depth of the region where any significant temperature changes take place is practically limited to not more than 100 \(\mu m\) (typically several \(\mu m\)).

Modification of any of the calculation parameters (pulse amplitude, pulse shape, array of times for which the thermal evolution is to be calculated, spatial nodes defining the sample structure and indicating points, where the thermal evolution is to be calculated, material constants, their temperature dependency) requires the ETLIT source code to be re-compiled.

The calculation results are returned in two text files of size approximately 16 kB and 1.3 MB. Physically significant data include temperature values and sample melting depth for all the fixed time moments \(t_j\). The small file contains description of thermal evolution in 4 nodes pre-selected from all declared 150 nodes. They may be selected arbitrarily, but the decision must be taken in advance, i.e. before the calculations start. The \(T(t)\) dependences for the four selected \(x_i\) nodes are ready to chart. The large file contains description of thermal evolution in all 150 declared nodes. The file data may be used to generate two-dimensional \(T(x,t)\) maps, \(T(x)\) cuts for any declared time moment \(t_i\), and \(T(t)\) cuts for any declared node \(x_i\), but its computation is laborious.

In case diffusion of a mass (an impurity) takes place into regions of lateral dimensions \((y,z)\) much larger than diffusion depth in the \(x\) direction in sample bulk, identical one-dimensional equation is valid:

\[
\frac{\partial n(x,t)}{\partial t} = \frac{\partial}{\partial x} \left[ D \frac{\partial n(x,t)}{\partial x} \right]
\]

where \(D\) is the diffusion constant, \(n\) is the impurity concentration in time \(t\) at depth \(x\) in the sample bulk. Analytical solution for diffusion from an infinitesimal thin layer of surface concentration \(N_0\) \([at/cm^2]\):

\[
n = \frac{N_0}{\sqrt{\pi Dt}} \exp\left(-\frac{x^2}{4Dt}\right)
\]

is very similar to the solution for thermal evolution after an infinitesimal short pulse of energy of density \(Q_0\) \([J/cm^2]\):

\[
\Delta T = \frac{Q_0}{C_s \rho V K} \exp\left(-\frac{x^2}{4\kappa t}\right)
\]

where \(\kappa = K/C_s \rho\). Both equation become identical after substitution \(n \rightarrow \Delta T, D \rightarrow \kappa, \) and \(N_0 \rightarrow Q_0 \frac{D}{C_s \rho \sqrt{\kappa}}\).

Therefore there exists a full correspondence between solutions of thermal evolution problems and solutions of mass diffusion problems, and numeric solutions obtained with the help of the ETLIT program may be used to simulate impurity diffusion in more complicated cases (e.g. multiple diffusion).
9.2 Interface in Ti-Al₂O₃ System Manufactured with the Use of High Intensity Pulsed Plasma Beams

by J. Piekoszewski, J. Stanislawski, R. Grötzschel, W. Matz, J. Jagielski

In our previous work [1] it was shown that the high intensity pulse plasma beam (HIIPBB) treatment can successfully be used in preparation of the alumina surface prior to manufacturing a good alumina-cooper joints. In the present work we focused our attention on investigation of the structure and kinetics of the interface layer in the Ti-Al₂O₃ system. Over 20 samples were prepared by irradiation of the alumina substrates with 2, 5 and 10 pulses of HIIPBB in deposition by erosion (DPE) mode, with titanium electrodes as the deposit source and nitrogen as the working gas. In addition some samples were also treated by 20 pulses.

To identify the phase structure of the processed samples, X-ray diffraction (XRD) measurements were performed on the step scan difractometer in grazing angle geometry (ω=1°) using CuKα radiation. The XRD patterns revealed an evidence for the presence of Al₅O₅N and AlN phases especially clearly observed in samples treated with 20 pulses. Ti₃AlN and Al₂TiO₅ phases can also be identified with a lower probability. The results are surprising, since the TiO₂ (rutil) is usually considered as a brazable phase when active filler (with titanium) is used. However, the rutil phase has not been identified in the samples. The results suggest that more detailed consideration should be undertaken toward the wettability of the phases observed in our samples.

In order to get insight into dependence of titanium depth profile on number of pulses, the Rutheford Back Scattering (RBS) measurements were performed on the processed samples. The RUMP program was used to fit the simulated spectra to the experimental data. The experimental spectrum for a given type of the sample i.e. for 2, 5 or 20 pulses was taken as an average spectrum from 4 samples. The results of these fittings can be summarized as follows.

1. The bulk concentration of Ti atoms in the alumina substrate, i.e. beneath the surface, increases with the number of pulses as 0.17 : 0.83 : 1 for 2, 5 and 10 pulses, respectively. This regularity is quite obvious in view of the fact that each pulse brings a new portion of Ti which is then mixed into the substrate by the liquid diffusion mechanism.

2. The aerial density of the metallic Ti film deposited on the surface (not mixed into the bulk) decreases with a number of pulses as 1 : 0.44 : 0.18 for 2, 5 and 10 pulses respectively. This is an unexpected result, since according to our understanding of the DPE process up to now, is that exclusively the last pulse in the series deposits a thin metallic film on the surface which is not mixed into the bulk. Therefore, we could have expected that the thickness of this film should not depend on the number of pulses and nominally should remain constant.

At present, we do not have yet a full understanding of the results. A tentative qualitative explanation of them can be as follows. Lifetime of the molten phase (LMP) is shorter for the initial state of the substrate then that after the substantial number of pulses. Therefore, if LMP is short, the metallic atoms (and or low energy ions) ablated from the electrodes reach the surface of the substrate when it is already solidified, being first molten by the nitrogen plasma pulse. On the contrary, if LMP is long enough, a fraction of the metallic atoms (and or low energy ions) reach the substrate when it is still molten and therefore they diffuse rapidly into the bulk. Hence, the amount of atoms forming the surface film is smaller then in the previous case. A possible reason for the difference in LMP in the virgin (or only slightly modified top layer after small number of pulses) can be twofold. First, it is possible that the new phases formed on the surface have lowered melting temperature as compare to that of initial material of the substrate. Second, the heat conductivity between the top layer and bulk of the substrate decreases with the number of pulses. This would also lead to the rise of the LMP. The verification of this hypothesis requires numerical calculations of heat evolution in the substrate, basing on the thermo-physical properties of the virgin and DPE modified top layer of the system as well as on the energy spectra of the ablated metallic species. Further studies of these issues are in progress.


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9.3 Alloymg of Silicon on Ti6Al4V Using High-Intensity Pulsed Plasma Beams
by E. Richter 1), J. Piekoszewski, F. Prokert 1), J. Stanislawski, L. Walisz 2) E. Wieser 1)

Titanium alloys have recently been increasingly used as dental materials (prosthesis, artificial teeth) since they are lightweight, have good biocompatibility and mechanical properties. However, stability of the titanium-ceramic system turns out to be insufficient considering long-term use inside human mouth. Strong affinity of titanium to oxygen causes reduction of the oxide ceramic during the coating procedure at elevated temperatures. On the other hand, it could be shown that a small amount of silicon in the titanium surface reduces the reduction rate of the facing ceramic. In particular, low dose implantation of silicon (1-3 x 10.16 Si cm-2) into the Ti skeleton has been found as a route to mitigate reduction of the oxide ceramic material and obtaining well adhering facing. In the present work we report the preliminary results of a new approach to alloy silicon into titanium by using high intensity pulsed plasma beams (HIPPB).

Commercially available Ti6Al4V was used as a substrate material. Several samples were coated with a thin (120 nm) film of silicon by e-beam vacuum evaporation and then treated by HIPPB in the PID mode. Another batch of uncovered substrates were treated by HIPPB in the DPE mode. Each set of electrodes (inner and outer) consisted of 32 metallic rods of 2 mm diameter and 250 mm length. Pure titanium rods were used in the PID mode of operation. In order to assure a source of silicon in the DPE mode, the conical shaped ends of titanium rods were coated with about 0.2 mm thick layer of silicon using the plasma flame spraying process. The coating extended about 50 mm from the end of the rods since – according to our observations – erosion of material occurs only in this part of the electrodes. The samples were placed 300 mm from the electrodes and irradiated by 5 or 10 plasma pulses. The processing conditions are summarized in Table 1.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Electrodes</th>
<th>Discharge gas</th>
<th>Delay time [μs]</th>
<th>Energy density [J/cm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PID</td>
<td>Ti rods</td>
<td>N₂</td>
<td>190</td>
<td>3.3 ± 0.16</td>
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<tr>
<td></td>
<td></td>
<td>Ar</td>
<td>210</td>
<td>2.7 ± 0.14</td>
</tr>
<tr>
<td>DPE</td>
<td>Si-coated</td>
<td>N₂</td>
<td>160</td>
<td>3.0 ± 0.40</td>
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<tr>
<td></td>
<td>Ti rods</td>
<td>Ar</td>
<td>170</td>
<td>4.0 ± 0.73</td>
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</tbody>
</table>

XRD, AES and SEM measurements reveal that in all cases irradiation with plasma pulses melts the near-surface layer. After the DPE irradiation the surface is characterized by some waviness distributed in a very homogeneous way. Small crater-like features indicate disturbances of the molten surface layer during irradiation. The PID samples exhibit a much higher roughness of the surface, which is not homogeneous across the sample diameter. The contribution of areas with high roughness increases with the number of pulses (5-10).

Liquid phase reactions between silicon and titanium lead to formation of the Ti3Si5 silicide. No significant influence of the kind of the working gas (N, Ar) on the outcomes of the treatment was revealed, while different processes (PID, DPE) result in different structure of the modified surface layer.

Patterns taken with 1°, 3° and 5° angles of grazing incidence on a sample prepared with 5 PID pulses indicate that the grain size is the largest at the vicinity of the surface. The Ti3Si5 phase can also be identified after DPE treatment with 5 pulses. However, the silicide reflections from DPE-processed samples are much broadened in comparison with the PID-processed samples. This is certainly due to a smaller grain size (~10 nm) of the Ti3Si5 phase formed by DPE.

From depth profiles measured by AES one can conclude that Si concentration amounts to about 45, 20, and 40 at% at 100 nm beneath the surface for treatment by 5 PID pulses, 10 PID pulses, and 5 DPE pulses, respectively. The range of existence of Ti3Si5 is around 40 at% of silicon according to the phase diagram of the Si-Ti system. Because only that silicide has been detected by XRD, the high Si concentrations indicate a complete silicide surface layer while a distribution of Ti3Si5 precipitates within the Ti matrix has to be assumed to explain the low silicon concentration of 20 at%. Scatter of the silicon signal vs. depth in the latter case is attributed to sample rotation during the measurements and indicates influence of the grain structure. Inhomogeneous melting features observed after the PID treatment are related to inhomogeneities in the silicon depth distribution concerning silicon concentration near the surface and penetration depth of silicon. The effect is more pronounced after treatment with 10 pulses.

In conclusion, feasibility of formation of stable Ti3Si5 silicide by alloying Si on Ti6Al4V by means of HIPPB techniques has been demonstrated. The formed silicide Ti3Si5 has the highest melting point (2130 °C) of all possible stable phases in the Si-Ti system. We expect that Ti3Si5 formed in this way could be a good candidate as a diffusion barrier for oxygen in ceramic-titanium joints e.g. in dentistry applications.

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2) Institute of Nuclear Chemistry and Technology, Dorodna 16, 03-145 Warsaw, Poland
9.4 Alloying of Pd into Ti by Pulsed Plasma Beams


High emissions of SO₂ and NOₓ from fossil fuel combustion in electric power plants create a major environmental problem over all Europe. One of the most perspective methods of these pollutants removal is the electron-beam dry scrubber process (EBDS), in which the flue gas is treated by high-power, high energy electron beam. Electron beam enters the process vessel through a 50μm thick Ti window. Important corrosion processes occur on the flue gas side of the window. Corrosion resistance of titanium in sulfuric acid can be improved by alloying with palladium.

The aim of the present work is to gain insight into the structural and compositional properties of the near surface layers formed by the deposition by pulse erosion (DPE) process.

50μm thick titanium foil (Goodfellow) was used as a substrate material. The plasma pulses were generated in a rod plasma injector (IBIS) type of accelerator. In the present experiment the electrode set consisted of 32 metallic rods of 2 mm diameter and 250 mm length. To provide a source of palladium in the DPE mode, the ends of titanium rods were tipped with palladium tubes. The samples were placed 300 mm from the electrodes and irradiated by 5, 10 or 20 plasma of nitrogen or argon plasma pulses. The pulse duration was 1μs. The pulse energy was kept around 4 J/cm².

Pd-Ti system belongs to a broad class of compound formers. Such systems produce upon cooling heterogeneous grained alloys with grain sizes inversely related to the cooling rate. Generally one can expect the presence of the following phases: αTi, βTi, TiPd, Ti₂Pd, Ti₃Pd, Ti₄Pd, Ti₅Pd, Ti₆Pd, Pd. Fig. 1 presents the diffractograms of samples treated with 20 pulses of nitrogen and argon plasma, respectively. Out of the above list of possible phases, only 3 can be identified. These are: hcp αTi, TiPd (manifested in N-treated sample by reflections at 2θ = 28.89° and 58.38°) and Ti₄Pd (seen in Ar-treated sample at 2θ=43.17°). Pd is present in our samples as a solute in αTi and as two Thus Pd distinctive crystallographic phases. From the width of TiPd and Ti₄Pd reflections, one can deduce that the grain size of these two phases is in the range of 20-30 nm, in contrast to the grain size of αTi phase which turns out to be in the 250-350 nm range.

Gravimetric measurements show that the increment of Pd content in N-treated samples is 47.5 μg/cm², 70 μg/cm², and 165 μg/cm² for samples treated with 5, 10, and 20 plasma pulses, respectively. In Ar treated samples these values are 97.5 μg/cm², 197 μg/cm², and 307.5 μg/cm², respectively. Thus we observe a linear increase of the Pd content with the number of plasma pulses and a higher efficiency for Ar-plasma treatment. On the other hand, the recorded RBS spectra show no evidence for Pd accumulation at the surface since the width of the surface Pd peak is preserved regardless of the number of pulses. This behavior confirms the interpretation that the Pd layer deposited at the end of the preceding pulse is completely dissolved in molten Ti layer created by the subsequent pulse.

In conclusion, the obtained results demonstrate that well-defined Pd-Ti alloy layers with Pd concentration reaching 40% and depth up to 2μm can be successfully produced in Ti by the DPE method. Since these layers extend deeper than those in ion-beam-related techniques, one can expect that the DPE process may be advantageous in comparison with those techniques in improving the corrosion properties of Ti windows used in EBDS systems.

Fig. 1 XRD patterns for Ti-Pd surface layers processed with 20 Ar-plasma (a), and N-plasma pulses (b), taken at grazing incidence angle of 1°.

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9.5 Ion Implantation for Improving Wear Resistance of Industrial Tools
by Z. Werner, G. Gawlik, J. Jagielski, and J. Piekoszewski

To optimize ion implantation technique applied for improving wear resistance of industrial tools, several cutting and forming tools have been treated and evaluated in industrial environments. The treated tools include:

1. Paper cutting knives. Tests performed up to now by the user have shown threefold increase of wear resistance as compared to the untreated knives. The treated knives are still operational.

2. Large (1.5 m long) paper cutting knives have been transferred to the user after treatment.

3. Forming knives made of the SK5M steel (for lathing opening and radii of the internal ring in the type 608 bearing). The knives have been implanted with 100 keV N ions at doses of 1, 2 and 3*10^{17} cm^{-2}. Wear tests have been subsequently performed in industrial environment on 6 knives, and the results have been compared to those taken for 10 untreated knives. Wear resistance increases with the implanted ion dose, reaching for the highest dose 157% of the resistance of untreated knives.

4. Screw nut forming tool (manufactured by TiL company) made of the BM2 steel (Polish equivalent: SW7M). The tools have been implanted with 80 keV N ions at doses of 1 and 3*10^{17} cm^{-2}, and tested in industrial environment in series of 5 items each. Wear resistance increased to 196% and 215% of the resistance of untreated tools (respectively for the two used doses). Further tests at modified geometry of the ion beam are in progress.

5. Large diameter drills. Tests performed by the user did not show any improvement as compared to the untreated drills.

Besides, some ceramic inserts for high-speed cutting (of type IN-11, manufactured by the ISCAR company) have been implanted in Forschungszentrum Rossendorf (Germany) with 200kV C, Cr and Ti ions (doses 3-30 x 10^{16} at/cm2). Two Ti-implanted samples will next be annealed at about 1000°, and tested in laboratory (T-10 tester), as well as at the Warsaw University of Technology in a semi-industrial environment. There is no literature data on effective improving the wear resistance of ceramic tools by means of implantation technique, therefore the ions for implantation have been selected rather arbitrarily.
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KINETICS OF THE PULSED EROSION DEPOSITION PROCESS INDUCED BY HIGH INTENSITY PLASMA BEAMS
J. Piekoszewski, F. Grötzschel, E. Wiester, J. Stanislawski, Z. Werner, W. Szmyczek, J. Langner
Surface and Coating Technology, 128-129 (2000) 394

SURFACE MODIFICATION OF CONSTRUCTIONAL STEELS BY IRRADIATION WITH HIGH INTENSITY PULSED
NITROGEN PLASMA BEAMS
Surface and Coating Technology, 128-129 (2000) 105

CORROSION PROTECTION OF TITANIUM BY PULSED PLASMA DEPOSITION OF PALLADIUM
Corrosion Science 42 (2000) 1213

INVESTIGATION OF ION ASSISTED PALLADIUM TREATMENTS FOR IMPROVED CORROSION RESISTANCE OF
TITANIUM FOIL IN THE ELECTRON BEAM DRY SCRUBBER PROCESS
Surface and Coatings Technology 127 (2000) 179

MOSSBAUER STUDY OF TITANIUM IMPLANTED α-Fe
M. Kopcewicz, J. Jagielski, A. Grabias

RBS STUDY OF FISSION PRODUCT MIGRATION IN ADVANCED NUCLEAR FUEL MATERIALS
J. Jagielski, L. Thomé, C. Binet, F. Gianido, M. Mozetic, A. Zalar

INTENSE PULSE PLASMA BEAMS IN CERAMICMETAL BRAZING
W. Wolszanski, A. Krajewski, J. Piekoszewski, J. Stanislawski, L. Walis
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PRESENT STATUS AND PROSPECTS OF RESEARCH IN SINS ON THE MODIFICATION OF SURFACE PROPERTIES BY
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A. Turos, G. Gawlik, J. Jagielski, A. Stonert, N. Madi, W. Matz, A. Mücklich, R. Grötzschel

STRUCTURAL PROPERTIES OF FISSION-PRODUCT DOPED ZrO2 AND MgAl2O4 SINGLE CRYSTALS
L. Thomé, J. Jagielski, C. Binet, F. Garido

ALLOYING OF Pd INTO Ti BY PULSED PLASMA BEAMS

PARTICIPATION IN CONFERENCES AND WORKSHOPS

invited talks

APPLICATIONS OF HIGH INTENSITY PULSED ION AND PLASMA BEAMS IN MODIFICATION OF MATERIALS
J. Piekoszewski, Z. Werner, W. Szmyczek

GENERATION OF HIGH-INTENSITY PULSED ION AND PLASMA BEAMS FOR MATERIAL PROCESSING
Z. Werner, J. Piekoszewski, W. Szmyczek
STRUCTURAL AND MICROMECHANICAL PROPERTIES OF ION-BEAM MIXED TUNGSTEN-ON-STEEL SYSTEM
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oral presentations
ALLOYING OF SILICON ON Ti6Al4V USING HIGH-INTENSITY PULSED PLASMA BEAMS
E. Richter, J. Piekoszewski, F. Prokert, J. Stanislawski, L. Walsi, E. Wieser

posters
ANALYSIS OF THE WEAR PROCESS OF NITROGEN-IMPLANTED HSS STAMPING DIES
J. Narojczyk, Z. Werner, J. Piekoszewski

ALLOYING OF Pd INTO Ti BY PULSED PLASMA BEAMS
Poster on 12th International Conference “Ion Beam Modification of Materials” IBMM, Canela, Brazil, September 3-8, 2000

PHASE TRANSFORMATIONS IN IMPLANTED IRON LAYERS
J. Jagielski, M. Kopcewicz, W. Matz, R. Grötzschel, L. Thome
Poster on 12th International Conference “Ion Beam Modification of Materials” IBMM, Canela, Brazil, September 3-8, 2000

LATTICE LOCATION OF CESIUM ATOMS IN ZrO2 AND MgAl2O4 SINGLE CRYSTALS
L. Thome, A. Gentils, J. Jagielski, F. Garrido
Poster on 12th International Conference “Ion Beam Modification of Materials” IBMM, Canela, Brazil, September 3-8, 2000

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Jerzy Zagórski, 1/2
Overview

In view of limited number of scientific and technical staff, it was necessary to focus the activity on most important subjects and to keep balance between current duties and development of future projects.

The dominant item was realisation of research and designing works in the Ordered Project for New Therapeutical Accelerator with two energies of photon beam 6 and 15 MeV. During the reported year, main efforts were oriented on:

- computation and experimental works on optimization of electron gun parameters and electron optics in the injection system for accelerating structure
- calculation and modelling of standing wave, S-band accelerating structure to achieve broad range of electron energy variation with good phase acceptance and narrow energy spectrum of the output beam
- calculation and design of beam focusing and transport system, with deflection of the output beam for 2700 in achromatic sector magnet
- design and modelling of microwave power system, with pilot generator, klystron 6 MW amplifier, pulse modulator, waveguide system, four-port circulator and automatic frequency control
- preparative works on metrological procedures and apparatus for accelerated beam diagnostics comprising measurements of energy spectrum, beam intensity, transmission factor, leakage radiation, and other important beam parameters.

Other important subject, worth mentioning are:

- Advance in forming and metrology of narrow X-ray photon beams, dedicated to stereotactic radiosurgery and radiotherapy.
- Adaptation of a new version of EGS-4, MC type code for computer simulation of dose distribution in therapeutic beams.
- Participation in selected items of the TESLA Project in cooperation with DESY - Hamburg:
  - theory and computer simulation of higher order modes in superconducting accelerating structures
  - technological research of methods and apparatus for thin layer coating of r.f. resonators and subunits in transmission circuits
- Conceptual studies of proposed new version of prebunchers and bunching structure for injector linac in Trieste synchrotron.

It is also worthwhile to notice the important proposal for research and construction works on a new electron accelerator with high beam power dedicated to radiation technology.

The offer for this project was presented in the frame of Multiyear Programme "ISOTOPES AND ACCELERATORS".

Most interesting results of recent works, were presented at the 7th European Particle Accelerator Conference EPAC 2000 - Vienna.
10.1 Optimization of Phase Acceptance Range and Energy Variation Procedure in Novel Solution of 6/15 Medical Accelerator
by J. Bigolas, S. Kulinski, M. Pachan, E. Plawski

The new medical linear electron accelerator 6/15 being designed in IPJ by common effort of two teams: IPJ - ZDAJ and P-X (Accelerator Physics and Technology Department) should have four electron energies: 6, 9, 12 and 15 MeV for electron therapy and two electron energies 6 and 15 MeV for X-ray therapy. This broad band of electron energies and also accelerated electron beam intensities create serious problems in the design and construction especially of the accelerating structure together with electron source and RF power supply. A short analysis of these problems and methods of their solutions were presented in [1]. Proposed solutions consisted in division of the accelerating structure in two parts: initial bunching section with seven (2x1/2+5) variable β (β = particle velocity/light velocity) cavities and 22(2x1/2+20) main accelerator part with practically constant length (β=1) cavities.

In the present paper the results of recent calculations and optimizations are given with the aim to find the necessary big phase acceptance of the accelerating structure especially for 6 MeV electrons used for X-ray generation.

For the same phase acceptance of 6 and 15 MeV electrons, to obtain the same X-ray intensity, the 6 MeV electron beam current must be at least 4 times bigger.

Another optimization was performed with respect to the gun injection energy. Although for accelerator 6/15 it is preferable to use the triode gun with the accelerating potential of (9-15) kV, in some cases it can be useful to have also the possibility to apply (30-40) kV modified diode gun, used e.g. in accelerators NEPTUN and COLINE.

The main results of these calculations are the following: phase acceptance for electron energies in the range (6-15) MeV and energy dispersion $\Delta E/E < 5\%$ is 160°-180° - Table. Phase change between the buncher and main accelerator is $\Delta \phi = 33.5^\circ$ for 15 keV injection energy and $\Delta \phi = 57.5^\circ$ for 40 keV. Some representatives results are also shown in Figs (1-4).

<table>
<thead>
<tr>
<th>$E_0$/MeV</th>
<th>$\Delta \phi$</th>
<th>$\Delta E/E$</th>
</tr>
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<td>6</td>
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<tr>
<td>$\Delta \phi$</td>
<td>$33.5^\circ$</td>
<td>$57.5^\circ$</td>
</tr>
</tbody>
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**Fig. 1** Electron beam accelerated to 6 MeV in 6/15 MeV structure.

**Fig. 2** Histogram of energy distribution.
10.2 Development, Design and Experimental Testing of Electron Injection Sources for Linear Medical Accelerators
by S. Kuśński, E. Pławski, W. Pęcilo, H. Wojnarowski, T. Ołdakowski

Electron sources

In medical electron accelerators built up to now in Poland: Neptun, Limex, Coline the source of electrons (gun) was a diode with a thermionic cathode made of tungsten. Parameters has been done with the aid of the Hermannsfeldt EGUN code followed by some measurements on specially built stands. Some results of these studies are given below.

For the new 6/15 medical accelerator the final solution will be a triode gun. However, for the sake of study and further development of electron sources, it was decided that both diode and triode guns could be used for the prototype accelerator. For this purpose optimization of gun geometrical and electrical...
electrons are too strongly focalized. They have rather narrow waist in the vicinity of anode, about 2 cm from cathode, and are strongly divergent later on. The entrance of the accelerating structure has 5 mm radius and is about 6 cm from the anode. It is seen from the picture, that if there were no focusing magnetic field, some part of electrons would be lost on the walls.

To avoid this and obtain more smooth and slightly convergent beam at the entrance to the structure some modification of the gun focusing electrode has been made giving the results shown in Fig. 2.

The diode gun with the modified geometry was constructed and tested in ZdAJ. The current above 400mA was measured, which fulfils requirements for 4, 6, 9 and 15 MeV medical accelerators.

**The Triode**

As an alternative, the use of triode type of the gun was studied. For that purpose spherical a cathode - grid assembly was bought with the following nominal data claimed by the producer: grid cut off = -60 V, grid drive = +60 V for 1 A at Ua = 12 kV; grid current = 12% Ic, grid load 1 W max; heater 6.3 V / 2.0 A;

Pulse width 100 μsec max, duty cycle 0.04 max is allowed. The cathode material is of dispenser type containing BaO-74.4%, CaO-9.1%, Al₂O₃-16.5%. The vacuum conditions for this type of cathode are rather severe (better than 5x10⁻⁷ Torr). The advantage of triode over diode gun is independent regulation of gun current and energy at much lower heater power and lower anode voltage.

The gun dimensions are reduced at least twice. The high vacuum stand equipped with the wire scanners was built to measure and verify the calculated (Fig. 3,4) optical parameters.

![Fig. 3 Triode GUN. Ua = 12 kV, Ug = 60 V, I = 0.4 A.](image)

![Fig. 4 The beam scanner wires positions in measuring stand and expected 15 keV / 200 mA beam profile as a function of solenoid field.](image)
10.3 Focusing, Transport and Deflection of Accelerated Electron Beam in 6/15 MeV Accelerator
by E. Plawski, S. Kuliński, A. Kucharczyk

The electron beam after leaving the gun has to pass through the RF accelerating structure and 270° bending electromagnet without losses. The transverse defocusing or bending forces acting on the electron originate from space charge of the beam itself, phase dependent rf field radial component, beam induced wakefields generated in the structure and the stray magnetic fields originating from magnetic fields of accelerator environment. These forces are to be compensated by superimposed magnetic force of external solenoids and correction coils. The beam leaving accelerating structure horizontally has to be well positioned vertically and focused on e/X converter or scattering foil of collimator head.

![RF electric field distribution in buncher part of 6/15 MeV accelerating structure](image1)

The RF electric field distribution in resonant accelerating structure shown in Fig. 1 and magnetic solenoidal fields shown in Fig. 2 were used in beam behaviour simulation (acceleration and focalisation in linac).

![One of possible solution of focusing solenoid](image2)

![Transverse focusing of electron beam in buncher section of 6/15 MeV medical linac](image3)

The dependence of beam transverse dimension on the RF input phase at several values of magnetic field of solenoid is shown in Fig. 3. The optimal value of magnetic field of solenoid is in the range of 900 Gs. To minimize the magnetic field at the gun cathode the bucking coil (Fig. 2) is added at the input instead of making burdensome iron magnetic shield inside the input side of accelerating structure. Similar procedure was adopted to study the beam behaviour in the whole linac accelerating electrons to energies 6 to 15 MeV.

![Bending achromatic 270° electromagnet of 6/15 MeV linac](image4)

Electron beam is analysed and directed toward conversion target by means of 270° achromatic electromagnet. The magnetic and focusing properties were calculated using POISSON and TRANSPORT codes. In Figs 4-6 the magnetic circuit simulation and beam transport simulation samples are shown.
The calculated working parameters of electromagnet are listed in the table below.

<table>
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The average radius of curvature in the electromagnet field was optimised to be 64 mm. The optimised parameters of electromagnet are the following: the magnetic gap $g = 18$ mm, the beam average curvature radius $\rho = 64$ mm, input/output angles $31^\circ / 51.5^\circ$, yoke type C from 1010 type soft iron ($\mu > 1400$ at $B = 13$ kGs). The beam trajectory length in magnetic field $L = 296$ mm, field index $n = -0.5$ in central part of 50 mm extension; $n = 0$ elsewhere.

Fig. 5 300mA/15MeV monoenergetic beam envelope in achromatic bending system composed of input quadrupole doublet and 270° electromagnet. Emittance $e_x = e_y = 2$ mm x 5 mrad, $Q1 = 0.0$, $Q2 = 0.0$; Beam size at e/X converter $x = 1.1$ mm, $y = 1.1$ mm.

Fig. 6 As in Fig. 5, with $E = 15$ MeV ± 3%.

10.4 Features of the Microwave System for 6/15 Linear Electron Accelerator

by J.Bigolas, S.Getka, M.Pachan, T.Oldakowski, S.Stępiński, J.Bogowicz

According to specified highest energy of accelerated electrons 15 MeV and a broad range of energy control, the most suitable solution for r.f. power system for feeding accelerating structure, was an application of the pulse klystron tube TH-2074 A of THOMSON with the peak power 6 MW in 5 µs pulse. Pulsing of the klystron is effectuated by a high voltage modulator with a peak output voltage of 130 kV.

To fulfil the requirements of operation in electron mode in energy range 6 to 15 MeV and in photon mode with two energies 6 and 15 MV, the accelerating structure was designed with two functional parts fed separately by the two coupled waveguide transmission lines after power splitting at the output of the klystron. It is shown in Fig. 1. The first section of the structure - the bunching section is fed from the main waveguide line through the directional coupler designed to couple out the definite part of total power. This power has a constant value.

The second part of the structure is supplied by variable level r.f. power. The control of this variation is effectuated by means of the waveguide reflector introducing into the transmission circuit a variable impedance.

Under these conditions, the buncher delivers at its output an optimal constant beam energy, and in the second part of the structure depending on the supplied r.f. power the output energy of electrons is controlled in the range 6 to 15 MeV. The above mentioned reflector is a microwave device incorporated into waveguide power transmission line. It contains in its interior a dielectric slab with remote control of positioning. Position of the slab determines the impedance and through it the level of the transmitted power.

Measurements were done to find variation of power and phase in function of reflector's position. In the case of possible solution joining both functional sections of accelerating structure in a single vacuum envelope with one feeding waveguide, the reflector plays an essential role in controlling total level of r.f. power supplied to the structure.
10.5 Testing Bench for Accelerating Structures with Accompanying Beam Diagnostics Equipment

by W. Maciszewski, A. Wysocka, J. Bigolas, W. Drabik, S. Getka, M. Śliwa, S. Stepniak, J. Bogowicz,

Simplified block diagram of the test bench is shown on Fig. 1.

The basic systems of the test bench are:
- high power RF generator,
- wave guide line,
- accelerating structure being tested,
- beam diagnostics and measurement devices,

As the RF power generator, the RF part of S-20 set up described elsewhere [1] is used.

Among the auxiliary systems, are power supply, control system, vacuum system, cooling system. To diminish thermal detuning of the structure, the temperature of cooling water should be stabilised at the level of 40±1°C or better. For improvement of the stability of the whole system operation, AFC (automatic frequency control) system is added.

Basic technical data of the test bench are as follows:
- destination - testing of accelerating structures and auxiliary systems of electron accelerators within energy 6-15 MeV
- accelerating structure to be tested - 2998 MHz RF
- standing-wave system of π/2 type, power supply 6 MW, pulse 4 μs, pulse repetition rate 10-50 Hz
- beam focusing system - solenoid and quadrupole lens
- pulse beam current - 50 mA max. beam deflection system - 2700 bending magnet.

For diagnostics and measurements of the output beam delivered by the accelerating structure, the following devices are proposed:
(a) Faraday cup, for direct verification of beam current;
(b) Ionex dosimeter, to measure on axis dose rate;
(c) Magnetic energy analyzer to measure beam energy and spectrum, within energy range of 4-20 MeV. The system is described elsewhere [2];
(d) POSEIDON, universal system of dosimetry. The system consists of water phantom, local control unit of the phantom, set of detectors and central PC work station with software in Windows environment. For testing of accelerating structures, most important functions of the system are measurements of: depth dose distribution, dose profile, point by point scanning on surface and in volume of phantom, tracing of isodoses, dose rate stability in time.

Stereotactic radiosurgery (SRS) using external beams of radiation has become an important method of treatment of small intracranial lesions. In this non-invasive technique a high dose of radiation is delivered to the stereotactically localized lesion, while minimally irradiating adjacent normal brain tissue [1], [2].

For many years radiosurgery was performed either with gamma beams from multi-mini cobalt sources so-called gamma knife unit or with heavy charged particle beams from cyclotrons. Now the photon beams from modified isocentre linear electron accelerators are a noteworthy alternative to these expensive and complex methods. The modifications which are needed to adapt modern linacs to radiosurgery, are relatively simple and consist typically of a set of additional tertiary collimators to define the beams with diameters from 10 to 30 mm, and brackets or a floor stand for a mounting the stereotactic frame.

We have designed in our laboratory a set of tertiary collimators and the collimator mount fittable to the head of the linac. The dosimetric features of these collimators in terms of beam characteristics were presented in [3].

The standard collimators of the linac consist of a conical primary collimator and two pairs of adjustable secondary collimator jaws. The primary collimator defines the maximum dispersion angle of the radiation beam. The secondary collimator jaws restrict the beam in x and y direction and define a rectangular radiation field. The source-to-axis distance (SAD), i.e. the distance between the beam focus and the isocentre, is 1000 mm.

The collimator mount is directly fixed to the collimator of linac and is fitted with an adjustment device, which permits the centering of the collimator at the isocentre. The tertiary collimators are made of lead and are lined with 2 mm aluminium. They have divergent edges inside, to reduce transmission penumbra. The three additional collimators are 110 mm thick with 10, 20 and 30 mm field size diameters, respectively, at the isocentre. The outer diameter of the collimators is 68 mm. The rectangular collimator of the linac is set to a field 5x5cm$^2$ when additional collimator is used.

Accurate dosimetry of small-field photon beams used in stereotactic radiosurgery (SRS) and radiotherapy (SRT) is difficult because of the presence of lateral electronic disequilibrium and steep dose gradients. The detectors used for measurements of absorbed dose distribution must be small with respect to the size of radiation field and must have a sufficient spatial resolution. Therefore small volume ion chamber, diode, diamond detector and film are proposed for that purpose [4].

In this study measurements were done with small-volume Scanditronix ion chamber type RK and Wellhöfer pinpoint chamber type IC04. Active volumes of the RK thimble chamber and IC04 pinpoint chamber are 0.12 cm$^3$ and 0.03 cm$^3$, respectively. We used the parallel and perpendicular
The following characteristics of the small fields for three additional collimators at the isocentre were determined:

- tissue maximum ratio (TMR),
- off axis ratios (OAR) and
- total scatter factors (St)

All measurements were performed at Source Surface Distance SSD equal 970, 975, 980 mm for 30, 20 and 10 mm diameter collimator respectively.

The $d_{\text{max}}$ depth of maximum calibrated TMR was found between 19 mm and 30 mm and increased with increasing field diameter.

Measurements of beam profiles were performed with parallel orientation of the ion chamber. The values of the penumbras for measured beams are in the range of 4.0 to 5.4 mm. Unfortunately we have no possibility to use diamond in our laboratory set-up, which would be a better choice and could yield more accurate results.

The Total Scatter Factors for the beam formed with collimators 10, 20 and 30 mm in diameter and with fixed primary jaws field size setting: 5x5 cm$^2$ were 0.69; 0.83 and 0.90, respectively.

The dosimetric characteristics of investigated collimators were found to be suitable for stereotactic radiosurgery and radiotherapy.


Depth dose curves and lateral dose profiles at 7.5cm in the water phantom were obtained for 6 MeV photon beams. Two separate calculations with different cube phantoms were done; one phantom had a high resolution along the beam axis to obtain depth doses, the other one had a high resolution in the xy-plane at 7.5 cm, to obtain lateral dose profiles.

Broad beam photon spectra calculated by Mohan et al. were used as input. The preliminary results are interesting and the work will be continued. In the next step it would be good to have the possibility of introducing real photon spectrum for each individual narrow beam collimator and then compare dose calculation with measurements.


10.8 The Accelerating Structures Development for TESLA Project
by E.Plawski, J.Sekutowicz

Within the frame of TESLA collaboration [1], part of the works on superconducting superstructures [2] is being performed in P-10 Department of IPJ, Świerk. After the experimental verification of the RF parameters on room temperature superstructure models [3,4], the production of cold models (high purity niobium) was decided by the end of 1999.

The replacement of the actual 9-cell TTF cavities by 4x7-cell superstructures would have very strong positive impact on cost and operational reliability of the planned future TESLA [1] collider.

In the beginning of 2000 the cells of 7-cell cavity were produced at SINS from high purity niobium (RRR>300) delivered from DESY. The technology used in deep-drawing of resonators was similar as in previous production of copper cavities[4]. The additional requirement for superconducting cavity is extremely clean inner surface of resonator cups. The particular attention has been paid to avoid any contamination by of foreign material during heavy deep-drawing and machining of parts. The shapes of drawing tools were modified slightly to accommodate 10µm guard reinforced polyethylene foils and assure at the same time necessary precision of final resonators' cups. The electron beam welding was done by DESY. The first bulk niobium superstructure model (4x7-cell set) will be cooled down to 2K and RF power tested in early 2001.

The superstructure, after successful cold RF test can be incorporated into the string of TTF 9-cell cavities. As from the principle of operation the beam tubes of both types are different, it is necessary to provide proper interconnections between adjacent cavities. The proposed solution is shown schematically in Fig. 1. The interconnection is composed of 114 mm dia. output tube of superstructure, 10 waves bellow and 78mm dia. input tube of 9-cell cavity. All parts are to be made from RRR>300 grade niobium.

![Fig. 1 Flexible interconnection between superstructure and TTF 9-cell cavity](image)
Since there is a sudden change of the diameter of the adjacent cavities, an increase of electron energy loss and transverse momentum kicks due to wake generation is expected. We calculated the loss parameters for the proposed interconnector using the procedures employed earlier in evaluation of beam induced wakepotentials in TTF cavities and superstructures [5, 6]. The loss parameters were calculated for the geometry including outer cells of both cavities. To arrive to some conclusion the comparison is made with the results obtained for flexible interconnection between the adjacent cavities of classic TTF 9-cells system.

The longitudinal and transverse wakes and corresponding loss factors were calculated for two typical bunch lengths. The gaussian bunches of standard deviation equal to 1mm and 0.5mm were taken and numerical code ABCI was used as in all previous calculations.

The sample examples of calculations are presented in Table 1 and Fig. 2 where longitudinal and transverse momentum loss factors are given for two typical bunch lengths.

In Fig. 2 the frequency spectrum of longitudinal modes excited by $\sigma = 0.5\text{mm}$ bunch passing the superconducting geometry of Fig. 1 is shown.

| Superstructure-to-9cell TTF Interconnection; $\sigma = 0.5\text{mm}$ Gaussian |
|-----------------------------|-----------------------------|-----------------------------|
| (qL/qV)/(qL/qV)max          | (qL/qV)/(qL/qV)max          | (qL/qV)/(qL/qV)max          |
| 1.00                        | 1.00                        | 1.00                        |
| 0.80                        | 0.80                        | 0.80                        |
| 0.60                        | 0.60                        | 0.60                        |
| 0.40                        | 0.40                        | 0.40                        |
| 0.20                        | 0.20                        | 0.20                        |
| 0.00                        | 0.00                        | 0.00                        |

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<th>$W_{l}$ at $\sigma \leq 1\text{mm}$</th>
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</tbody>
</table>

Table 1

Fig. 2 Frequency spectrum of $k_{l}$ of interconnection shown in Fig. 1 for $\sigma = 0.5\text{mm}$ bunch.


1) DESY Hamburg, Germany
10.9 Technologies and Apparatus for thin Layer Coatings of Accelerator rf Subunits
by J.Lorkiewicz, B.Dwersteg, A.Brinkmann

Multipacting in high power rf components takes place whenever certain resonance conditions for electron trajectories are fulfilled and the impacted surface has a secondary electron emission coefficient bigger than one. Multipacting currents absorb rf power and deposit it as heat in localized areas. They often cause breakdowns in couplers, higher order mode absorbers, rf windows etc. A number of means has been proposed to avoid the above effects. Apart from avoiding geometric resonant conditions in couplers, transmission lines or resonant cavities one can use thin layer surface coating to reduce the secondary electron emission. Of the commonly used coating materials (chromium oxides, titanium or titanium compounds) titanium nitride shows sufficiently low secondary electron emission and good stability in the rf field. To cope with multipactoring problems a number of components of rf couplers for TESLA facility at DESY has been TiN coated [1,2]:

- DESY-TTF-II coupler coaxial line metallic components
- DESY-TTF-III coupler cylindrical 300 K ("warm") ceramic windows (20 pieces)
- DESY-TTF-III coupler cylindrical 70 K ("cold") ceramic windows (21 pieces)
- flat waveguide ceramic windows for the main TTF coupler (21 pieces).

Before the TiN coating the performance of the flat waveguide windows of the main TESLA coupler showed problems with power transmission associated with intense secondary electron and light emission. The window of this type consists of an alumina disc installed in a stainless pillbox-type container. It fulfills the resonant condition for two side multipacting in an electric field.

TiN layers on ceramic or metallic surfaces has been created by deposition from titanium vapour in ammonia. The vapour was sublimated from electrically heated Ti wire. The effect of coating procedure on multipactoring suppression was first studied using a multipactor test resonator at DESY [3]. The device enables a straightforward measurement of rf multipactoring current between two electrodes of a specially designed coaxial resonator. Twelve pairs of electrodes of aluminum or copper were TiN coated using different processing conditions and next tested. Time needed to overcome multipactoring (suppress the current) was used for selection of processing parameters. The best results were reached for single coating operations at titanium deposition rates on a substrate between 6 and 15 nm/min. at a pressure of ammonia of 10-3 mbar. For better Ti - TiN chemical conversion the substrate with the deposited Ti layer was kept for 1-3 days at a pressure of ammonia increased to several hundred mbar. The chemical composition of a layer has been further checked using SIMS method [4]. TiN content reached typically more than 80% and there were some small titanium oxide admixtures.

TiN coating of the above rf power components was performed in a vacuum vessel evacuated by a turbopump. The sublimation setup for each sort of components consisted of vertical, 1 mm diam. titanium wires or wire loops (catenaries), appropriate platforms and shields. Due to a complicated geometry the setup for coating the flat waveguide windows was designed after numerical simulation of the layer thickness distribution. The surface processing improved significantly the rf operation of the waveguide windows:

- full power transmission has been reached
- no secondary or light emission was detected and
- rf performance was insensitive to a previous 1 day exposition to the atmosphere.

In addition two pairs of 300 K and 70 K coated ceramic cylindrical windows have been installed in couplers.

[2] J. Lorkiewicz, B; Dwersteg, Example for coating by sublimation: TiN for RF windows, Workshop on Thin Film Coating Methods for Superconducting Accelerating Cavities, DESY, July 10, 2000,

1) IPJ, Otwock-Świerk, Poland
2) Deutsches Elektronen Synchrotron (DESY), Hamburg, Germany
3) Now at DESY, Hamburg, Germany
10.10 Conceptual Design of a New Bunching and Pre-injector System for ELETTRA Synchrotron in Trieste
by S.Kulinski, E.Plawski, G.D'Auria1, C.Rossi1,

The Sincrotrone Trieste is considering to change the existing injection system of ELETTRA storage ring consisting of 1 GeV linear accelerator into a new full energy (2 - 2.4) GeV injection system composed of 100 MeV pre-injector Linac and a Booster Synchrotron. The Department of Accelerator Physics and Technology was invited to participate in the works connected with 100 MeV Linac and especially in the 10 MeV bunching system of it [1]. A short description of works done in IPJ in collaboration with Sincrotrone Trieste is given below.

Buncher

The bunching system will be composed of:
- 100 keV thermionic electron gun
- 500 MHz subharmonic prebuncher
- 12 MeV 3 GHz buncher

Schematic picture of the gun is shown in Fig. 1 together with computed by the EGUN code equipotential and beam lines. The cathode is a Thomson TH306 planar 1 cm² (0.6 cm radius) cathode with a wire grid at 100 μm from the emitting area.

Subharmonic prebuncher

- frequency 499.654 MHz
- material stainless steel covered with copper
- modulation voltage 20 - 30 kV
- input power P = 500 W
- quality factor Q 11 000

3 GHz Buncher

Main parameters of the buncher are:
- Frequency 2997.924 MHz
- Type of accel.struc. SW biperiodic 1/2π axially coupled
- Shunt impedance (ZT²) > 75 MΩ/m
- Length 1.18 m
- Energy (12+13) MeV
- Unloaded power input (2.5±3) MW

Cross section of accelerating and coupling cell together with electric field lines is shown in Fig. 2.

Axial distribution of electric field is presented in Fig. 3.

Calculated by the SUPERFISH code RF pulse power to excite the average field intensity of 12.5 MV/m in 25 accelerating cells will be 1.6 MW.
The results of single particle beam dynamics from the gun to the buncher output are shown in Fig. 4.

About 50% of all phases are accepted by the system and accelerated to an energy of 13 MeV with energy spread of 5%. About 40% of all particles have energy spread of 2%.

The phase spread of electrons at the output is about 30 degrees - (170°-200°) degrees.


1) Sincrotrone Trieste, Italy
LIST OF PUBLICATIONS

DOSIMETRIC CHARACTERISTICS OF CIRCULAR 6MeV X-RAY BEAMS FOR STEREOTACTIC RADIOTHERAPY WITH A LINEAR ACCELERATOR
A. Wysocka, J. Rostkowski, M. Kania, W. Bulski, J. Fijuth

PARTICIPATION IN CONFERENCES AND WORKSHOPS

PRACTICAL SOLUTION OF HIGH GRADIENT ACCELERATING STRUCTURE FOR LOW ENERGY MEDICAL LINEAR ACCELERATOR
S. Getka, J. Bigolas, S. Kulinski, J. Oldziewski, M. Pachan, E. Plawski
7th European Particle Accelerator Conference A Europhysics Conference, Austria, Vienna, 26 - 30 June 2000 (Poster)

THE PHOTON BEAM CHARACTERISTICS OF LINEAR ACCELERATOR EQUIPPED WITH ADDITIONAL NARROW BEAM COLLIMATOR
A. Wysocka, W. Maciszewski
7th European Particle Accelerator Conference A Europhysics Conference, Austria, Vienna, 26 - 30 June 2000 (Poster)

THE 100 MeV PRE-INJECTOR LINAC FOR THE PROPOSED BOOSTER SYNCHROTRON OF ELETTRA
G.D. D'Auria, S. Kulinski, E. Plawski, C. Rossi
7th European Particle Accelerator Conference A Europhysics Conference, Austria, Vienna, 26 - 30 June 2000 (Poster)
A. Wysocka

COMMUNICATIONS PUBLISHED IN CONFERENCES' MATERIALS

PRACTICAL SOLUTION OF HIGH GRADIENT ACCELERATING STRUCTURE FOR LOW ENERGY MEDICAL LINEAR ACCELERATOR
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DOSIMETRY FOR 6-MV X-RAY BEAMS IN STEREOTACTIC RADIOSURGERY
J. Rostkowski, M. Kania, A. Wysocka, W. Bulski, S. Pszona
19th Annual ESTRO Meeting Istanbul, Turkey, 19-23 September, 2000
Abstract in Radioth. Oncology, 2000, Vol. 56, (Suppl. 1), 198

LECTURES, COURSES AND EXTERNAL SEMINARS

Electron Beam Transport Optimisation In High Power Accelerator
J. Bigolas, S. Kulinski, W. Maciszewski, M. Pachan, E. Plawski, Z. Zimek
Seminar in Institute of Nuclear Chemistry, 15 May 2000, Warsaw

Perspectives of Polish-German cooperation in science and technique (poster)
Symp. organised by the Committee of Scientific Research and German Federal Ministry of Research and Education, 2 - 4 Oct. 2000

a) in Polish
b) in English
PERSONNEL

Research scientists

Stanisław Kuliński, Professor
Wiesław Maciszewski, Dr.
Marian Pachan, MSc. 3/5
Eugeniusz Pławski, Dr.
Anna Wysocka, MSc.

Technical and administrative staff

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<tr>
<td>Jerzy Bigolas</td>
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<td>Krzysztof Bigolas</td>
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<td>Józef Bogowicz</td>
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<td>Wojciech Drabik</td>
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<td>Stanisław Getka</td>
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Overview

The main goal of the Department is centered around education of pupils, students and social groups interested in ionising radiation. Close to 2100 students from various secondary schools were visiting the Department last year. In addition, we were servicing a few groups of students from some Polish Universities and Academies as well as a group of local governement.

The building in which the Department is situated underwent important reconstruction which permitted the start of the atomic and nuclear physics laboratory for pupils and students. The laboratory is meant as a place in which young persons can perform relatively simple experiments. At present, one can conduct a series of experiments with X-rays. These include measurements of the emission spectrum from an X-ray (Mo) tube, the optical properties of X-rays through the diffraction by crystals, one can measure absorption in various materials also in dependence on the material thickness, employ X-ray transmission to visualise what is contained in a plastic box, etc. The experimental set with the Thompson tube permits one to measure $e/m$ and see the influence of electrical and magnetic fields on the electron beam. Another set served to make experimentalists acquainted with the essence of luminescence induced by electrons and ultra-violet light. For more demanding pupils, the nuclear spectrum can be measured with the High-Purity Ge-detector with full possibilities of standard energy-analysis, which can be used for learning the features of the Rutherford and Compton scatterings. We hope to introduce soon another small size solid-state detector to measure energy spectrum of X-rays in the aforementioned X-ray set.

The lecture room was equipped by a TV-video set and the video-camera for projecting the pictures arising in experiments (for example with a small Wilson chamber) carried out on the desk onto the TV screen. The room was also decorated by large tableaux of the The Periodic Table of Elements and the Table of Isotopes (actual for the end of 2000), as well as a series of pictures illustrating the very essence of the environmental radiation.

The permanent exhibition „Nuclear wastes: problems, solutions” has been enriched in new themes like the use of reversed osmosis for filtering and condensing the radioactive wastes, and the problems of handling the high-activity wastes. In a sense, our center presents in pictures most of the problems connected with ionising radiation, starting from its physical principles, through environmental radioactivity to the very basis of nuclear reactors, and finally application of isotopes and problems of the nuclear wastes treatment.

On the scientific side, one member of the Staff successfully passed the PhD procedure in the University of Uppsala, Sweden. Activity was quite varied which is illustrated by the titles of published papers. Probably the most intriguing results were obtained for Cr-Mn-Fe and Th-U-Al alloys. Both families of alloys show non-standard magnetic structures whose determination presents many experimental problems. Important progress was also made in the reconstructions of the charge- and electron momentum-densities by the Maximum Entropy Method (MEM). The aforementioned studies of alloys as well as the development of MEM technique were conducted essentially at the Institute of Experimental Physics, University of Białystok. Some experiments have been carried out at Hahn-Meitner Institute in Berlin and in HASYLAB/DESY in Hamburg, both in Germany, as well as in collaboration with the University of Paris 6, France.
11.1 Mössbauer, X-ray, Compton, Magnetisation and Electric Transport Studies of Cr-Fe-Mn Alloys

The studies of disordered Cr-Mn-Fe alloys with bcc structure were undertaken with the goal to find the interrelation between electric transport (especially magnetotransport) and electronic properties. Two group of samples are studied: one with the average electron concentration constant, and the other one, in which this concentration varies in a maximal way. There is no doubt that relatively high magnetoresistance appears in the samples which exhibit apparent ferromagnetism. The transition to the paramagnetic or antiferromagnetic phases results in disappearance of the magnetoresistivity, the latter measured in the fields up to 2 T. The attempts to estimate the concentration of conduction electrons from the measured Hall effect were generally inconclusive except of one sample only. In all, the value of the Hall constant turned out to be lower than the practical detection limit of the equipment used.

The measurements of Compton scattering have been carried out in order to find whether observed changes in electric properties may be due to the d-s electron transfer. Indeed, such a transfer was found for two samples, in particular the one with apparently high conduction electron concentration.

In order to study the magnetic structure of the alloys in question, the Mössbauer polarimetry with the circularly polarised, monochromatic source (MCPMS) was applied. The shape of the spectra, their dependence on external magnetic field etc. Leave no doubt that it is iron which is responsible for the appearance of ferromagnetism in the alloys. Moreover, iron can induce some ferromagnetic moment in the otherwise antiferromagnetic matrix formed by Cr and Mn. The distribution of the magnetisation is highly inhomogeneous. Not only are there two sorts of iron atoms with high and low hyperfine magnetic field, but also the magnetic moments of iron from the former group exhibits large orientational disorder. The number of iron atoms which belong to the second group, those with the low field is apparently correlated with the probability of finding eight chromium atoms around iron, so it is concluded that the low hyperfine magnetic field is characterising iron surrounded uniquely by chromium atoms.

[1] Institute of Experimental Physics, University of Białystok, Lipowa Str. 41, 15-424 Białystok, Poland
[2] The Soltan Institute for Nuclear Studies, 05-400 Otwock-Swierk, Poland

11.2 Mössbauer and X-ray Studies of Er-Fe-B Amorphous Alloys
by K. Szymański, B. Kalska, D. Satuła, R. Wäppling, P. Nordgren, L. Häggström, L. Dobrzyński

Er-Fe-B amorphous alloys were studied by X-ray and Mössbauer techniques. This system is characterised by a large orientational disorder of magnetic moments due to a distribution of local anisotropy fields. In general, the orientation of iron and erbium magnetic moments is antiparallel with erbium moments dominating at low temperatures. This conclusion can be drawn based on the results of the Mössbauer measurements using the circularly polarised, monochromatic source (MCPMS). Above about 230 K the situation reverses and it is iron whose magnetic moments decide about orientation of the total magnetisation.

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11.3 Electron Distribution in GaN Single Crystal
by J. Waliszewski, L. Dobrzyński, Th. Lippmann, M. M. Costa, S. Porowski, T. Suski

The single crystal X-ray and synchrotron radiation diffraction experiments for low (LN) and room (RT) temperatures studies of GaN have been carried out on the instruments at the University of Coimbra, Portugal, and at the HASYLAB/DESY center in Germany. The structure factors obtained served as an input to the Maximum Entropy procedure used for reconstruction of the charge density distribution in this important, wide-gap semiconductor. The non-uniform prior charge density was used. The non-nuclear maxima in the interstitial positions (0,0,0) and (0,0,0.5) are observed. In fact, a similar picture was obtained in our earlier powder studies (to be published in J. Phys. Soc. Jpn 70, No. 1, 2001). The differences
Magnetic Form Factor of Cu$_2$MnAl Determined by White Beam X-Ray Diffraction

Circulary polarised synchrotron radiation of a white beam has been used at the ESRF Station BL28-XMAS to study magnetic form factor of Cu$_2$MnAl single crystal (Heusler alloy) at room temperature for (110)- and (111)-type reflections. The results extend beyond the momentum transfer range accessed by neutrons, sin(θ)/λ < 0.9 Å, up to about 2.4 Å$^{-1}$. The substantial extension of this range results in an increase of the spatial resolution in the spin-density analysis. This makes it possible to study crystal effects on 3d wave functions in greater detail than possible with the use of neutrons.

The polarised neutron results indicated a spherical 3d spin density and a positive conduction electron contribution of +0.17 μ$_B$. Our studies confirm the nearly spherical character of the spin-density distribution. However, spin-dependent electron momentum distribution in Cu$_2$MnAl studied by Compton scattering was first interpreted in terms of a negative spin polarization of -0.4 μ$_B$. On the other hand, 3D reconstruction of this momentum density by the Maximum Entropy Method turned out to be possible under an assumption of a strictly positive distribution. Current data analysis aims at providing answers to controversies mentioned above and to compare the experimental data with a new theoretical calculations of the magnetic form factor, based on the Korringa-Kohn-Rostoker (KKR) band technique.

Directional Compton Profiles Studies of Cadmium

Studies of cadmium form part of the project concerning the electronic structure studies of hexagonal metals: Mg, Zn and Cd. Only powder data exist so far while the single crystal data for another hcp metal – Be are not consisted with KKR calculations. Similar calculations have been carried out for cadmium and, earlier, for zinc. An important improvement of the theoretical results with the experimental ones obtained for zinc gave us confidence in the correctness of the theoretical approach. However, in the case of cadmium relativistic corrections are of importance. The experimental results are now in the process of the data handling and it is positively too early to give any reliable statements on them.

Magnetic Properties of U-Th-Al Intermetallic Alloys

Unpolarized neutron powder diffraction and conventional magnetic experiments were carried out on ThFe$_{4+x}$Al$_{2-x}$ (x=4, 4.5 and 5) family of alloys with the goal of determining the crystal and magnetic structures. All selected ThFe$_{12-x}$Al$_x$ (x = 4, 4.5, 5) intermetallic compounds belong to space group...
14/mmm with body centred tetragonal symmetry. The magnetic behaviour of these compounds is non-trivial and the magnetic structures were not characterised so far. The neutron measurements were supplemented by standard X-ray and Mössbauer techniques including modern Monochromatic Circularly Polarised Mössbauer Source (MCPMS). The project forms a part of a wider research program aiming at qualitative and quantitative determination of magnetic ordering of the MFe, Al_{2-x} (M = U, Th, Sc) intermetallic alloys.

The crystal structures were determined by means of the neutron and X-ray powder diffraction above magnetic phase transition temperatures. The magnetic scattering was measured at the Hahn-Meitner Institut in Berlin in the temperature range 1.5 - 220 K with the 239,6 pm neutrons. At present, the most important conclusions from our research are as follows: all tested samples exhibit well ordered ThMn_{12} - type structure. ThFe_{4}Al_{5} is single phase within the accuracy of measurements. Amounts of extra phases of β-FeAl and ThO_{2} in the samples with higher iron concentration have been found. In spite of the presence of these phases, the presence of stoichiometric composition of the ThFe_{4}Al_{5} was confirmed within the accuracy of the refinements by Fullprof program. Our measurements confirmed the change of magnetic structure with an increase of the iron concentration. In the case of ThFe_{4}Al_{5} the magnetic atoms occupy one sublattice only. Four magnetic peaks were found below the transition temperature. The peaks appear shifted with respect to the nuclear peaks and broadened to such extent that they seem to present unresolved doublets. In contrast to the uranium containing sample, no evidence of antiferromagnetic structure was found.

From our magnetisation measurements it follows that certain spontaneous magnetisation characterises all samples. This corresponds, at 10 K, to 0.6 mB/atom, 3.3 mB/atom and 2.6 mB/atom for ThFe_{4}Al_{5}, ThFe_{4}Al_{5} and ThFe_{4}Al_{5}, respectively. Because iron is the only magnetic moment carrier, these values correspond to the average iron moments from 0.15 mB/atom through 0.74 mB/atom up to 0.53 mB/atom for x = 4, 4.5 and 5, respectively. It seems that the ferromagnetic kind of ordering appears in the last two samples. Unfortunately, we found no neutron evidence of the ferromagnetic contributions to the nuclear peaks. The overall situation is unclear and needs further studies with either better statistics or with the use of single crystals, if available.

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11.7 Exchange Coupling Between Fe Atoms in Fe/V Multilayers

by B. Kalska, L. Häggström, E. Nordström, P. Blomquist and R. Wäppling

Fe/V multilayers prepared by the sputtering method were studied by Conversion Electron Mössbauer Spectroscopy. The Mössbauer studies on a complete series of samples from Fe(x)V(y) system has been done at room temperature and 10K. The series contains samples with x=5ML, 7ML, 10ML and y=5ML, 10ML, 14ML. The interlayer influence on the Fe hyperfine field distributions has been found. The influence on hyperfine field distribution from the oscillation coupling between layers has been found and is not dependent on the temperature.

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11.8 Magnetic Moment Arrangement in Amorphous Fe_{96}Er_{0.19}B_{0.15}

by B. Kalska, K. Szymański, R. Wäppling, P. Nordbland and L. Dobrzyński

Standard Mössbauer spectroscopy, spectroscopy using a monochromatic circularly polarized Mössbauer source (MCPMS) and magnetisation measurements have been performed at room and low temperatures with and without external magnetic field in order to find the magnetic properties of the amorphous Fe_{96}Er_{0.19}B_{0.15} alloy. The reorientation of the magnetic moments of iron and erbium during sample cooling through the compensation point in a magnetic field is clearly seen. The amorphous metal is found to order ferromagnetically at T_{c} = 330 K and shows a compensation temperature, T_{comp}, at 120 K. The net magnetic moment is dominated by parallel Fe moments above T_{comp} and by the antiparallel but "randomly" oriented Er moments at low temperatures. The results are compatible with predominantly antiferromagnetic Fe-Er coupling combined with strong magneto-crystalline interactions for Er.

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11.9 Interface Roughness/Intermixing and Magnetic Moments in a Co/Fe(001) Superlattice

by B. Kalska, P. Blomquist, L. Hägström and R. Wappling

The superiority of a local probe method over diffraction methods in determining the interface details is demonstrated by a comparison between Fe/Co and Fe/V superlattice data. From Mössbauer spectra, the higher interface quality in the Fe/Co superlattice was evident although the X-ray diffraction data was similar in the two cases. In fact, by comparison of the details of the Mössbauer spectrum for the Fe/Co case with published values of the magnetic hyperfine field for iron in cobalt no detectable roughness/intermixing was found. From the variation of the iron magnetic hyperfine field as a function of location of the iron atoms, with respect to the interface, the individual iron magnetic moments could be derived. The magnitude of the magnetic moments thus obtained correlate well with recently calculated values.

11.10 A Study of the Different Interfaces in Fe/V Superlattices

by B. Kalska, P. Blomquist, L. Hägström and R. Wappling

Interfaces in Fe/V multilayers have been examined by $^{57}$Fe Mössbauer spectroscopy. Two samples were prepared using the same deposition process and the same elemental variations with the $^{57}$Fe probe layers interfoliated between completed V and Fe (natural abundance) layers. The only difference was the deposition ordering. The superlattice structure was analyzed by X-ray diffraction and Conversion Electron Mössbauer Spectroscopy at room temperature and at 10K. The $^{57}$Fe magnetic hyperfine field distribution for the two samples is found to be significantly different and can be interpreted as due to the Fe layer being smoother than the V one. The magnetic moments derived for the interface layer as well as for the subsequent atomic layer are significantly lower than calculated values.

11.11 The Influence of V and Fe Thicknesses on the Magnetic Exchange in Fe/V Multilayers

by B. Kalska, L. Hägström, P. Blomquist and R. Wappling

The Fe hyperfine field distribution in Fe (x ML)/V (y ML) with x=5 and 10 and y=5, 10 and 14 has been determined. A strong dependence in Fe magnetic field distribution as a function of thickness V as well as Fe layers has been found.

11.12 A Hyperfine Interaction Study of the (Fe$_{1-x}$Mn$_x$)$_3$P (0.25 < x < 0.65) Alloys

by D. Satula, L. Hägström and B. Kalska

The isostructural materials Fe$_3$P (ferromagnetic, $T_c$=692 K) as well as Mn$_3$P (antiferromagnetic, $T_N$=30K) are very interesting from magnetic point of view. These alloys, except for 0.25 < x < 0.65, crystallise in a tetragonal structure with three different transition metal positions with quite different site magnetic moments. Increasing Mn concentration leads to a magnetic phase transition from ferro- to antiferromagnetic state with decreasing magnetic moments. Moreover, the manganese atoms substitute the three metal positions with different concentrations. The Mössbauer study of (Fe$_{1-x}$Mn$_x$)$_3$P alloys in the temperature range from 739K to 4.2K were carried out. The room temperature Mössbauer measurements show magnetically split spectra for x < 0.25 and asymmetric doublet shape for x ≥ 0.65. The analysis of the experimental data for both sides of Mn concentration reveals that the centroid shift and...
quadrupole splitting are mostly dependent on the number of phosphorus atoms as nearest neighbours and the corresponding distances. The Curie temperature derived from the magnetisation measurement \((x \leq 0.25)\) as well as Néel temperature derived from the analysis of the Mössbauer data \((0.65 \leq x)\) shows a decrease of both with increasing Mn concentration. The Mössbauer measurements for Mn rich part \((x \geq 0.65)\) carried out at 4.2K for \(x = 0.985\) and 10K for other samples show that the recorded spectra are broader than the corresponding pattern observed at room temperature. The broadening of these spectra are attributed to the finite magnetic hyperfine field. Because the magnetic dipole and electric quadrupole interaction are of the same order the analysis were done be solving the full Hamiltonian. The site magnetic hyperfine field decreases smoothly with increase of manganese concentration. The magnetic moments of iron sites depend on manganese concentration.

The lithium insertion process has been studied in rhombohedral \(\text{Li}_3\text{Fe}_2(\text{PO}_4)_3\) (NASICON type structure) by electrochemical and Mössbauer spectroscopic methods. The form of the discharge curve and the effective discharge capacity is found to depend on the mode of cathode preparation: two plateaus (one clear at \(-2.80\) V and one less distinct at \(-2.65\) V vs.Li/Li\(^+\)), corresponding to ca. \(1.5\)-\(1.6\) inserted lithium ions during the first cycle, are seen after more extreme grinding; milder treatment gave only the \(-2.8\) V plateau and ca. \(1.1\) inserted lithium ions. Mössbauer spectra for the more extensively ground material show the Fe environments in \(\text{R}-\text{Li}_3\text{Fe}_2(\text{PO}_4)_3\) to be highly symmetric; only a very narrow doublet with small quadrupolar splitting is observed, and the two crystallographically independent Fe-atoms cannot be distinguished. As lithium insertion proceeds, two doublets (average intensity ratio \(1.5:1\)) appear, which can be assigned to two Fe\(^{2+}\) sites. The average intensity ratio of \(1.5:1\) suggests that the extra lithium ions occupy sites closer to one of the Fe-atoms.

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11.13 Lithium Insertion Into Rhombohedral \(\text{Li}_3\text{Fe}_2(\text{PO}_4)_3\)

by A.S. Andersson \(^{1}\), B. Kalska \(^{2,3}\), P. Eyob \(^{1}\), D. Aernout \(^{2}\), L. Häggström \(^{2}\) and J.O. Thomas \(^{1}\)

The lithium insertion process has been studied in rhombohedral \(\text{Li}_3\text{Fe}_2(\text{PO}_4)_3\) (NASICON type structure) by electrochemical and Mössbauer spectroscopic methods. The form of the discharge curve and the effective discharge capacity is found to depend on the mode of cathode preparation: two plateaus (one clear at \(-2.80\) V and one less distinct at \(-2.65\) V vs.Li/Li\(^+\)), corresponding to ca. \(1.5\)-\(1.6\) inserted lithium ions during the first cycle, are seen after more extreme grinding; milder treatment gave only the \(-2.8\) V plateau and ca. \(1.1\) inserted lithium ions. Mössbauer spectra for the more extensively ground material show the Fe environments in \(\text{R}-\text{Li}_3\text{Fe}_2(\text{PO}_4)_3\) to be highly symmetric; only a very narrow doublet with small quadrupolar splitting is observed, and the two crystallographically independent Fe-atoms cannot be distinguished. As lithium insertion proceeds, two doublets (average intensity ratio \(1.5:1\)) appear, which can be assigned to two Fe\(^{2+}\) sites. The average intensity ratio of \(1.5:1\) suggests that the extra lithium ions occupy sites closer to one of the Fe-atoms.

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L. Dobrzyński, Faculty of Mathematics and Physics, University of Bialystok, Poland, Oct.-99-Jan.2000

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L. Dobrzyński, Instytut Laue-Longevin, Grenoble, April 7, 1999

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L. Dobrzyński, Universite de Versailles, France, April 9, 1999

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Nuclear Physics in Medicine
L. Dobrzyński, Institute of Physics, University of Bialystok, Poland

a) in Polish
b) in English

PARTICIPATION IN PROGRAM AND ORGANIZING COMMITTEES OF CONFERENCES

CHAIRMENSHIP

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PERSONNEL

Research scientists
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Beata Kalska, MSc.

Technical and administrative staff
Teresa Piotrowska
Overview

The activity of ZdAJ in 2000 was focused on realisation of the Government-Ordered Project – 6/15 MeV Accelerator. The realisation was accomplished in two stages:

- stage 1 should result in deriving principal operational parameters of the accelerator
- stage 2 will result in full implementation of the control system providing optimum control of the equipment and automatic maintaining of its parameters.

Within the frames of the first stage, a klystron modulator panel was finished and the design documentation of the mechanical supporting structure, the arm, accelerating structure, collimator and control panel were advanced. Manufacturing of the above sub-units in the workshop has started.

In the frames of the Specific Project of the State Committee for Scientific Research, the improvement of Neptun 10PC accelerator was undertaken. The read-out of the monitor dose with atmospheric pressure and ambient temperature compensation has been introduced. New filters for equalising the photon and electron beam and new wedge filters have been designed. Changes in programming have been introduced, which improve the patient’s safety by eliminating possible personnel errors and increase the accuracy of radiation fields read-out.

12.1 Collimator for 6/15 Accelerator

The aim of the work was to design a new collimator for 6/15 accelerator.

The new design differs substantially from previously developed collimators for Neptun 10PC and Co-Line accelerators. In view of two photon energies, 6 and 15 MeV, a target strip movable in air in front of electron window of the accelerating structure was applied.

Additionally, the target strip accommodates upper electron scattering filters for energies 6, 9, 12, and 15 MeV. The target strip is slide-mounted in the fixed collimator.

The filter plate with attached collimators is located under the fixed collimator. These collimators are equipped with two equalising filters for photons, four lower filters for electron scattering, and a new system of optical simulation. The distance between the upper and the lower filters amounts to about 100 mm.

A double ionisation chamber is located under the filter plate. The ionisation chamber is mounted in a tilting mechanism allowing for rotation of the filter plate in one direction.

The lower part of the collimator is formed by a system of mobile diaphragms (jaws). The adopted design solutions of the drives and position reproduction allow for precise, asymmetric motion of two pairs of jaws with a possibility of crossing the zero position.

The design of the final version will allow an additional use of the upper pair of jaws as a dynamic wedge.

Due to the use of sintered tungsten of density 18 g/cm$^3$ as shielding material for collimators and jaws, the vertical size of the collimator has been reduced. The attained overall dimensions make possible to mount an additional multi-plate collimator and a number of accessories under the present collimator.

The design calculations of the size of fixed collimator, of the collimators in filter plate and jaws take into account the contemporary tendencies in radiological safety. The whole design of the collimator of 6/15 accelerator conforms to the provisions of IEC Standard.

12.2 6/15 Accelerator Modulator Panel

The aim of the work was to design a new modulator capable of providing higher radiation energy as compared with Neptun 10PC accelerator.

The modulator consists of:
1. Modulator panel – dimensions 120x180x120 cm
2. Auxiliary panel – dimensions 60x150x60 cm
3. Pulse klystron transformer

The modulator panel consists of two separated compartments
a) high-voltage compartment
b) low-voltage compartment

The auxiliary panel accommodates a number of high-power supplies and a 3 GHz microwave generator.

The parameters of the klystron modulation pulse are:
1. Maximum pulse voltage – 150 [kV]
2. Maximum pulse current – 105 [A]
3. Pulse power – 15.75 [MW]
4. Pulse width at 50% of height – 5 [μs]
5. Pulse width at 99.5% height – 3.5 [μs]
6. Pulse rise time – 1 [μs]
7. Pulse fall time – 1.7 [μs]
8. Repetition rate – 100 [Hz]

The new modulator features a new method of controlling the charging voltage of the delay line. In Neptun this was accomplished by a change of the output voltage of HV power supply. In 6/15 accelerator a change of the charging voltage of the delay line is accomplished by varying the quality factor of the resonance charging circuit.

12.3 A Concept of Controlling 6/15 Accelerator
by E.Jankowski, R.Hornung, J.Pracz, J.Kuczyński, M.Kaczynski, A.Salaga, J.Trzuskowski

The aim of the work was to develop a concept of computer system together with appropriate programming for therapeutic 6/15 accelerator, taking into account provisions of IEC 976 and IEC 977 Standards with regard to the operational parameters and of IEC 60601-2-1 and IEC 60601-1 Standards with regard to safety requirements.
The following system concept was adopted:
1. VME multiprocessor system – 4 object processors and central processing unit. The distribution of tasks between individual processors followed from an analysis of functions, types of signals and their frequency.
2. Communication with a PC computer by Ethernet.
3. PC computer used for communication with VME system and for:
   - Acquisition of data on each session.
   - Acquisition of data on accelerator operation time with error recording.
   - Recording total operation time of accelerator and operation with beam.
   - Controlling the therapeutic, dosimetric, and service modes.
   - Controlling the setting monitor.
   - Servicing data-base.
   - Communication with TREATMENT PLANNING system and with COMPLEX INFORMATIVE SERVICE of the medical centre.
4. IN/OUT signals of VME system, together:
   - analog inputs – 55
   - analog outputs – 18
   - digital inputs – 104
   - digital outputs – 37
5. Dose monitoring:
   - double monitoring of dose and dose power.
   - ambient temperature and atmospheric pressure compensation of the dosimetric channels.
   - system of securing the dose monitoring.
6. Checking and interlocking circuits:
   - checking of closing the door to the therapeutic bunker.
   - locking the collimator drives after closing the door (dead man lock).
   - checking: the power supply, water cooling, water flow, air blow, temperature, SF₆ gas pressure in the wave-guide, modulator sub-units and others.
   - checking the conformity of the master and slave signals with the set energy.
   - checking the conformity of filter plate position and target strip (appropriate selection).
7. A time dependence of signals with respect to the START signal has been determined.
8. The grounding circuits and the signals have been separated to minimise interference.
9. A/C, C/A, and C/C converters of VME system with galvanic separation have been selected.

12.4 Diode Electron Gun for a Double-Energy Accelerator

by S.Kuliński, J.Babik, Z.Sienkiewicz, A.Wądołkowski

The objectives of the work undertaken to design and manufacture a new diode electron gun for double-energy accelerating structure are as follows:
- to increase the emission current of the gun.
- to extend the lifetime of the filament.
- to improve the optics.
- to improve the reproducibility of individual guns.

The work performed till now comprises the choice of the filament shape and the choice of the gun geometry relating to distance dimensions, hole diameters etc. The investigations were based on calculations related to changes in the gun geometry.

One of the basic changes in the gun geometry was change of the cone of the Wehnelt cylinder. In the presently designed cylinder, an angle 135° was applied which differs from the solution used in the accelerating structures produced thus far in ZdAJ. Special attention was paid to distances between the anode and cathode and the first resonator. Optimisation of these distances has greatly improved the beam optics.

In the result of the performed tests, the spiral filament of 0.7 mm diameter tungsten wire was selected for further application which is more reliable and mechanically stable as compared to a bifilar shape.

A series of tests was performed. They confirmed as the operational ranges for the following parameters:
- Anode-cathode voltage: 15 – 40 kV
- Emission current: 200 – 400 mA
- Pulse duration: 1 – 10 μs
- Repetition rate: 50 – 300 Hz
- Filament temperature: ≈ 2200° C

The introduced changes have fully confirmed the adopted assumption on feasibility of improving the previous diode electron gun. The new gun can be applied in 4, 6, and 9 MeV accelerators.
12.5 Optical Simulation System for 6/15 MeV Accelerator
by J. Marjanowski, L. Kotulski, K. Gryn, M. Mitek, P. Kraszewski, E. Słowińska, R. Karas

The work was aimed at designing a system of optical simulation to be applied in the equipment for cancer radiotherapy, specifically in 6/15 MeV medical accelerator. The purpose of the system is to create on the patient's body a visible light image of the region to be irradiated by ionising radiation.

This task was realised in the following way. The simulation system has to be located in a place with a free access to the light source (necessity of replacement and adjusting). In view of the space available in the medical accelerator such a solution appeared to be not feasible therefore the simulation system has been split into four parts: mirror system, simulation lamp system translatable in three axes, light source system (halogen bulb) with adjustable filament position, and light-guide. One end of the light-guide has been placed in the light source system and the second in simulation lamp system, thus creating a secondary light source. The application of light-guide allowed for placing the light source at practically any position, thus enabling for its easy replacement.

The above solution fully meets three basic requirements imposed upon optical simulation systems:

- Homogeneous illumination of the simulation field
- Possibility of aligning the optical simulation axis with radiation beam axis
- Possibility of adjusting the size of optical simulation field to the actual size of irradiation field.

12.6 Optimisation of the Shape of “Matching Chimney” in Hf Line Supplying the Electron Accelerating Structures in S Band

The basic task of the “chimney” in a line supplying the electron accelerating structures is to match a high impedance of the supplying wave-guide terminated with a ceramic window to a low input impedance of the structure accelerating electrons. At the same time, having in mind the safe operation of the ceramic window, the probability of its break-down, especially by multipactoring effect, should be kept at minimum. Therefore, the length of the chimney should be adjusted in such a way that under the condition of full reflection of HF power from the accelerating structure, the location of ceramic the window should coincide with the maximum of HF electric field. Such design results in a vanishing axial component of the electric field at the ceramic window.

In the course of work:
1. A controlled, precision-made wave-guide switch for a wave-guide with transverse dimensions of 66.4x17, used in ZdAJ equipment has been designed and manufactured.
2. Two versions of chimneys have been designed and manufactured
   (a) with a wave-guide of input dimensions of 66.4x34
   (b) with a wave-guide of input dimensions of 72x34
3. Microwave measurements of these chimneys fixed to ceramic window have been performed.
4. A new design of joining these chimneys with the structure and the HF window providing correct and secure microwave contact has been developed.

The performed measurements of chimneys (a) and (b) fixed to ceramic window, for frequency $f_0 = 3.0$ GHz have revealed a match between a standard PP wave-guide 72x34 at the input and 66.4x17 wave-guide at the output. The standing wave coefficient in both cases was $WFS \leq 1.1$. In the case of chimney $L=53.3$ (66.4x29.5) the standing wave coefficient was $WFS = 1.33$.

Conclusions:
It is recommended to use a chimney of height $L=85.5$ (66.4x29.5) with wave-guide 66.4x34 at the input, because of good electric parameters and easier preparation than in the case of chimney with $L=81$ with wave-guide 72x34 at the input.
12.7 New Design of Ionisation Chamber
by A.Kazimierski, J.Olszewski, M.Rutkowska, D.Ornat, K.Ozon

The dosimetric system of 6/15 accelerator includes a detector in the form of a double, open-air ionisation chamber with flat electrode system. Each of two chambers (cf. Figure): chamber A and chamber B contains a two-segment collecting electrode (C1-C2, C3-C4), with the segment division lines in two chambers being mutually perpendicular.

Such detection system allows for a two-track, duplicated dose measurement, on-line testing of correct operation of the measurement system, homogeneity control of the transversal beam distribution and automatic alignment. The adopted design of the ionisation chamber is similar to KM-10 ionisation chamber used in accelerators produced previously with some adaptation necessary to satisfy the conditions of 6/15 accelerator occurring in the region of main collimator and filter plate. These conditions determine the size of the chamber that must be limited to 115-130 mm.

The presented drawings originate from the complete design documentation used at manufacturing of the parts of the chamber. The chamber is assembled using the technology of straining, gluing and photo-etching of thin Kapton electrodes, developed at ZdAI.

The materials used in the construction of the chamber are:
- Frame and electrode supports: PA2N duralumin
- Electrodes: Cu laminated Kapton, manufactured by Goodfellow, Cambridge Ltd
- Photochemical materials: Kodak Ltd,
- Insulating materials: Teflon, Kapto

Fig. 1

12.8 6 and 9 MV Photons from (Upgraded) NEPTUN Accelerator
by S.Kulinski, K.Gryn, A.Hilger, J.Kowalski, J.Babik, A.Godziszewski, B.Osuch

To fulfil the growing requirements for two photon energies for X-ray therapy both theoretical and practical works were done to assure dose rate of 200 cgy/min/m for 6 MV photon and 300 cgy/min/m for 9 MV photons. The dose rate production of X ray on the sufficiently thick target is given by

$$X = k \cdot I_{av} \cdot V^n$$ [cgy/min/m]

where \( k = 0.07 \), \( I_{av} \) - average electron current in \( \mu A \), \( V \) in MV.

For photons voltages between 6 and 9 MV \( n \) is approximately equal to \( n = 2.9 \). It means that to obtain the same X-ray dose rate the average current of 6 MV electrons should be about 3 times bigger than that of 9 MV electrons.

To obtain the above mentioned increase of 6 MeV electron current following changes were done:
1. The initial (bunching) part of the accelerating structure was changed to increase the phase acceptance of 6 MeV electrons.

2. The electron source (gun) was modified to get higher electron current with smaller divergence (emittance).

3. The coupling $\beta$ between power transmission line and the accelerating structure has been optimized taking into account the bigger current necessary for 6 MeV electrons.

The accelerator with all these changes was designed and constructed. Below are given some results of the measured parameters. It can be seen that the main objectives of sufficiently high dose rates: 342 cGy/min for 6 and 359 cGy/min for 9 MV photons have been obtained.

12.9 Measurements of the Beam Current in the Accelerating Structure of Coline Accelerator

by W. Wolski, J. Bąbik, M. Szymański, A. Wądolkowski, R. Kiełnia

The measurements were performed in the accelerating structure of Coline accelerator. Modifications in the electron gun included application of the Wehnelt electrode with conical angle of 135° and a flattened, 5-turn cathode made of 0.685 mm dia. tungsten wire. Instead of a conversion plate, a 0.1 mm thick, 9 mm dia. window made of 1H18N9T stainless steel was placed. The beam current was measured by a special collector with electrodes made of aluminium disks of various thickness, separated from each other by ceramic insulators. Such design of the collector made possible to measure the electron range in aluminium and hence – to estimate the electron energy.

It is commonly assumed for high-energy electrons that the range of electrons with energy exceeding 1 MeV in matter is approximately proportional to their energy and inversely proportional to the specific density of the absorber. Accordingly, the following formula, based on empirical relation between the electron energy $E$ and the practical electron range in water $z_p$ has been assumed:

$$ E = \frac{2.7 \cdot z_p + 0.376}{0.527} $$

Conclusions:

1. At the filament current $I_f = 28$ A, the beam pulse current amounts to about 160 mA whereas the gun current, measured with the same $I_f$, at a special measurement stand amounts to about 300 mA.

2. It is observed that the beam is strongly divergent, the electron energy is distributed over a wide range and the distribution is strongly dependent on HF power and the filament current. The measured energies are comprised in a range 1 to 6.5 MeV, however most of electrons have energies in the range 2 to 4.5 MeV.

3. The width of the beam current pulse ranges from 3.8 to 4.4 $\mu$s, depending on HF power and the filament current. The pulse width decreases with an increase of the beam current and decreases with an increase of HF power.

12.10 Concept of Reconstruction of Produced Mammographs

by T. Krawiel, A. Baczewski, A. Zając, K. Dębowski, E. Brzezińska, I. Wicik, A. Kazimierski

The concept concerns a mammograph supplied with single-phase voltage, utilising a 3.5 kW high voltage generator operating at a frequency of 100 kHz and a voltage of 21 to 35 kV.

The applied X-ray lamp will feature a molybdenum anode with two angles, rotated at a minimum speed of 3000 rpm, approaching 9000 rpm. The lamp is equipped with two focuses of dimensions 0.1 and 0.3 mm$^2$. The radiation beam is filtered by a permanent molybdenum filter and auxiliary rhodium filter of 25-30 $\mu$m thickness. The rhodium filter will be automatically selected for thicker breast. The beam will be collimated by 3 automatically selected collimators of dimensions 18x24 cm, 24x30 cm, and 14 cm.

To make an exposure, automatic exposure control (AEC) will be used, consisting of fully automatic adjustment of kV and mAs in relation to the measured density of compressed breast. The density measurement is enabled due to 9 detectors recording the real breast density prior to each exposure (so called pre-exposition lasting less than 10 ms). The detectors will be selected electrically (3 positions) depending on the size of a compressed breast. A possibility of fully manual mode of selecting kV and mAs as well as semi-automatic mode (manual choice
of kV and automatic adjustment of mAs) will be provided.

The vertical motion of the C-arm will be accomplished by an electric motor drive (55 - 145 cm) and the rotation will be accomplished either manually or using a motor (option) by an angle of ± 180°. The C-arm will be locked by two electromagnets.

The vertical motion of the C-arm will be accomplished by an electric motor drive (55 - 145 cm) and the rotation will be accomplished either manually or using a motor (option) by an angle of ± 180°. The C-arm will be locked by two electromagnets.

The breast compression will be accomplished either automatically by a motor drive or manually, depending on the choice of the operator. After exposure the pressure will be automatically released (the release occurs also in the case of voltage failure). The table with mobile Potter-Bucky anti-diffusion screen has a size compatible with 18x24 and 24x30 film cassettes.

The mammograph is controlled by a PC computer. The set exposure parameters and the information related to the state of mammograph, such as kV, mAs, pressure force, size of selected focus, type of applied AEC as well as information for service purposes about the occurring faults (service operation mode) will be displayed on the computer monitor. The computer memory will store all information on patients and the number and values of applied doses. The data on patient and the values of applied doses will be sent to device describing the photograph.

12.11 Adapting Neptun Accelerator for TBI Therapy
by J.Pracz, W.Szczeblewski, W.Kulesz, K.Jałosiński, Z.Zero, H.Szewczyk, J.Kopec

The work consisted in adapting Neptun accelerator for the therapy by the method of total patient body irradiation using 9 MeV photon beam. It is assumed that patients with height up to 160 cm will be irradiated. This size is dictated by a condition that the maximum displacement of a patient from the apparatus head in the equipment of Wielkopolski Oncology Centre allows for irradiation at SSD = 285 cm with the maximum diagonal of irradiation field equal to 165 cm.

The collimator head of the accelerator has been modified to improve filters equalising the dose distribution. Necessary corrections in the control systems have been made to provide a dose power reasonable from the viewpoint of therapy time. For this purpose new filters were used. Measurements of the photon beam in order to evaluate the absolute dose and dose-depth dependence in a water phantom and in air have been performed. To perform the measurements in air, a device for remote translation of the probe with 1 mm accuracy has been designed and manufactured.

As a result, the total body irradiation with a dose of 12 Gy has been accomplished in 8 fractions in the course of 4 days. The equipment and the implemented technology can be applied to patients of larger height in bunkers of larger dimensions.

12.12 A Technology of Resonator Machining
by M.Gołębiewski, A.Trzaskowski, J.Ucho, Z.Trzepałko, Z.Kunicki

The basic objective in the manufacturing of resonators is to achieve a high reproducibility of the geometrical shape of the cavity, accuracy of preparing the leading holes and the accuracy of the location of holes in the cavity bottom. The whole manufacturing process has to provide an appropriate roughness class (9-th class for the cavity) which is a theoretical limit of machining by turning or milling.

ZdAJ has developed and implemented the programs of machining the resonators on numerically controlled milling machines. In co-operation with cutting tool manufacturer Sandvik, new generation tools have been applied. The TiN coated or plain WC-Co tools, specially adjusted tool geometry and the machining parameters warrant the reproducibility and the required roughness class.

New technological solutions have resulted in savings. The accuracy of manufacturing on numerically controlled milling machines made possible to eliminate the tuning process accomplished by correcting the "nose" shape. Previously this correction required work and experience of a qualified worker.

The production process of a series of resonators using only three numerically controlled milling machines has been shortened by almost a factor of two.
12.13 Implementation of New Solutions in POLKAM 15 Therapeutic Tables

POLKAM 15 therapeutic table is used in direct conjunction with such devices as NEPTUN 10p accelerator, SIMAX simulator and others.

The precision of the table operation often determines the precision of tumour irradiation of the patient.

The precision of the table functioning covers the following movements:
- Rotation of the table basis
- X-Y translation
- Rotation of the table column
- Vertical translation Z

The accuracy of these movements depends on the play-free operation of brakes and clutches of these pieces of equipment.

The drive reduction gear in the table basis was a multi-plate splined brake. The design of this brake allows for a spline clearance which results in about 3 mm play at the end of 1350 mm long arm.

The application of single-plate brake has minimised the clearance to almost 0 degree.

The application of a system of controlled pressure of reduction gear wheel to the crown wheel of basis rotation makes possible to regulate fluently the intertooth clearance.

The replacement of a split nut in the Z-axis drive by a solid one resulted in an increase of allowed loading of this axis.

The application of axial bearing resulted in fluent motion in Z-axis.

The design of brake releases used for blocking the X and Y movements in the desired positions has been altered.

The new solution resulted in marked improvement of the functioning of these systems.

The modifications introduced thus far resulted in significant improvement of the table functioning and its reliability.
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