Nuclear Physics Institute

public research institution

Academy of Sciences of the Czech Republic

Řež near Prague

BIENNIAL REPORT

2009-2010

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FOREWORD

The Report presents the activities and selected results of the Nuclear Physics Institute of the Academy of Sciences of the Czech Republic (NPI) during the years 2009 – 2010. The structure of the Report is slightly different from that used in the previous institute's Biennial reports in which presentations have been structured under departmental scheme. This time, the organization of the Report follows the subject matter of our activities. Many of our studies are performed in cooperation of different departments and, on the other hand, various topics are pursued within particular departments. We believe that this arrangement could make Report more lucid and compact.

The structure of the Report thus also corresponds to the sorting that has been employed in the evaluation process of the Institute. The five year 2005- 2009 period of the NPI as well as other institutes of the Academy of Sciences of the Czech Republic began in 2010. The preparation of the relevant materials and data was an important task in 2010 and I have to thank all the involved for their thorough and responsible approach. The evaluation process then continued and was concluded in 2011.

The principal activity of the NPI is scientific research in the field of nuclear physics and related scientific disciplines and the use of the nuclear physics methods and procedures in interdisciplinary areas of science and research, especially in biology, environmental science, medicine, radiopharmacy and material science. In this brochure, we would like to provide information how activities of the NPI have proceeded in years 2009 – 2010.

Finally, thanks are due to the NPI scientists and all NPI staff for their considerable effort and dedicated attitude in carrying out the task and mission of the institute.

Jan Dobeš
director

Phases of Nuclear Matter

A. KUGLER, M.ŠUMBERA

The Phases of Nuclear Matter unit consisting of two teams – Ultra-relativistic Heavy Ion Collisions group (URHIC) and Relativistic Heavy Ion group (RHI) – studies properties of strongly interacting matter over wide range of incident energy, temperature, energy density and baryon chemical potential. While URHIC group participates in ALICE experiment at CERN [1] and STAR experiment at BNL [2], RHI group devotes itself to study of baryon-rich media exploiting di-lepton pairs and strange particle production in experiments carried out by of HADES collaboration at GSI SIS [3].

For ALICE, the years 2009-2010 represent a new chapter in its program: in November 2009, after many years of preparations, Large Hadron Collider (LHC) has delivered the first colliding beams. The operations started with p+p collisions at $\sqrt{s}$= 900 GeV, continued in 2010 at energy of $\sqrt{s}$= 7 TeV culminating with a month of Pb+Pb run at $\sqrt{s_{NN}}$=2.76 TeV in November 2010. The detector and the data taking and processing system of ALICE were prepared excellently for the LHC operations start-up as well as for the first heavy ion beams. Within first week of p+p and Pb+Pb running first scientific results appeared (see [4] and [5,6], respectively). The papers [5,6] were marked as "Suggested reading" by the Physical Review Letters (PRL) editors and the paper [5] was selected for the "Viewpoint in Physics" by PRL.

The strongly interacting medium produced in Pb+Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV shows features very similar, sometimes even identical to those observed for the first time in $\sqrt{s_{NN}}$=200 GeV Au+Au collisions at Relativistic Heavy Ion Collider (RHIC) at BNL, New York [2]. Similarly to RHIC the hot and dense matter created in the Pb+Pb at LHC behaves as a nearly perfect liquid [2] and not as a gas of weakly interacting quarks and gluons. This quality becomes even more striking taking into account the latest STAR measurements [7] performed at c.m.s. energy 70× smaller than the LHC energy.

The next decade will very likely be dedicated to detailed studies of this perfect strongly interacting liquid both at LHC and RHIC. While ALICE will, besides other studies, try to discover a possible disappearance of the perfect liquid at higher LHC energies, the focus of the STAR experiment will be to go to in the opposite direction trying to find an ideal liquid low-energy limit [8].

Another interesting research topics pursued actively by both ALICE and STAR experiments is production of light nuclei and antinuclei, including those containing strange quarks. First observation of antihypertritons - composed of an antiproton, antineutron, and antilambda hyperon - was recently reported by STAR collaboration [9].

The HADES collaboration concentrated in period 2009-2010 to substantial upgrade of several sub-detectors as well as DAQ system with the aim to extend in following years experiments to heavy systems, beyond Ar+KCl and up to Au+Au, as well as to higher beam energies up to 8 AGeV planned at forthcoming FAIR facility. The Czech group participated in several tasks, mainly in installation of Forward Hodoscope and in upgrade of DAQ electronics of TOF sub-detector we are responsible for. Further, we together with other members of collaboration lunched new project, electromagnetic calorimeter to be exploited by HADES installation at FAIR, see further RHI contribution in this volume. Besides that several analysis of experiments carried out by HADES in previous years were finished and/or substantially progressed. We reveal a significant di-lepton excess which can be associated with the compressed baryonic matter phase of heavy-ion collisions [3, 10]. Similar behavior was observed even at normal nuclear matter density in proton+Nb collisions, see another RHI contributions to this volume.

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The Silicon Drift Detector subsystem of the ALICE detector

S. KUSHPIL, V. KUSHPIL, V. PETRÁČEK, M. ŠUMBERA

The NPI ultra-relativistic heavy ion collisions group participates in the ALICE experiment at the Large Hadron Collider (LHC) at CERN [1] where, beside others, it is involved in the operation, calibration and performance studies of the Silicon Drift Detectors (SDD) of the Inner Tracking System (ITS) of the ALICE detector.

The SDD basic characteristics, the drift speed, is significantly influenced by fluctuations of the ambient temperature, which results in the 0.8%/K variation at the room temperature. To achieve the required resolution, it is necessary to ensure a temperature uniformity of 0.1 K, or, alternatively, implement a precise monitoring for the drift velocity during the operations. For a good monitoring it is crucial to have perfect calibration procedures. An overview of the operations and calibration procedures of the SDD is given in [2]. In [3], the alignment of the ALICE ITS with cosmic-ray tracks is described in detail.

With the first collisions data collected in 2009-2010, the SDD calibration procedures were significantly improved, allowing to achieve the nominal resolution of ~ 30 μm along the drift direction. A new important characteristics - the SDD recovery time after technical stops when high voltage (HV) is switched on - was suggested to be under control from June 2010. This determines how long it takes to resume the nominal detector operational conditions for new physics measurements. An analysis of injector events taken during the LHC beam energy ramp-up has shown, that the injectors of 55% of the modules start to work immediately after the HV switch-on and 42% start working within 1 day. Only for 3% of the modules the recovery time takes more than 1 day (due to internal defects).

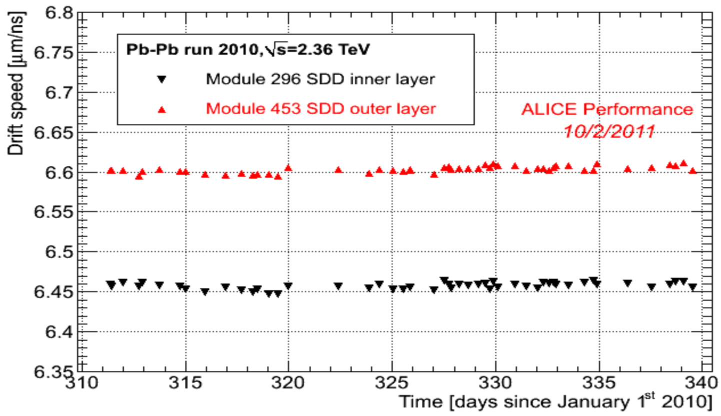

Figure 1: Drift speed in two selected SDD modules as a function of time during Pb-Pb 2010 data taking. The difference of average values between inner and outer layer is due to different temperature on the two layers.

Monitoring the uniformity of the drift velocity across the sensitive area as well as its time variations are of paramount importance when working with the SDD. It is expected that the actual drift velocity is not constant in every point of the module, but it changes due to the fact that the temperature of the silicon bulk depends on the anode coordinate. The temperature is higher near the voltage divider in both sides of the detector. For the same reason the inner SDD layer has a drift speed systematically lower than the outer one as shown on Fig.1.

During p+p and Pb+Pb period dedicated runs of 50 events each were collected in which the average drift speed was measured every 6-12 hours. Figure 1 demonstrates stability of the drift speed for 2 typical SDD modules during a Pb+Pb run. All monitored parameters (baseline, noise, gain) proved to be stable during the entire period (within 1% for the drift speed).

This work was supported in part by the by grants LC07048 and LA08015 of the MŠMT, Czech Republic.

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Computing in ALICE and STAR experiments

D. ADAMOVÁ, M. ZEROLA

The NPI group of ultra-relativistic heavy ion collisions (URHIC) participates in two experiments studying strongly interacting matter and the quark-gluon plasma, ALICE at the Large Hadron Collider (LHC) at CERN [1] and STAR at the Relativistic Heavy Ion Collider (RHIC) at BNL [2]. In both experiments, the data flow from the detectors is enormous: in 2010, ALICE recorded almost 3 PetaBytes (PB, 1 PB=1 million GB) of RAW data and STAR recorded over 1 PB. This data must be replicated and pushed through multiple reconstruction and analysis processing, accompanied by a number of Monte Carlo simulation productions. This way, the original RAW data size is usually tripled (~10 PB in total for ALICE).

To manage this huge quantity of data, ALICE has built a distributed computing infrastructure partly integrated into the Worldwide LHC Computing Grid (WLCG) [3]. The ALICE Grid currently includes ~ 80 sites worldwide, providing about 30 thousands of CPUs and over 10 PB of disk storage. The NPI ALICE group delivers into this system about 2% of CPU and 3% of disk hardware and over 4% of the processed jobs. The services are provided in cooperation with the regional computing center Golias [4] in Prague. The group's responsibility covers local production of simulated data, management of analysis jobs and maintenance/upgrades of the Grid services provided by the Czech Republic. The Prague site and in particular our storage servers excel in the stability and reliability, which is crucial during the LHC operations, when the sustained data flow from the detector reaches 2.5 GBytes/s and any instability or bottlenecks in the Grid infrastructure represent a threat of a loss of data. The contribution of the NPI group into the ALICE data processing framework was described in [5,6,7].

The massive data processing in a multi-collaboration environment with geographically spread diverse facilities, like STAR is, will be hardly "fair" to users and hardly using network bandwidth efficiently unless we address and deal with planning and reasoning related to data movement and placement. The NPI STAR group is involved in such a research - it is engaged in designing and developing an automated planning system acting in a multi-user and multi-service environment. The system acts as a "centralized" decision making component with the emphasis on the optimization, coordination and load-balancing. The optimization guarantees the resources are not wasted and could be shared and re-used among users and sources. Coordination ensures multiple resources do not act independently so starvation or clogging do not occur, while load-balancing avoids creating bottlenecks on the resources. The intent is not to create another point-to-point data transfer tool, but to use available and practical ones in an efficient manner. The progress and results of the NPI STAR group contribution to this project have been continuously presented in STAR Collaboration Meetings as well as in peer-reviewed international conferences. More detailed explanation of model and solving strategy in a theoretical way can be found in [8,9,10] while the technical implementation and real use experience was presented in [11].

This work was supported in part by the grant GACR 202/07/0079 and by grants LC07048, LA08015 and LA09013 of the MŠMT, Czech Republic.

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System size dependence of associated yields in hadron-triggered jets

J. Bielčíková for the STAR Collaboration

One of the most important results at RHIC was the observation of jet quenching in central Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. This jet quenching effect is visible in the suppression of inclusive particle production at high transverse momentum (p_T) and away-side jet-like peak in azimuthal di-hadron correlations relative to p+p and d+Au collisions [1, 2]. Previous studies of di-hadron correlations showed that the observed suppression of the correlated away-side yield increases with centrality expressed as the number of participating nucleons (N_{part}). Several theoretical calculations of partonic energy loss in the medium were used to derive medium properties like the transport coefficient $\hat{q}$. The energy loss of partons propagating the medium depends on the path length (L) traversed in a way that is characteristic of the energy loss mechanism. For radiative energy loss, which is expected to be dominant for light quarks, the energy loss is expected to depend on L^2. For elastic energy loss, only a linear dependence on L is expected. The models differ in implementation of a given energy loss calculation as different path length distributions and density profiles are used. Therefore it is important to study in detail the system-size dependence of away-side suppression to provide constraints on the models.

A systematic study of di-hadron correlations in d+Au, Cu+Cu and Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV was performed in [3]. The near-side ($\Delta\phi \approx 0$) associated yields are equal within the experimental uncertainties for all the systems studied and independent of the collision centrality. Away-side ($\Delta\phi \approx \pi$) associated yields are suppressed in heavy-ion collisions with respect to the d+Au reference as demonstrated in Fig. 1 for two trigger p_T ranges. The suppression increases steadily with N_{part} and shows no significant dependence on the collision system for a given N_{part}. The Parton Quenching Model (PQM) [4] is not able to describe the similarity of the away-side yields in Cu+Cu and Au+Au collisions at the same N_{part}. The Modified Fragmentation Model (MFM) [5, 6] describes the data relatively well for the higher p_T trigger range (p_T^{trig} = 6-10 GeV/c) but fails at lower p_T trigger values. Further comparisons of these measurements together with single-hadron suppression data to models will allow the extraction of the path length dependence of energy loss.

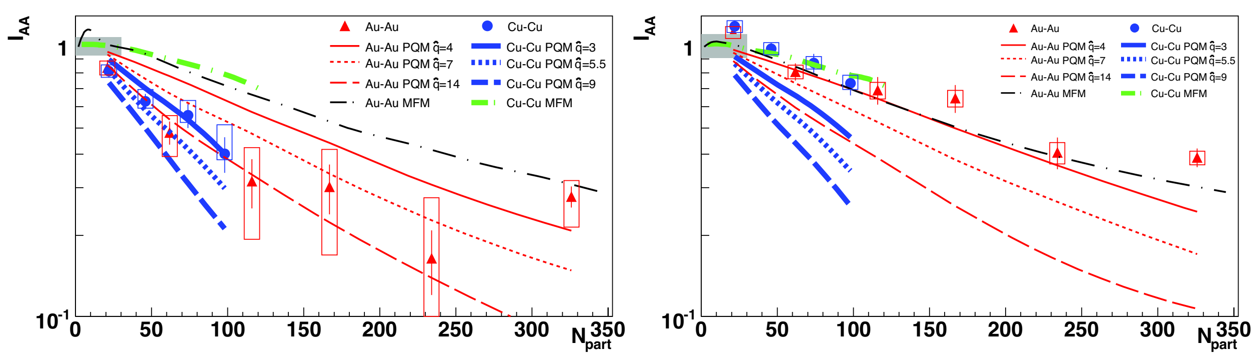

Fig. 1: *N_{part} dependence of the away-side associated yield relative to d+Au (I_{AA}) for two trigger p_T ranges: (left) p_T^{trig} = 4-6 GeV/c, (right) p_T^{trig} = 6-10 GeV/c. For both panels 3 GeV/c < p_T^{assoc} < p_T^{trig}. The boxes represent the point-to-point systematic errors. The gray band represents the correlated error due to the statistical error in the d+Au data. The lines represent calculations in PQM and MFM models. The values of $\hat{q}$ are expressed in GeV^2/fm.*

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Jets in $\sqrt{s_{\rm NN}} = 200$ GeV p+p and d+Au collisions from the STAR experiment

J. Kapitán for the STAR Collaboration

Recent progress in full jet reconstruction in heavy-ion collisions at RHIC makes it a promising tool for study of the QCD at high energy density [1, 2]. Measurements in d+Au collisions are important to disentangle initial state nuclear effects from medium-induced $k_{\rm T}$ broadening and jet quenching. Furthermore, comparison to measurements in p+p gives access to Cold Nuclear Matter (CNM) effects. To constrain these, inclusive jet spectrum and di-jet correlations are measured in p+p and d+Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV recorded during RHIC run 8 (2007-2008). To maximize possible CNM effects, most central (0-20%) d+Au events are selected.

Jets are reconstructed combining the charged tracks from the Time Projection Chamber (TPC) and neutral towers from the Barrel Electromagnetic Calorimeter (BEMC). Recombination jet algorithms $k_{\rm T}$ and anti$-k_{\rm T}$ from the FastJet package [3, 4] are used for jet reconstruction with resolution parameter $R = 0.4$ (inclusive jet spectrum) and $R = 0.5$ (di-jet analysis). To subtract the d+Au underlying event background, a method based on active jet areas and event-wise background level determination [5, 6] is applied. Pythia 6.410 and GEANT detector simulations were used to correct for experimental effects. To study residual effects of the d+Au background (such as background fluctuations) Pythia events are embedded into real d+Au collisions.

Di-jet azimuthal correlations in p+p and d+Au can be used to estimate nuclear $k_{\rm T}$ broadening [7]. To select a clean di-jet sample the two highest energetic jets ($p_{\rm T,1} > p_{\rm T,2}$) in each event were used with $p_{\rm T,2} > 10$ GeV/c [8]. The total transverse momentum of a di-jet, $k_{\rm T}$, is measured from its azimuthal component, experimentally accessible as $k_{\rm T,raw} = p_{\rm T,1}\sin(\Delta\phi)$, where $\Delta\phi$ is the di-jet opening angle. The $k_{\rm T}$ values extracted from the Gaussian fits to $k_{\rm T,raw}$ are $\sigma^{p+p}_{k_{\rm T,raw}} = 2.8 \pm 0.1$ (stat) GeV/c and $\sigma^{d+Au}_{k_{\rm T,raw}} = 3.0 \pm 0.1$ (stat) GeV/c [9, 10, 11, 12].

To compare measured jet yield in d+Au to jet cross section in p+p collisions, the published STAR p+p jet spectrum [13] was scaled by $\langle N_{\rm bin}\rangle$. Inclusive jet spectrum in d+Au collisions was measured up to $p_{\rm T} = 30$ GeV/c [10, 11, 12], as shown in Fig. 1 together with the scaled p+p jet spectrum. The systematic errors are indicated by dashed lines and by the gray boxes. The dominant source of systematic uncertainty in d+Au is imprecise knowledge of TPC tracking efficiency in jets for run 8 d+Au running.

No significant broadening from p+p to d+Au was observed in the measurement of di-jet $k_{\rm T}$ widths. Jet $p_{\rm T}$ spectrum from 200 GeV 0-20% most central d+Au collisions is consistent with $\langle N_{\rm bin}\rangle$ scaled p+p jet spectrum within systematic uncertainties. These uncertainties have to be decreased in order to construct the jet $R_{\rm dAu}$ and this will be achieved by a precise tracking efficiency determination in d+Au and jet cross section measurement in run 8 p+p data.

This work was supported by the grant GACR 202/07/0079 and by grants LC07048 and LA09013 of the MSMT, Czech Republic.

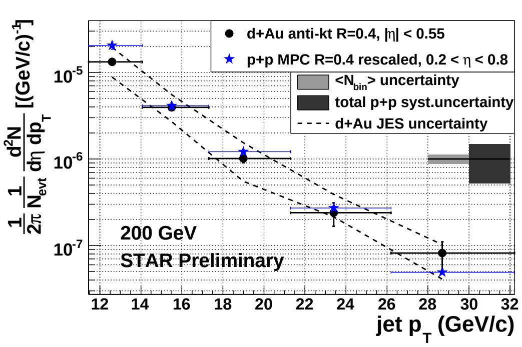

Fig. 1: Jet $p_{\rm T}$ spectrum from d+Au collisions compared to $\langle N_{\rm bin}\rangle$ scaled p+p jet spectrum.

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Exploring cold nuclear matter with HADES

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for the HADES [1] collaboration

Theoretical calculations, see for example [1], predict significant in-medium effects, which should manifest themselves in measurable modifications of the in-medium properties of hadrons, in particular of the masses of the light vector mesons (ρ, ω and ϕ) and/or kaons. Such an effect can be experimentaly observed already in cold nuclear matter, for example in pA collisions, and it has to be even more pronounced in AA collisions. To reveal contributions from the nuclear matter to the total yield of the studied particles (di-electrons, kaon's etc.), one has to measure both the production due to elementary first chance-like collisions of pp and np, and the production from the pA and AA collisions.

The High-Acceptance Di-Electron Spectrometer HADES [2] at GSI is used to perform exactly these tasks: with an excellent lepton/hadron discrimination, a mass resolution $\Delta M/M \approx 2.5\%$ in the region of the ω pole mass and a polar coverage of $18^0 \leq \theta \leq 85^0$.

Final results of the analysis of pp and quasi-free np collisions and of the C+C data were published in [3, 4, 5]. From the dilepton spectra we subtract the contribution from the Dalitz decay of η mesons, which are coming mainly from the freeze-out phase using the η yields measured by the TAPS collaboration [6]. The resulting data from C+C collisions are in the region of invariant masses 150-550 MeV/c^2 only very slightly above the data corresponding to the first chance collisions. However, in the medium-heavy collision systems Ar+KCl, the dilepton yield in the region of invariant masses 150-550 MeV/c^2 overshoots clearly the yield from first chance collisions by about a factor 3 (see [7]).

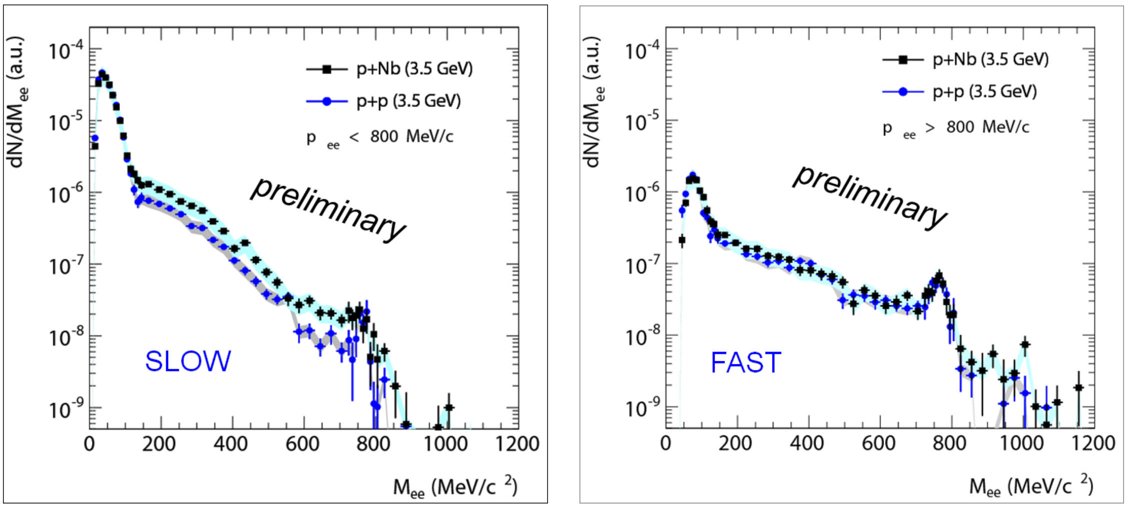

Fig. 1: Comparison of the di-electron yield (corrected for reconstruction efficiencies and normalized to the same number of pions) in the acceptance of HADES, between p+p (blue dots) and p+Nb (black squares). Systematic uncertainties are shown by the error bands.

HADES recently started series of experiments aimed to study the predicted change of hadron properties embedded into cold nuclear matter. In our experiments, a proton beam with a kinetic energy of $E_{kin} = 3.5\ GeV$ was incident on a liquid hydrogen target for the p + p collisions [8] and on a 12-fold ^{93}Nb target for the p + Nb collisions [9]. The absolute normalization of the

[1]LNS Catania, Univ. Coimbra, JU Cracow, NINP Cracow, GSI Darmstadt, FZR Dresden, JINR Dubna, IKPF Frankfurt, Univ. Giessen, INFN Milano, Univ. Milano, INR Moscow, TUM Muenchen, UCY Nikosia, IPN Orsay, NPI Řež, Univ. Santiago de Compostela, Univ. Valencia

measured di-electron yields were obtained exploiting measured elastic scattering of protons in p+p collisions and measured yield of charged pions in p+Nb collisons [10].

According to our simulations most of the produced ρ mesons decay inside the Nb nuclei, however, a significant part of fast moving relatively long living ω and ϕ mesons decay outside (see the discussion in [11]). Therefore, to enhance in-medium decays, we divided our data into two sets, i.e. e^+e^- pairs with momenta below and above $800 MeV/c$, respectively (see left and right panel of figure 1). While the peak around $780 MeV/c^2$ in the right panel, corresponding to the decay $\omega \to e^+e^-$, is the same in pp and pNb collisions, it is diminished in the left panel, i.e. for "slow" e^+e^- pairs. This experimental finding is in agreement with the scenario of significant broadening and/or strong absorption of slow ω mesons decaying inside the Nb nuclei. Further, the comparison of the pp and the pNb data in the right panel of figure 1, indicates that possible absorption of fast ω mesons in Nb is similar to that of pions. A significant excess of di-electron yield from pNb collisions over the pp case is observed for "slow" e^+e^- pairs (left panel) both in the intermediate part ($150 MeV/c^2 \leq M_{ee} \leq 550 MeV/c^2$), which in pp collisions can be attributed to $\Delta(1232)$ and η Dalitz decays [8], and in the high mass part of the distribution ($550 MeV/c^2 \leq M_{ee} \leq 700 MeV/c^2$), which can be attributed to $\Delta(1232)$ Dalitz decay as well as to direct decay of the light vector meson ρ. This finding can be interpreted as the manifestation of additional slowly moving sources of ρ, η and Δ due to secondary production processes propagating through the cold nuclear matter. Such an interpretation is further supported by the observation of a significant shift (≈ 0.1) of the corresponding rapidity distribution in the case of pNb collisions toward the target rapidity as compared to the pp case.

To conclude, we reveal a significant dilepton excess, both in cold nuclear matter and in the compressed baryonic matter phase of heavy-ion collisions, as compare to elementary NN collisions. These findings suggest as possible source the decay of baryonic resonances propagating through the matter - like the $\Delta(1232)$ - which are indeed known to mediate pion production at SIS18 bombarding energies.

The participation of Czech team in HADES collaboration was supported by grants GA AS CR IAA100480803 and MSMT LC 07050.

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Production of charged pions in reaction p+Nb at 3.5 GeV

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for the HADES [1] collaboration

The High Acceptance DiElectron Spectrometer HADES [1] is devoted mainly to study production of dielectron pairs from proton, pion and nucleus induced reactions at 1-2 AGeV. At the same time, the spectrometer provides detection and high quality identification of charged particles in a large solid angle.
In this contribution we focus on the analysis of charged pion production in p + ^{93}Nb collisions at 3.5 GeV. The results contribute to the data from systematic studies of pion production in proton-nucleus collisions (see e.g. [2]), and serve as a reliable tool for normalization of the dielectron data obtained in the same experiment.

For the particle identification, the energy loss of particles detected in the time-of-flight detectors was used.

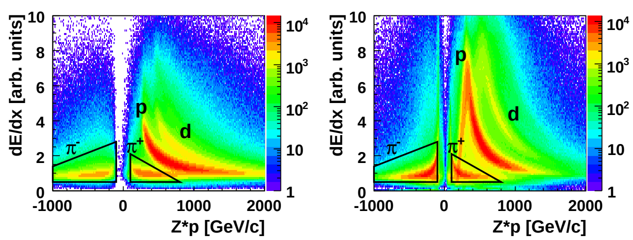

Fig. 1: Distribution of the energy loss versus charge*momentum of particles detected in inner TOFINO (left) and outer TOF (right) detectors

Fig. 1 shows the distribution of the energy loss versus charge × momentum, together with cuts selecting regions with positive and negative pions. π^- mesons can be identified with high purity in a large interval of momenta $p \geq 150 MeV/c$, while the range for π^+ is limited to the region $150 \leq p \leq 600 MeV/c$ due to an overlap with protons at higher momenta.

The resulting pion multiplicities are compared to existing data from a systematic study of pion production from p+A reactions measured by the HARP-CDP Collaboration [2], and in this way provide a natural normalization of the measured dielectron data (usually normalized to a number of neutral pions).

The cross section was obtained from the pion multiplicity in the following way: first we corrected it for enhancement by a factor of 1.42 caused by the LVL1 trigger (deduced from simulations), and then scaled it to the HARP-CDP data interpolated from 4 measurements for p+Cu and p+Ta at 2.20 and 4.15 GeV. The scaling factor $\sigma_R = \sigma_{\pi^-}(HARP)/M_{\pi^-}(HADES)$ is in fact the total reaction cross section for p + ^{93}Nb at 3.5 GeV.

The resulting total reaction cross section is 848 mb. Statistical errors are negligible, while the systematic error is estimated as 15%, with uncertainty of the trigger enhancement factor as a main source.

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[1] LNS Catania, Univ. Coimbra, JU Cracow, NINP Cracow, GSI Darmstadt, FZR Dresden, JINR Dubna, IKPF Frankfurt, Univ. Giessen, INFN Milano, Univ. Milano, INR Moscow, TUM Muenchen, UCY Nikosia, IPN Orsay, NPI Řež, Univ. Santiago de Compostela, Univ. Valencia

The HADES lead glass calorimeter

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for the HADES [1] collaboration

The HADES collaboration has finished recently the upgrade project which focused on improving the experimental apparatus [1] for measuring heavy systems at the current SIS18 (energy up to 2 A GeV) and later at SIS100 accellerator at the future FAIR facility (energy up to 15 A GeV).
One of the main physics objectives of HADES at SIS100 will be to provide high-quality dielectron data at baryon densities and temperatures not accessible by other detectors, neither in the past nor in the foreseeable future. For the SIS18 energy range, production of neutral mesons has been studied extensively by the TAPS collaboration via photon calorimetry. However, for the 2-40A GeV range no data at all do presently exist, with the consequence that any interpretation of future dielectron data would have to depend solely on theoretical models, e.g. transport calculations or appropriate hydrodynamical models. In order to remedy this situation the HADES collaboration proposes to measure the respective π^0 and η meson yields together with the dielectron data. This can be achieved by replacing the HADES PreShower detector, located at forward angles ($18° < \theta < 45°$), with an electromagnetic calorimeter of a total area of about $8\,\mathrm{m}^2$, see Fig. 1 (left).

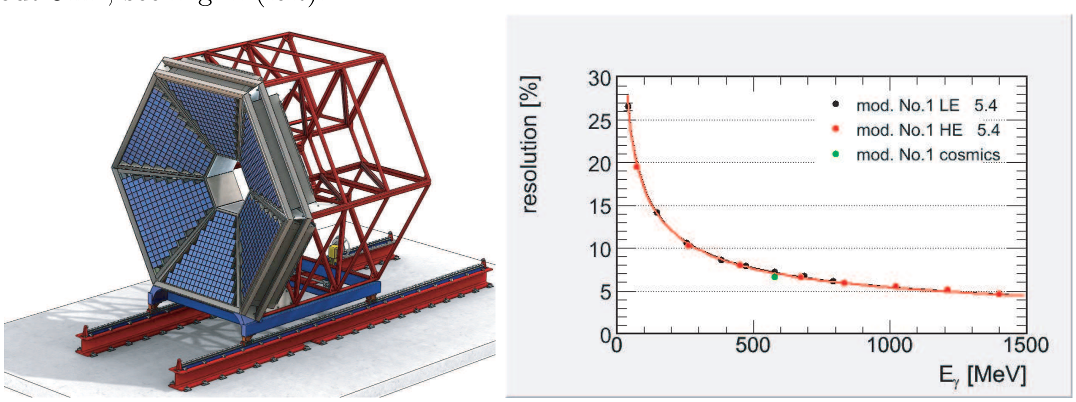

Fig. 1: Left: 3D view of the Calorimeter model. Right: Energy resolution of lead glass measured with photon beams as a function of photon energy.

The calorimeter should serve the following two main functions in HADES: (1) detection of photons emitted from HI and p,π induced reactions allowing π^0 and η reconstruction from the measurement of their decays into 2 γ and (2) improved electron identification and pion rejection. For this detector we plan to recuperate a lead-glass calorimeter from the former OPAL experiment at LEP and adapt it to HADES. The existing OPAL modules are 9.4x9.4 cm^2 and their use would hence result in smaller granularity (about 840 modules in total) than presently available from the PreShower detector. The energy resolution of this solution is comparable to the one of shashlik modules and amounts to about 6 % at 1 GeV. Mainly due to the cost, time constraints and good performance expected for lead glass we follow the latter option.

Several lead glass modules were assembled by the team from NPI Rez with help of technicians from the Optical workshop of the Charles University, Prague. Then they tested at the MAMI accelerator in Mainz with photon beams in order to measure the detailed energy resolution for the whole energy range relevant for the reactions at FAIR. The measured energy resolution is below 6% at 1 GeV, as shown in Fig. 1 (right) , and is consistent with our detector requirements.

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The second important function of the planned calorimeter for HADES, e/pi separation, has been measured at CERN with secondary pion/electron beams. The ability of the lead-glass detectors to separate electrons from pions was extracted from the data in a following way: The electron/pion separation factor is defined as a number of pions outside of the electron peak divided by the total number of pions, assuming the same electron and pion abundancy. The result is displayed in Fig. 2 (left).

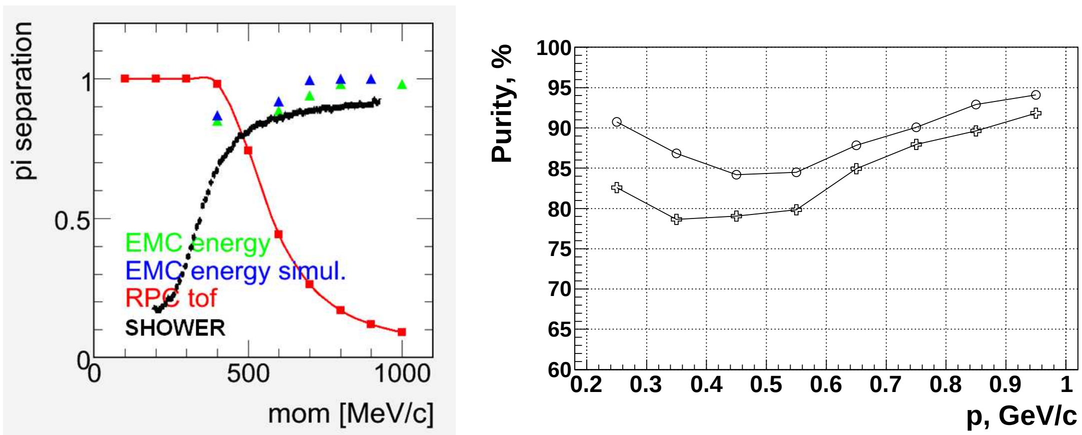

Fig. 2: Left: e/π separation factor as a function of momentum. Right: Purity of the electron (upper curve) and positron (lower curve) identification in Ni+Ni collisions at 8 A GeV at the cut efficiency of 75%.

As seen from the figure, the calorimeter is more efficient in e/pi separation than the existing SHOWER detector. The experimental results are perfectly reproduced in the simulation prepared for the lead glass calorimeter. Based on these results we obtain the purity of dielectrons from Ni+Ni at 8 A GeV for the momentum range from 0.25 GeV/c up to 1.0 GeV, see Fig. 2 (right). For the momenta below 450 MeV/c very good π/e separation can be obtained based only on the ToF measurement in RPC (100 ps time resolution). For higher momenta the ToF method is not sufficient and the calorimenter has to be employed to obtain a purity close to 95 % for e^- and 90% for e^+.

As the total weight of the lead glass modules for the electromagnetic calorimeter, together with its mechanical installation, will exceed 20 tons, special attention has been paid to the integration of the detector into the HADES spectrometer. The proposed solution is shown in Fig. 1 (left) and is based on completely separated mechanical infrastructure for the calorimeter.

This work was supported by the GA AS CR IAA100480803 and MSMT LC 07050.

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Low Energy Experimental Nuclear Physics

Program of the astrophysical research continued in study of the nucleosynthesis and particle transfer reactions relevant to the stellar environment. We investigated especially the radiative (n,γ) capture via the (d,p) reactions important for the processes in CNO cycle. These studies included reactions on ^{14}N, ^{17}O, ^{18}O and ^{14}C nuclei. The last nucleus plays an important role in inhomogeneous big bang models.

The proton radiative capture was investigated on the same nuclei using (^{3}He,d) transfer reactions. Similar experiments were realized in Texas laboratory on the ^{17}O and ^{22}Ne beams. Interpretation of experimental results was carried out in the well known Asymptotic Normalization Coefficient (ANC) method.

A large research effort was devoted to study of the particle transfer reactions at the lowest energies using the Trojan Horse Method (THM). This program included measurements of the astrophysical S-factors and study of the resonant structure in low energy region in reactions (p,α), (d,α), (d,p) and (n,α) on light nuclei ^{6}Li, ^{7}Li, ^{9}Be, ^{10}B and ^{11}B using both ^{3}He beams of the cyclotron at NPI Řež and beams of heavier ions such as ^{10}B, ^{11}B, ^{17}O or ^{18}O. Astrophysical program was realized under a large international cooperation of NPI at Řež, Cyclotron laboratory of Texas A&M University, LNS at Catania and ATOMKI Debrecen. Results of astrophysical research were published in prestigious journals and international conferences.

Activities in the field of neutrino physics, as the second branch, are connected with our participation in the KArlsruhe TRItium Neutrino experiment (KATRIN). The aim of this international project is to measure precisely the endpoint region of the tritium β-spectrum and thus to improve the neutrino mass sensitivity to 0.2 eV/c^2. Since the experimental observable is the neutrino mass squared, the KATRIN represents 100 times improvement in comparison with the best current model independent determinations. The indicated sensitivity is of great importance for the particle physics, cosmology and astrophysics. The responsibility of the Czech participants is to develop radioactive sources of monoenergetic electrons enabling long term monitoring of the 18.6 kV analyzing retarding voltage of the β-ray spectrometer with stability of ±60 mV/(2 months). The 18635.68±0.23 eV photoelectrons from the source ^{241}Am/Co, based on the 26.3 keV gamma transition and K-shell electrons of cobalt, were considered first. Because the photoelectron intensity appeared to be too low for the continual monitoring the solid source of the 17824.3±0.5 eV internal conversion electrons using generator ^{83}Rb(86d)/^{83m}Kr(2h) was developed. Besides, the radioactive source with ^{83}Rb deposited in zeolite which finds its use in the dark matter search project XENON was also tested.

Low Energy Experimental Nuclear Physics Group takes part in the experiments testing the Standard Model of electroweak interactions which describes β-decay in the well-known V–A form. Nevertheless, the other possible interaction types (Scalar S and Tensor T) are not fully ruled out yet experimentally. The measurement of the β asymmetry parameter in nuclear β decay is a potentially very sensitive tool to search for new time reversal invariant tensor component in the weak interaction. For this purpose two experimental setups using the low-temperature nuclear orientation (LTNO) method are employed - online LTNO facility NICOLE at ISOLDE, CERN, Switzerland and Brute-Force LTNO set-up at IKS Leuven, Belgium. Both facilities look for the forbidden tensor component in the weak interactions and first experimental results putting limits to its possible presence were already published [1,2].

Another correlation in β-decay sensitive to the new physics outside of Standard Model is a β-ν correlation which can be replaced (due to difficulty to detect neutrinos) by the study of recoiling nuclei. The WITCH experiment at ISOLDE, CERN, Switzerland, the world unique combination of 2 Penning traps and retardation spectrometer, allows us to trap radioactive ions produced by ISOLDE separator, cool them, let them decay and probe the energy spectrum of recoiling nuclei by the retardation spectrometer. The precise measurement of the shape of the recoil ion energy spectrum aims to study a possible admixture of scalar interaction in nuclear β-decay.

All 3 different projects looking for exotic types of weak interactions are operational and proof-of principle experiments were already performed, current results are competitive to best world average of comparable experimental data and we take new data in order to get well bellow the existing experimental limits on the admixtures of Standard Model forbidden components of weak interactions. This work was supported by the Grant of the Ministry of Education of the Czech Republic LA08015.

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New high accuracy measurement of the $^{17}O(p,\alpha)^{14}N$ reaction rate at astrophysical temperatures

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The reaction $^{17}O(p,\alpha)^{14}N$ was studied by an indirect THM method in a common collaboration in INFN-LNS, Catania. The reaction is of fundamental relevance in novae, AGB branch nucleosynthesis and gamma-ray astronomy. This isotope is produced in CNO cycle and the reaction (p,γ) leads to CNO III cycle and the formation of the short-lived ^{18}F isotope, that is observed in novae in gamma-ray window. As gamma rays have a relatively short mean free path in the material, the observations of ^{18}F give an information on supply of ^{17}O into the nova envelope. The studied reaction is a concurrent reaction that removes possible ^{18}F from the process. The relevant temperatures for ^{17}O nucleosynthesis are T_9=0.01-0.1 for red giants, AGB and massive stars and T_9=0.01-0.4 for classical nova explosions.

The cross section in low energy region for the $^{17}O(p,\alpha)^{14}N$ reaction is dominated by two resonances at 65 keV and 183 keV. In this work the region below 300 keV was studied.

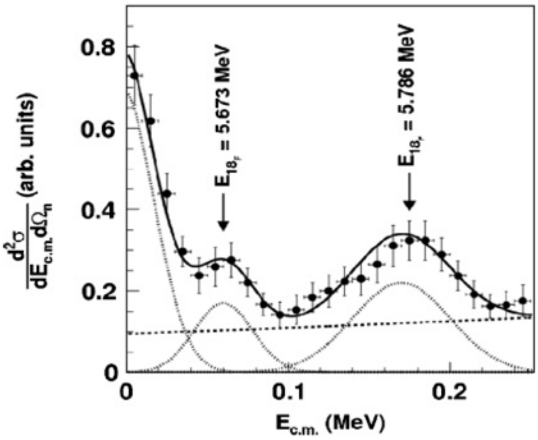

Fig. 1. Cross section of the TH reaction.

The $^{17}O(p,\alpha)^{14}N$ process was studied using $^{2}H(^{17}O,^{14}N\ \alpha)n$ reaction. The target Deuterium was used as a Trojan horse taking the proton into the nuclear region of the ^{17}O and ^{14}N and alpha outgoing particles were detected in coincidence.

The experiment was performed with 41 MeV ^{17}O beam impinging 150 ug/cm2 thick CD_2 target. The detection system consisted of six Si position sensitive detectors and two ionization chambers used as dE detectors to discriminate amongst heavier ions.

The resulting spectrum was deduced from the three body cross section data analysis and PWIA analysis and is shown in Fig. 1. The full line represents a result of the fit, a first-order polynomial was used to take into account the nonresonant contribution to the cross section.

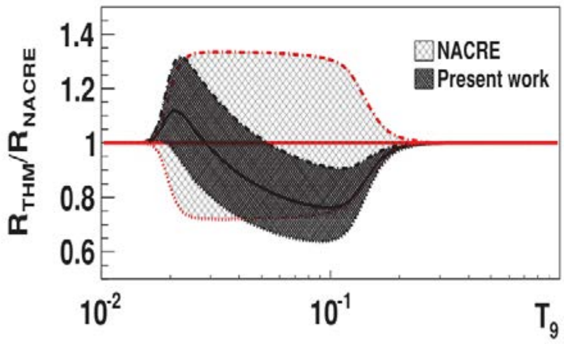

Fig.2. Comparison of the reaction rate to NACRE reaction rates.

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The strength of 65 keV resonance was deduced as $(\omega\gamma)_1 = 3.66^{+0.76}_{-0.64}\ 10^{-9}$ eV from the experimental data and a comparison to a previously measured strength of the 183 keV resonance $(\omega\gamma)_2$. This value overlaps that from NACRE $(\omega\gamma)_N = 5.5^{+1.8}_{-1.5}\ 10^{-9}$ eV. The resulting reaction rate is compared to the NACRE code in Fig. 2 where red lines stand for the NACRE rate ratio and uncertainties and black lines show the current measurement to NACRE ratio and the experimental uncertainties connected to the 65 keV resonance only. The figure shows that in the low temperature region the extracted value of the reaction rate is up to 20% different than the used one. The discrepancy could be assigned to electron screening effect that was not taken into account in direct measurement as seen in Fig. 3 where $(\omega\gamma)_{SCREEN} = 1.148\ (\omega\gamma)_1 = 4.21^{+0.87}_{-0.73}\ 10^{-9}$ eV.

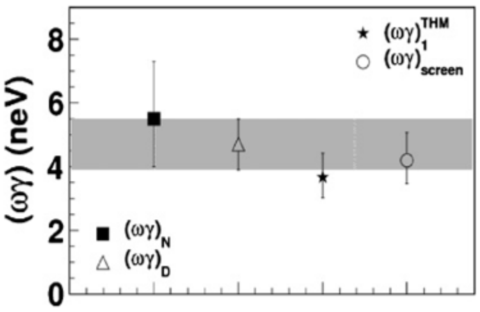

Fig.3. Comparison amongst different values of the 65 keV strength. The gray band is a deduced range.

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Asymptotic Normalization Coefficients from the $^{14}C(d,p)^{15}C$ reaction

A.M. MUKHAMEDZHANOV[1], V. BURJAN, M. GULINO[2], Z. HONS, V. KROHA, M. McCLESKEY[1], J. MRÁZEK, N. NGUYEN[3], F.M. NUNES[3], Š. PISKOŘ, S. ROMANO[2], M.L. SERGI[2], C. SPITALERI[2], L. TRACHE[1], R.E. TRIBBLE[1]

In inhomogeneous big bang models the $^{14}C(n,\gamma)^{15}C$ reaction plays an important role being the part of the chain $^{7}Li(n,\gamma)^{8}Li(\alpha,n)^{11}B(n,\gamma)^{12}B(\beta^{-})^{12}C(n,\gamma)^{13}C(n,\gamma)^{14}C(n,\gamma)^{15}C$. Due to the high neutron abundance the $^{14}C(n,\gamma)^{15}C$ reaction can compete strongly with the other reactions on ^{14}C, which all lead to the production of heavier nuclei (A >20). In [1] it was shown that the radiative capture $^{14}C(n,\gamma)^{15}C$ at astrophysically relevant energies is a peripheral reaction, i.e. the overall normalization of its cross section is determined by the asymptotic normalization coefficient (ANC) for $^{15}C \rightarrow {}^{14}C + n$. This ANC has been determined in [1] using the mirror symmetry from the width of the broad resonance in ^{15}F. The recommended value is $C^2(0\ ½) = 1.89\pm0.11\ fm^{-1}$. Here 0 and ½ are the orbital and total angular momentum of the neutron in ^{15}C. The uncertainty of the ANC determined from the mirror symmetry can be in this case large. In [2] the ANC $C^2(0\ ½) = 1.64\pm0.03\ fm^{-1}$was determined from the analysis of the Coulomb dissociation of ^{15}C on ^{208}Pb at 68 MeV/nucl. The calculated cross section for the direct radiative capture $^{14}C(n,\gamma)^{15}C$ using this ANC is in an excellent agreement with the latest direct measurements [3]. Such an agreement allows us to conclude that the ANC determined in [2] can be refered as a recommended value.

To check the consistency of the ANC for the neutron removal from ^{15}C the (d,p) reactions can be used. In [4] the analysis of the $^{14}C(d,p)^{15}C$ experimental data [5] obtained at 14 MeV deuteron energy was carried out testing different approaches to the reaction theory: (1) DWBA (Distorted Wave Born Approximation) with the global deuteron optical potential, (2) DWBA using fits of d–^{14}C elastic scattering, and (3) ADWA (adiabatic wave approximation) where deuteron potential is constructed as the sum of the proton and neutron optical potentials at half of the deuteron energy [6] with finite range corrections as in [7]. This last method takes into account deuteron breakup explicitly. For the choice (1) and (2) the obtained interval of C^2 was 2.516 –2.777 fm^{-1}. For choice (3) a significant reduction was observed, 2.08–2.44 fm^{-1}, but this reduction was not enough to reconsile the ANC extracted from the (d,p) reaction with values determined from breakup reactions and (n,γ) processes which are significantly lower [2].

We present here new and improved measurements of the angular distributions of $^{14}C(d,p)^{15}C$ for a deuteron energy of 17.06 MeV. In comparison with [5], we decreased the minimal angle to 6.6^0 which is important for the more reliable normalization at the main stripping peak of the angular distribution for determination of ANCs. In addition we used the finite range adiabatic model to extract the ANCs for transfer to the ground and first excited states of ^{15}C, taking into account the most important higher order effect, deuteron breakup.

The experiment was realized on the isochronous cyclotron U-120M at the Nuclear Physics Institute of ASCR, p.r.i. The deuteron beam was led on ^{14}C and Mylar targets. At all angles we alternately measured spectra from both these targets to be able to determine exact contents of the isotope ^{14}C in ^{14}C target. Admixtures in target included ^{12}C carbon, oxygen, hydrogen, nitrogen and ^{28}Si silicon. The effective thickness of ^{14}C target was 174.9μg/cm^2. Reaction products were registered by four ΔE-E telescopes with detector 200μ and Si(Li) 4000μ respectively. Experimental angular distributions were measured at 6^0 – 75^0 angular range in laboratory system. The total systematic uncertainty is estimated to be 10 %. In Fig.1 a typical proton spectrum is shown together with target contaminations. Experimental angular distributions of protons from $^{14}C(d,p)^{15}C$ reaction populating the ground state 01/2 and the first

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excited state 25/2 (E_x = 0.740 MeV) in ^{15}C are shown in Fig.2 and 3, correspondingly. The calculations from ADWA (thick solid line) as well as DWBA calculations with different combinations of the optical potentials are also shown.

The calculated angular distribution for the transition to the ground state reproduces the experimental data in the vicinity of the first peak, and this is sufficient to determine an ANC by normalizing the calculated ADWA differential cross section to the experimental one at forward angles. Region of the first minimum of the angular distribution usually corresponds to different mechanism of reaction and for determination of ANCs is not important. However, for the method to work, one must first ensure the reaction is peripheral. We found 13% interior contribution for the transfer to the ground state and 7 % contribution for the transfer to the first

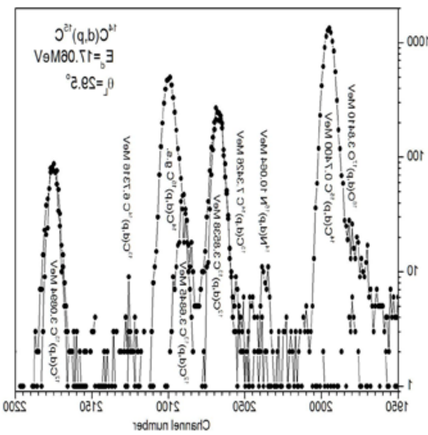

Fig.1

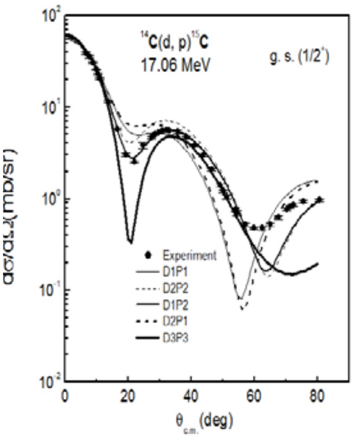

Fig.2

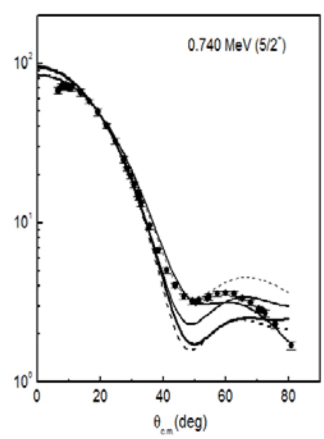

Fig.3

excited state. We have added these errors in quadrature to the systematic error in extracted ANC squared. The overall normalization is determined by the square of the product of ANC for the neutron removal from ^{15}C and the ANC for deuteron wave function. Since the ANC for deuteron is known, the $C^2(l,j)$ for ^{15}C can be readily extracted. Our result for $C^2(01/2)=1.72\pm0.17\ fm^{-1}$ agrees very well with the result obtained in [2] and with the value dictated by the direct radiative (n,γ) capture [3]. For the first excited state we obtained $C^2(2\ 5/2)=0.0037\pm0.00037 fm^{-1}$. For extraction of ANCs we used ADWA approach. All the DWBA calculations give much higher values of ANCs demonstrating the shortcomings of the DWBA procedure. One of the main conclusion of our study is that the $^{14}C(d,p)^{15}C$ reaction can be used to determine the ANCs but one needs to go beyond DWBA for reliable extraction of ANCs.

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Long-term monitoring of high-voltage stability at the KATRIN experiment

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One of the necessary conditions to achieve the 0.2 eV neutrino mass sensitivity in the Karlsruhe Tritium Neutrino experiment (KATRIN) is to avoid any unrecognized changes of the retarding high-voltage applied to the electrostatic electron spectrometer. The fluctuations exceeding ±60 mV at 18.6 kV (the endpoint energy of the ^{3}H β-spectrum amounts to 18575 eV) would cause an unacceptable systematic error in the derived value of the neutrino mass. Therefore the long-term stability of the KATRIN energy scale will be monitored also by means of monoenergetic internal conversion electrons emitted from an $^{83}Rb/^{83m}Kr$ source. The ^{83}Rb productions, vacuum evaporations and the first electron measurements of about 30 sources were carried out at the NPI at Řež. Tests of the electron line energy stability at 17.8 keV were performed at the IP of the Mainz University. The drifts Δ< 1 ppm/month shown in Fig. 1 fulfil the KATRIN requirements. Since typical tritium runs of the KATRIN set-up will last 2-3 months, additional tests of the monitoring line stability will follow with the upgraded Mainz spectrometer transferred to the KATRIN site at Karlsruhe. In addition, the investigation has been extended to mass separated implanted $^{83}Rb/^{83m}Kr$ sources that might be less sensitive to possible changes of vacuum conditions.

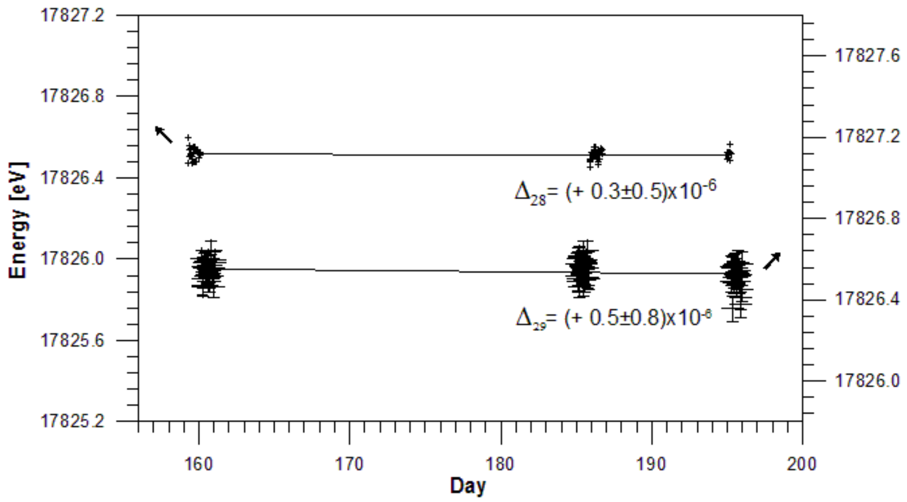

Fig. 1. Time dependence of the energy of the K-32 conversion electrons emitted from two vacuum evaporated $^{83}Rb/^{83m}Kr$ sources (No. 28 and 29) measured for 36 days with the Mainz spectrometer. The observed energy drifts Δ are expressed in relative units per month. The arrows mark the corresponding energy scales.

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^{83m}Kr electron source for calibration of the XENON dark matter experiment

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Astronomical and cosmological observations indicate that one quarter mass-energy density of the Universe is composed of cold nonbaryonic matter which does not interact with electromagnetic radiation, does not absorb or emit light and hence is called dark matter. So far dark matter has revealed its existence only through gravitational effects with normal matter. The only particle provided by the standard model of particle physics which is stable, uncharged and carries mass, and as such could act as dark matter is the neutrino. However, from recent observation it is known that the mass of the neutrino is too low to account for the required total mass. Several extensions of the standard model of particle physics predict new particles that would appear as Weakly Interacting Massive Particles (WIMPs) that may be detectable via rare scatter interactions that deposit up to tens of keV in recoiling target nuclei. These WIMPs are candidates to solve the dark matter problem. It is expected that WIMPs are interacting directly in detectors with typical values for the cross-section between 10^{-6} pb and 10^{-11} pb [1]. Liquid xenon (LXe) particle detector with photomultiplier tubes was developed for dark matter detection in the frame of XENON collaboration. In this application the energy deposition in LXe volume is measured by counting scintillation photons and detecting the ionization signal. LXe response depends on electronic stopping power (*dE/dx*) to the incoming particle, which itself depends on both the identity and energy of the particle. It is necessary to calibrate the detector energy scale with a suitable source. A promising calibration source is metastable ^{83m}Kr, which diffuses uniformly in LXe detector fulfilling the demand for the spatial uniformity. Additionally, its two de-excitation gamma transitions at 9.4 and 32.2 keV lie in the range of interest for dark matter searches and its half-life of only 1.8 h allows short waiting time, until ^{83m}Kr will decay after calibration, in order to accomplish the dark matter search measurement at the necessary low background. The ^{83m}Kr is generated in the decay of ^{83}Rb with the half-life of 86.2 d. For the calibration of the XENON dark matter detector, a source in form of ^{83}Rb deposited in zeolite beads in amount of about 3 kBq was successfully tested [2]. The zeolite allows for efficient emanation of ^{83m}Kr in vacuum (~50%) and at the same time for preventing release of the long-lived ^{83}Rb even at 300 °C [3]. Another ^{83}Rb dedicated emanation test was accomplished at INP Münster [4]. The upper limit for ^{83}Rb release was found to be 1 mBq from ca 1 MBq source. It means that the source might be suitable for the purposes of the XENON experiment.

Until now, 15 samples of ^{83}Rb in zeolite were prepared for the XENON collaboration. Besides that, this type of calibration source was also tested for the use in Large Underground Xenon (LUX) experiment in Homestake Mine in South Dakota [5].

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Theoretical Physics

Research activities of the research group 'Theoretical Physics' include the studies of:

- **production and structure of hypernuclei**
- **strong interactions of π, K, Σ and antiproton atoms**
- **mesonic and nonmesonic decays of light hypernuclei**
- **effective chiral models for low-energy meson-baryon interaction**
- **electroproduction of *K* on protons (isobaric and Regge models)**
- **algebraic models for nuclear structure**
- **electromagnetic and weak meson exchange currents**
- **few-nucleon systems both in v/c expansion approach and covariant framework**
- **processes with high transverse momenta at relativistic energies**
- **inclusive particle production at high energies**
- **solutions of Schwinger-Dyson equations in Minkowski space**
- **diquarks and internal baryon structure**
- **models of dynamical mass generation**
- **properties of the Goldstone modes**

The group annually organizes the international Indian-Summer School of Physics:
Nuclear Many-Body Problem, Aug 31-Sept 4, 2009
Strangeness Nuclear Physics, Sept 7-11, 2010

Some members of the group give lectures at the Czech Technical University in Prague and supervise both the doctoral and the diploma theses.

Multi-$\bar{K}$ hypernuclei

D. Gazda, E. Friedman [1], A. Gal [1], J. Mareš

We perfomed relativistic mean-field (RMF) calculations of baryonic systems containing several antikaons. We focused on the question whether or not kaon condensation could occur in strong interaction self-bound nuclear matter, thus whether the K^- mesons could be the relevant degrees of freedom of self-bound strange matter, as suggested in Ref. [1]. This scenario requires that $\bar{K}$ separation energy exceeds the threshold value of roughly $m_K + \mu_N - m_\Lambda \approx 320$ MeV, thus allowing for the conversion $\Lambda \to \bar{K}N$ in matter. In Ref. [2], we observed that the binding energy of K^- mesons, as well as the associated nuclear and K^- density distributions *saturate* upon increasing the number of the K^- mesons embedded in the nuclear medium. The saturation pattern was found to be a robust feature of these multi-strange configurations. It is present across the entire periodic table, independent of the RMF model used, and occurs for any mean field composition containing the dominant ω-meson exchange. In Refs. [3,4], we generalized our calculations into the domain of hypernuclei and studied whether the presence of hyperons could alter our previous conclusions. In Fig. 1 we present the $1s$ K^- separation energies B_{K^-} as a function of the number κ of antikaons bound in several particle-stable hypernuclear systems. These configurations were built on top of selected core nuclei by adding first the Λ and then Ξ hyperons until both conversions $\Lambda\Lambda \leftrightarrow \Xi N$ were kinematically forbidden, thus the resulting system being particle-stable against strong interactions (for details see Ref. [4]). It is to be stressed that in all cases the B_{K^-} does not exceed 120 MeV in these multistrange configurations, which is considerably short of the threshold value of ≈320 MeV necessary for the onset of kaon condensation under laboratory conditions.

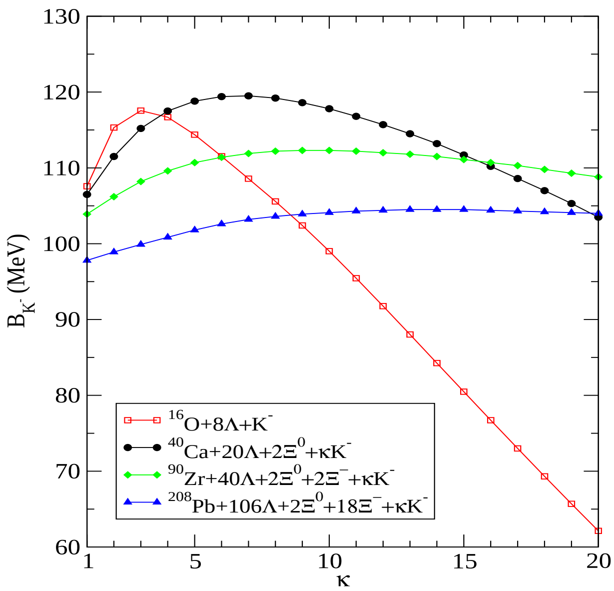

Fig. 1: *The $1s$ K^- separation energy B_{K^-} as a function of the number κ of antikaons in several hypernuclear configurations.*

This work was supported by the Grant Agency of the Czech Republic (grant No. 202/09/1441).

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Electroproduction and spectroscopy of hypernuclei

P. Bydžovský and M. Sotona

Studying the electroproduction and properties of Λ hypernuclei, the long-living multibaryonic systems with non-zero strangeness, is an important source of information about the baryon-baryon interactions. Producing the Λ hyperon inside the ordinary nuclei allows us to probe a structure deep inside the nucleus because the Λs are not Pauli blocked there. Revealing the production mechanism and structure of hypernuclei we get more information about the hyperon-nucleon interactions, especially about the spin-dependent part, which is not accessible by today viable experiments on the Λ-nucleon scattering.

Measurements of the electroproduction of hypernuclei, ${}^{A}Z(e,e'K^+){}^{A}(Z\text{-}1)_\Lambda$, with high resolution, which have been performed at Jefferson Laboratory (JLab) [1-4], allow a systematical study of the structure of p-shell hypernuclei. We have participated actively in the hypernuclear experiment in Hall A at JLab [1] providing a theoretical support in the preparation of the experiment and in the analysis and interpretation of data [3,4]. ${}^{12}B_\Lambda$ and ${}^{16}N_\Lambda$ hypernuclei investigated in Hall A experiment are mirror partners of ${}^{12}C_\Lambda$ and ${}^{16}O_\Lambda$ hypernuclei studied intensively in meson induced reactions [5]. The comparison of precise values of the Λ binding energies and energy spectra of such mirror hypernuclei can also shed new light on the problem of possible charge symmetry breaking part of the hyperon-nucleon interaction.

The cross sections for the electroproduction of hypernuclei are calculated in the framework of the distorted-wave impulse approximation (DWIA), which has approved to be a powerful tool in studies of the electromagnetic production of hypernuclei [2-4, 6]. In these calculations a reliable prescription for the amplitude of the elementary $p(e,e'K^+)\Lambda$ reaction is necessary to reduce uncertainty of predictions. We have analyzed models for the elementary process [7] to have this part of input information in DWIA calculations under control.

The theoretical cross sections obtained in DWIA using the Saclay-Lyon model [8] for the elementary amplitude are shown in Fig. 1 in comparison with recent data [4] obtained for the ${}^{16}O$ target nucleus. The ground state of ${}^{16}O$ is assumed to be a simple closed shell and the shell-model wave functions for ${}^{16}N_\Lambda$ are computed in a particle-hole model space. For the $p_N^{-1}s_\Lambda$ states, a multirange Gaussian (YNG) interaction is adjusted to reproduce the spectra of ${}^{16}O_\Lambda$ and ${}^{15}N_\Lambda$ [9,10] when matrix elements of the ΛN effective interaction are evaluated with Wood-Saxon wave functions. The same YNG interaction is used for the $p_N^{-1}p_\Lambda$ states. The effect of $\Lambda - \Sigma$ coupling is also taken into account [10].

The four pronounced peaks in the energy spectrum in Fig. 1 are reproduced by the shell-model calculation. It is significant that the energy separation between the two lowest peaks agrees very well with that deduced from the theoretical centroids, and hence with the precise γ-ray data [9]. The largest discrepancy between theory and experiment is in the position of the fourth peak. A firm prediction of the simple particle-hole model is that the gap between the third and fourth peaks should be significantly larger (6.5 MeV) than the underlying separation (6.324 MeV) of the p-hole states in ${}^{15}N$, in contrast to the observed splitting of 6.18 MeV. A more elaborate shell-model $1h\omega$ calculation, which includes s_Λ states coupled to positive-parity 1p2h states of the ${}^{15}N$ core, is needed to investigate this problem.

The Λ separation energy $B_\Lambda = 13.76 \pm 0.16$ MeV obtained for the first peak is an important quantity because (i) it depends on the average central ΛN and perhaps ΛNN interactions in addition to the spin-dependence of the ΛN interaction that primarily affect energy level spacings, (ii) there are few emulsion events for the hevier p-shell hypernuclei which tend to have ambiguous interpretations, and (iii) the reactions involving the production of a Λ from a neutron are more difficult to normalize.

This work was supported by the Grant Agency of the Czech Republic (grant No. 202/08/0984).

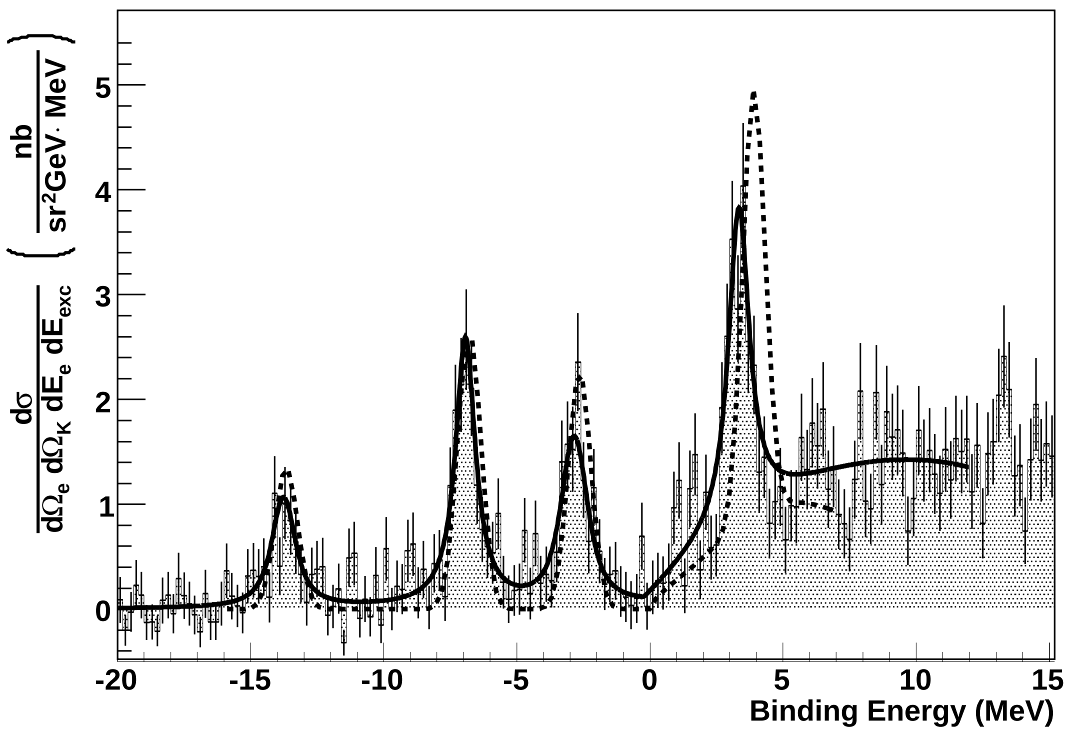

Fig. 1: *The binding-energy spectrum in the electroproduction of* $^{16}N_\Lambda$ *hypernucleus on the* ^{16}O *target nucleus. The theoretical DWIA calculations with the Saclay-Lyon elementary-production amplitude (dashed curve) are compared with experimental data. The solid curve is the best fit to the data [4].*

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Λ hypernuclear production in $(K^-_{\rm stop}, \pi^-)$ reactions

A. Cieplý, E. Friedman [1], A. Gal [1], V. Krejčiřík

The new experimental data [1] on the Λ-hypernuclear production in $(K^-_{\rm stop},\pi^-)$ reactions allow to study the A-dependence of the formation rates for the p-shell nuclear targets. The calculated capture rates significantly underestimate the measured ones, the deeper the K^- potential, the smaller is the capture rate [2]. Thus, one should look at relative rates and the A-dependence of the production rates where the impact of both the theoretical ambiguities and the experimental systematic errors should not obscure our observations. Within a framework of the distorted wave impulse approximation the nuclear capture rate per stopped kaon R_{fi}/K can be expressed [2] as a product of three terms, a kinematical factor, the elementary branching ratio (BR) of the process $R(K^-N \to \pi\Lambda)$, and a rate per hyperon R_{fi}/Y. While the BR has standardly been taken as a constant fixed at its threshold value, our work [3] demonstrates the importance of considering the energy and density dependence of the BR.

In Figure 1 we show the calculated $1s_\Lambda$ formation rates (per stopped kaon) in comparison with the FINUDA data for nuclear targets from ^{7}Li to ^{16}O. The presented theoretical rates were normalized to reproduce exactly the experimental rate for the ^{7}Li target, so one can focus on the A-dependence of the rates. The calculated rates in the l.h.s. of the Figure assume a constant BR generated by an effective chiral model, taken at the $\bar{K}N$ threshold and for an intermediate nuclear density. In this case the A-dependence is solely driven by the rate per hyperon that contains the overlap of the initial and the final state wave functions and the chirally motivated kaon-nuclear optical potential does a better job than the phenomenological one. The calculated rates presented in the r.h.s. of the figure incorporate in addition the energy and density dependence of the BR that appears due to an energy shift from threshold to subthreshold $\bar{K}N$ energies [3]. This feature provides a link between the shallow $\bar{K}$-nuclear optical potentials obtained microscopically from threshold $\bar{K}N$ interactions and the phenomonelogical deep ones deduced from kaonic atoms data. Both the phenomenological and the chirally motivated optical potentials are deep at the subthreshold energies relevant for the evaluation of the energy dependent BR, so they lead to similar $1s_\Lambda$ formation rates.

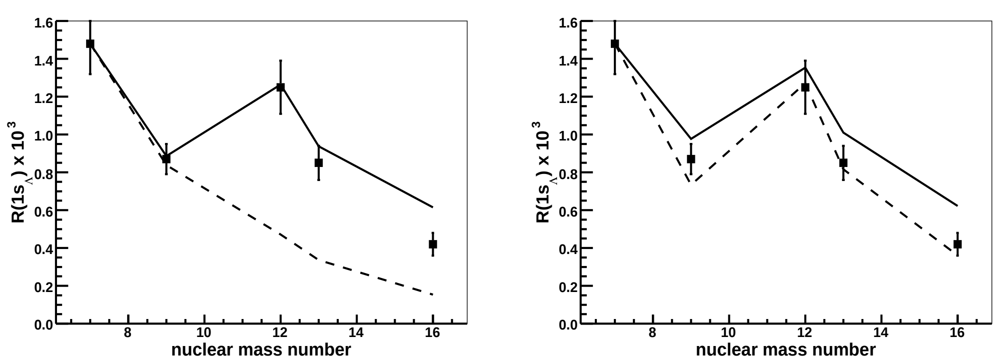

Fig. 1: *Comparison between the FINUDA capture at rest data and the theoretical rates obtained with two different K^--nuclear optical potentials: a density dependent phenomenological one fitted to kaonic atoms data (dashed lines) and a microscopical chirally motivated model (full lines). See text and Ref.[3] for more details.*

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Spontaneous Symmetry Breaking and Nambu–Goldstone Bosons in Quantum Many-Body Systems

T. Brauner

Lorentz invariance ensures that in case of a spontaneously broken continuous global internal symmetry, the number of Nambu–Goldstone (NG) bosons equals the number of broken symmetry generators and they share the common, linear dispersion relation. On the other hand, in more general many-body systems, neither of these two properties survives. The actual number of NG bosons turns out to be tightly connected to their dispersion relations and to the possibility that the broken charges acquire nonzero density. In this contribution [1] we summarize the results of the series of papers [2] as well as review the work of others, and offer some new observations.

The fundamental theorem of Nielsen and Chadha asserts that, provided there are no long-range interactions, NG bosons can be classified as type-I or type-II, depending on whether their dispersion relation is proportional to an odd or even power of momentum in the low-energy limit. The number of type-I NG bosons plus the number of type-II NG bosons is then greater than or equal to the number of broken generators. Numerous examples of type-II NG bosons are known, the most famous one being the spin-wave in ferromagnets. No system has been reported so far in which a sharp inequality in the Nielsen–Chadha counting rule would actually occur. Also, in all systems studied so far the NG dispersion relation is either linear or quadratic.

The relation between the number of NG bosons and charge densities in the ground state is partially settled by the theorem of Schäfer et. al: the number of NG bosons is usual (that is, equal to the number of broken generators) if the commutators of all pairs of broken generators have zero expectation value. Since the generators typically furnish a Lie algebra, this implies that some of the generators must have nonzero density in order for the number of NG bosons to be "abnormal". In [2] it was conjectured, and proved within the general class of relativistic linear sigma models with chemical potential at tree level, that once the basis of generators is chosen so that only mutually commuting generators have nonzero density, there is exactly one type-II NG boson for each pair of generators whose commutator has nonzero density. Within this class of systems, one has thus established an exact correspondence between the number of NG bosons, their dispersion relations, and charge densities in the ground state. However, there are also systems where the quantized generators no longer satisfy the commutation relations of the classical Lie algebra. The simplest example is the free nonrelativistic particle which can be interpreted as a type-II NG boson of a spontaneously broken global ISO(2) symmetry. The symmetry group is noncompact in this case and acquires a central charge upon quantization. Thus a type-II NG boson can exist even if all generators have zero densities.

The NG bosons of a spontaneously broken symmetry are often described using a local low-energy effective field theory (EFT). The general construction of the EFT for nonrelativistic NG bosons was worked out by Leutwyler with the surprising result that unlike in the relativistic case, the EFT can no longer be encoded in an invariant Lagrangian density. On the contrary, when type-II NG bosons are present, the Lagrangian is only invariant up to a total derivative as a consequence of a term of a topological nature with a single time derivative. Also surprisingly, there are even spontaneously broken symmetries which cannot be described by a local EFT at all. In such systems, the interaction is of sufficiently short range to preserve the validity of the Goldstone theorem, yet of long range enough to preclude the existence of a local EFT. The associated NG bosons can have dispersion relation proportional to a noninteger power of momentum. First examples of such NG bosons were reported in [1].

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MATHEMATICAL PHYSICS

The group can report in 2009–10 numerous results in research and education, in particular

- ***Approximations of graph vertex coupling***: Scaled Schrödinger operators on thin Neumann networks have been analyzed (Exner–Post), an approximation of general vertex coupling was worked out on the graph level (Cheon–Exner-Turek, see below)
- ***Spectral properties of quantum graphs***: A generic absence of *ac* spectrum on sparse regular trees was proved (Exner–Lipovský). Types of high-energy spectral behaviors for square-lattice graphs were classified (Exner-Turek). Location of band edges in the Brillouin zone for $\mathbb{Z}$-periodic graphs was analyzed (Exner–Kuchment–Winn).
- ***Resonance properties of quantum graphs***: Resonances coming from geometric perturbations have been analyzed (Exner–Lipovský). Conditions under which resonances have a non-Weyl asymptotics at high energies were derived (Davies–Exner–Lipovský) and the influence of a magnetic field was demonstrated (Exner–Lipovský).
- ***Spectral analysis of $\mathcal{PT}$-symmetric operators***: A number of models has been analyzed: point interactions (Siegl), Coulomb potentials (Lévai–Siegl-Znojil), time-dependent metrics (Bíla), Sturm-Schrödinger operators (Znojil–Geyer), non-Hermitean models on curved manifolds (Krejčiřík–Siegl, see below), Gegenbauer-solvable quantum chains (Znojil), $\mathcal{CPT}$-symmetric discrete square well (Znojil-Tater), etc. General features like fundamental length, topological properties, graph structure (Znojil) or Krein-space description of such systems (Krejčiřík–Železný) were discussed.
- ***Spectral geometry and quantum waveguides***: Thin-width asymptotics for eigenvalues in the curved waveguide with combined boundary conditions was found (Krejčiřík). Norm resolvent convergence in the squeezing limit was established under minimum regularity for curved Dirichlet waveguides (Krejčiřík–Šediváková). Effects of geometric perturbations were analyzed for the Neumann Laplacian (Krejčiřík–Arrieta) and for Schrödinger operators with surface interactions (Exner–Fraas). Discrete spectrum of conical Dirichlet layers was found (Exner-Tater).
- ***Heat equation***: Results on Hardy inequality and large-time behavior of heat kernels in various geometric settings, such as waveguides or Riemannian manifolds, have been established (Krejčiřík with Zuazua, Fraas, Pinchover and Malenová).
- ***Hidden symmetries and supersymmetry*** have been studied for electrons in presence of a magnetic vortex and interacting anyons (Jakubský, see below), supersymmetry on Riemannian manifolds was discussed (Jakubský–Znojil).
- ***Other results*** concern properties of spin chains (Dittrich–Inozemtsev), integer topological charges in the $O(3)$ sigma model (Dittrich), correlations in cities structure (Exner–Šeba–Vašata), coherent states for Pöschl–Teller potetials (Siegl et al., see below), Krein spaces in de Sitter quantum theories (Gazeau–Siegl–Youssef).
- ***The 16th International Congress on Mathematical Physics***: The group was the main driving force behind the organization of the main meeting in the field which convened in Prague on August 3-8, 2009, with more than 600 participants.
- ***Other meetings***: The group organized several other conferences and workshops in Czech Republic and elsewhere, in the first place the ***QMath11 Conference*** in Hradec Králové on September 6-10, 2010, with about 140 participants.
- ***Students:*** Two PhD theses were defended during the period, by ***Hynek Bíla*** (supervised by M. Znojil) and ***Ondřej Turek*** (supervised by P. Exner). In addition, BSc theses were defended by ***Gabriela Malenová*** (supervised by D. Krejčiřík) and ***Michal Jex*** (supervised by P. Exner). Four other students have been supervised.

Approximation of general vertex coupling in quantum graphs

T. Cheon[1], P. Exner[2], O. Turek[1]

Quantum graph models have been intensively studied in the last two decades — cf. [1] for a bibliography. One of the important questions concerns the physical meaning of a general self-adjoint coupling in graph vertices. The answer was known for the so-called δ couplings, a small part of the couplings with wave functions continuous at the vertex, for the other ones it remained an open problem — recall that in a vertex joining n edges one has to fix n^2 real parameters. Using the seminal idea of the paper [2], one can deal with the so-called $\delta'_{\rm s}$ couplings [3], and more generally a $2n$-parameter family [4]. Approximations of more general couplings require a local change of graph topology; a solution of the problem was obtained in the paper [5].

To describe the result we write the coupling conditions between the vectors of boundary values of functions Ψ and derivatives Ψ' at the vertex in the following unique matrix form [5]

$$\begin{pmatrix} I^{(m)} & T \\ 0 & 0 \end{pmatrix} \Psi' = \begin{pmatrix} S & 0 \\ -T^* & I^{(n-m)} \end{pmatrix} \Psi \tag{1}$$

where $S \in \mathbb{C}^{m,m}$ with $m \leq n$ is a Hermitean matrix and $T \in \mathbb{C}^{m,n-m}$. We disconnect the edges and join them by additional segments of length $2d$ according to sketched scheme; we put δ couplings of strengths v_k and $w_{(j,k)}$ at the indicated places and add vector potentials $A_{(j,k)}$ at the (j,k)-th connecting segment. Choosing all these quantities in the form $c\,d^{-1}$ where the c's are constants constructed from the elements of the matrices S, T in a way described in [5], one can prove that the corresponding operator converges to the graph Laplacian with the coupling (1) in the *norm-resolvent sense* as $d \to 0$ with the error of $\mathcal{O}(\sqrt{d})$ — cf. [5] for details.

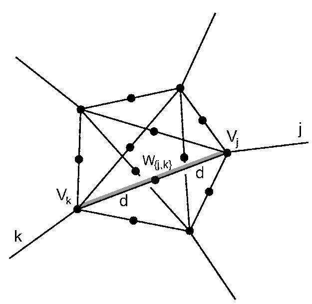

Fig. 1: *Scheme of the approximation. Grey line symbolizes the vector potential.*

Apart from solving a longstanding open question, the described result opens in combination with the analysis performed in the paper [6] a way to prove approximation of a general quantum graph in terms of networks of thin tubes with Neumann boundaries and suitably scaled potentials.

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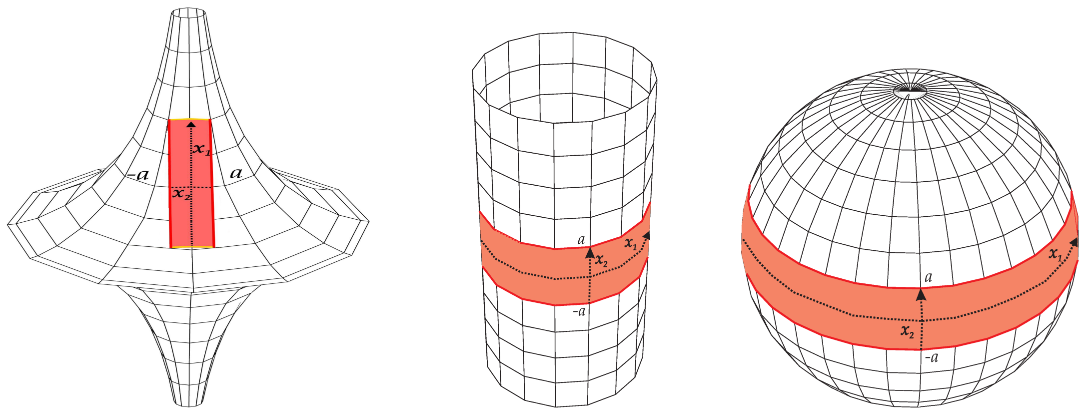
Non-Hermitian models in curved manifolds

D. Krejčiřík, P. Siegl

In the last two years, we were interested in the interplay between the curvature of the ambient space and the spectrum of the Helmholtz equation subjected to general non-Hermitian 'parity and time preserving' boundary conditions. We chose the simplest non-trivial model by considering the Laplacian in a tubular neighbourhood of a closed curve in a two-dimensional Riemannian manifold (not necessarily embedded in the three-dimensional Euclidean space), see Figure 1.



pseudosphere (negative curvature) cylinder (zero curvature) sphere (positive curvature)

Fig. 1: *Strips on realizations of constantly curved manifolds*

The (stationary) Schrödinger equation in tubular neighbourhoods of submanifolds of curved Riemannian manifolds has been extensively studied in the context of quantum waveguides and molecular dynamics (see [3] for an overview). The confinement to the vicinity of the submanifold is usually modelled by constraining potentials or hard-wall (Dirichlet) boundary conditions.

Our model is more general in the sense that it enables us to model a leak/supply of energy from/into the subsystem, since the non-Hermitian nature of our boundary conditions implies that the probability current does not vanish on the boundary. However, our primary motivation to consider the spectral problem comes from the so-called 'PT-symmetric quantum mechanics' [1], in which the simultaneous P-parity and T-time reversal invariance is suggested as an alternative condition to the conventional Hermiticity requirement.

Our contribution consists in introducing a suitable Hilbert space framework, which enables us to realize the Laplacian operator as a well-defined, albeit non-Hermitian operator, and in performing a detailed spectral analysis of models defined on manifolds of constant curvature. In some situations, we are able to prove either the reality of the spectrum or the existence of complex conjugate pairs of eigenvalues. Moreover, we establish similarity of the non-Hermitian Laplacian to normal or self-adjoint operators, providing in this way a potential interpretation of the models as Hamiltonians in conventional quantum mechanics.

The results of our study have been published in [2] and presented in several seminars and international conferences.

This work was supported by the Czech Ministry of Education, Youth and Sports (grant No. LC06002), the Grant Agency of the Czech Republic (grant No. 202/08/H072) and the Czech Technical University (grant No. CTU0910114).

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The extension of the formalism of PT-symmetric quantum theory to the scattering dynamical regime

M. Znojil

One of the most characteristic paradoxes encountered during all of the history of development of quantum physics may be seen in the sharp contrast between the robust stability of its abstract principles and the permanent emergence of dramatic changes in their concrete use. Such an observation also applies, in its full strength, to the so called PT-symmetric quantum mechanics (PTSQM, cf. its recent review [1]) in which the *unmodfied first principles* found a number of *new applications*, first of all, in the quantum bound state problem.

The formalism emerged via a prominent, pioneering, grounds-setting example published, not yet under the name of PTSQM, as shedding new light on the tractability of heavy nuclei within the so called interacting boson model [2]. A few years later, in the framework of field theory the same idea has independently been discovered and made popular by Bender with multiple coauthors [1,3]. A true boom of the research activities followed, during which a new understanding of the quantum bound-state problem has been achieved (cf. also a compact updated summary of these developments in [4]).

A crisis started with the H. Jones's talk [5] in London in 2007. The problem has been shown to lie in the fact that the enhanced model-building capacity of PTSQM has only been achieved at the expense of the loss of immediate quantum-classical correspondence. Jones correctly pointed out (cf. also his publication [6] and my subsequent comment [7]) that in the PTSQM formalism the current use of localized point particles is being replaced by the new paradigm in which the measurability of a *local* coordinate is lost (cf. also [8]). The measurability of another, *global* quantity called "charge" is required instead. In such an innovative setting the argument ξ of the formal wave function $\psi(\xi)$ is not measurable. According to Jones, the core of the difficulty lies then in the contrast between the strictly local form of the phenomenological position-dependent interactions (i.e., of a dynamical input information carried, typically, by an external potential) and the manifestly long-range nature of the PTSQM operator of charge $\mathcal{C}$. In the Jones' own words this seems to imply the theoretical as well as practical impossibility of a consistent PTSQM description of unitarity-preserving scattering experiments [9].

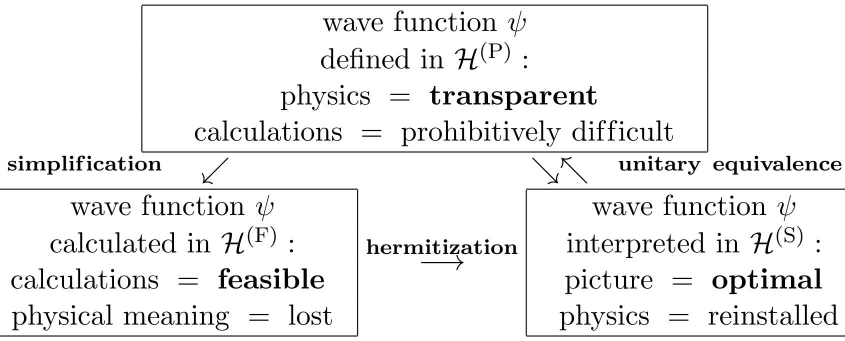
In our subsequent paper [10] we resolved the whole puzzle. In our present annotation of this result we intend to explain briefly the point. Our basic message may be read as follows:

- on conceptual side, the source of difficulty is found in the undeservedly popular requirement of the strict locality of the interactions, $V(x, x') = V(x)\delta(x - x')$. A "short-range-smearing" weakening of this postulate is proposed and shown unexpectedly productive. First of all, the intuitively acceptable short-range smearing of the interactions (with $V(x, x') = 0$ whenever $|x - x'| > \theta =$ "a fundamental length") is introduced and tested to be mathematically admissible and internally consistent;

- on practical side, the technical obstacles represented by the difficult mathematics of scattering are circumvented by the replacement of the real line of coordinates ξ by its equidistant-lattice discretization. As long as these obstacles formed the "hardly feasible" argument and one of the main roots of the Jones' scepticism as formulated in [9], the discretization returns many new and highly relevant models of scattering into play and it renders them amenable to qualitative as well as quantitative analyses;

- in constructive setting, the fundamental-length requirement appeared to open, very unexpectedly, the entirely new way towards a *feasible* return to the general formalism of Refs. [2,4]. In other words, the non-generic use of the artificial and, which is worst, infinite-ranged charge $\mathcal{C}$ of Bender et al [1] is abandoned. The role of coordinate is taken over by some other, not always specified short-ranged and smearing-compatible observable.

The structure of the resulting extended-PTSQM (a.k.a. crypto-Hermitian) formalism may be characterized again by the three-Hilbert-space diagram of Ref. [4],



In this scheme the physics is prescribed in the inaccessible Hilbert space $\mathcal{H}^{(P)}$ while the feasibility of computations necessitates a transfer of wave functions to the unphysical but computation-facilitating Hilbert space $\mathcal{H}^{(F)}$. This transfer is realized in a way explained in [4].

The very concrete and exactly solvable class of illustrative models employed in our paper [10] enabled us to demonstrate that the contents of the usual textbooks on quantum scattering could be complemented by an innovative use of certain unusual, minimally non-local PT-symmetric interactions $V \neq V^{\dagger}$. In our concrete solvable models the method of matching has been shown sufficiently efficient and led to the reflection R and transmission T in closed form satisfying the unitarity $|R|^2 + |T|^2 = 1$ as required. This means that the global or asymptotic flow of probability is conserved in spite of the manifest non-Hermiticity of the Hamiltonian.

Our constructions were shown to imply that in effect, the above-mentioned loss of observability of the coordinates remains restricted just to a very small vicinity of the scattering center or centers. In the language of physics and phenomenology this enabled us to conclude that in contrast to the Jones' sceptical expectations as formulated in [9] and as shared by a number of other authors, the appropriately amended Hilbert space of states may still exist even in the crypto-Hermitian scattering scenario. In full detail we proved that our particular extended-PTSQM class of models of scattering processes remains causal, unitary and, moreover, fully compatible also with the existence of re-scattering and multiple-scattering phenomena.

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Hidden supersymmetry in Aharonov-Bohm system and interacting anyons

V. Jakubský

In their seminal work [1], Aharonov and Bohm demonstrated significance of the electromagnetic potential in quantum physics. Unlike in classical mechanics, it has direct impact on the quantum dynamics even when the electromagnetic field vanishes everywhere in the region that is accessible for charged particles. As a model can serve a planar system of the electron moving in presence of an infinitely thin solenoid that punctures the plane perpendicularly at $x_1 = x_2 = 0$. The electromagnetic potential in the symmetric gauge and the corresponding magnetic field are

$$\vec{A} = \Phi \left(-\frac{x_2}{x_1^2 + x_2^2}, \frac{x_1}{x_1^2 + x_2^2}, 0 \right), \quad \vec{B} = (0, 0, \Phi\, \delta^2(x_1, x_2)). \tag{1}$$

The only non-vanishing component of the singular magnetic field $\vec{B}$ is given in terms of the two-dimensional Dirac delta function.

In comparison with the free particle on the punctured plane, the physics is changed due to the nontrivial phase factor acquired by wave functions when the electron goes around the solenoid. This is the core of the Aharonov-Bohm (AB) effect which was confirmed experimentally. In this context, let us mention observation of Aharonov-Bohm oscillations in carbon nanotubes [2]. The phenomenon found its application in various branches of quantum physics. For instance, this setting was used in dynamical realization of anyons [3].

In [4] and [5], we tested this system (both spin-less and with spin-1/2) on presence of hidden symmetries and supersymmetry. We used the theory of self-adjoint extensions of symmetric operators to deal with the ambiguity in definition of the model, which is related to the singular behavior of wave functions at the origin. We found a rich super-algebraic structure based on existence of both local ($Q_1 = \mathcal{P}_1\sigma_1 + \mathcal{P}_2\sigma_2$ and $Q_2 = i\sigma_3\, Q_1$) and non-local integrals of motion ($\tilde{Q}_1 = \mathcal{P}_1 + i\sigma_3 R\mathcal{P}_2$ and $\tilde{Q}_2 = iR\tilde{Q}_1$), which provided additional insight into the degeneracy of the spectrum. Here we denote $\mathcal{P}_a = -i\frac{\partial}{\partial x_a} + A_a$, $a = 1, 2$, the operator R represents spatial reflections ($R\vec{x}R = -\vec{x}$), and σ_j are Pauli matrices. The operators are perfect square-roots of the Hamiltonian $\mathcal{H}$ of the system:

$$\{\tilde{Q}_a^\gamma, \tilde{Q}_b^\gamma\} = \{Q_a^\gamma, Q_b^\gamma\} = 2\delta_{ab}\mathcal{H} \quad \text{where} \quad a, b = 1, 2. \tag{2}$$

It was revealed that these integrals are interrelated by a non-local unitary transformation [6].

Inclusion of dynamical symmetries (generators of dilatations and of special conformal transformations) gave rise to an infinitely generated algebra that contained several representations of the superconformal $osp(2|2)$ symmetry. We applied the results to the theory of anyons, reinterpreting the system and its algebraic structure in terms of the supersymmetric two-body model of the anyons with contact interaction [5].

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Coherent states for Pöschl-Teller potential

H. Bergeron[1], J.-P. Gazeau[2], P. Siegl[2,3], A. Youssef[2]

The quantum states possessing semi-classical time behaviour, *i.e.* coherent states (CS) in modern terminology, were firstly found for harmonic oscillator by Schrödinger [1]. Since then, various CS have been studied, see *e.g.* [2]. Huge number of recent works on quantum dots and quantum wells in nanophysics inspired us to construct coherent states for infinite wells modelled by Pöschl-Teller potential, *cf.* [3]. These states exhibit desired properties: they are phase space labelled, yield a resolution of the identity with respect to the usual uniform measure on phase space, provide a classical-quantum correspondence ("CS quantization"), and exhibit semi-classical time evolution features comparable to original Schrödinger states.

Pöschl-Teller potential belongs to the class of shape-invariant potentials that are intensively studied within supersymmetric quantum mechanics. The CS are defined as eigenstates of a lowering operator obtained from the Darboux factorization of Hamiltonian and they read

$$|\eta_{p,q}\rangle := N_\nu(q)|\xi_{W(q)+ip}\rangle, \quad \xi_z(x) := e^{zx/\hbar}\sin^{\nu+1}\left(\frac{\pi}{L}x\right),$$

where ν is a parameter characterizing the shape of the potential, W is a corresponding superpotential, L is a width of the well, and N_ν is a normalization constant. The detailed overview of "CS quantization" using these states is presented in [3]. A phase space distribution is illustrated in Figure 1 and the animated time evolution showing evolution stability features can be found in [4]. The developed approach can be extended to other shape-invariant potentials, however, the question whether all properties of Pöschl-Teller coherent states are preserved remains open.

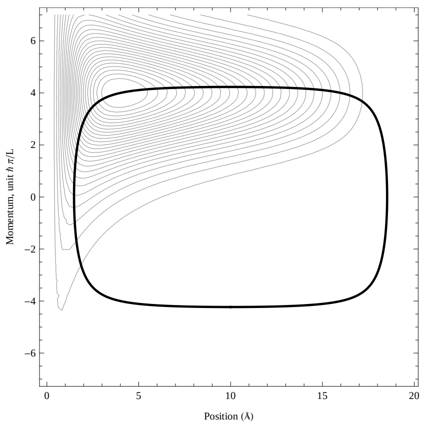

Fig. 1: *Phase space distribution for $\nu = 0$ of the state η_{q_0,p_0} with $q_0 = L/5$, $p_0 = 4\pi\hbar/L$ and $L = 20\text{Å}$. The thick curve, on which the maximum of the function is localized, is the expected phase trajectory in the infinite square well.*

This work was supported by the Czech Ministry of Education, Youth and Sports within the project LC06002 and by the Grant Agency of the Czech Republic (grant No. 202/08/H072).

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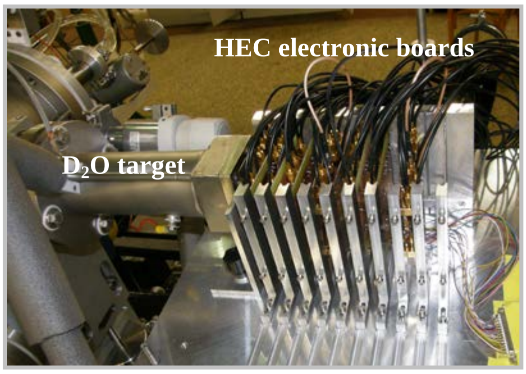
Nuclear Data for Technology

The safe and economical operation of nuclear facilities and systems exposed to radiation require detailed and reliable design calculations, based on the completeness and accuracy of nuclear databases and on validated computational procedures as well. In the ***Nuclear Reaction Department (NRD)***, the set of target stations on the NPI cyclotron beam lines was developed for investigation of nuclear data (below about 35 MeV) relevant to the irradiation by fast neutrons and by charge-particles in the fusion, fusion-fission and non-power applications. Among the facilities, the quasimonoenergetic p-^{7}Li(C) neutron source and high-power p-D_2O fast neutron source are well established in testing the neutron-hardness of the electronic components and for obtaining and benchmarking nuclear data relevant to the fusion technologies within the EU Fusion Energy program (F4E). The scintillation - and silicon detector telescope technique for neutron spectrometry are supplied by HPGe detector technique for investigation of irradiated nuclides by gamma-spectrometry method as well.

The gamma-spectrometry method is widely utilized in the ***Nuclear Spectroscopy Department (NSD)*** at home laboratory and at JINR Dubna for experimental study of activation cross section relevant to the transmutation projects. Using high-energy JINR accelerators (GeV Nuclotron and 0,6 GeV Phasotron), the production of neutrons in spallation reactions and their usage for the transmutation of long-lived fission products and minor actinides are investigated by means of complex setups consisting of the lead target and uranium or plutonium blanket assembly. The quasi-monoenergetic p-^{7}Li source of TSL at Uppsala (Sweden) is utilized as well to obtain cross sections of neutron reactions with higher energies up to energy 100 MeV.

Neutron response of high-integration electronic components

The current readout electronics of the ATLAS Hadronic End-cap Calorimeter (HEC) is designed to operate at irradiation levels expected for the Large Hadron Collider (LHC). For operation at the sLHC, the irradiation level is evaluated to be of a factor 10 higher. Therefore, the generic studies of different technologies are under way at the transistor level to understand the radiation hardness up to integrated neutron fluxes of ~ 2 10^{16} n/cm^2 and the behavior during operation at cryogenic temperatures. ***Neutron hardness test experiments of HEC read-out electronics***** are currently provided using the high-power p-D_2O neutron source. The program is supported by the NRD/MPI München Contract (2008-12) within the ATLAS Collaboration. To perform the radiation tests of HEC read-out electronics at NPI neutron facility inside the LN cryostat, the ***upgrade of the D_2O target station*** is carried out under the support of the NRD grant MTICzR No 2A-1TP1/101 (2008-2011). Within the same support, ***the investigation of fast-neutron response functions of a single-crystal diamond detector*** using the p-7Li(C) quasi-monoenergetic source is proposed for the next program within the NRD – IRMM Giel collaboration.



Neutron data for International Fusion Material Irradiation Facility (IFMIF)

The existing and projected accelerator driven high-power neutron facilities such as IFMIF will produce a white spectrum of neutrons with energies up to 55 MeV. The multiple foil activation technique is proposed as suitable for the experimental characterization of the neutron fluxes in such harsh radiation environment (test cell). Its application for accelerator driven systems requires, in particular, an extension of the dosimetry cross section libraries, e.g. IRDF-2002, above 20 MeV. To respond to this need a programme is presently underway in framework of NRD and KIT Karlsruhe

* H. Oberlack et al., http://atlas-speakers-committee.web.cern.ch/atlas-speakers committee/AllConfTalks2009.html.

collaboration to measure ***neutron cross sections of dosimetry reactions for the IFMIF test-cell detectors and to validate the evaluated data*** with the NPI quasi-monoenergetic ^{7}Li(p,xn) neutron source under a support of *the F4E/GRT-056 (2008-11)*. ***Determination of spectral flux of the NPI p-^{7}Li(C) neutron source at sample positions***, supported by the NRD grant MTICzR No 2A-1TP1/101 (2008-2011) is a constituent part of this program.

The high-flux test module (HFTM) of the International Fusion Materials Irradiation Facility (IFMIF) will be exposed to an intense flux of fast neutrons with energy values of up to approximately 55 MeV. Hydrogen and helium are produced when energetic neutrons interact with materials, and these gases can lead to significant changes in materials properties such as embrittlement and swelling. Such effects have been seen in fission reactors and a significant effort has been made for the development of fusion reactors where the effects are expected to be larger because of the higher neutron energy. ***Hydrogen and helium production in IFMIF/ITER structural materials by fast neutrons*** is the next NRD research program within F4E/GRT-support for 2012-14 years.

Neutron data for ADS transmutation

The measurement of neutron fields produced inside simple and more complex accelerator driven set-ups are performed by means of Nuclotron accelerator at JINR Dubna. International collaboration "Energy and Transmutation of Radioactive waste" studies neutron production by spallation reactions and usage of such neutrons for transmutation. Our group is mainly concentrated on neutron measurement using activation detectors and transmutation of radioactive samples from nuclear waste. We made systematic studies of set-up "Energy+Transmutation" consisting of big lead target with uranium blanket and irradiated by relativistic protons (energy from 0.7 GeV up to 2.0 GeV) and deuterons (energy from 1.6 GeV up to 4 GeV). New version of "water bath method" is used to determine integral number of neutrons. The obtained results are compared with simulations by MCNPX code and they are used for benchmark of this and similar codes. We have already started to study neutron production on big uranium target irradiated by high energy deuterons (energy up to 6 GeV).

Deuteron/proton activation of the accelerator components

The proton and deuteron induced reaction have a great interest for the assessment of induced radioactivity of accelerator components (elements such Al, Cu, Fe, Cr, Nb, etc.). The IFMIF accelerator needs cross sections data in the energy range from the threshold (2 - 10 MeV) up to 40 MeV, both for deuterons and protons. Present status of the measured and evaluated data needs urgent and strong improvement. In order to investigate the first important nuclides relevant to the IFMIF, ***low and medium energy deuteron-induced reactions on Cu and Al*** were carried out at energies below 20 MeV using the irradiation station on "negative-ion beam line" of variable-energy cyclotron U–120M. Experiments were supported by the NRD/KIT Karlsruhe Contract (2010-11), data were compared with recommended values from the EXFOR database and analyzed in frame of wide EAF collaboration with specialists from KIT Karlsruhe, NIPNE Bucharest and CSC Culham.

At higher energy domain (20-40 MeV) where data are not existing or known with poor accuracy, the measurement of excitation functions will be performed in frame of the task ***proton and deuteron induced activation (First-day experiment, NFS SPIRAL-2, Ganil, 2009-12)**[*)]***. Within this program, a ***development of the reaction chamber hardware incorporated with pneumatic sample transport system for NFS SPIRAL-2*** is under way at NRD within the NRD/KIT Karlsruhe collaboration and the ASCR Support of the international cooperation, No M10048090, 2009-11.

***** P. Bém et al., Lett. of Intent in http://pro.ganil-spiral2.eu/spiral2/instrumentation/nfs

Analysis of the dosimetry cross sections measurements up to 35 MeV with a ^{7}Li(p,xn) quasi- monoenergetic neutron source

S.P. SIMAKOV [1], P. BÉM , U. FISCHER [1], M. HONUSEK, M. MAJERLE and E. ŠIMEČKOVÁ

The characterization of the neutron fluxes for accelerator driven systems like IFMIF (International Fusion Material Irradiation Facility) requires, in particular, an extension of the well established dosimetry cross section libraries, e.g. IRDF-2002, above 20 MeV. To respond to this need, a program is presently underway at NPI/Řež and KIT/INR to measure activation cross sections (XS) with a quasi-monoenergetic ^{7}Li(p,xn) neutron source and to validate the evaluated data. During the selection of the appropriate elements the first priority has been given to Au, Bi, Co and Nb since the set of reactions (n,2-5n) produce residuals with suitable γ-lines and half lives and they cover the energy domain of interest. Up to now the relevant XS above 20 MeV have been measured only in Japan labs.

These materials have been irradiated at the NPI/Řež cyclotron facility using a thin lithium foil to produce neutrons and thick carbon to stop the proton beam [1]. Beside a mono-energetic peak, the target simultaneously produces "parasitic" low energy neutrons. The analysis of their impact on the activation cross sections and extraction of activation cross sections from the measured induced radioactivities have been performed [2-3]. It includes the Monte-Carlo simulation of the experimental set-up with the MCNPX code and relevant cross section data for proton and neutron induced reactions to predict the energy differential neutron flux in the irradiated foils. This approach has been validated against p-Li neutron spectra measured by different techniques [4].

To derive activation cross sections in such complex neutron field, the modified version of the SAND-II code – traditionally used for the neutron spectrum adjustment – was utilized with reversed adjustment procedure: the neutron spectra for every foil were supposed to be known and fixed, whereas the activation cross section was allowed to vary to get C/E ratio close to unity at all proton energies. The iteration procedure starts from the guess cross sections. To check how the guess XS affects on the final results the ^{197}Au(n,2n)^{196}Au reaction has been selected (see left side of Fig. 1). This is the worst case, since the difference between two available evaluations, EAF-2007 and

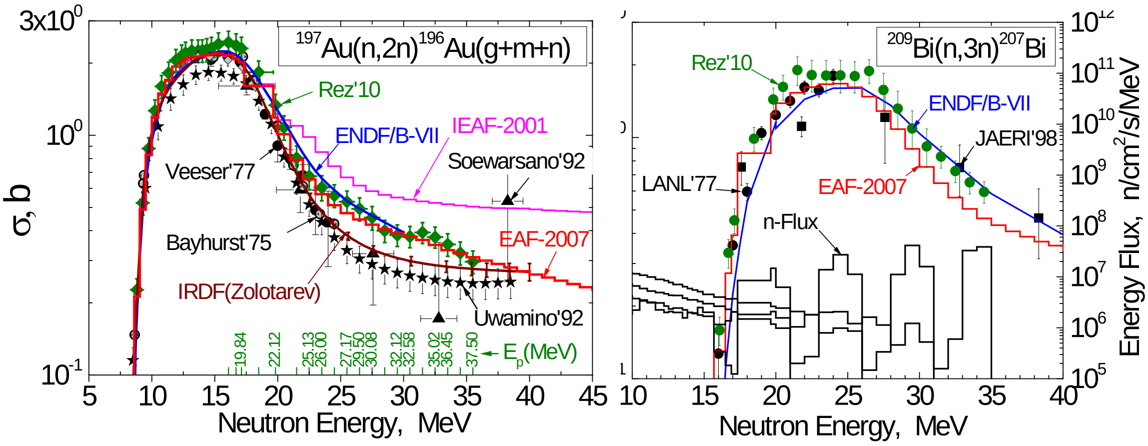


Fig. 1. The cross section for ^{197}Au(n,2n)^{196}Au reactions (left) and for ^{209}Bi(n,3n)^{207}Bi reaction (right) obtained from NPI/Řež measurements (Rez´10)) in comparison with available experimental and evaluated data.

IEAF-2001 are extremely large. The large differences between the final adjusted XS are observed below 15 MeV, i.e. below the minimal energy of the Li(p,n) peak, and above 25-30 MeV, where the

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difference between the guesses reaches the order of magnitude. In the case of the $^{209}Bi(n,3n)^{207}Bi$ reaction (see right side of Fig. 1), the set of the mono-energetic peaks cover the excitation function from its threshold to the energies well above the maximum. It is seen that the obtained cross sections reasonably agree with the available rare experimental data. The whole set of now available measurements require a slight increase of EAF-2007 data in the energy domain above 25 MeV. Full analysis was presented in Ref. 2.

To improve the status of the dosimetry reaction data above 20 MeV, the activation cross sections on Bi, Au, Co and Nb have been measured. Results have brought the new experimental data in the neutron energy domain between 18 and 35 MeV and compared with available measured and evaluated data. Agreeing with known experimental results below 20-25 MeV the present measurements do improve the dosimetry cross sections status at higher energies [5-6]. The comparison with ENDF/B-VII, EAF-2007, IEAF-2001 and IRDF has indicated the need for the further correction of the specific reaction cross sections.

Acknowledgement

This work was supported by the F4E grant contract No. F4E-2008-GRT-014 (ES-AC) and by the Grant of MTI CR No. 2A-1TP1/101. The authors are indebted to the operating crew of the U-120M cyclotron for their ready assistance.

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^{65}Cu(d,p)^{66}Cu excitation function at deuteron energies up to 20 MeV

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Continuing the NPI program on investigation of p/d-activation of the IFMIF relevant materials [1], the previous irradiation experiment on copper [2] with the NPI variable-energy cyclotron U-120M was completed by investigation of short lived ($T_{1/2}$ = 5,120 min) ^{66}Cu product of the d+^{65}Cu reaction. The activation cross-section was measured by the stacked-foil technique. The high purity natural Cu (25 µm) and Al(50 µm) irradiated by deuterons at 19,8±0.2 and 20,1±0.2 MeV energy were placed in the reaction chamber by turns, the Al foils served for additional monitoring of beam current and for appropriate reduction of deuteron energy as well. During two runs of 335 and 300 s duration, the beam current of 0.24 µA and 0.36 µA, was recorded with the uncertainty of 5 % in a PC keeping time synchronization with the gamma-ray spectrometry device. Activated isotopes were investigated by the HPGe gamma-spectrometry of reaction products on the basis of $T_{1/2}$, γ-ray energies and intensities. Special care was devoted to avoid the effect of a strong annihilation peak.

The cross-sections were calculated from the induced activities. The comparison of the present as well as previously measured [EXFOR] activation cross sections for ^{63,65}Cu is shown in Fig. 1.

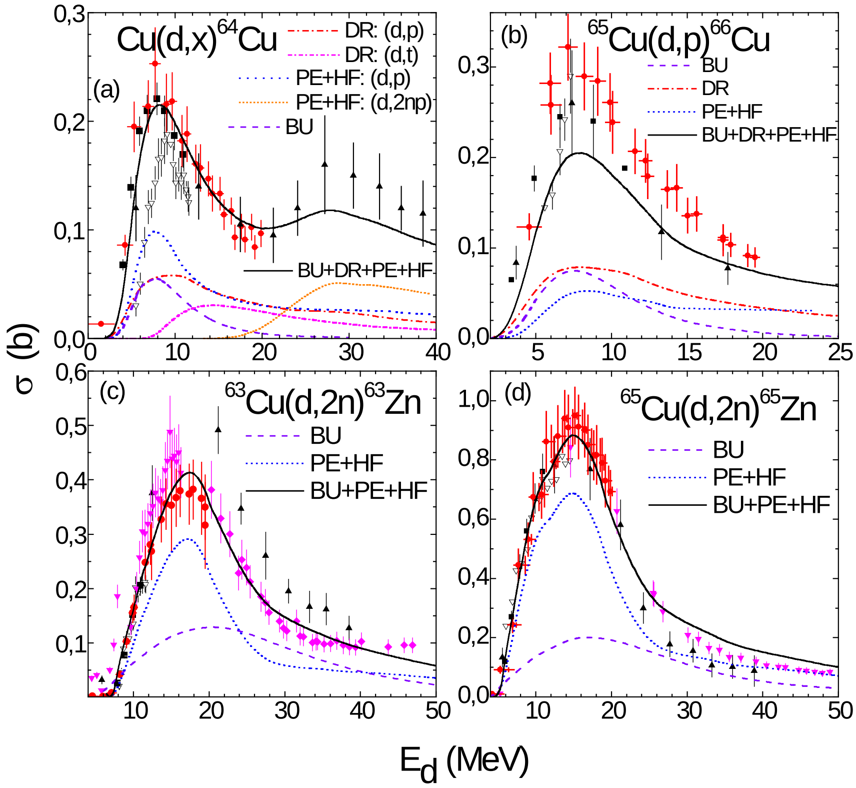

Fig. 1. Comparison of measured (this work, solid circles, and EXFOR) and calculated activation cross sections for deuterons on ^{63,65}Cu, provided by the code TALYS (dotted curves), the library TENDL-2009 (dashed), and local analysis (thick solid) using the stripping (DR) contribution (dash-dotted) for the *(d,p)* reaction, the deuteron breakup (BF) (thin solid) for the *(d,p)* and *(d,2n)* reactions, and the PE+HF for components (dotted).

The deuteron activation cross section calculations require the contributions from all reaction

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mechanisms involved in the deuteron-target nucleus interaction process, such as: direct reaction (DR processes (breakup, stripping and pickup), preequilibrium emission (PE) and the evaporation from the fully equilibrated compound nucleus (CN) [1]. In Fig. 1, the comparison of measured and calculated activation cross sections for ^{63,65}Cu (thick curves) is shown. The sum of the inelastic breakup cross sections, the DR cross sections provided by the code FRESCO and the PE + CN (Geometry Dependent Hybrid model + **H**auser-**F**eshbah, HF, formalism) contributions are shown together with the global predictions given by TALYS-1.0 [3] code and within the TENDL-2009 library [4]. The appropriate consideration of the deuteron breakup as well as that of the DR contributions to the *(d,p)* activation cross sections increase the agreement of the measured and calculated data. A continuing underestimation of the *(d,p)* reaction cross section decreasing with the incident energy could be due to the limited excitation-energy range for which spectroscopic factors exist so that additional assumptions should be involved.

The main aim of present work has been to carry out new deuteron cross section measurement and to provide a unitary analysis of the nuclear reaction mechanisms responsible for the deuteron interactions with ^{63,65}Cu target nuclei. The agreement between the measured data and model calculations proves the correctness of nuclear mechanism description taken into account for the deuteron-nucleus interaction. Finally the comparison of the present calculations with global predictions of the TALYS code stresses out the importance of an appropriate consideration of the deuteron breakup mechanism contribution to the activation cross section calculations.

Acknowledgments

This work was supported partly by the Grant of MTI CR No. 2A-1TP1/101, by the Contract with KIT Karlsruhe and by the Romanian Nat. Authority for Sci. Res. under the Contract No. PN 09370105. The authors are indebted to the operating crew of the U-120M cyclotron for their ready assistance.

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Studies of neutron production in spallation reactions on ADS precursors

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Studies of neutron production in spallation reactions are motivated by the need of high neutron fluxes for material research, transmutation of nuclear waste or production of nuclear fuel from thorium. New international spallation sources are planned (European Spallation Source) or already commissioned (American Spallation Neutron Source) to fulfill scientist requirements. With advances in accelerator technology Accelerator Driven Systems (ADS), thanks to their high safety and unique properties, seem to be a perspective energy source for the future.

We are a part of the international research program Energy and Transmutation of Radioactive Waste (E&T RAW). Within this project, groups from 15 countries study various aspects of spallation reaction, neutron production, transport and its usage for transmutation of nuclear waste. Six different setups of massive target surrounded with blanket and neutron moderator are used to measure differential as well as global data for ADS. Our group is mostly focused on the experiments on the setup called Energy plus Transmutation (E+T), which consists of thick lead target surrounded by natural uranium blanket and biological shielding of polyethylene.

High energy neutrons from spallation reactions are measured using activation detectors from Al, Au, Bi, Co, In, Ta, and Y materials. The (n,xn), (n,α), and (n,p) threshold reactions observed on foils are used to distinguish neutrons with different energies. Non-threshold (n,γ) reactions on Au and Ta foils with combination of polyethylene shielding were used to assess total number of produced neutrons in Energy plus Transmutation setup (see Fig 1).

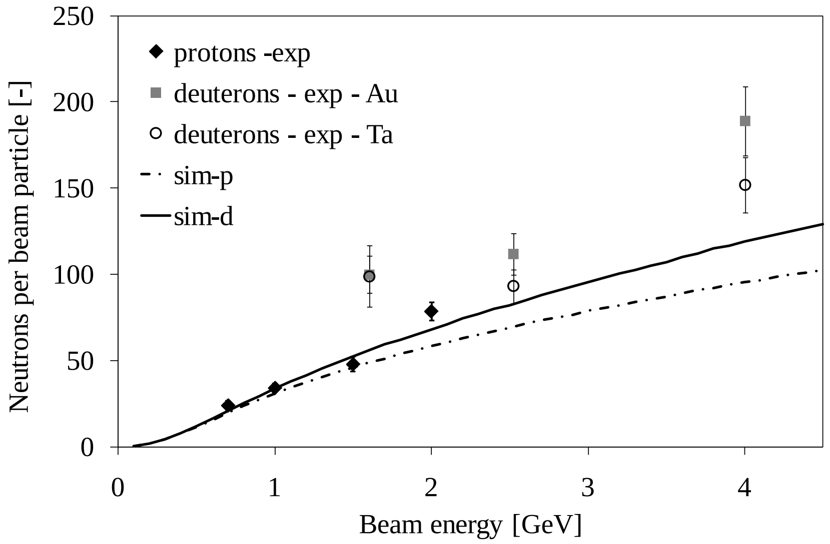

Fig 1: Neutron multiplicities on Energy plus Transmutation setup irradiated by protons and deuterons.

Experiments are performed using the Nuclotron Accelerator at the Veksler and Baldin Laboratory of High Energy Physics of the Joint Institute for Nuclear Research (JINR) in Dubna, Russia. Large systematics of Energy plus Transmutation setup gained in previous years was closed at the end of 2009 with the 4 GeV deuteron irradiation (summarizing publication is [1]). During 2010/11 new uranium setup called Kvinta was irradiated with 2 – 6 GeV deuterons.

MCNPX simulations of the experiments are being performed, calculated data are compared with the experimental data (three of the E&T setups are already acknowledged as IAEA benchmark targets). Good agreement was observed for deuteron experiments on E+T setup.

Cross sections of used (n,xn) threshold reactions

Au, Al, Bi, Co, In, Ta, and Y foils are widely used in E+T experiments as activation neutron detectors, but unfortunately almost no experimental cross-section data are known for energies higher than 40 MeV or order of (n,xn) reaction higher than 4.

With the financial support from European Facilities for Nuclear Data Measurements grant organization (EFNUDAT) [2] quasi-monoenergetic neutron source at The Svedberg Laboratory (TSL) at Uppsala, Sweden, was used. Seven irradiations with energies 22, 47, 59, 66, 73, 89 and 94 MeV were performed in June 2008 and February 2010. They were supplemented with 17, 22, 30, 32, and 35 MeV irradiations on similar neutron source at cyclotron in NPI Řež. Special procedure for subtraction of the neutron background contribution was developed and successfully used. Measured cross sections were compared with the data from EXFOR database and with results calculated in deterministic code TALYS.

A substantial part of measured data was measured for the first time and is thus unique. Part of the data was already published [3] and is being transferred to the EXFOR database (example in Fig 2.).

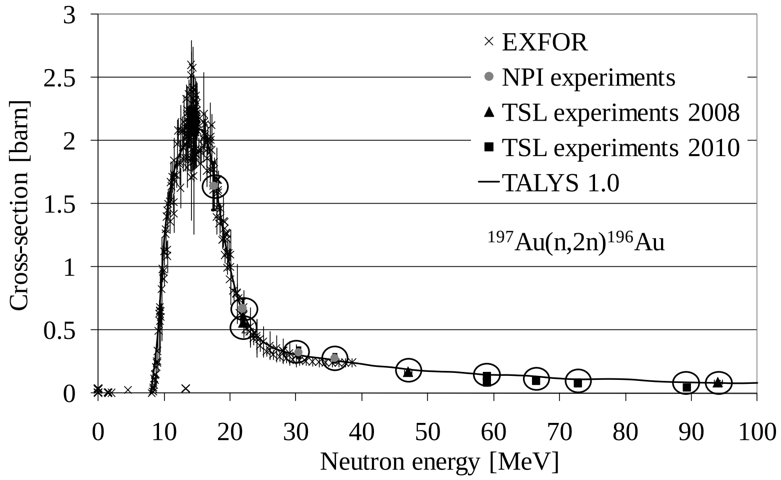

Fig 2: Cross-section values of the ^{197}Au(n,2n)^{196}Au reaction, comparison among EXFOR, TALYS 1.0 and our values.

Acknowledgements

This work was financially supported from the Grant Agency of the Czech Republic (grant No. 202/03/H043), Internal Grant Competition (grant number CTU0808214), Grant Agency of the Academy of Sciences of the Czech Republic (grant No. K2067107), F4E program of the Nuclear Reaction Department of the Nuclear Physics Institute (grant number F4E-2008-GRT-014), and from the EFNUDAT (European Facilities for Nuclear Data Measurements).

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Nuclear Analytical Methods

The Laboratory of Nuclear Analytical Methods (LNAM) of NPI is the most important operator of facilities for material analyses by the above methods and for material modification by ionizing radiation in the Czech Republic. Facilities for irradiation with both ion and neutron beams are available at LNAM. The laboratory operates a 3-MV Tandetron 4130MC accelerator with devices for material characterization by Rutherford Back Scattering (RBS, RBS-channeling), Elastic Recoil Detection Analysis (ERDA, ERDA-TOF), Proton Induced X-Ray Emission (PIXE), Particle Induced Gamma-Ray Emission (PIGE) and an ion-microprobe with lateral resolution of 1 μm (μ-PIXE). A device for high-energy ion implantation is also part of the accelerator. Also available is an old 3-MV Van de Graaff accelerator with devices for RBS, PIXE and PIGE analyses. At the LVR-15 research reactor of the Nuclear Research Institute Řež, plc., devices for neutron depth profiling (NDP) and prompt gamma neutron activation analysis (PGNAA), both installed at a horizontal neutron channel, are accessible, as well as facilities for short- (10 - 180 s) and long-time (several hours - several days) irradiation in vertical channels for neutron activation analysis (NAA). In these channels, irradiation behind a Cd shield can also be performed allowing for epithermal neutron activation analysis (ENAA). Radiochemical neutron activation analysis (RNAA), which is rarely available at other institutions, is carried out whenever element detection limits of nondestructive, instrumental neutron activation analysis (INAA) or ENAA are not sufficiently low. For photon activation analysis (PAA) irradiation with high energy photons at the microtron MT-25 of the Department of accelerators of NPI is used.

In the 2009-2010 period the ion microprobe was installed and put into operation and construction of a new target chamber for PIXE/PIGE analyses was finished in the Tandetron laboratory. The laboratory infrastructure has continuously been upgraded by installation of new vacuum components, nuclear electronics parts and by installation of new, laboratory made measuring software. There are several other devices intended for preparation of nano- and micro-structures using different deposition techniques, namely by magnetron sputtering, ion sputtering and vacuum evaporation. Under construction are new devices for molecular beam epitaxy (MBE) and low energy ion implantation. Most of the accelerator operating time was devoted to analyses of different materials and structures prepared in the laboratory or in several collaborating research institutions in Czech Republic and abroad. Part of the Tandetron operating time was spent on high-energy implantation with different ions. Most remarkable were preparation and characterization of prospective optical materials, metal-polymer and metal-carbon allotrope composites with potential applications in microelectronics and sensor construction, various kinds of hard coatings and materials and structures applicable in biomedicine. Processes of diffusion, phase separation, segregation, aging and self-organization in different systems were also investigated. Great effort was also devoted to systematic study of atmospheric aerosols and ashes, microscopic-sized geological objects, determination of provenance, authenticity and production technology of archeological objects and characterization of selected biological objects. Successful experiments on micromashining were performed at the ion microprobe too. In the NAA group, trace element concentrations were studied by INAA and RNAA in minute brain sections of mutant mice in the course of neurodegeneration, elemental analysis by INAA, ENAA and PAA was performed of geological objects, such as meteorites and tektites, the INAA, RNAA, PAA, PIXE and RBS techniques were employed for the preparation and elemental characterization of environmental, biological and geochemical reference materials, and INAA was also used for forensic purposes. These studies were performed within grants awarded by Czech grant agencies and in co-operation with several Czech institutions and those from abroad, namely the International Atomic Energy Agency, Vienna, the U.S. National Institute of Standards and Technology, the Meteoritical Society, etc. Methodological research concerned mostly implementation and improvements of the prospective methods of k_0 standardization in NAA.

It can be concluded that the existence of ion- and neutron-beam techniques, and neutron and photon activation techniques, which are in many aspects complementary, forms a powerful arsenal of nuclear analytical techniques in one institution, which is quite unique at the European scale.

Ion Microbeam at Tandetron Laboratory – Two Year Experience

V. HAVRÁNEK, J. NOVOTNÝ, V. VOSEČEK

The new micro-beam line has been installed on the 3MV Tandetron accelerator in the middle of the year 2009. The beam line is based on Oxford microbeams Ltd. components [1], OM150 quadrupole triplet, OM10 beam defining slits, OM25 deflector box, precise XYZ sample manipulator and OM70 target chamber equipped with three detectors for PIXE, RBS and ON/OFF STIM analyses. The detector signals are sorted by the OM-DAQ Data acquisition system. The detector signals together with actual beam position can be recorded in the list mode format and later evaluated with the QMDAQ2007 code. It contains both RBS spectra simulation and Gupix [2] software for the PIXE spectra evaluation. Since the end of the 2010 year, the Geopixe software [3] is also available for the spectral data end maps processing.

Microbeam specification

Length of the optical parts: object slits to sample 5m, object slits to collimator 4m.
Aligned for 2 MeV protons and routinely operated with protons from 0.8 MeV to 2.6 MeV.
Other ions tested: 2MeV He, 9-12 MeV multiply charged C, O, Si (all in μm resolution)

Typical operating parameters:

Ion source	Object slits opening	Collimator slits op.	Typical current	Resolution
Duoplasmatron	20 x 80 μm	800 x 800 μm	40 – 60 pA	1.2 μm
Duoplasmatron	40 x 160 μm	800 x 800 μm	120 – 300 pA	2 μm
Cs sputter	60 x 240 μm	800 x 800 μm	40 – 60 pA	2-3 μm
Both	almost closed	100 x 100 μm	5000 ions/s	0.5 μm

In the first two years of operation, the micro-probe was used in various applications, such as analysis of geological samples (zircons, garnets, granits), biological samples (brain tissue, hair), archaeological objects (Chinese ceramics - fig.1, cloisonné jewellery, medieval wall painting). We are also involved in the study of Tycho Brahe remains project. The focused ions of C, O and Si was also used for ion writing into thin layers of PDMS (in cooperation with Atomki Debrecen, HUS).

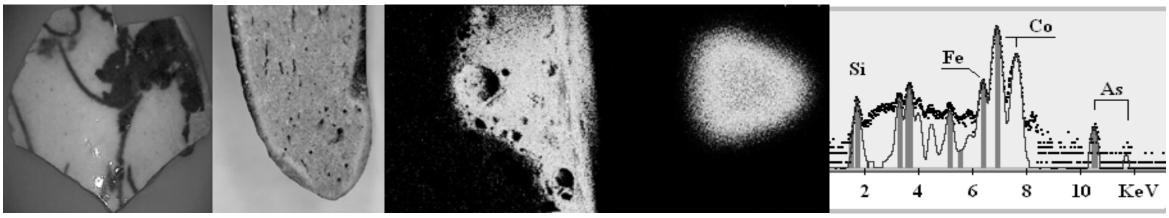

Figure 1. Analysis of the shred of ancient Chinese pottery, found near the Royal Palace at Angcor Thom [4]. From left to right: The shred, cross section of the shred prepared for an analysis, Ca map of the glaze (1.5 x 1.5 mm scan), Co pigment particle (25 x 25 μm scan, particle size cca 10μm), the GUPIX fit of the PIXE spectra collected from the central part of Co particle. The typical glaze thickness is around 300 μm and is increased up to 800 μm at the fold. The Co mass concentration at blue glaze was about 0.6 % and Ca concentration both in the blue and white glaze ranged from 9 to 12 %. The Fe:Co and As:Co ratio in the pigment particle were 0.017 and 0.006, respectively.

The work has been supported by Ministry of Education, Youth and Sport of the CR under the project LC06041.

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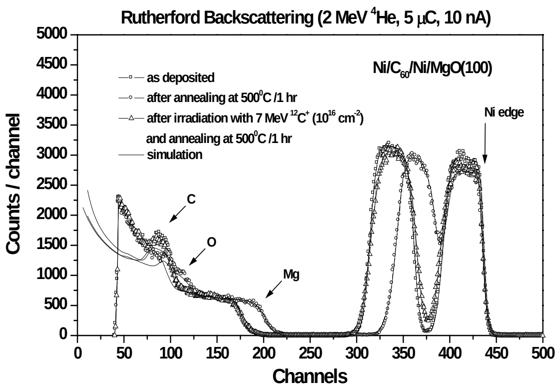
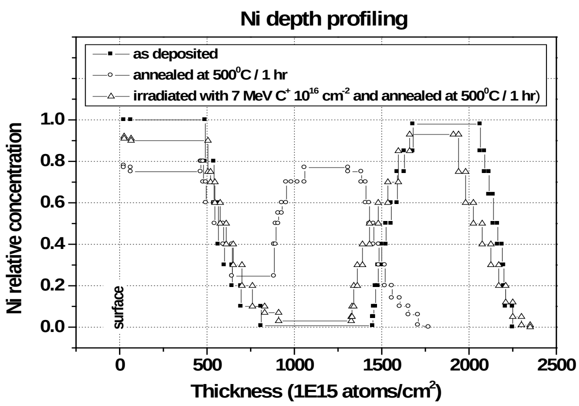
Effect of ion irradiation on structure and thermal evolution of the Ni–C_{60} hybrid systems

J. VACÍK, V. LAVRENTIEV, V. VORLÍČEK[1], L. BAČÁKOVÁ[2], K. NARUMI[3]

In the paper [1] we report on the thermal response of the transition metal/fullerene thin hybrid multilayers, pristine and ion-modified (using 7 MeV C^+ ions up to a fluence 10^{16} cm^{-2}), i.e., Ni/C_{60}/Ni and Ni/a-C/Ni (a-C amorphous carbon), both prepared on the MgO(100) monocrystalline substrate. The multilayer sequences were gradually annealed in vacuum up to high temperatures (1000°C), and their structures were inspected using RBS and SEM analytical techniques. The inspection evidenced differences in the evolution of the virgin (non-irradiated) and ion-irradiated systems. In pristine composites a significant part of the C_{60} molecules out-diffused during annealing < 500°C. At temperatures around (and above) 500°C fullerenes underwent (in the vicinity of Ni) massive fragmentation and conversion to a-C. Very high temperature (1000°C) annealing resulted in fabrication of a large array of micrometer-sized octagonal pits and rod-type particles emerging from the encompassing a-C + Ni composite. Ion irradiated multilayers developed in a different way. Thermal annealing < 500°C had only a minor effect on the integrity and composition of the system. Higher temperatures > 500°C, however, induced a forceful (a-C/Ni) phase separation. The nominal annealing at 1000°C resulted in the formation of facetted, sub-micrometer-sized (round, plate and rod-type) particles (with a Ni core and a thin a-C rind) that were spread individually on a thin a-C/MgO(100) interface. The main axes of the particles were oriented according to the crystallographic axis of the MgO(100) substrate.



The 2 MeV alpha particle RBS spectra for the Ni/C_{60}/Ni/MgO(100) multilayer: (i) as-deposited, (ii) after annealing (at 500°C for 1 hr), and (iii) after irradiation (with 7 MeV C^+ ions) and annealing (at 500°C for 1 hr).



The Ni depth profiles evaluated using the SIMNRA 6.04 code. The annealing of the non-irradiated multilayer induces diffusion of C out of the system and towards the Ni/MgO interface. For the irradiated and annealed

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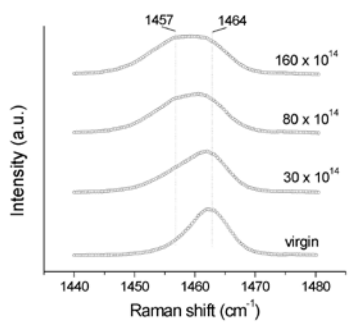
Fullerene nanostructure design with cluster ion impacts

V. LAVRENTIEV, J. VACÍK, H. NARAMOTO[1], K. NARUMI[1]

Carbon is a unique element of periodic table revealing a number of attractive structural forms (graphite, diamond, amorphous carbon, carbon onions, fullerene, carbon nanotubes, graphene, etc.). The remarkable carbon polymorphism induces great activity aiming to discover new carbon structures or carbon structure transitions under various fabrication conditions or under various post-fabrication loadings. In this study we have modified the fcc-C_{60} film (fullerite) deposited on sapphire substrate by means of the energetic C_{60} cluster ion bombardment. We have applied 50 keV C_{60}^+ cluster ions for creation of the modified thin layer on the surface of fcc-C_{60} film [1, 2]. Variation of the surface layer structure due to the ion fluence increase was analyzed using atomic force microscopy (AFM) and Raman spectroscopy (488 nm laser). The sputtering effect was evaluated through surface profiling across the border between the irradiated and non-irradiated surface areas. The C_{60} modification was found to be depending on the implantation fluence. The low-fluence ion implantation (fluence is less than 25×10^{14} ions/cm^2) the cluster ion bombardment (CIB) results in purification of C_{60} film surface (by ejection of the hydrocarbons) and formation of the 3-5 nm sized clusters of pure C_{60} within the modified layer. After completing the film purification (above the fluence of 25×10^{14} ions/cm^2) the pronounced film sputtering is started. Respectively, the Raman spectra show creation of 1D C_{60} polymer in the cluster bombarded C_{60} film as arising of the satellite peak nearby the $A_g(2)$ –related peak (Fig. 1). The satellite peak (at 1457 cm^{-1}) gradually increases with fluence suggesting growth of fraction of the C_{60} polymer in the modified layer. After treatment of the film surface with very high fluence the aligned C_{60} chains of the polymeric phase are observed on the surface (Fig. 2) [1, 2]. These results argue that the C_{60} polymer is created in the film depth by the shock wave effect. Due to the film sputtering the polymerized C_{60} layer appears on the film surface.



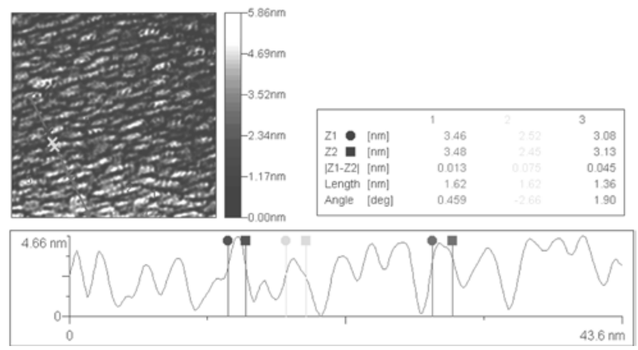


Figure 1 (in the left). Raman spectra of C_{60} film irradiated by 50 keV C_{60}^+ ions with high fluences.
Figure 2 (in the right). AFM analysis (image and surface profiling) of the C_{60} film surface irradiated by the 50 keV C_{60}^+ cluster ions to fluence of 160×10^{14} ions/cm^2.

Financial support from the Grant Agency of the Czech Republic (Research projects Nos. IAA400100702 and 106/09/1264) is highly acknowledged.

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RBS and RBS/channeling study of lithium niobate implanted with Er ions and annealed

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$LiNbO_3$ (LN), doped with optically active rare earths find applications in optical devices such as solid state lasers, amplifiers, sensors. Crystalline field in the surroundings of the active ions and their distribution in various centers strongly affect LN optical properties. Pre-cleaned LN wafers (X cuts <11–20>, Z cuts <0001> and specially designed Y_{II} cuts <10–14> and $Y_{\perp}$ <01–12>) were implanted with 330 keV Er^+ ions, 7° off-axis in HZDR Germany to the fluences from 1.0×10^{15} to 1.0×10^{16} cm^{-2}. Five hours annealing at 350 °C was applied to re-crystallize the as-implanted layer and to avoid clustering of Er. RBS and RBS/channeling measurements were performed with 2 MeV He ions from NPI Tandetron accelerator. The projected range R_p and the range straggling ΔR_p of erbium ions calculated by SRIM 2008 are R_p = 70 nm, ΔR_p = 22 nm. As implanted samples exhibit concentration maximum slightly shifted to the depth and broader Er distribution (see Fig. 1A), which could be explained by the higher energy straggling of implanted ions in host matrix and by the fact, that SRIM simulation doesn't take into account the different crystallographic orientations. The subsequent annealing influenced Er profiles for both Y cuts more significantly than for other cuts. In the $Y_{\perp}$ cut, the erbium concentration maximum practically disappeared and Er concentration at R_p decreased (see Fig. 1A). RBS/channeling analysis shows broadest modified-amorphous layer in the $Y_{\perp}$cut, which also exhibits the lowest reconstruction rate after the annealing (see Fig. 1B). Thinness modified layer and good recovery after the annealing are observed in the Z cut. The amount of disordered atoms in the implanted region is similar in all cuts, but the thicknesses of the modified layer differ for the various cuts, which means that the depth of the introduced defects differed for the various cuts as well. The RBS measurements done on as implanted and annealed LN samples show faster migration of the Er ions in the $Y_{\perp}$ cut (see Fig.1A), which may be related to the lower ability to the recovery. We suppose that the recovery of the interface between the implanted LN surface layer and the LN bulk reduces the mobility of the Er implanted atoms because of the migration of the introduced defects [1, 2].

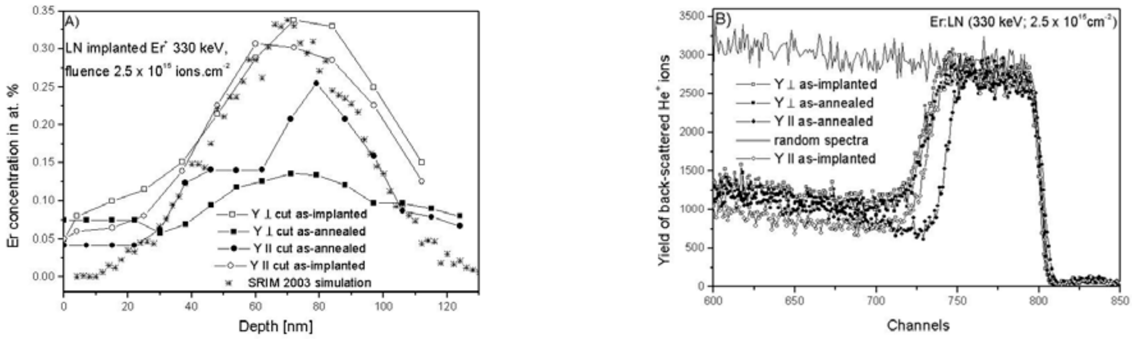

Fig. 1. A) The Er depth profiles and B) RBS/channelling spectra of LN Y_{II} and $Y_{\perp}$ cuts – a comparison of the as-implanted samples and as-annealed samples.

The research has been supported by the LC06041 and 106/09/0125 research programs. The implantation experiment was done within SPIRIT Contract No. 025646.

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A contribution to the certification of V and Ni contents in a new NIST SRM 1577c Bovine Liver by radiochemical neutron activation analysis

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There are several modes used at the U.S. National Institute of Standards and Technology (NIST) for value-assignment of standard reference materials (SRMs) for chemical measurement, i.e., the establishment of NIST certified, reference or noncertified values [1]. One of those leading to a certified value is based on using one method at NIST and different methods by outside collaborating laboratories, if such methods do not exist at NIST. The NIST method and the methods of the outside collaborating laboratories must have been critically evaluated and demonstrated to provide accurate results for the matrix under investigation. The method(s) used by outside collaborating laboratories should be different from the method used at NIST.

Our laboratory of activation analysis participated in several certification campaigns of new NIST SRMs, lastly to provide independent radiochemical neutron activation analysis (RNAA) data for certification of contents of V and Ni in the newly prepared NIST SRM 1577c Bovine Liver. Vanadium was determined by pre-separation neutron activation analysis and inductively coupled plasma optical emission spectrometry at NIST, while Ni was determined by inductively coupled plasma mass spectrometry at NIST and in one collaborating laboratory. Thus, there was a need to determine Ni by another independent method and to provide supplementary data for V, as well. The competence of our laboratory in low-level, low uncertainty determination of V and Ni in biological materials using RNAA procedures developed earlier [2,3] has been proved by analysis of NIST SRM 1515 Apple Leaves, NIST SRM 1548a Typical Diet, and NIST RM 8433 Corn Bran [4] as demonstrated in Table 1. Thus, our laboratory qualified for participation in the certification campaign of the new NIST SRM 1577c by using RNAA. A comparison of our RNAA results, which were used for deriving the certified values, with the eventually certified contents of V and Ni in NIST SRM 1577c is also shown in Table 1 (in bold).

Table 1. RNAA results for V and Ni in older NIST SRMs and new NIST SRM 1577c [4]

Element	V, ng g^{-1} (dry mass)		Ni, ng g^{-1} (dry mass)	
Material	This work[a]	NIST value[b]	This work[a]	NIST value[b]
NIST SRM 1515	243 ± 8	260 ± 30	NA	910 ± 120
NIST SRM 1548a	NA	-	359 ± 20	369 ± 23
NIST RM 8433	4.8 ± 0.6	5 ± 2	179 ± 38	158 ± 54
NIST SRM 1577c	**8.4 ± 0.9**	**8.17 ± 0.66**	**44.0 ± 3.4**	**44.5 ± 9.2**

[a]-Mean ± s.d. of 3-5 determinations
[b]-certified value ± expanded uncertainty (coverage factor k=2)

The analytical approach to the value assignment in the certification process of NIST SRM 1577c had to address the challenges of accurate low level trace element determination and proved the indispensable role of RNAA for this purpose. It can be expected that the recent recognition of NAA as a primary measurement method [5] will further enhance the role of this technique in chemical metrology, including the certification of reference materials.

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Determination of fluorine in geochemical reference materials and coal by instrumental photon activation analysis

I. KRAUSOVÁ, J. MIZERA, Z. ŘANDA, D. CHVÁTIL

Reliable determination of very low concentrations of fluorine in coal and other geologic materials has been a challenge for analysts for a long time, not only due to its importance from the environmental and toxicological standpoints, but mostly due to its analytical difficulty. Standard analytical methods require tedious procedures for sample dissolution and chemical conversion of fluorine into the anionic form, which are threatened by loss or incomplete release of fluorine from the sample or its contamination. Nondestructive instrumental determination of fluorine has so far been governed by radioanalytical methods. Among them, PIGE (proton induced gamma-ray emission) is the most sensitive technique. Application of neutron activation analysis is limited due to relatively high detection limits, even with selective activation by fast neutrons. Activation by photons may have a greater potential. However, the analytical radionuclide ^{18}F, product of the photonuclear reaction $^{19}F(\gamma, n)^{18}F$, is a pure positron emitter. Only the non-specific 511 keV annihilation gamma rays of ^{18}F are available for its detection, which is interfered by simultaneous formation of several other positron emitters, particularly ^{45}Ti and ^{34m}Cl. Interference contributions from other radionuclides as ^{22}Na, ^{44}Sc, ^{89}Zr, ^{74}As, and ^{84}Rb are small or negligible. Thus, photon activation has been utilized in fluorine assay in conjunction with radiochemical separation [1].

The present work has been aimed at studying possibilities of nondestructive determination of fluorine in coal and other geological materials by instrumental photon activation analysis (IPAA). By optimization of beam energy and irradiation-decay-counting times, and using correction standards for the interfering nuclides, IPAA allowed determination of fluorine in selected USGS geochemical reference materials and NIST coal standards down to the ten μg g^{-1} level (see Table 1). Fluorine in the reference materials has been determined by the IPAA method in good agreement with certified values except for NIST SRM 1632b, where the values determined by IPAA are by ca. 30 % higher than the certified value, but agree well with other reference values obtained by PIGE [2].

Table 1: Results of F assay in geochemical reference materials by IPAA at various irradiation energies (in μg g^{-1}, ± 1 s)

Sample	Beam energy $E_{\gamma,max}$ (MeV)				Certified value	Other reference value [2]
	18	17	16	15		
USGS QLO-1 Quartz Latite	278 ±14	332 ± 16	306 ± 20	317 ± 37	280 ± 20	-
USGS SCo-1 Cody Shale	760 ± 26	814 ± 22	760 ±26	726 ± 33	770 ± 60	-
NIST SRM 1632b Subbituminous Coal	53.3 ± 4.2	61.4 ± 2.7	51.4 ± 5.7	69.5 ± 4.6 *	41.7± 3.2	58.7± 3.6
NIST SRM 1635 Bituminous Coal	28.4 ± 2.9	26.4 ± 3.5	26.9 ± 6.6	35.6 ± 4.4 *	25.9 ± 3.3	30.5 ± 2.2

* ^{45}Ti interference could not be corrected.

Based on the results of the method optimization and verification, a simplified procedure for routine IPAA assay of fluorine has been suggested. The routine procedure was applied in F assay in selected samples of coals mined in the Czech Republic and used primarily as fuel for both power plants and local fireplaces. For quality control on the analyses, the four reference materials used in the method optimizing were analyzed with results matching perfectly the reference values. The fluorine contents found in the coals within the range of ca. 20 – 480 μg g^{-1} are correlated mainly with their ash content, which supports the primary association of F in coal with mineral matter.

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Accumulation and Hyperaccumulation of Metals in Fruiting Bodies of Macrofungi Studied by Neutron Activation Analysis and Other Methods

J. BOROVIČKA, Z. ŘANDA

Geomycology has been defined [1] as "the impact of fungi on geological processes including the alteration and weathering of rocks and minerals, the accumulation of metals and their role in nutrient cycling and influence on proliferation of microbial communities in mineral substrates". Macrofungi, commonly called mushrooms, represent the most known and popular group of fungi; the number of species growing in Europe is estimated from 8 to 15 000.

Macrofungi, in general, are able to dissolve soil compounds, mobilize trace elements, absorb, transport and deposit them in the fruiting bodies. The ability to accumulate particular elements in macrofungi is much higher than that in vascular plants. Furthermore, this ability is species-dependent: the ability to take up particular element is a characteristic feature of some fungus or group of fungi.

The species with an exceptional ability to take up particular element(s) are called "hyperaccumulators". Among the kingdom of fungi, hyperaccumulation of vanadium in *Amanita muscaria* (and allies), arsenic in *Sarcosphaera coronaria* and silver in several *Amanita* species of the section *Lepidella* have been reported. The biological importance of this phenomenon is poorly understood. However, as has been demonstrated in vascular plants, high levels of metals in biomass might have some protective effect against natural enemies (herbivores). This defense hypothesis has never been tested in macrofungi but it might be hypothesized that high concentrations of metals might play some protective role, especially in early stages of the fruiting body development.

Plant hyperaccumulators are studied worldwide and possible biotechnological applications (e.g., bioremediation) have been considered. On the other hand, macrofungi have been poorly investigated. We have focused on a wide screening of macrofungi from both clean and polluted environments and their accumulation abilities. The use of instrumental neutron activation analysis (INAA) enables to analyze practically all elements of interest. We have analyzed several hundreds of species and found several new hyperaccumulators: cadmium (*Cystoderma* sp.), selenium (*Amanita* sp.), and arsenic (*Inocybe* spp., *Hebeloma* sp., *Russula* spp.). Our detailed screening of various species of *Amanita*, sect. *Lepidella*, has revealed that silver hyperaccumulation is a worldwide phenomenon and is not restricted to European species.

Our investigation in a silver-polluted area has revealed highly elevated silver concentrations in all fungal species [2]. The highest levels were found in ectomycorrhizal *Amanita submembranacea* with silver concentrations commonly in hundreds of mg kg^{-1} (dry weight). The intracellular speciation of Ag in fruit-bodies of this species was inspected at the Institute of Chemical Technology in Prague by size exclusion chromatography followed by sulfhydryl-specific fluorimetric assays of ligands using reverse phase high performance liquid chromatography and improved polyacrylamide gel electrophoresis. Virtually all Ag was found to be intracellular and sequestered in the major 7 kDa and minor 3.3 kDa complexes. The lack of glutathione and phytochelatins and the presence of a single 3 kDa sulfhydryl-containing peptide in the isolated Ag-complexes suggest that detoxification of Ag in *Amanita submembranacea* may rely on metallothionein.

The investigation of macrofungi in an auriferous area has shown relatively high gold concentrations, especially in saprotrophic species [3]; the gold concentrations (up to 8 mg kg^{-1}) found in *Lycoperdon perlatum* are the highest ever reported in eucaryotic organisms under natural conditions.

This work was supported by the Grant Agency of the Academy of Sciences of the Czech Republic (grant No. IAA600480801).

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Neutron Diffraction and Scattering

The activity of the Neutron diffraction and scattering group in the last two years has been focusing basically in Fundamental and Applied Research with Thermal Neutrons at the Reactor LWR-15. The research has been carried out at five horizontal beam channels of the reactor LWR-15 which are hired at the Research Centre Ltd. The experiments have been opened and free for external users. The group has successfully participated in the *Transnational Access to Large Facilities* programme in the frame of FP7 NMI3 project where the Řež´s experimental facilities for Neutron strain scanning, Small-angle neutron scattering, Neutron powder diffraction which together with Neutron depth profiling and Neutron activation analysis from the group of Nuclear Analytical Methods have been offered for European neutron community. Within the existing collaborations many complementary experiments have also been carried out in abroad. The most attention has been paid to the following research programmes.

Small-angle neutron scattering (SANS)
Investigations of large-scale structures by neutron scattering technique was focused on investigation of new high-temperature alloys based on Co-Re (cooperation with TU Braunschweig and TU Munich), on study of Ni-base superalloys (cooperation with TU Braunschweig, TU Munich and TU Košice) and at characterization of nanostructures prepared from two-phase alloys (cooperation with TU Braunschweig). Phase transformations in a Co-Re-based high temperature alloys and high temperature stability of Cr-carbides in these alloys were studied. The measurements brought information on high-temperature characteristics of Co-Re alloys. In the field of superalloys, a method for SANS contrast dependence determination using difference in thermal expansions of phases was developed and tested. Further, SANS investigation of porous structure and in-situ diffusion measurement in nanoporous metallic membrane was carried out. High resolution of the instrument allowed us to measure volume fractions and size distributions of relatively large pores (~100 nm) with high accuracy in high-density alumina-based ceramics (collaboration with UACH Bratislava).

Neutron powder diffraction
At the beginning of the 2009 the new powder diffractometer instrument called MEREDIT was made fully operational. This instrument is mainly dedicated to the study of the atomic and/or magnetic structure of the polycrystalline or powder samples. Due to the different sample environments is possible to study *in-situ* the structural/magnetic changes within vast interval of temperatures form 10 to 1200 K, under uni-axial tension and/or compression or use the automatic sample exchanger for up to 6 samples. Serious demand for the use of the neutron powder diffraction mainly comes from the laboratories studying the new materials such as magnetocaloric and hydrogen storage materials, oxygen conductors, antiferromagnetic semiconductors or where the non-destructive structure analysis is needed as geology or archaeology. The instrument MEREDIT equipped with the deformation rig was also used as tool for study of the phase changes in the cycled austempered ductile cast irons or in the new TRIP (transformation induced plasticity) steels. By building and made operational of this instrument the NPI ASCR, v.v.i. has diversified its research activities into the field where investigations could not be done before.

Neutron diffraction studies of materials in situ upon thermomechanical loads
Neutron diffraction methods are particularly suitable for *in situ* characterization of structural materials under extreme external conditions such as high or low temperature, deformation, high pressure, high magnetic field, etc. Due to a high penetration ability of thermal neutrons, this probe can easily enter the corresponding auxiliary experimental equipment like furnaces, cryostats and high pressure cells, respectively. In the Neutron Diffraction and Scattering group, the high-resolution neutron diffraction method has been applied *in situ* during mechanical and combined thermomechanical testing of various materials. The analysis of the neutron diffraction profiles gathered *in situ* during loading yields accurate bulk information on the structural changes which can be associated with deformation or transformation processes. Recently, this method has been utilized for characterization of deformation mechanisms in different materials as steels, hexagonal materials, as well as phase transformations in

solids, such as shape memory alloys (SMA) and TRIP steels. In the latter case, the integrated intensity of particular reflexions exhibits high sensitivity to the structural change (e.g. martensitic transformation) or reorientation of the crystal lattice (e.g. twinning, deformation texture) during the loading.

Bragg diffraction optics

Experimental investigations in this field have been concentrated on experimental studies of the dispersive monochromators providing high and ultra-high angular and/or energy resolution. Recently, several tests of ultra-high resolution dispersive monochromators with the aim of their possible employment at high-flux neutron sources have been carried out. High-resolution monochromatic neutron beams have also opened new possibilities of application for an alternative radiography technique. World wide collaborations in application of Bragg diffraction optics for neutron scattering instrumentation have been developed within two CRP-IAEA Projects and FP7-NMI3-JRA activity - Neutron optics. Further, Monte Carlo simulations of properties of several instruments equipped with focusing elements for the home laboratory as well as for the foreign ones have been carried out.

Pore structure characterization of nanoporous membrane using SANS

P. STRUNZ, D. MUKHERJI[1], J. ŠAROUN, U. KEIDERLING[2] AND J. RÖSLER[1]

Using a selective phase dissolution technique, nano-porous membrane can be produced from simple two-phase metallic alloys [1]. It contains through-thickness elongated channel-like pores of only a few hundred nanometre width. This unique porous material with fine open porosity and a high degree of regularity is suitable for many applications (catalysis, miniature heat exchanger, filtering and separation processes - gas permeable membrane, separation of gas from liquid). Being metallic, the membranes can be easily heated using electric current and can be sterilized in-situ.

Knowledge of microstructural parameters is essential for the membrane optimization. Non-destructive characterisation of the pore microstructure (see scheme in Fig. 1) was carried out by small-angle neutron scattering (SANS) technique at NPI Řež (double-crystal SANS facility MAUD) and at BENSC, HZB Berlin, Germany (pinhole SANS). An example of the measured scattering curve is shown in Fig. 2.

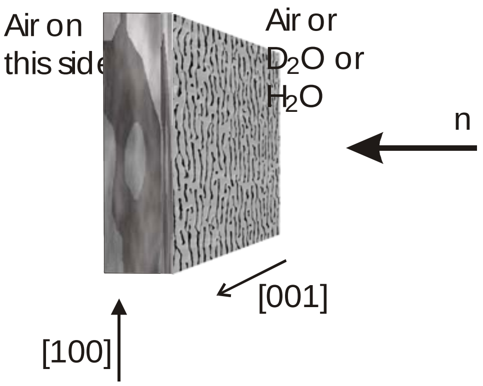

Fig. 1. Membrane and its orientation for double-crystal SANS experiment.

The combined results [2] from pinhole and double-crystal facilities enabled to determine microstructural parameters of the nanoporous membrane: pore-to-pore distance (480 nm), raft thickness (280 nm), pore volume fraction (36%), specific interface (49000 cm^2/cm^3). The model of the microstructure resulting from the fit is depicted in Fig. 3. The advantage of complementarities of both types of facilities has to be stressed. The used contrast variation method using D_2O and H_2O helped to conclude on scattering length density of pore walls (73.0-74.0×10^9 cm^{-2}).

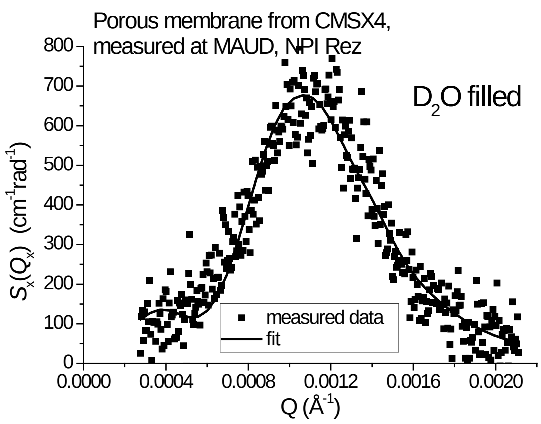

Fig. 2. Double-crystal SANS data (pores filled by D_2O), facility MAUD (NPI Řež). $S_x(Q_x)$ is the cross-section $d\Sigma/d\Omega(Q_x,Q_y)$ integrated over the vertical angular component.

The kinetics experiment showed that the pores are filled instantly (in less than 20s) by D_2O, H_2O or even by silicon oil. This is attributed to strong capillary effects. The subsequent emptying of pores by evaporation, which is a much slower process, was observed from the gradual change (increase) of the integral intensity with time. The observation provides qualitative information on the diffusion process through the high aspect ratio pores and indicates that diffusion slows down when evaporation occurs at larger depths (> 10 µm). This is likely to have consequences on the electrolytic phase dissolution step in the membrane fabrication.

This work was supported through the EC contract No. RII3-CT-2003-505925 (NMI3).

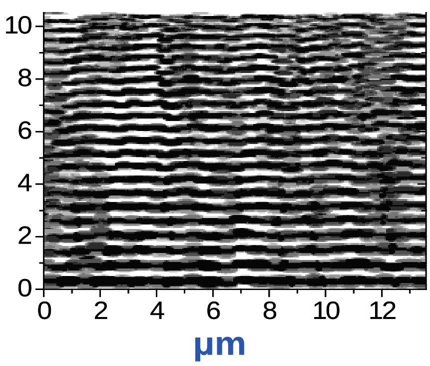

Fig. 3. Slice through the 3D model corresponding to the optimum fit to SANS data. Black and gray: γ' rafts; white: pores.

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Monte Carlo simulations of parasitic and multiple reflections in elastically bent perfect single-crystals

JAN ŠAROUN, JIŘÍ KULDA[1], PAVOL MIKULA, MIROSLAV VRÁNA

A new model of neutron transport in elastically bent perfect crystals including simultaneous reflections on multiple diffracting planes [1] has been developed and implemented within the neutron Monte Carlo ray-tracing code of the RESTRAX [2] simulation package. The new model provides quantitative prediction of the intensity of parasitic reflections and of the Renninger effect, both of which can significantly modify the intensity of primary reflections and increase the attenuation of a neutron beam traversing a bent perfect crystal. Experimentally observed multiple reflection effects [3] have been compared with simulated data. The results prove that the new model can predict neutron transport in bent perfect crystals much more realistically. For example, we were able to reproduce complex details of incident neutron spectrum of the three axis spectrometer equipped with Si monochromator (IN20, ILL Grenoble). Also recent experiments with multiple diffraction effect in bent Si crystals were well reproduced by simulations. As an illustration, the Fig.1 shows how multiple diffraction can significantly amplify the scattered intensity (discrete peaks), while the intensity of primary reflection 111 in symmetric Laue geometry remains very weak (seen as the smooth background). Note that several different pairs of secondary and tertiary reflections may contribute to the same primary reflection simultaneously. For example, four alternative paths ($\underline{3}1\underline{3}$+404, 133+0$\underline{22}$, $\underline{2}0\underline{2}$+313 and 044+1$\underline{33}$) contribute to the intensity of the peak No. 5. These complex processes are well described by the simulation as regards both the peak positions and integrated intensities (Fig. 2). Simulations using the new crystal model should be particularly useful in development of new monochromators, solid-state benders and lenses or multianalyzer systems, where the neutron beam may have to pass through a large volume of elastically bent silicon.

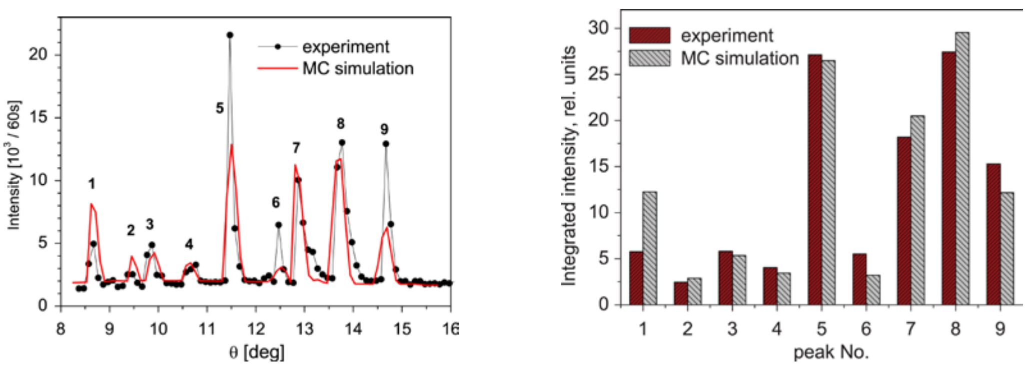

Fig.1. Comparison of measured and simulated *Umweganregung* peaks (left) and their integrated intensities (right) observed on top of the primary Si(1 1 1) reflection in symmetric Laue geometry.

The work was supported in Czech Republic by the projects GACR-P204/10/0654, MSM2672244501 and AVOZ104805505, and by the European Community through the 'Research Infrastructures' action under the FP7 Programme (CP-CSA_INFRA-2008-1.1.1 No. 226507-NMI3).

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Dispersive double bent crystal setting for high resolution diffractometry

P. MIKULA, M. VRÁNA, J. ŠAROUN

In this contribution we are desribing some excellent properties of the Si(111)+bent Si(220) dispersive double-bent-crystal (DDBC) setting (see Fig. 1). For this experiment we used neutron optics diffractometer installed at the research reactor LWR-15 in Řež. The diffractometer operates at fixed neutron wave length of λ=0.163 nm provided by bent perfect Si(111) crystal of the dimensions of 200×40×4 mm^3 (length × width × thickness). Si(220) analyzer was in the form of sandwich of two slabs of 200×40×1.3 mm^3. The properties of the DDBC setting were tested for various curvatures of the Si(220) slabs. Thanks to an easy manipulation with focusing of the monochromatic beam, high reflection probability of bent crystals and very narrow (1-3 mm) obtained monochromatic beam such an arrangement could be attractive for an employment. By using a standard polycrystalline Fe(211) sample (Φ=2 mm) it has been found that besides an excellent resolution the neutron current is sufficient high resolution diffractometry e.g. for powder diffraction.

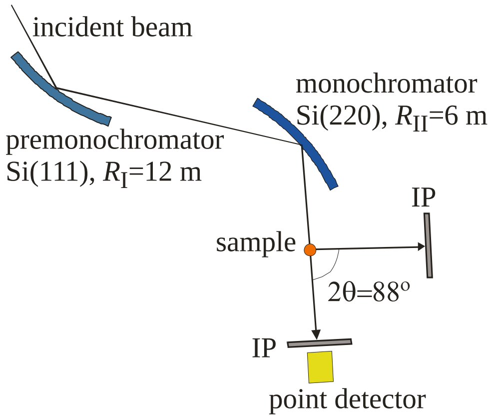

Fig. 1. Experimental setting as used for the measurement

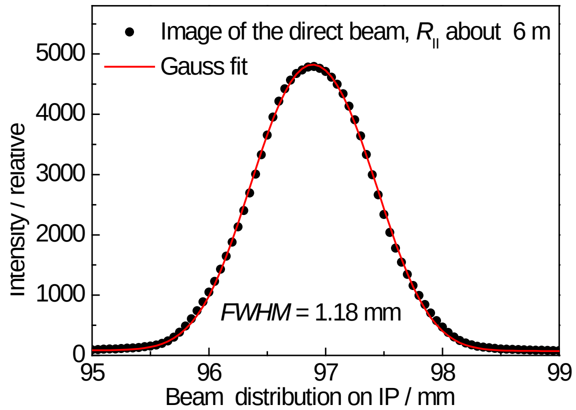

Fig. 2. Profiles of the diffracted beam taken by IP at the distance of 80 cm from the second crystal.

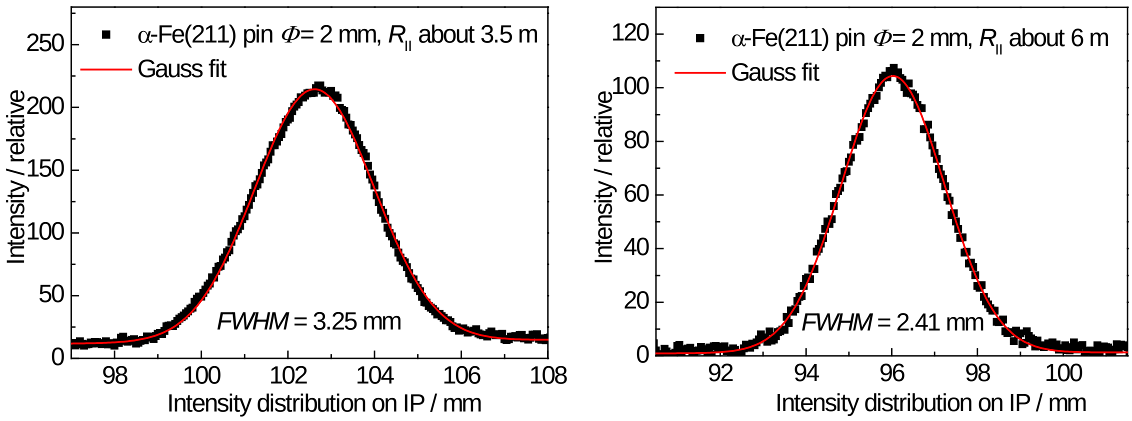

Fig. 3. Powder diffraction profiles from the α-Fe(211) standard sample situated at 50 cm from the Si(220) crystal and with IP at 45 cm from the sample for two different curvatures.

This work was supported by the Grant Agency of the Czech Republic (grant No. 204/10/0654) and the ASCR project M100480901.

A new material for hydrogen storage; $ScAl_{0.8}Mg_{0.2}$

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A novel aluminium rich alloy for hydrogen storage has been discovered, $ScAl_{0.8}Mg_{0.2}$, which has very promising properties regarding hydrogen storage capacity, kinetics and stability towards air oxidation in comparison to hydrogen absorption in state-of-the-art intermetallic compounds. The absorption of hydrogen was found to be very fast, even without adding any catalyst, and reversible. The discovered alloy crystallizes in a CsCl-type structure, but decomposes to ScH_2 and Al(Mg) during hydrogen absorption. Detailed analysis of the hydrogen absorption in $ScAl_{0.8}Mg_{0.2}$ has been performed using in situ synchrotron radiation powder X-ray diffraction, neutron powder diffraction and quantum mechanical calculations. The results from theory and experiments are in good agreement with each other.

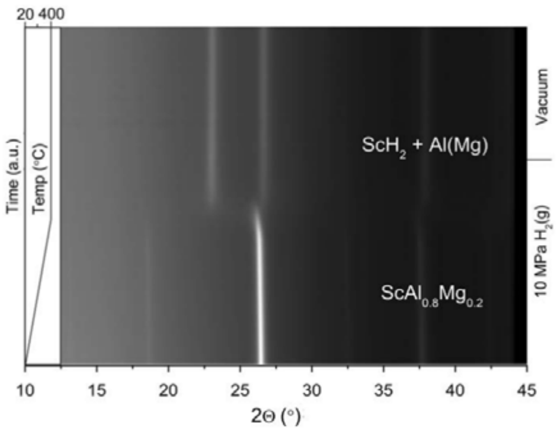

Fig. 1: Hydrogenation of $ScAl_{0.8}Mg_{0.2}$ investigated by in-situ *SR-PXD. The structure transformation occurs around 400 1C. The pressure is shown on the right side of the figure.*

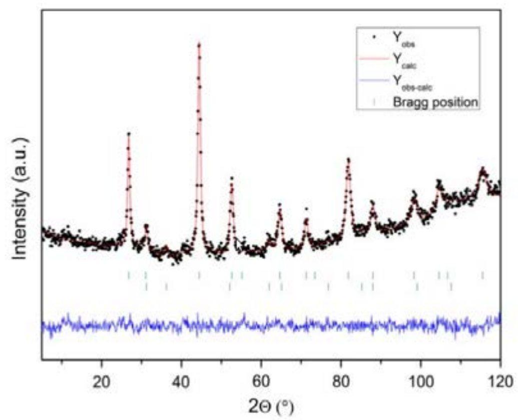

Fig. 2: Rietveld refinement of the sample deutered at 4 MPa and400 1C. The upper and lower ticks mark the Bragg positions of ScD2 and Al(Mg)respectively.

This work was supported from Research Centre Rez (AV0Z10480505, MSM2672244501) .

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Radiopharmaceuticals

Research activities of the radiopharmaceuticals department were distributed in the years 2009–2010 among all the main stages in the R&D of a new radiopharmaceutical, i.e. production of medical radionuclides, design, synthesis and analysis of new labelled compounds and their biological evaluation. In the meantime, the former structure of the department became obsolete due to transfer of routine production of radiopharmaceuticals in the subsidiary company of the Nuclear Physics Institute ASCR, p.r.i. – RadioMedic Ltd. Therefore, in the end of the year 2010, the department was also re-organized in order to define scientific goals and to reflect the above mentioned three fields of our research. We have also started to build up a new laboratory of cell cultures to extend our possibilities of biological testing of new radiopharmaceuticals. Our activities span topics from excitation function measurements to preclinical tests.

We have also acquired two colleagues from abroad and the team strived to prevent Europe from extinction by delivering several potential scientists to our country.

Excitation functions of the ^{nat}Mo(px,) and ^{nat}Mo(d,x) reactions with special regard to formation of ^{95m}Tc, $^{96m+g}$Tc, ^{99}Mo and ^{99m}Tc

ONDŘEJ LEBEDA, MAREK FIKRLE, MAREK PRUSZYNSKI [1], JAN ŠTURSA

Cross-sections of many nuclear reactions are of interest in various fields: radionuclide production, beam monitoring, thin layer activation, estimating activation of materials exposed to cyclotron beams, testing and improving codes for calculation of excitation functions. It is true also for proton and deuteron activation of natural molybdenum. Cross-sections have been measured several times for both the proton induced[1–8] and deuteron induced[9–13] reactions, however, some data are either less reliable or incomplete. We have, therefore, re-measured excitation functions for formation of about 15 radionuclides in the energy range of 8–37 MeV (protons) and 3–20 MeV (deuterons) using the external beam of the U-120M cyclotron[14,15]. We were focused on cross-sections for production of ^{95m}Tc as a suitable tracer of ^{99}Tc in environmental samples, $^{96m+g}$Tc as a potential beam monitor and, of course, ^{99m}Tc and ^{99}Mo that are of interest for alternative production of ^{99m}Tc and ^{99}Mo on cyclotrons due to a real danger of significant cut-off in supply of the ^{99}Mo/^{99m}Tc generators. Some of the most interesting results are displayed in Figs. 1–4.

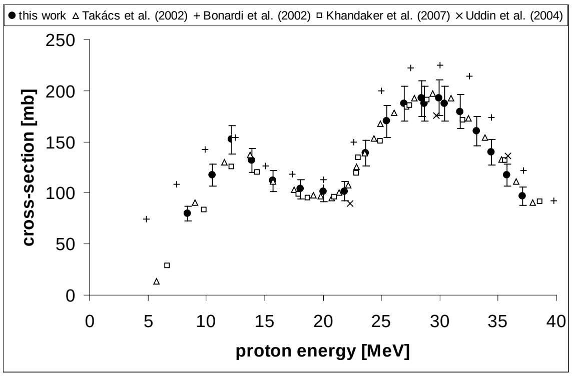

Fig. 1 CS for the ^{nat}Mo(p,x)$^{96m+g}$Tc reactions

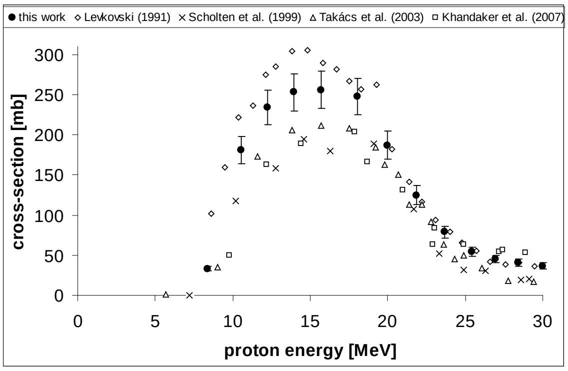

Fig. 3 CS for the ^{100}Mo(p,2n)^{99m}Tc reaction

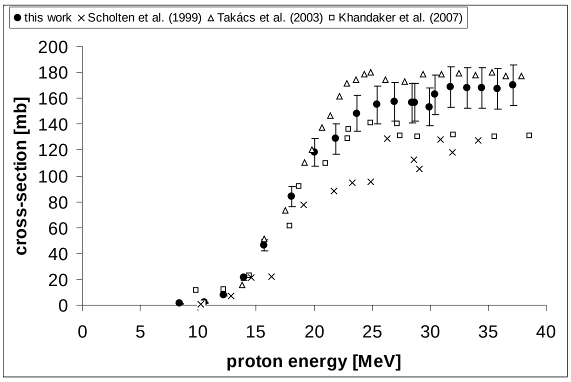

Fig. 2 CS for the ^{100}Mo(p,x)^{99}Mo reactions

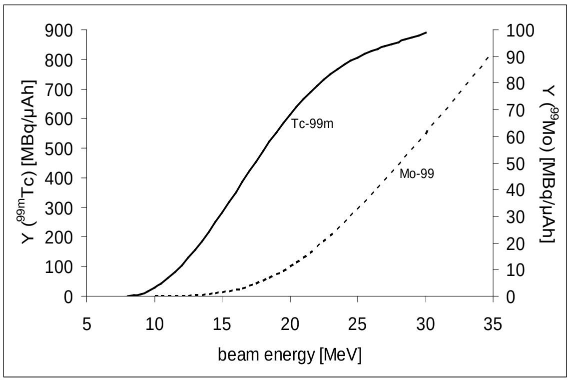

Fig. 4 Physical yields for the production of ^{99m}Tc and ^{99}Mo on highly enriched ^{100}Mo by protons

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Fig. 1 shows very good agreement between our data and data of 2,6,7 – since the reaction $^{nat}Mo(p,x)^{96m+g}Tc$ has been proposed and used for monitoring purposes, the agreement can be also considered as a reliability test of the input parameters used for the cross-sections calculation.

In the Figs. 2–4, there are both cross-sections and physical thick target yields of medically relevant ^{99}Mo and ^{99m}Tc formed by proton activatio of ^{nat}Mo. In both cases, the measured cross-sections on ^{nat}Mo could be converted to the cross-sections on the pure ^{100}Mo isotope[14]. Although the yields of ^{99}Mo for production of generators are hardly competitive to reactor-produced ^{99}Mo, the yields of ^{99m}Tc seem to be more promising for direct, non-reactor-based production of this most widespread radionuclide in nuclear medicine. In principle, a single batch (24 MeV, 500 μA, 6 h) can represent up to 1.8 TBq of ^{99m}Tc at the EOB. It opens door for de-centralized cyclotron production of ^{99m}Tc by $^{100}Mo(p,2n)$ reaction. In contrast, production of ^{99}Mo or ^{99m}Tc via deuteron activation of Mo isotopes requires relatively high energies of deuterons (> 20 MeV) that are not available on production cyclotrons[15].

The only radionuclide that can be produced directly on ^{nat}Mo in sufficient radionuclidic purity and acceptable amount of for its intended use is – thanks to its half-life – ^{95m}Tc (61 d). In both proton and deuteron induced reactions on ^{nat}Mo, its yield is 0.54 and 0.27 MBq/μAh for 20 MeV protons and deuterons, respectively[14,15].

Besides the mentioned excitation functions, cross-sections for formation of ^{93m}Tc, $^{93m+g}Tc$, ^{94}Tc, ^{94m}Tc, ^{95}Tc, ^{101}Mo, $^{90m+g}Nb$, ^{92m}Nb, ^{95}Nb and $^{89m+g}Zr$ were measured, too[14,15].

The work was supported by the Academy of Sciences of the Czech Republic under the NPI research plan AV0Z10480505, by the grant 203/08/1276 provided by the Czech Science Foundation and by the project MSM 2672244501. We also thank the IAEA for their financial support of Marek Pruszynski within the framework of a four-month-long training programme (POL/05004).

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Preclinical imaging of protein synthesis: Comparison of ^{68}Ga-DOTA-Puromycin and ^{44}Sc-DOTA-Puromycin

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Introduction

Multiple attempts to measure protein synthesis *in vivo* have been made through the last decades, using mostly radiolabeled amino acids, with limited or unsatisfactory success. The difficulties in utilizing radiolabeled amino acids for *in vivo* determination of protein synthesis are due to the wide variety of possible metabolic pathways of amino acids [1]. Puromycin has played an important role in our understanding of the eukaryotic ribosome and protein synthesis. It has been known for more than 40 years that this antibiotic is a universal protein synthesis inhibitor that acts as a structural analog of an aminoacyl-tRNA (aa-tRNA) [2]. Applying pharmaceutical concentrations, premature proteins are produced. Puromycin, in low concentrations, binds specifically to the C-terminus of full-length proteins. The purpose of this study was to compare ^{68}Ga-DOTA-Puromycin and ^{44}Sc-DOTA-Puromycin as suitable radioconjugates for *in vivo* determination of protein synthesis.

Methods

DOTA-Puromycin was synthesized following our design. ^{44}Sc was obtained from ^{44}Ti/^{44}Sc-generator as described previously by Filosofov *et al.* in 2010 [3]. ^{68}Ga was obtained from ^{68}Ge/^{68}Ga-generator as described previously by Zhernosekov *et al.* 2007 [4]. In both case the purified generator eluate was directly used for labeling of DOTA-Puromycin at 95°C for 20 minutes. Radioconjugates were purified using C18 Sep-pack. For µPET-studies 20-25 MBq of purified, labeled DOTA-Puromycin was administered to tumor bearing rats and animals were scanned for 45 minutes (^{68}Ga) and 2 hours (^{44}Sc) dynamically.

Results

The µPET-images of tumor bearing rats showed significant higher tumor uptake for ^{68}Ga-DOTA-Puromycin compared with ^{44}Sc-DOTA-Puromycin (Fig. 2). Images with both DOTA-Puromycin conjugates showed clearly visible tumor outlines. Tumor/reference ratios (T/nT) have been significantly higher for ^{68}Ga-DOTA-Puromycin (T/nT = 45:1) than for ^{44}Sc-DOTA-Puromycin (T/nT = 33:1). Uptake in cultured tumor cells (DU145) after 2 hours has been 2.0 ± 0.1% applied dose per 1×10^6 cells for both compounds. Uptake in normal skin fibroblasts (BJ) has been 0.2 ± 0.1% applied dose per 1×10^6 cells. Incorporation for both cell lines was determined as 93 ± 2.1% of uptake for both cell lines after 2 hours. *Ex vivo* biodistribution in tumor bearing mice revealed protein incorporation after 1 hour of 35 ± 3,9 % of uptake for DU145 and PC3 xenografts. Protein incorporation and uptake could be blocked using puromycin and cycloheximide for inhibition of protein synthesis (Fig. 1), thus confirming that for puromycin-conjugates the uptake is regulated by the amount of intracellular protein synthesis.

Conclusion

In respect of preparation time for labeled DOTA-Puromycin (75 minutes), ^{44}Sc with its $T_{1/2}$ = 3.97 h would be the radionuclide of choice. Regarding the biological properties and imaging resolutions ^{68}Ga-DOTA-Puromycin seems to be superior over ^{44}Sc-DOTA-Puromycin for determination of ribosomal activity and hence protein synthesis via PET. Since both radioconjugates are suitable for imaging of ribosomal activity, the choice of the used radionuclide can be based on the availability of the radionuclides.

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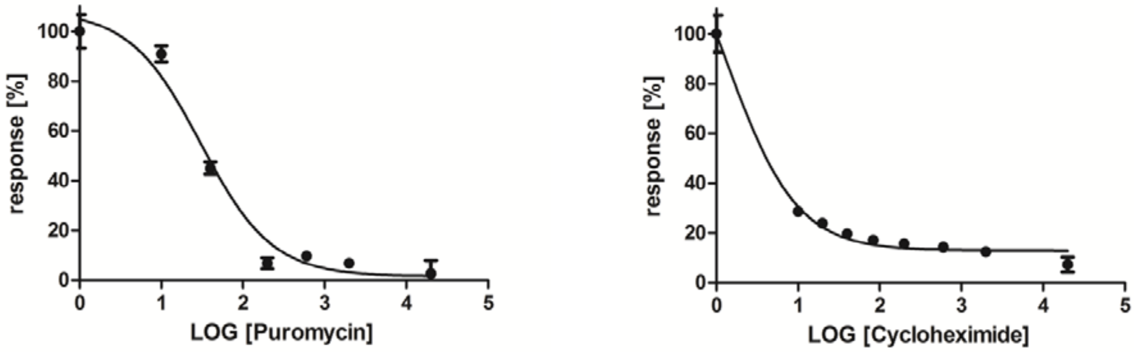

Figure 1. Inhibition of DOTA-Pur uptake by inhibiting protein synthesis utilizing Puromycin (competitive) or Cycloheximide (non-competitive).

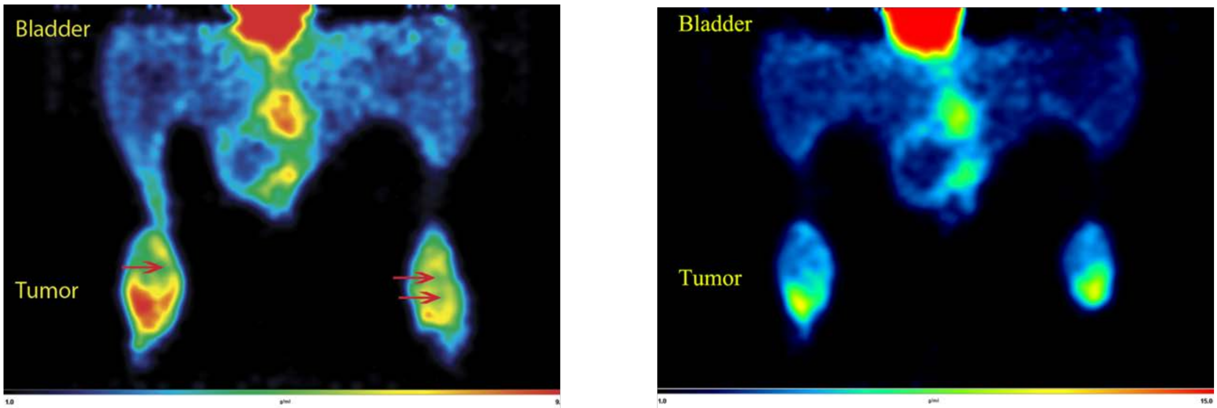

Figure 2. µPET images of ^{68}Ga-DOTA-Puromycin (left) and ^{44}Sc-DOTA-Puromycin (right)

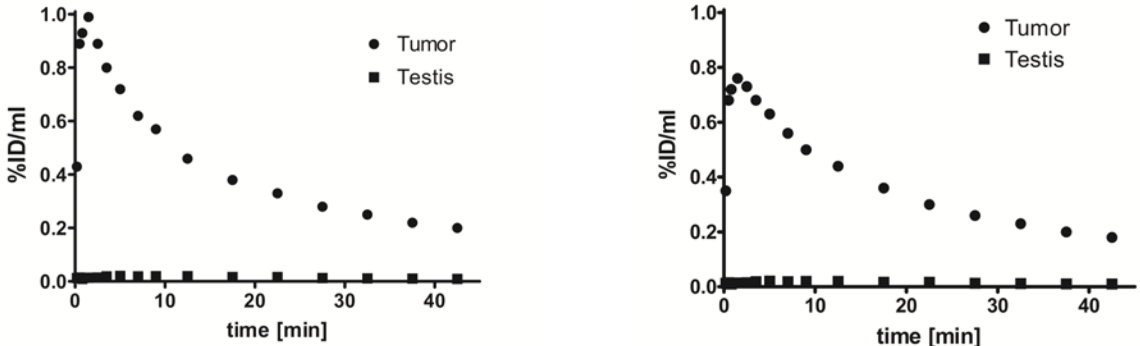

Figure 3. TAC´s of ^{68}Ga-DOTA-Puromycin (left) and ^{44}Sc-DOTA-Puromycin (right)

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Synthesis and preclinical evaluation of ^{177}Lu, ^{86,90}Y – intermediate affinity monoclonal antibodies targeting EGF and HER2/c-neu receptors as potential radiopharmaceutics for solid tumors

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Objectives

The encouraging results observed in the radioimmunotherapy of hematologic tumors have not yet been translated to solid tumors. For tumors associated antigents like EGFR, monoclonal antibodies (mAbs) with intermediate affinity might have preferential uptake in target tissues overexpressing target antigen while might have low uptake in normal tissue[1]. Nimotuzumab (h-R3) and Trastuzumab (Herceptin) are monoclonal antibodies with intermediate affinity which recognize the epidermal growth factor (EGF) and HER2/c-neu receptors, respectively. Residualizing radionuclides, such as ^{86,90}Y and ^{177}Lu, are potentially more suitable radionuclides for RIT[2]. The aim of this study was to prepare and evaluate the targeting properties of radioimmunoconjugates formed by ^{177}Lu, ^{86,90}Y-and monoclonal antibodies with intermediate affinity to EGF and HER2/c-neu receptors.

Methods

Nimotuzumab and Trastuzumab were labeled with n.c.a. ^{177}Lu, ^{86,90}Y using p-SCN-Bz-DOTA and p-SCN-Bz-DTPA[3]. Radioimmunoconjugates were characterized by HPLC, SDS-PAGE and flow cytometric assay. In vitro tumor targeting properties of ^{177}Lu, ^{86,90}Y -immunoconjugates were studied in human cancirnoma and normal cultured cell lines with varying EGFR and HER2/c-neu expression levels. Immunoreactive fraction, IC_{50} and Kd were determined. Toxicity of ^{90}Y-h-R3/Herceptin was evaluated in cultured cell lines. Optimization of the tracers was performed in healthy mice. Tumor-targeting properties of ^{177}Lu-h-R3 were evaluated in athymic mice bearing human cancer xenografts with varying EGFRs expression levels. Preliminary dosimetric evaluation was performed using OLINDA/EXM.

Results

Complexation of ^{177}Lu and ^{86,90}Y to h-R3/Herceptin resulted in radiolabeling efficiencies higher than 95% and specific activities up to 1.3 GBq/mg without considerable loss of immunoreactivity (IF > 90 %); suitable for radiopharmacueticals preparation as a kit. In vitro studies showed that the binding of the radioimmunoconjugates was receptor specific and the affinities was similar than those for the unmodified mAbs. ^{90}Y-h-R3/Herceptin increased cell growth inhibition compared to unmodified mAbs or $^{90}YCl3$ alone in cell lines with overexpression of the target antigen, while no significant differences were observed in cell lines with lower expression of the target antigen[4]. In vivo studies performed with ^{177}Lu-hR3 showed significantly higher uptake in A431 (22.8 ± 3.1 %ID/g) than in SNU-C2B (8.8 ± 4.1 %ID/g) xenografts at 72h post injection[5,6]. ^{177}Lu-h-R3 showed strong association between tumor uptake and EGFR expression levels (Fig. 1). Tumor to normal tissue ratio increased markedly with increasing EGFR expression levels. Dosimetric calculations showed that ^{177}Lu-h-R3 will deliver the highest dose into the tumor.

Summary

Antibodies with intermediate affinity, preferentially targeting overexpressing target antigen, labeled with radiometals might offer a potential radiopharmaceuticals for assessing and/or radioimmunotherapy of tumors associated antigens like EGFRs. ^{177}Lu-h-R3 showed potential as a radioimmunotherapeutic for tumors overexpressing EGFR.

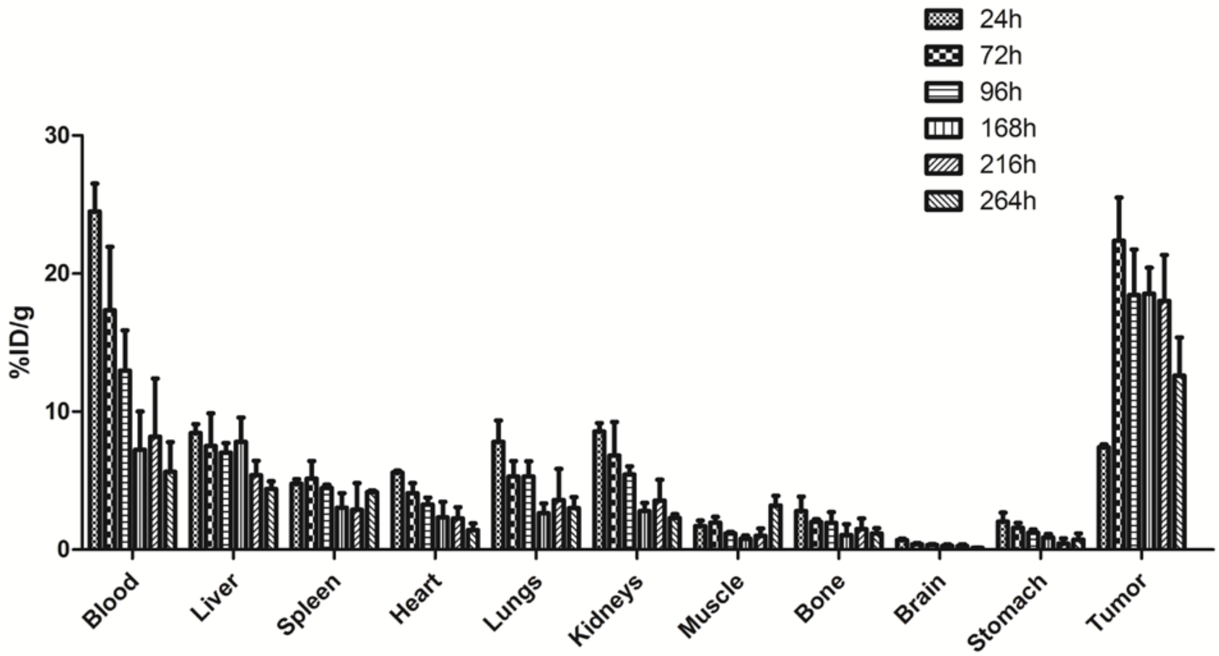

Figure 1. Biodistribution of ^{177}Lu-(DOTA)$_n$-h-R3 (n=4–5) radioimmunoconjugate in tissue/organs collected at different time points from A431 tumor-bearing mice. Values are expressed as mean % injected dose/g (%ID/g) ±SD in groups of three to four animals for each time point.

This work was supported by the Ministry of Education, Youth and Sports of the Czech Republic (EUREKA project no. OE08018 and Project no. NPV II 2B06165).

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Development of a Standard Labeling Test (SLT) for the quality control of ^{68}Ga as a radiopharmaceutical precursor: Influence of metallic cations on the labeling reaction with NOTA

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Introduction Generator-produced ^{68}Ga has attracted increasing interest in labeling of radiopharmaceuticals for use in diagnostic and functional PET imaging. As the determination of all trace impurities including estimation of their acceptable concentrations is nearly impossible, a binding efficiency test seems to be much more predictive for declaring the quality than estimating the admissible limits of individual chemical, in particular metallic impurities. The standard labeling test (SLT) developed by Eigner Henke et al. (2008)[1] for quality control of no-carrier-added radioyttrium was modified. DOTA is a strong coordinating agent for many metallic cations, so the presence of metallic impurities in ^{68}Ga eluted from commercially available ^{68}Ge/^{68}Ga generators can interfere with the labeling reaction. Here, we describe an approach to develop a fast method as part of the quality control of ^{68}Ga produced as a radiopharmaceutical precursor for the labeling of DOTA-conjugated molecules. Since NOTA is the most specific chelator commercially available for the coordination of gallium, the developed SLT is based on the reaction of ^{68}Ga with NOTA.

Methods A commercially available ^{68}Ga generator was eluted including online purification as described previously by Zhernosekov *et al.* in 2007[2]. ^{68}Ga was obtained as ready to use sterile solution in 96% acetone in 0.05M HCl. Samples were prepared by adding different amounts of metallic cations (Zn^{2+} (0.1–1.0 g/L), Fe^{3+} (0.1–1.0 g/L), Ti^{4+} (0.1–1.0 g/L)) to reaction mixtures containing always the same amount of NOTA (0.05 g/L in H_2O) and ^{68}Ga (4 µL, MBq/µL). The reactions were carried out in HEPES 1M, pH=3.4. The reactions were performed by heating the solutions at 98 °C for 20 minutes. The labeling yields were assessed by radio-ITLC.

Results Standard labeling conditions and concentration dependency for NOTA and ^{68}Ga were carried out with a mean labeling yield of 95.3±1.8% over investigated concentration range of NOTA (Fig. 1). The coordination of ^{68}Ga was influenced by all investigated metal cations used. A complete profile of the labeling yields of ^{68}Ga as a function of the concentration of Zn^{2+}, Fe^{3+} and Ti^{4+} cations was obtained. The coordination of ^{68}Ga was dramatically affected by Fe^{3+}. While Ti^{4+} also showed strong competition at high concentrations, Zn^{2+} had nearly no effect on the labeling reaction. Concentrations causing 50% reduction in the labeling yields are 0.85 g/L for Zn^{2+}, 0.4 g/L for Ti^{4+} and 0.08 g/L for Fe^{3+}, respectively. Measured data are displayed in Fig. 2.

Summary The "ionic" ^{68}Ge/^{68}Ga radionuclide generator is not necessarily optimized for the synthesis of ^{68}Ga-labelled radiopharmaceuticals. An important aspect for wide use of ^{68}Ga in clinical PET is its chemical form and concentration after elution from the generator. The most effective method to eliminate the ^{68}Ge-breakthrough and metal cation contaminants from the product was developed by Zhernosekov et al. (2007)[2]. The initially generator eluted ^{68}Ga is pre-concentrated and purified using miniaturized column with organic cation-exchanger.

Much attention is paid to develop and validate the analytical methods for quality control of gallium (^{68}Ga) chloride solution for radiolabelling according to the criteria usual in the European Pharmacopoeia (radionuclidic, radiochemical and chemical purity). Solution of ^{68}Ga meeting such criteria can be used for labelling of chelator-conjugated biomolecules, allowing for kit production and enabling wide availability. Here we present an easy and fast method for detection of metal cation impurities in the generator eluate. Although a differentiation of cationic impurities is not possible using the presented methods, the test can be used for fast and easy evaluation of their overall content with respect to their effect on the labelling.

Conclusion The developed SLT can be used for estimation of metallic impurities and, therefore, be integrated as part of the QC procedure for ^{68}Ga when used as a radiopharmaceutical precursor.

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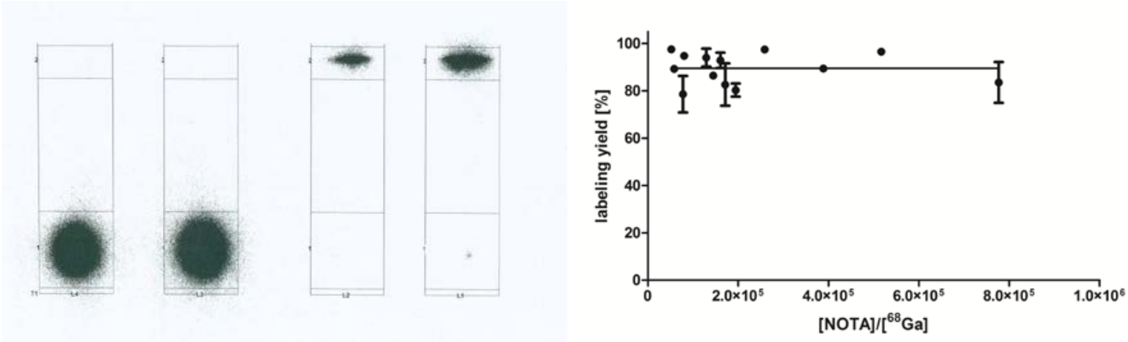

Figure 1. left: ^{68}Ga-NOTA radio ITLC (^{68}Ga: bottom; ^{68}Ga-NOTA: top) and right: dependence of labeling efficiency on NOTA/^{68}Ga ratio.

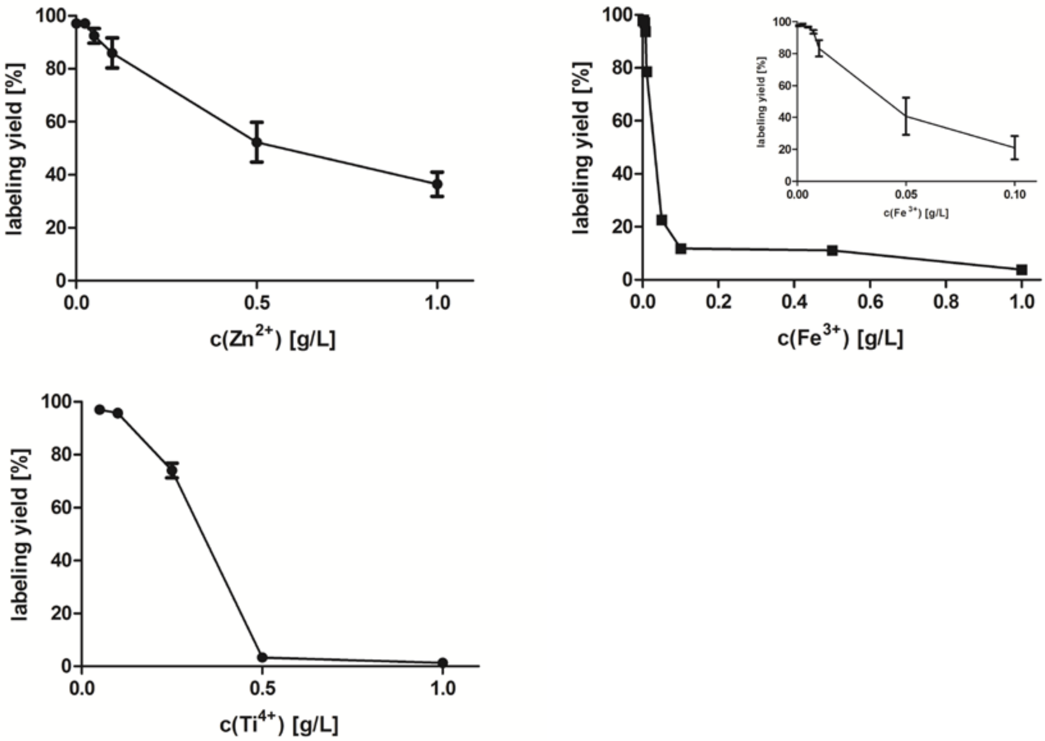

Figure 2. Effect of increasing amounts of Zn^{2+}, Fe^{3+} and Ti^{4+} on the yield of the ^{68}Ga labeling reaction with NOTA under identical conditions.

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Liquid target system for automated preparation of radionuclides

J. RÁLIŠ, O.LEBEDA, J. KUČERA

Many medical radionuclides are produced by irradiation of solid targets on cyclotrons. Handling and processing of those targets have several disadvantages for routine production. There is an interesting alternative to this approach, namely irradiation of a liquid target filled with aqueous solution of salts[2,3]. It makes the target processing significantly easier and allows for automation of the process. We have tested production of two non-conventional PET radionuclides, ^{86}Y and ^{68}Ga.

The main part of target assembly is a water cooled chamber (volume 2.4 ml) made out of pure Nb with Ti or Nb entrance window and remote controlled filling system (Fig. 1,2).

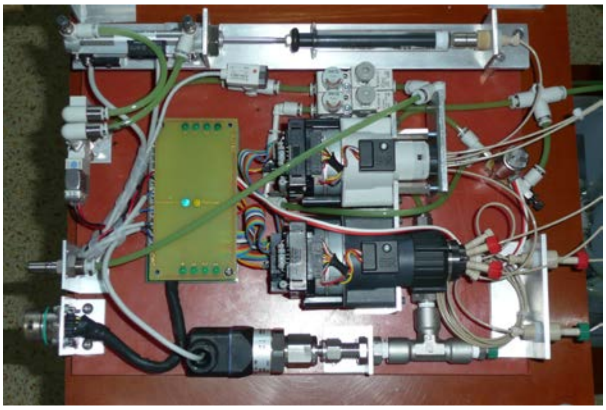

Fig. 1. Filling system.

Fig. 2. Target body.

The concentration of irradiated solution of strontium nitrate (enrichment 96.3% ^{86}Sr) was 35% (w/w). After irradiation, the solution was transferred to the separation unit, and the target was washed with 10 mM nitric acid and water. Both eluates were joined, pH was set to 10, filtered through PVDF filter and washed with 50 ml water. Filtrate was collected for Sr recovery. Yttrium was eluted from the filter with 10 ml 1M HCl. Eluate was evaporated to dryness and re-disolved in 100–300 µl of 0.05M HCl as a stock solution for labelling.

Radionuclidic purity and activity of produced yttrium was measured with γ-ray spectrometry. Content of chemical impurities (Fe, Cu, Zn) was determined via ICP-MS at the Institute of Chemical Technology Prague. We used two alternative methods for determination of the purity of the produced ^{86}Y: differential pulse voltametry and labelling efficiency of DOTATOC. Ca. 40 MBq of ^{86}Y stock solution was mixed with 20 µg of DOTATOC in 300 µl of 0.4 M sodium acetate and heated in for 30 min at 80 °C. The labelling yield was determined using TLC on silica gel plates developed with 10 % NH_4OAc aq. / MeOH = 1:1, $R_f = 0.46$.

Enriched ^{86}Sr was recovered by precipitation of strontium carbonate with ammonium carbonate[1]. The precipitate was decanted with water and acetone. Strontium carbonate was then dissolved in concentrated nitric acid, evaporated to dryness and re-dissolved in water for further use.

The physical yield was 33 MBq/µAh. It corresponds well to the published data[1] and given content of ^{86}Sr in the target matrix. Radionuclide purity was excellent (^{86}Y > 99.4 %, ^{87}Y < 0.55 %, ^{88}Y < 0.025 %). Separation yield was > 90 %.

In the case of ^{68}Ga, the irradiated solution was zinc chloride (enrichment 99.23% ^{68}Zn) with concentration 50% (w/w). After irradiation, the solution was passed through preconditioned Waters C-18 Sep-pak[4]. The column was then washed with 20 ml of water. The gallium was eluted with 2–3 ml of 0.1M HCl. All solutions with enriched zinc were collected together and evaporated to 50% solution for further irradiation.

The 45 minutes irradiation at 10 µA resulted in 3.5 GBq of ^{68}Ga (EOB) and the after the separation, 2.5 GBq (decay corrected) were available in the final product. Labelling efficiency determined with analogous DOTA labelling test as in the case of ^{86}Y seems to be high enough for the labelling purposes. The radionuclidic impurities detected in the product (^{66}Ga, ^{67}Ga) were at the acceptable levels, too ($< 10^{-2}$ % at the EOB).

Solution targets are interesting alternative for production of several highly interesting non-conventional PET emitters or other medically relevant radionuclides. Transport of irradiated target matrix via a capillary to a separation unit minimizes problematic handling of radioactive material and losses of expensive enriched material. It also reduces significantly personnel radiation burden.

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Thermoresponsive polymeric radionuclide delivery system

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Recently, we suggested an alternative to surgically applied brachytherapy: thermoresponsive polymer labeled with a therapeutic radionuclide [1]. Thermoresponsive polymers are well soluble in water, but as the temperature increses, they get precipitated in a very narrow temperature range as the energy of hydrophobic interactions between their molecules prevails the energy of hydrophobic interactions with water. Local delivery of high radiation dose to a malignant tissue by injection of such a radiolabeled polymer can be achieved by setting the precipitation temperature a few degrees below the body temperature, ensuring good retention of the polymer in the site of aplication and efficient excretion complying with the half-life of the therapeutic radionuclide.

Biodistribution study of the ^{131}I-labeled thermoresponsive polymer [poly(N-isopropyl acrylamide)] confirmed both high retention of the polymer in the application site and also suggested that the polymer slowly dissolves and is predominantly excreted via urine and faeces [1]. The results encouraged us to test tumor growth reduction on murine xenograft model (PC3 human prostate adenocarcinoma) using a single injection of the labeled thermoresponsive polymer [2]. We used two activities for application: 2 MBq/mouse and 25 MBq/mouse. The latter resulted in gradual tumor volume reduction and 2 of 6 mice from this group were cured. The former caused only tumor growth retardation. In both cases, no signs of inflammation were observed. Statistical significance of both doses' effect compared to untreated controls was demonstrated (cf. Fig. 1–2).

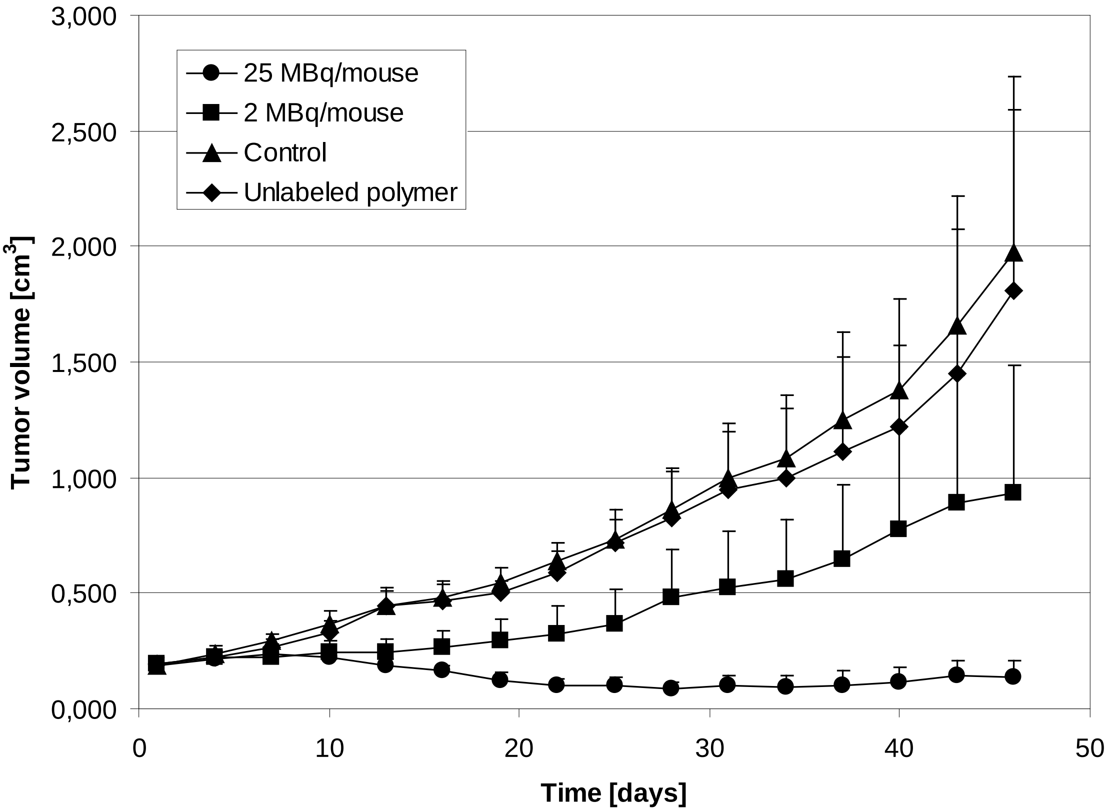

Fig. 1 Tumor volume as a function of time after application of the radiolabeled polymer (n = 6)

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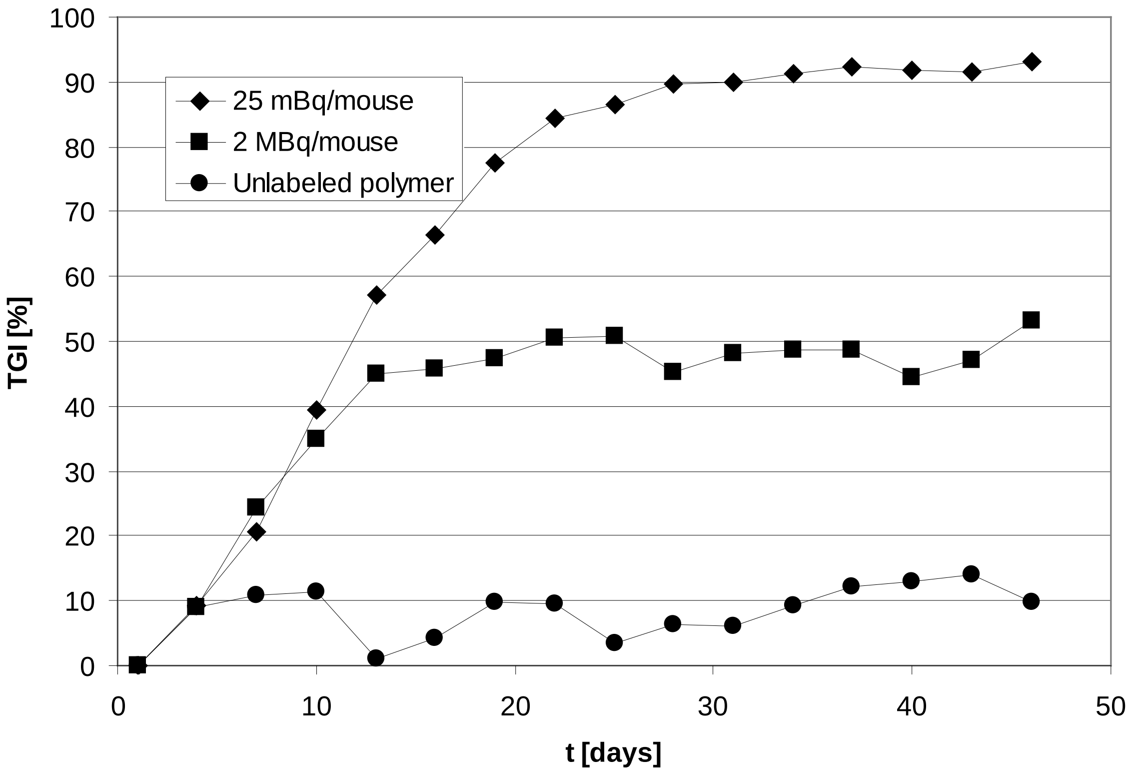

Fig. 2. Tumor growth inhibition (TGI) as a function of time

This injectable system is a sort of brachytherapy that makes administration easier and less invasive (injection vs implantation), patient-tailored (easy distribution of a dose into several places) and the labeled compound is non-immunogenic and easily excreted after the radionuclide's decay. It might be an interesting clinical approach in the case of well-localized tumors that cannot be easily accessible by surgery [2].

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Radiation Dosimetry

The activities of the Department of Radiation Dosimetry (DRD) in 2009–2010 concerned the basic and applied research in dosimetry and microdosimetry of ionising radiation, namely studies related to the applications of these methods in radiation protection and radiotherapy, radioecology and radiocarbon dating.

Long-term studies of anthropogenic influences on the environment have continued. These studies are focused on determination of some radionuclides with semiartificial/artificial origin, particularly ^{14}C. In the last century nuclear weapon tests were important sources of anthropogenic ^{14}C. After the nuclear moratorium on the atmospheric nuclear bomb tests, the ^{14}C concentration in the atmosphere has been decreasing due to an intensive transfer into oceanic and terrestrial carbon sinks. Actual type of the anthropogenic influence on activity of atmospheric $^{14}CO_2$ is characterized by the Suess effect, which can be observed on local, regional, and global scale. This effect causes a decrease of $^{14}CO_2$ activity as a result of diluting by CO_2 released from fossil fuel combustion. Monitoring of atmospheric $^{14}CO_2$ in several localities, and comparison with results abroad, gives a tool to quantify fossil carbon occurrence from local and regional sources, estimate actual amount of $^{14}CO_2$ in the atmosphere (as a tracer of atmospheric CO_2), and also specify actual ^{14}C activity level more precisely.

The main topic of fundamental research represents radiation damage to specific DNA-protein complexes. Theoretical model RADAMOL based on Monte Carlo technique allows simulation of direct and indirect radiation damage to biological target represented by its atomistic conformation. The calculations provide the assessment of sequence-, structure- and ligand-dependent modulation of damages within DNA (strand breaks and base damages), proteins (peptide chain breaks and modified amino-acid side chains) and their complexes. Recently, experimental techniques of molecular biology have been established in the laboratory in order to extend potentiality of radiobiology studies. Experimental studies combined with theoretical modeling have been applied for instance to DNA-protein complexes involved in the regulation of gene expression (DNA *lac* operator – *lac* repressor), in the hormone signal transduction (DNA estrogen response element – estrogen receptor), or in the repair of oxidative lesions of DNA (DNA bearing analog of abasic site – formamidopyrimidine glycosylase). Other studies have been focused to function of restriction enzymes under irradiation and/or DNA damage induced by nanosecond XUV-laser and soft-X-ray pulsed radiation.

Biological effects of the ionizing radiation depend both on the radiation quantity (absorbed dose) and the radiation quality (space and time distributions on the microscopic level). The radiation quality is the most commonly characterized by the physical quantity linear energy transfer (LET) (ICRU, 1970). Determining of radiation quality requires measuring the whole spectra of LET, in particular for complex radiation fields. Such environment can be found namely on board aircraft and spacecraft (mainly International Space Station – ISS), in high-energy charged ion therapy beams, and around high-energy particle accelerators. To improve the LET spectrometry methodology, studies in heavy high-energy charged particle beams are fruitful. LET spectrometry studies of primary ion fragmentation and related health risk of secondary particles have been performed at heavy ion accelerator HIMAC at NIRS, Chiba, Japan. Methodical studies concerning the development and use of track etched detectors have been focused mainly to detector responses at nm-scale, to long-term response sensitivity and stability and to uncertainty budget.

Selected research topics are presented further more in detail. Applied studies in 2009–2010 have been realized mostly in these directions:

1. The reference standard laboratory of the DRD has calibrated and/or or re-calibrated 44 reference dosimetry systems of Czech radiotherapy centres in air-kerma and/or in absorbed dose in water.
2. Important effort was devoted to the development and application of methods used to estimate environmental radiation, particularly liquid scintillation spectrometry and its use to determine radionuclides like T, ^{14}C, ^{89}Sr, ^{90}Sr, and ^{90}Y. Methods were applied mostly in and around nuclear power plants Temelín a Dukovany.
3. The DRD has continued to perform individual dosimetry of aircraft crew members of Czech companies. The number of monitored aircrew in 2009 and 2010 was 2111 and 2047 respectively; 1656 resp. 1535 of them received annual effective dose higher than 1 mSv. The mean and

maximum annual effective dose of aircraft crews were 1.8 mSv and 3.9 mSv in 2009 and 1.6 and 3.3 in 2010.

Radiation exposure of aircraft and spacecraft crews evaluated with semiconductor detector Liulin

O. Ploc, F. Spurný†, A. Malušek, I. Kovář, T. Dachev, J. Kubančák

Dosimetry onboard aircrafts and spacecrafts is complicated by the presence of neutrons and heavy ions. Exposure levels among air crew regularly exceed the occupational limit of 1 mSv per year and, in case of solar flares, exposures of spacecraft crews may be even lethal. The development and validation of corresponding dosimetry methods is thus of great importance. A promising option is the deployment of active detectors like silicon energy deposition spectrometer Liulin [1] whose electronics can store information about energy deposition spectra obtained in pre-defined time intervals during long-term measurements.

Since 2001, a simple method employing the energy deposition spectra had been used to determine the ambient dose equivalent *H*(10)* onboard aircrafts [2]. Later, in 2004, it became clear that the resulting values were strongly biased at locations close to Earth's equator. An improved method has been developed taking into account the composition of the radiation field via the ratio of absorbed doses D_{low} and D_{neut} reflecting the contributions from particles with low linear energy transfer (LET) and neutrons, respectively [3]. The good agreement between the measured data and data calculated with computer code EPCARD was observed. This method was validated by comparing values of *H*(10)* with data measured with the tissue equivalent proportional counter HAWK which is often used as a reference detector for measurements onboard aircrafts [4].

Long term measurements onboard aircrafts [5] performed with Liulin during the decreasing phase of the 23^{rd} solar cycle showed a 21% increase of *H*(10)* rate from 4.8 µSv/h during solar maximum to 5.8 µSv/h during solar minimum. Further, an important solar particle event GLE60 was observed on April 2001 during which *H*(10)* rate temporarily increased almost three times compared with normal conditions [6].

The Liulin detector was used to verify the standard method of aircrew radiation monitoring in the Czech Republic. The routine calculation of effective doses using computer code CARI has been performed since 1998. It was found that average annual effective doses in the period from 1998 to 2008 were in the range from 1.2 to 2.0 mSv and followed the trend of solar cycle. Annual collective effective doses increased from 1.4 manSv in 1998 to 4.1 manSv in 2008 as the number of aircrew increased from 857 to 2158 [7].

Liulin was also placed on board the International Space Station, ISS (May–August 2001 and January–June 2009) and the Foton M satellites (June 2005 and September 2007). In contrast to aircrafts, more complicated methods to evaluate dose equivalent had to be used in this case because of different properties of galactic cosmic rays (GCR), South Atlantic anomaly (SAA) and outer radiation belt (ORB) [4]. In case of the ISS, resulting values of dose equivalent rate were for GCR: 0.24 mSv/d, and for SAA: 0.10 mSv/d. They were compared with other measurements on board ISS. Generally good agreement was observed for the SAA area. GCR values measured with Liulin were systematically lower because Liulin's LET spectrometry is limited to 30 keV/µm. Other dosimetry methods should be used for the higher LET region which partially corresponds to heavy ions.

The work has been supported by the Grant Agency of the Czech Republic (grant No. 205/09/0171) and Grant Agency of the Academy of Sciences (grant No. KJB100480901). All experiments were performed in cooperation with the Czech Airlines j.s.c. and the Bulgarian Academy of Sciences.

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Radiation monitoring onboard spacecraft by means of passive detectors

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During the flights, astronauts are exposed to cosmic radiation, which represents an important health risk, particularly during long-term missions. In order to secure the safety of the astronauts and minimize their risks, it is important to evaluate the impact of space radiation on human health and to determine the exposure level as accurately as possible.

Since 2005, we have been participating in Matroshka-R experiment, led by the Institute of Biomedical Problems of the Russian Academy of Sciences. The purpose of this experiment is to study the radiation environment inside the compartments of the International Space Station (ISS) and the dose accumulation in the spherical phantom, mounted inside the station, in order to improve the methods of space dosimetry and radiation hazard assessment.

For the measurements of linear energy transfer spectra, absorbed dose, and dose equivalent we have used a combination of luminescence and plastic nuclear track detectors, which is very suitable and often used onboard spacecraft. The detectors were placed at different positions in the Russian Service Module and in the Piers-1 Module (in so called SPD boxes), on and inside the tissue-equivalent spherical phantom [1–4].

The amount of the acquired results enabled us to study variation of dosimetric quantities with the phase of solar cycle, occupation mode and time, and position inside the ISS [3–5]. The data accumulated in these studies bring additional information on individual monitoring of spacecraft crew members and help to estimate their radiation risk.

To determine the dosimetric characteristics in complex fields such as onboard spacecraft properly, the calibration of detectors in known reference fields that are as similar as possible to the real ones is necessary. During recent years, several ground based experiments were realized with the goal to investigate detector responses to various heavy ions and neutrons with a wide range of energies [4, 6–8] and to improve the methods used for estimation of exposure level onboard spacecraft.

This work has been supported by the Grant Agency of the Czech Republic (grant No. 205/09/0171), Grant Agency of the Academy of Sciences (grant No. KJB100480901) and by bilateral scientific cooperation agreement of the Academy of Sciences of the Czech Republic and the Russian Academy of Sciences.

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Theoretical prediction of radiation damage to DNA-protein complexes

M. DAVÍDKOVÁ, V. ŠTĚPÁN

All functions of DNA in living cells depend on interactions with proteins. These interactions can be either non-specific, or the protein can bind specifically to a single DNA sequence. Detailed understanding of the effect of ionizing radiation on DNA interaction with proteins is important in order to correctly assess radiation toxicity for the whole cell.

When a supramolecular target is irradiated by low LET radiation in oxygenated solution, the most important contributors to target damage are sparsely produced hydroxyl (OH·) radicals produced by water radiolysis. In case of high LET radiation the contribution of indirect effect to target damage is reduced due to higher recombination and reaction probability of the water radiolysis products.

An original model of simulation of radiolytic attack based on the Monte Carlo technique, RADACK model, allows calculating the relative probability of OH· radical reactions with DNA nucleotides and protein amino-acids. The model takes into account not only the accessibility of attack sites, but also the chemical reactivity of deoxyribose, particular bases, and amino-acids [1–3]. As an example, the probabilities of OH· radical attack to DNA deoxyriboses and bases predicted for *lac* operator DNA with bound *lac* repressor protein and free DNA are presented in Figure 1. The corresponding predictions for irradiated free lactose repressor headpiece and in the complex with DNA are summarized in Figure 2 [4–7].

With development of hadrontherapy and space expedition projects, concerns about biological effects of high LET charged particles are increasing. As compared to gamma radiation, ion beams induce complex and clustered damage more frequently [8]. This fact can influence many parameters of cellular response to irradiation and cell survival. Formation of multiple complex lesions after ion beam irradiation may increase the proportion of non-repairable damages, which is beneficial for tumor radiotherapy. However, the risk of repair errors may also increase, which comprises the risk of formation of cancerogenous DNA mutations and chromosomal aberrations in normal healthy tissues.

Theoretical model RADAMOL, an extension of RADACK model, has been developed to simulate direct and indirect radiation damage to a biological target. Time-space evolution of charged particle tracks is followed from initial energy deposition by charged particle in water up to the end of chemical stage with non-homogeneous distribution of radical species (10^{-6} s). Direct ionizations of DNA or surrounding bound water molecules lead to electron and hole generation followed by charge migration and localization in DNA. Indirect damage comprises lesions formed by chemical reactions of deoxyribose, nucleobases and amino-acids with OH·, e_{aq}^{-} and H· radical species. The complete spectrum of simple and complex damages can be obtained if the molecular structure of the target is known [9].

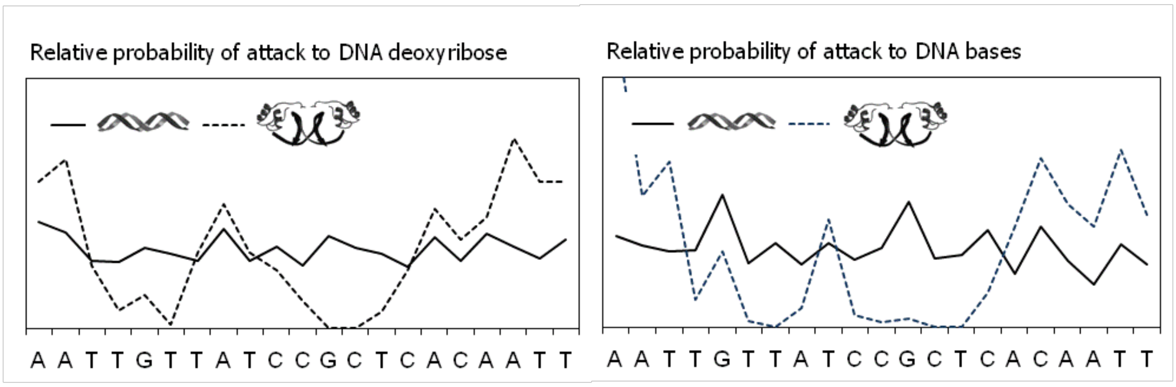

Fig. 1 – Calculated relative probabilities of reaction of OH· radicals with the DNA bearing *lac* operator base sequence along the free irradiated DNA (full line) and along the DNA irradiated in complex with *lac* repressor (structure extracted from 1CJG entry from PDB Databank) (dashed line).

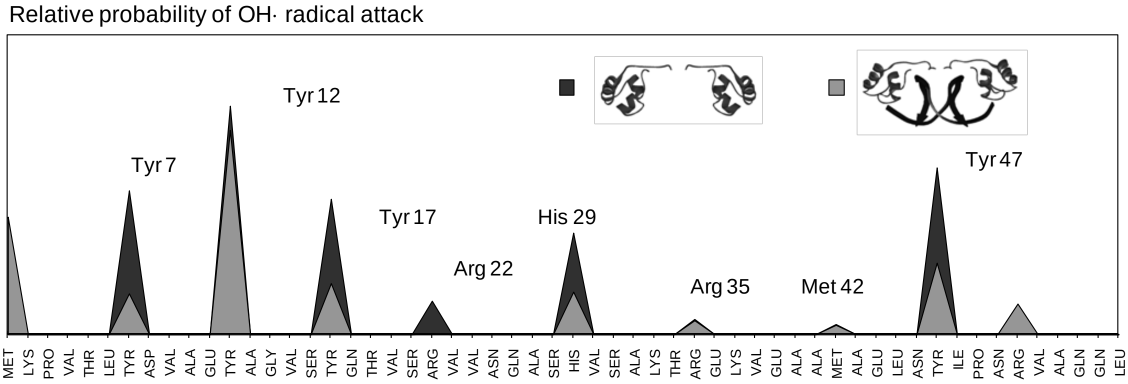

Fig. 2 – Calculated relative probabilities of reaction of OH· radicals with the amino-acids of lactose repressor headpiece along the free irradiated headpiece (structure extracted from 1LQC entry from PDB Databank) (black) and along the headpiece irradiated in complex with DNA (structure extracted from 1CJG entry from PDB Databank) (grey).

Performed theoretical simulations allow to observe and to explain at a large extent the variations of radiation-induced damage yields and distribution in free DNA and in DNA involved in supramolecular complexes. This approach emphasizes for the first time the critical role of structural parameters of DNA and its complexes with small and large molecules in the induction of radiation-induced DNA damage.

This work was partially supported by the Grant Agency of the Academy of Sciences (grants No. A1048103, KJB4048401), by the Ministry of Education, Youth and Sports of the Czech Republic (grants No. 1P05OC085, OC09012) and bilateral French-Czech programs (CNRS-ASCR, Barrande-Egide) and the European actions COST P9 and CM0603. Theoretical calculations were performed using the MetaCentrum computing facilities provided under the program "Projects of Large Infrastructure for Research, Development, and Innovations" LM2010005 funded by the Ministry of Education, Youth, and Sports of the Czech Republic.

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Applications and quality assurance of ^{14}C determination method

I. SVĚTLÍK, D. DRESLEROVÁ[1], L. TOMÁŠKOVÁ

Exact determination of ^{14}C activity can provide important information for several various applications.

(1) Nowadays, the influence of fossil fuel combustion on climatic changes is frequently discussed. Fossil carbon does not contain ^{14}C and causes dilution of radiocarbon in carbon isotopic mixture of atmospheric CO_2. In consequence, monitoring of atmospheric $^{14}CO_2$ can precise parameters related to the transport of atmospheric CO_2. Realistic parameters in prediction models can avoid economy problems ensuing from overestimation or underestimation of fossil fuel combustion impact [1–4].

(2) Radiocarbon makes a major contribution to the collective effective dose from all radionuclides released by nuclear power plants (NPP) with light-water pressurized reactors during normal operation. Hence, monitoring of ^{14}C in the NPPs surrounding and in the reference areas is essential [5].

(3) Radiocarbon dating is an important tool, namely for archaeological, geological, and paleoenvironmental studies. This challenging application also provides an excellent tool for validation of analytical routines utilized in ^{14}C determination [6–8].

Table 1. Comparison of our results with available data from other dating laboratories (bold). Ordering side: Dr. I. Boháčová, AI Prague AS CR, wood samples from flood sediments, Stará Boleslav.

Lab. Code	Sample description	Conventional radiocarbon age, years BP	Calibrated age, main interval, years BC, AD	P^{**}, %
10 010	5-R8330_VS_1370	408 ± 73	**1410–1645 AD (after 1376 AD)***	95
10 012	21-R9053 N1540-60	440 ± 74	**1393–1642 AD (1549–1563 AD)**	92
10 014	38-R9119-Px	**2710 ± 76 (Poz: 2710 ± 40)**	1055–763 BC	95
10 018	6-R8331_VS_1379	488 ± 73	**1298–1523 AD (after 1379 AD)***	87
10 019	22-R9054 N1545-61	498 ± 73	**1293–1521 AD (1545–1561 AD)**	90

* *Tree trunk without bark part*

** *Absolute probability of reported interval of calibrated age*

Table 2. Comparison of our results with available data from dendrochronoly dating (bold). Ordering side: Dr. K. Žák, GI AS CR.

Lab. code	Sample description	Conventional radiocarbon age, years BP	Calibrated age, main interval, years AD	P, %
10 002	Beroun, oak trunk in the vicinity of Berounka river	695 ± 74	**1207–1413 (1363–1364 AD)**	95

All reported applications of ^{14}C activity determination have considerable requirements on the uncertainty of the analytical method used (typical ^{14}C activities in environmental samples are in the range from 0.1 to 0.25 Bq of ^{14}C per gram of carbon isotopic mixture, and the resulting uncertainties of determination of only several per mil are usually necessary). Since 2002 our laboratory performs exact ^{14}C activity determination based on benzene synthesis and liquid scintillation measurement utilizing Quantulus 1220. Systematic monitoring of atmospheric $^{14}CO_2$ and sampling of biota in the vicinity of nuclear power plants Temelín and Dukovany were launched in the same year. In the year

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2005, routines of sample pretreatment and isolation of carbon chemical forms were implemented for radiocarbon dating purposes. Consequently, ^{14}C dating in the collaboration with the Archaeological Institute ASCR is performed in our laboratory with assigned international code CRL. Sample preparation routines were gradually modified to reduce uncertainties of determination, economy costs, and effectiveness of sample processing. Contemporaneously with routine modifications, control analyses based on repeated dating of previous samples were performed, if sufficient quantity of such material was available. Another very valuable component of our QC/QA is the possibility of results comparison with other dating laboratories, as shown in Tables 1, 2. Dating of these wood samples was performed in our laboratory at the beginning of 2010 [9–10]. After submission of our results, we received from the ordering side data for comparison (in Tables 1, 2 reported in brackets). Prevailing part of these data are results from the dendrochronology dating from the DendroLab Brno and intervals of the calibrated age are compared with the year when the tree was chopped down. Relatively old sample (No. 10 014) of oak wood was concurrently processed in the Poznaň Radiocarbon Laboratory, with international code Poz, by Accelerator Mass Spectrometry (values of conventional radiocarbon age are compared at this case).

As evident from both Tables, our dating results are in a good agreement with the control data from other laboratories and even with the other dating method. Likewise, radiocarbon dating assures a crucial instrument of QA/QC also for other applications based on precise ^{14}C determination.

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Cyclic Accelerators

1. Isochronous cyclotron U-120M

Isochronous cyclotron U-120M is operated in the Department of accelerators. In the period 2009–2010 as in previous years, the main objective was to maintain reliable and trouble-free operation of the accelerator and upgrade selected cyclotron sub-systems. In this period several new cooperations with national and foreign laboratories have been established and resulted in joint research projects.

Cyclotron upgrade

RF system
A new coupling loop of the RF generator was redesigned and manufactured. After completion it was successfully tested and installed on the cyclotron.
An old input amplifier of the RF generator cascade was replaced by the new one which was purchased from commercial supplier. For this installation the design and realization of new duty cycle generator and matching of input circuits was necessary. Operation of RF generator is now much more stable.

Diagnostics
Design and construction of a new integral probe (no. 3) of the cyclotron for diagnostics and measurement of internal accelerated beams was realized and completed. The new design enables also the irradiation of the solid targets including rotating ones on internal beams where the beam intensities can reach hundreds of μA and incident energy can be changed within the full energy range for each particle. This system will be mainly used for irradiation of targets with the ^{3}He a ^{4}He beams.

Technological subsystems
The following technological subsystems were newly designed and assembled:

- a new distribution system of pressurized air in the cyclotron hall including control
- a new distribution of de-ionized cooling water in the cyclotron hall including control
- a new system for measuring of temperature and flow of cooling water and cooling He
- a design and implementation heavy-current switchboards for cyclotron technology and electric power distribution of the cyclotron building

Experimental stend for testing of cyclotron ion sources
On the experimental stend for development and optimization of ion sources with cold cathode for the cyclotron a series works were realized:

- a commissioning of the vacuum system
- a design and implementation of high-voltage platform which allows electrical insulation of ion source and its location on high voltage (HV) potential
- a design and implementation of communication and control of ion source power supply located on HV potential

Collaborations and new projects

In collaboration with the Institute of Organic Chemistry and Biochemistry AS CR p.r.i. preparation of fluorescent nanodiamonds (FNDs) started in 2009. FNDs are a new nanomaterial which exhibits fluorescent properties when irradiated by laser of particular wavelength. The FNDs have excellent photostability and biocompatibility and facile surface functionalizability. They are suitable for non-invasive investigations and imaging at the cellular level. The FNDs are formed by irradiation of nanodiamond powder (grain size 30 – 150 nm) with accelerated ions or electrons. Series of irradiations with the ions available on the cyclotron U-120M and electrons of microtron MT25 were accomplished. For these purposes various types of cyclotron target holders were modified and tested. The project will continue in 2011, when we expect publication of results. Preparation of FNDs at NPI has also a vital contribution to DINAMO project (Development of diamond Intracellular NAnoprobes for oncogene transformation dynamics in living cells MOnitoring), which is funded and supported under the FP7 project.

In collaboration with the Institute of Experimental and Applied Research of CTU and Laboratory of Fast Neutrons of NPI parameters of special neutron sensitive devices (MediPix) for future scientific needs of the European Space Agency (ESA) were tested with fast neutrons. The project will continue in 2011.

In cooperation with the Technical University of Dresden (Institute for Nuclear and Particle Physics) and Department of Radiopharmaceuticals of NPI irradiations of samples of natural Nd with proton beams were carried out. The goal was to measure excitation function of natural Nd leading to the production of isotopes of Pm and Pr. Study of production of these isotopes is important for the SNO + (Sudbury Neutrino Observatory Plus scintillator) experiment having among other objectives a study of neutrinoless double beta decay. Excitation functions of Nd were measured for the first time in the world. Work will continue in 2011 when the results will be published.

For FLNR JINR in Dubna several variants of magnetic field measurements of the cyclotron DC60 (Astana, Kazakhstan) were evaluated and analyzed as well as the detailed mathematical simulations of ion acceleration in real magnetic field.

For Max Planck Institute in Munich first irradiation tests and preparation work including realization of 6 m long rotational mechanical arm for cable tray of electronic detection system (Liquid Argon Hadronic End-cap calorimeter - ATLAS HEC) were realized. Irradiation by fast neutrons on the cyclotron is planned for 2011.

Mathematical simulations

In order to reduce radial and vertical losses of accelerated beams on the first orbits, the influence of geometric dimensions of the cyclotron ion source and extraction puller electrode were studied in details. Optimal variant of central geometry which resulted in minimalization of axial beam divergence after injection and catching into acceleration was found out.

Influence of various cyclotron parameters and ion source extraction slit dimensions on the energy spread of accelerated and extracted H^- , D^- beams were studied as well.

Software for analysis of magnetic field and mathematical simulations of beam acceleration and extraction for general cyclotron with a given magnetic field structure and the accelerating RF field was completed.

New radionuclides production, target technology

Within the frame of cooperation with ITU Karlsruhe Germany, production of radionuclide ^{230}U via reaction ^{232}Th(p,3n)^{230}U was tested on the cyclotron for the first time. A new target holder for irradiation of a thick target was successfully completed and tested with a beam of 700 W power dissipation on the dummy Al target capsule. Irradiation of encapsulated metal disc of ^{232}Th caused deformation and finally damage of the capsule during irradiation process. This effect is being examined. Project will continue in 2011.

2. Microtron MT-25

Microtron MT–25 is operated at the Microtron laboratory which is a detached part of the Department of Accelerators. The main microtron upgrade was accomplished by replacement of extraction beam channel. An old beam extractor was replaced by the new one which was designed and constructed at the Microtron laboratory. The new beam extractor was equipped with new stepping motors for accurate adjustment. The full automation of the microtron continued doing simulation of fuzzy regulators for increase beam current stability. The more sophisticated mathematical model of the microtron was designed for testing some parameters of accelerating resonators and for the setting up the new accelerator control system.

The microtron served as a source of relativistic electrons (primary electron beam), secondary photon beam (bremsstrahlung) and neutrons from gamma-n or gamma fission processes. In the years 2009-2010, electron beams was used for radiation netting, radiation polymerization, irradiation of biological samples, testing new type of the pixel detector Medipix and for production of NV colour centres in nanodiamonds. Photon beams served mainly for the instrumental photon activation analysis of geological samples and for the determination of fluorine in selected reference materials. Sensors and detectors were tested and calibrated in neutron fields in the frame of ESA Project.

The microtron beam parameters.

Electron beam (primary)	
Energy range	6 – 25 MeV
Mean electron current	max. 25 μA
Pulse length	3,5 μs
Repetition rate	423 Hz
Photon beam (secondary)	
Energy range	continuous spectrum up to primary electron energy
Dose rate	d = 1m, approx. 10 $Gy.min^{-1}.\mu A^{-1}$
Neutron beam (secondary)	
Yields – Pb target	d = 75 cm, 4π , Y = $1,5 \cdot 10^{11}$ $n \cdot s^{-1} \mu A^{-1}$
Yields – U target	d = 75 cm, 4π , Y = $3 \cdot 10^{11}$ $n \cdot s^{-1} \mu A^{-1}$

Utilization of the cyclotron U-120M

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Cyclotron beam time distribution according to the different means of utilisation is shown in the following Table 1. The diagram of the cyclotron operational hours during the period 2007 - 2010 is in the Figure1.

The decrease of the total beam time in 2010 was caused mainly by the drop in ^{18}F – FDG production for commercial customer.

Table 1: Cyclotron beam time statistics

year:	2009	2010
Beam to experiments [hours]:		
Astrophysics, nuclear reactions	668	775
Fast neutron generation, ADS, fusion	282	213
^{18}F – FDG production	1816	1159
^{18}F new compounds	42	11
^{18}F gas target	0	36
^{81}Rb /^{81m}Kr generator production	332	359
^{83}Rb production	13	13
^{123}I production	7	14
^{124}I, ^{86}Y, ^{99m}Tc test production	74	63
Production of fluorescent nanodiamonds	8	78
^{nat}Nd – excitation function measurements	–	16
Beam diagnostics, regime preparation	188	79
Total beam time [hours]	**3 463**	**2 828**

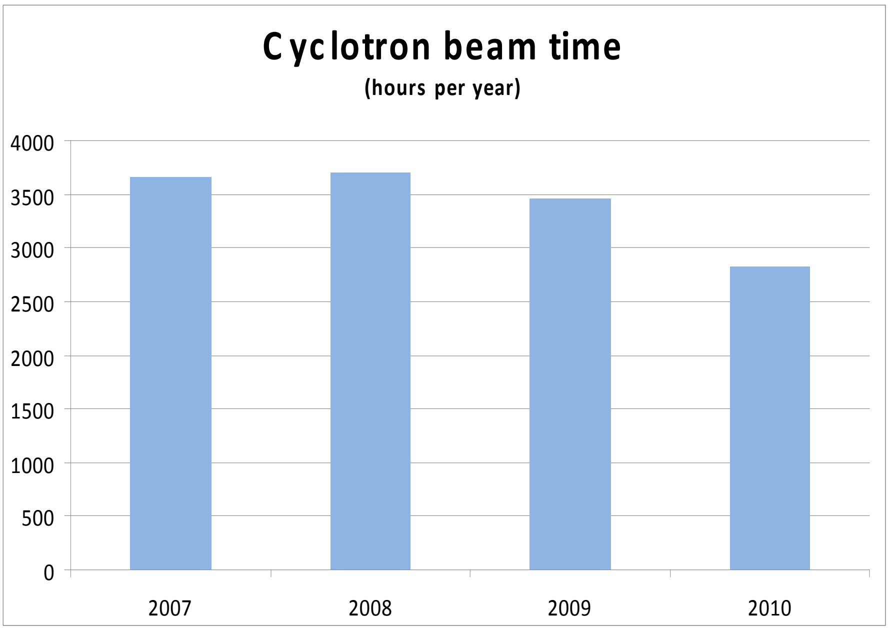

Fig. 1: Cyclotron beam time in the period 2007 – 2010

Ionization energy loss of fast electrons in silicon

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Direct determination of energy loss rate (or stopping power) of charged particles deposited across short distances is valuable for many tasks in radiation detection and nuclear and high energy particle physics as well as radiation physics and applications in biology and material sciences. Tasks include studies of interaction of radiation in matter for e.g. charge transport in semiconductors [1], microdosimetry [2], particle channeling [3] and nuclear beta decay spectroscopy. Additionally, models of electron energy loss [4] as well as adopted values and computer simulations [5] require validation by experiment.

In this work we present the direct measurement of energy loss and on–line observation of passage of fast electrons with discrete energies selected in the range 7–21 MeV across small volumes in silicon which is a widely used material in radiation detectors and electronics components. We make use of the high granularity quantum counting hybrid pixel detectors with highly integrated electronics [6] of which the Timepix device [7] provide in addition energy sensitivity per pixel. This device stands as a high resolution ΔE/Δx probe for sequential sampling of energy loss rate in path lengths ranging from the pixel pitch size (55 μm) up to the full sensor size (14 mm) by suitable choice of the incidence angle of the beam onto the detector plane.

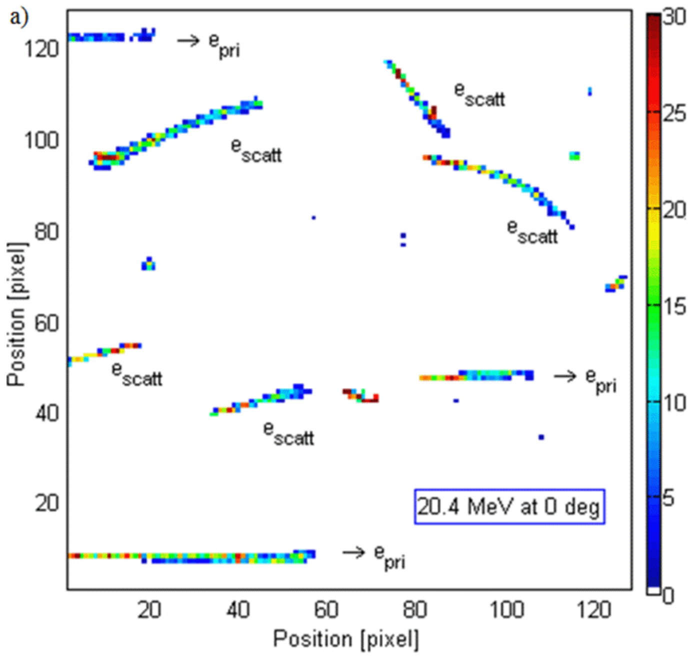

Figure 1. Detection of individual relativistic electrons with energy 20.4 MeV at 0 by Timepix in TOT mode. The beam was incident from left. The energy measured per pixel is given by the vertical bar shown in color in keV. Data frames collected in 10 ms. Only a quarter (128×128 pixels) of the full sensor area is shown.

The energy loss and straggling of electrons in the 7–21 MeV range in silicon have been determined at pixel-scale path lengths. This direct and online method can be applied with variable sampling path length ranging from the detector pixel size 55 μm up to a few mm and in principle up to the whole sensor size 14 mm. Measured values for ΔE/Δx are given for selected energies (7.8, 12.4 and 20.4 MeV) at two sampling paths (55 and 300 μm). Model and numerical

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calculations agree with the measured values which exhibit broad Landau fluctuations which are satisfactorily fitted by an approximate function. Thanks to the resolution and sensitivity of the detector, the small differences of the most probable stopping powers for electrons of different (but close) energies are resolved. Similarly, the small changes in the straggling distributions are registered too.

Electron energy [MeV]	Data	ΔE [keV]	
		Δx = 55 μm	Δx = 300 μm
7.8	Experiment	18.4 (16.5)	89.3 (57.9)
	Bethe-Bloch	19.3	105
	ESTAR	25	134
	MCNPX	21.3	116.1
	Gann et. al.	22.2	122.2
	Kovalev	20.5	111.8
12.4	Experiment	17.9 (15.0)	89.8 (64.7)
	Bethe-Bloch	20.7	113
	ESTAR	27	148
	MCNPX	21.9	119.4
	Gann et. al.	24.0	131.9
	Kovalev	21.1	115.2
20.4	Experiment	17.3 (14.6)	94.9 (47.7)
	Bethe-Bloch	21.8	119
	ESTAR	32	174
	MCNPX	22.6	123.2
	Gann et. al.	27.4	150
	Kovalev	21.8	118.8

Table 1: Measured values of ΔE/Δx for electrons at 7.8 MeV, 12.4 MeV and 20.4 MeV in silicon at 55 μm and 300 μm. Experimental results are given with the full width at half maximum (fwhm) predictions of Bethe-Bloch formula, Monte-Carlo mcnpx simulations and estar database are included. For comparison are included also data for 3 MeV electrons [8] as well as interpolated data [9].

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Publications in 2009

Only the first and the NPI authors are given for the papers of large collaborations.

I. Journal papers

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III. Preprints and Reports

1. **Kovář, I.; Malušek, A.; Orčíková, H.; Spurný, F.** *Vyhodnocení úrovně ozáření posádek letadel společnosti ABS JETS, a.s. za rok 2008*. Praha, *2009*. 3 p. (Výzkumná zpráva ODZ *ÚJF* AV ČR 605/09).
2. **Kovář, I.; Malušek, A.; Orčíková, H.; Spurný, F.** *Vyhodnocení úrovně ozáření posádek letadel společnosti ČSA a.s. za rok 2008*. Praha, *2009*. 10 p. (Výzkumná zpráva ODZ *ÚJF* AV ČR 606/09).
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IV. Popular papers, editorials and other articles without original results

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III. Proceedings contributions (abstracts not included)

1. **Brabcová, K.**; **Vlček, B.**; Molokanov, A. G.; **Spurný, F.**; **Jadrníčková, I.** LPE-spektrometrija pučka ionov 12C. In *Sbornik materialov*. Moskva, *2010*. P. 22-24. [Evrazijskij kongress po medicinskoj fizike i inženerii /3./ "Medicinskaja fizika - *2010*". 21.06.*2010*-25.06.*2010*, Moskva, RU].
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IV. Preprints and Reports

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V. Popular papers, editorials and other articles without original results

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   Srážky atomových jader olova produkují kvark-gluonové plazma. 2.12.2010.
   Rok 2010 – zlomový pro rychlé jaderné reaktory. 12.2.2010.
   Urychlovač LHC – rekapitulace a plány. 1.1.2010.
   Jak se zkoumají reakce neutronů v Uppsale. 30.3.2010.
   Jaderné reaktory IV. generace využívající roztavené soli. 10.6.2010.
   Internet journal OSEL. http://www.osel.cz.
6. **Wagner, V.** Stroj na zkoumání počátku vesmíru se konečně rozběhl. *Kozmos*, Vol. XLI, 2010, Iss.2.
7. **Wagner, V.** Přichází zlatý věk neutrinové astronomie. *Kozmos*, Vol. XLI, 2010, Iss.6.
8. **Wagner, V.** Neutrinové okno do vesmíru. *Astropis*, Vol. XVII, Spec. iss. 14.10.2010.
9. **Wagner, V.** Záření gama – okno do nejenergetičtější části vesmíru. *Astropis*, Vol. XVII, Spec. iss. 14.10.2010.

OTHER ACTIVITIES IN 2009-2010

Conferences and meetings organized or co-organized by NPI

Computing in High Energy and Nuclear Physics - CHEP 2009, Prague 21-27 March 2009

International Workshop European Activation File – EAF 2009, Prague, 25 – 27 March 2009

XVI International Congress on Mathematical Physics – ICMP 09, Prague, 3-8 August 2009

XXI Indian-Summer School on Nuclear Many-Body Problem, Řež, 31 August - 4 September 2009

Research Coordination Meeting on “Development of Therapeutic Radiopharmaceuticals Based on ^{177}Lu Radionuclide Therapy”, Prague, 23 – 27 November 2009

Workshop „Energy calibration of the KATRIN experiment“, Münster, 4-5 May 2010

Analytic and algebraic methods in physics VI, Prague 10-11 May 2010

Korea-Czech Workshop on Neutron Science 2010, Prague 17-19 May 2010

Meeting of General Assembly SPIRAL 2 preparatory phase, Prague 21 June 2010

Jets in Proton-Proton and Heavy-Ion Collisions, Prague 12-14 August 2010

ESF exploratory workshop: Mathematical aspects of the physics with non-self-adjoint operators, Prague 30 August – 3 September 2010

Joint SPHERE and JSPS Meeting 2010, Prague 4-6 September 2010

Mathematical Results in Quantum Physics - QMath11, Hradec Králové 6-10 September 2010

XXII Indian-Summer School on Strangeness Nuclear Physics, Řež 7-11 September 2010

University courses given by NPI staff members

J. Adam: *Quantum Mechanics II*
J. Adam: *Field Theory*
J. Adam, J. Mareš: *Physics of Atomic Nuclei*
J. Adam: *Relativistic Quantum Mechanics*
D. Adamová: *Data Evaluation in Physical Experiments*
Integral Methods of Ionizing Radiation Dosimetry
I. Ambrožová: *Neutron Dosimetry*
J. Bielčík: *Basic Exercises in Experimental Physics*
JJ. Bielčík: *Statistical Physics for Nuclear Physicists*
J. Bielčík, J. Bielčíková: *Discussions on the Quark-Gluon Plasma*
J. Bielčíková: *Foundations of Quantum Chromodynamics*
D. Chvátil: *Exercises in Radiation Detection and Dosimetry*
D. Chvátil: *Selected Analytical Methods*
M. Davídková: *Foundations of Clinical Radiobiology*
M. Davídková: *Radiation Protection*
M. Davídková: *Radiobiology*
M. Davídková: *Microdosimetry*
M. Davídková: *Microscopic aspects of ionizing radiation energy deposition to matter*
J. Dobeš: *Theory of the Atomic Nucleus*
P. Exner: *Mathematical Methods of the Quantum Theory*

J. Kučera: *Instrumental Radioanalytical Methods and Their Applications for Environment Monitoring*
V. Kushpil: *Inteligent Systems in the High-Energy Physics*
O. Lebeda: *Radionuclids Preparation*
O. Lebeda: *Radiopharmaceuticals*
A. Macková: *Experimental Analytical Methods in the Physics of Materials*
A. Macková: *Introduction to the Measurement Theory*
A. Macková: *Physics IV – Atomic and Nuclear Physics*
F. Melichar: *Foundations of Nuclear Medicine - Radiopharmaceuticals*
J. Mizera: *Radionuclids Applications I, II*
A. Krása, A. Kugler, J. Novák, J. Štursa: *Neutron Sources for Accelerator Driven Systems*
J. Novotný: *Quantum Mechnics II – Exercises*
Z. Řanda: *Radioanalytical Methods in Geochemistry*
D. Seifert, Vetrík: *Exercises in Nuclear Chemistry*
F. Spurný: *Integral Methods of Ionizing Radiation Dosimetry*
F. Spurný: *Microdosimetry*
F. Spurný: *Neutron Dosimetry*
V. Štěpán: *Informatics in Medicine*
M. Šumbera: *Introduction to the Physics of Relativistic Nuclear Collisions*
M. Šumbera: *Physics of Relativistic and Ultrarelavistic Nuclear Collisions*
M. Šumbera: *Extreme States of the Matter*
M. Šumbera: *Foundations of Quantum Chromodynamics*
J. Vacík, J. Šaroun: *Neutron physics*
V. Wagner: *Foundations of Nuclear Physics*
V. Wagner: *Foundations of Nuclear Spectroscopy*

Seminars presented in other institutions

T. Brauner

Helical ordering in spin-one color superconductors
4.2.2009, Frankfurt University

Strongly interacting relativistic Fermi systems and BCS–BEC crossover
19.2.2009, Niels Bohr Institute, Copenhagen

Two-color QCD: Confinement and chiral symmetry breaking
20.8.2009, NTNU Trondheim

Ultracold atomic gases and quark matter: Interconnections of physics of low temperatures and high energies
23.11.2009, Charles University, Faculty of Mathematicas and Physics, Prague

Confinement and chiral symmetry breaking in QCD-like theories
1.12.2009, Vienna University of Technology & University of Vienna

Quarkyonic superfluidity and axial symmetry restoration in two-color quark matter
2.12.2009, Institute for Physics, University of Graz

Confinement and chiral symmetry breaking in QCD-like theories
12 .1.2010Heidelberg University

Confinement, chiral symmetry breaking, and Bose–Einstein condensation in QCD-like theories
22.2.2010, NTNU Trondheim

Confinement, chiral symmetry breaking, and Bose–Einstein condensation in QCD-like Theories
16.4.2010, INT Seattle

QCD-like theories and dense quark matter
18.5.2010, Bielefeld University

M. Davídková

The relation between absorbed dose and biological effect of ionizing radiation
8.11.2010, Charles University, Faculty of Mathematics and Physics, Prague

Biological effects of the ionizing radiation
1.2., 22.9., 30.11.2010, Institute for Health-care Postgraduate Education, Prague

P. Exner

Approximation of quantum graph Hamiltonians by Schrödinger operators on manifolds
2.12.2009, Basque Center for Applied Mathematics, Bilbao, Spain

On the meaning of quantum graph Hamiltonians: approximations by Schrödinger operators on manifolds
14.1.2010, Universität Ulm

Spectral properties of curved Dirichlet layers
7.6.2010, Université de Kairouan, Tunisia

Lectures on Quantum Graphs, standard, leaky, and generalized, a minicourse
8.-11.6.2010, Université de Monastir, Tunisia

On loops and trees: spectral and resonance properties of quantum graphs
21.9.2010, Okayama University, Japan

Some spectral and resonance properties of quantum graphs
28.9.2010, University of Tokyo-Komaba, Japan

Approximation of quantum graphs by families of squeezed networks
14.10.2010, Capital Normal University, Beijing, China

V. Havránek

Present status, perspectives and solved subjects at the Nuclear analytic methods laboratory of NPI ASCR
8.10.2009, ATOMKI Debrecen, Hungary

I. Jadrníčková

Dosimetry and LET spectrometry in C 290 MeV/n and Ne 400 MeV/n HIMAC ion beam by different TLDs, TED based LET spectrometers, and Si energy-deposition spectrometer
14.1. 2009, National Institute of Radiological Sciences (NIRS), Chiba, Japan

D. Krejčiřík

The death of a Brownian particle in twisted domains, DI Prague,
13.1.2009, Czech Technical University, Faculty of Nuclear Sciences and Physical Engineering, Prague

The Hardy inequality and the asymptotic behaviour of the heat equation in twisted Domains
21.1.2009, Bilbao, Spain

L'inegalite de Hardy et le comportement asymptotique de l'equation de la chaleur dans les domaines tubulaires
24.9.2009, Univ. Toulon-Var, France

The Hardy inequality and the asymptotic behaviour of the heat equation in twisted Domains
10.11.2009, Technion Haifa, Israel

Twisting versus bending in quantum waveguides
24.11.2009, University of Tuebingen

Schrodinger operators and their spectra
22.-24.3.2010, University of Bilbao, Spain

The Hardy inequality and the asymptotic behaviour of the heat equation in twisted Waveguides
5.11.2010 and 18.11.2010, University of Bilbao, Spain

V. Lavrentiev

Structure organizations in C_{60} *film induced by energetic cluster ion bombardments*
17.2.2009, Open Seminar of Japan Atomic Energy Agency, JAEA, Takasaki-branch, Japan

Access to promising nanostructures through interplay of metallic atoms with fullerene molecules: let look on Co-C_{60} *system*
1.12.2010, JINR Dubna, Russia

P. Mikula

Development and optimization of high-resolution neutron scattering instruments dedicated to characterization and testing of materials of relevance to nuclear energy sector and related experiments in SANS, residual strain/stress and texture studies
5.5.2010, 31.5.2010, IAEA Vienna

Research activities of Neutron Physics Department of NPI Řež
16.11.2010, KAERI Daejeon, South Korea

Recent progress of Bragg diffraction optics based on cylindrically bent perfect crystals with respect to collaboration with KAERI
12.11.2010, KAERI Daejeon, South Korea

Development and optimization of a curved wide-wavelength band monochromator based on strongly cylindrically bent perfect Si-slabs in a sandwich for microfocusing small-angle neutron scattering (mfSANS) device
6.12.2010, IAEA Vienna.

Imaging by means of dispersive multiple reflections
11.4.2011, Hokkaido University, Sapporo, Japan

Neutron optics
14.4.2011, Hokkaido University, Sapporo, Japan

Z. Mrázová

Simulation of spectrometr Liulin using PHITS
3.2.2010, JAEA, Tokai-Mura, Japan

Simulations at the International Space Station board with the program PHITS
14.12.2010, Czech Tecnical Univeristy, Faculty of Nuclear Sciences and Physical Engineering, Prague

K. Pachnerová Brabcová

The use of chemically treated trace detectors for the dosimetric purposes
8.12.2010, Czech Tecnical Univeristy, Faculty of Nuclear Sciences and Physical Engineering, Prague

O. Ploc

Measurements of Exposure to Cosmic Radiation with Energy Deposition Spectrometer Liulin onboard Aircrafts and Spacecrafts
19.1.2010, JAEA, Tokai-Mura, Japan

SimpleGeo - An Interactive Solid Modeler
3.2.2010, JAEA, Tokai-Mura, Japan

N. Shevchenko

Isospin mixing antiK N - πΣ interaction and antiK NN- πΣN state
4.-5.6.2009, Mainz

Two- and three-body resonances in the antiK NN- πΣN system
25.11.2009, Charles University, Faculty of Mathematicas and Physics, Prague

Coupled-channels Faddeev calculations of antiK NN - πΣN system
19.10.2010, JINR Dubna, Russia

P. Siegl

PT-symmetric models in curved manifolds
11.3.2009, Comenius University, Faculty of Mathematics, Physics and Informatics, Bratislava

PT-symmetric models in curved manifolds
6.10.2009, University of Ufa, Russia

PT-symmetric Robin boundary conditions
1.7.2010, University of Beijing, China

Perfect transmission scattering as a PT-symmetric spectral problem
24.11.2010, University of Sao Paulo, Brasilia

V. Štěpán

Biological effects of the ionizing radiation
17.5.2010, Institute for Health-care Postgraduate Education, Prague

J. Vacík

Thermal neutron depth profiling
2.11.2009, National Institute of Standards and Technology (NIST), Gaitherburg, Washington

M. Znojil

Quantum Toboggans
18.2.2009, Pretoria University, South Africa

Quantum Toboggans
24.4.2009, Nantes University, France

Pseudo-Hermitean hamiltonians in Quantum Physics
20.4.2010, Slovak Technical University, Faculty of Electrical Engineering, Bratislava

Two paradoxes of the time evolution desription in quantum theory
20.4.2010, Comenius University, Faculty of Mathematics, Physics and Informatics, Bratislava

Seminars in NPI given by external speakers

G. Japaridze (University Atlanta, USA), 20.1.2009
IceCube - the next generation neutrino telescope at the South Pole

P. Cejnar (Charles University, FMP, Prague), 27.3.2009
Chaos in the collective dynamics of atomic nuclei

J. Vrbik (Brock Uni, St. Catharines, Canada), 22.5.2009
Mathematical treatment of Kirkwood gap creation

A. Pratelli (Dip. Mat., Univ. Pavia, Italy), 18.6.2009
Stability versions for isoperimetric inequality and other functional inequalities

T. Mine (Kyoto Institute of Technology, Japan), 25.6.2009
Absolutely continuous spectrum for the Schroedinger operators with periodic mangetic fields

S. Moroz (Inst. Theor. Phys., Heidelberg, Germany), 8.9.2009
Functional renormalization group and conformal invariance in cold atoms

L. Sihver (Chalmers University of Technology, Gothenburg, Sweden), 30.11.2009
PHITS (Particle and Heavy-Ion Transport code System) – Applications in Cancer Therapy and Space Radiation Risk Estimation

T. Ullrich (BNL and Yale University), 10.12.2009
The Emerging QCD Frontier: The Electron Ion Collider

P. Sulc (Los Alamos Nat. Lab., USA), 7.1.2010
Belief propagation and its application to graph partitioning

F. Lehar (Czech Technical University, ITEP, Prague), 19.2.2010
Nucleon Charge Exchange on the Deuteron: A Critical Review

T. Mine (Kyoto Institute of Technology, Japan), 11.3.2010
Self-adjoint extensions of the Schroedinger operators with singular magnetic fields

S. Kuzhel (Institute of Mathematics NAS, Kiev, Ukraine), 13.5.2010
On J-Self-Adjoint Operators with C-Symmetries: Extension Theory Approach

Osamu Hashimoto (Tohoku, Sendai, Japan), 28.5.2010
Test of charge symmetry breaking in the A=7, T=1 Lambda hypernuclei by the (e, e'K^+) Reaction

S.-N. Yang (National Taiwan University, Taipei, Taiwan), 18. 6. 2010
Recent developments in the study of pion elecromagnetic production

B. Saghai (CEA-Saclay, France), 22. 6. 2010
Baryon spectroscopy and meson production on the nucleon

D. Mukherji, J. Rösler (Technische Universität Braunschweig), 8.7.2010
Design Considerations and Strengthening Mechanisms in Developing Co-Re-Based Alloys for Applications at + 100°C above Ni-Superalloys

L. Alfonta (Ben-Gurion University of the Negev), 16.7.2010
Genetically modified bio-fuel cells

Robert Kamin'ski (INP, Krakow, Poland), 10.11.2010
Facts and myths about singularities in scattering amplitudes (6D)

T. Sato (Japan Atomic Energy Agency, Tokaimura, Japan) and L. Sihver (Chalmers University of Technology, Gothenburg, Sweden), 18.11.2010
Overview of the Particle and Heavy Ion Transport code System PHITS and its applications

L. Sihver (Chalmers University of Technology, Sweden), 18.11.2010
Computer Simulations for Cancer Therapy and Radiation Risk Estimation in Space

H. Rauch (TU Vienna), 24.11.2010
Quantum phenomena observed with neutrons

V.V. Sumin (JINR Dubna), 26.11.2010
Determination of the residual stress tensor in textured zirconium alloy by neutron diffraction

N. Yasuda (National Institute of Radiological Sciences, Chiba, Japan), 13.12.2010
Introduction of NIRS and Activities on CR-39 group

M. Tušek (Czech Technical University, FNSPE, Prague), 17. 12.2010
Point Interaction in Momentum Representation

STRUCTURE OF THE INSTITUTE

(July 2011)

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Vice-Director	Petr Lukáš
Scientific Secretary	Jaroslav Dittrich
Chairman of the Board (elected)	Jan Kučera

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Head of department:	Jiří Hošek
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Senior scientists:	Jaroslav Dittrich, Pavel Exner, Jiří Mareš, Emil Truhlík, Miloslav Znojil
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Research assistant:	Milan Vymazal

Department of Nuclear Spectroscopy

Head of department:	Andrej Kugler
Secretary:	Ilona Hrdá (phone 220 940 149, 212 241 672)
Senior scientists:	Otokar Dragoun, Aloiz Kovalík, Karel Kranda, Jan Kučera, Zdeněk Řanda, Michal Šumbera

Scientists:	Jindřich Adam, Dagmar Adamová, Jaroslav Bielčík, Jana Bielčíková, Jan Borovička, Paul Anami Chung, Jaroslav Frána, Milan Honusek, Svetlana Kouchpil, Vassili Kouchpil, Jiří Mizera, Vojtěch Petráček, Miloš Ryšavý, Yuri Sobolev, Antonín Špalek, Pavel Tlustý, Drahoslav Vénos, Vladimír Wagner, Dalibor Zákoucký
Postdoctoral fellows:	Petr Chaloupka, Jan Kameník, Jaromír Kašpar, Antonín Krása, Filip Křížek
Graduate students:	Marek Fikrle, Jan Kapitán, Marie Kubešová, Jan Rusňák, Martin Suchopár, Ondřej Svoboda, David Tlustý, Michal Vajzer, Jitka Vrzalová, Michal Zerola
Undergraduate students:	Zuzana Barnovská, Zdeněk Huňa, Vít Kučera, Martin Slezák
Research assistants:	Josef Hampl, Zbyněk Horák, Ivana Krausová
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Department of Neutron Physics

Head of department:	Pavol Mikula
Secretary:	Ivana Johanisová (phone/fax 220 940 141)
Senior scientists:	Vladimír Hnatowicz, Vratislav Peřina, Jiří Vacík
Scientists:	Václav Bejšovec, Přemysl Beran, Vladimír Havránek, Vasyl Lavrentiev, Anna Macková, Pavel Strunz, Jan Šaroun, Ivo Tomandl, Miroslav Vrána
Postdoctoral fellows:	Vadim Davydov, Ondrej Muránský, Vasyl Ryukhtin
Graduate students:	Pavel Horák, Petr Malinský, Romana Mikšová
Research assistants:	Pavel Čaloun, Jiří Novotný, Jan Pilch, Olexander Polypchuk, Václav Voseček
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Department of Nuclear Reactions

Head of department:	Václav Kroha
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Senior scientists:	Pavel Bém
Scientists:	Václav Burjan, Zdeněk Hons, Jaromír Mrázek, Jan Novák, Eva Šimečková, Gabriela Thiamová
Postdoctoral fellows:	Mitja Majerle
Graduate student:	Milan Štefánik
Undergraduate students:	Lukáš Závorka
Research assistants:	Miloslav Götz, Štěpán Piskoř
Technical staff:	Jaroslav Červeňanský, Jan Diviš, Otakar Juřenčák, Ludvík Király, Jaroslav Polák, František Veselý, Jiří Záluský

Department of Radiation Dosimetry

Head of department:	Davídková Marie
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Scientists:	Ivan Kovář, Ivo Světlík, Karel Turek
Postdoctoral fellows:	Iva Ambrožová, Kateřina Pachnerová Brabcová, Ondřej Ploc, Viktorie Madhusudhan Štísová
Graduate students:	Ján Kubančák, Zlata Mrázová, Eva Rosová, Lucie Súkupová, Václav Štěpán
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Research assistants:	František Ryska, Lenka Tománková, Lenka Tomášková, Richard Wagner, Markéta Wagnerová
Technical staff:	Renata Fafková, Petr Fořt, Miloslav Kvapil, Natália Megisová, Hana Orčíková, Pavel Soukup, Daniela Staníčková, Václav Sýkora, Otýlie Šimšová, Svitlana Vénosová, Bohumil Vlček

Department of Radiopharmaceuticals

Head of department:	Ondřej Lebeda
Secretary:	Kateřina Hemmerová (phone 266 173 253 / fax 220 941 002)
Senior scientists:	František Melichar
Research Scientistst:	Miloš Beran, Martin Kropáček
Postdoctoral fellows:	Kateřina Eigner Henke, Veronika Kocurová, Kateřina Kontrová, Jan Kučka, Michaela Málková, Helena Švecová, Jana Zimová
Graduate students:	Denis Rolando Beckford Vera, Jan Ráliš, Daniel Seifert, Marek Tomeš, Miroslav Vetrík
Research assistants:	Sebastian Eigner, Aliona Frai, Petr Hanč, Pavel Hradílek, Marcela Mirzajevová, Jiří Šrank, Jiří Ventruba, Libor Procházka
Technical staff:	Jiří Bašta, Ondřej Čerepušťák, Michaela Klejzarová, Jan Pavlík, Vladislava Mojžíšová

Department of Accelerators

Head of department:	Jan Štursa
Secretary:	Miroslava Cinegrová (phone 220 940 152)
Senior scientist:	Čestmír Šimáně
Scientist:	Milan Čihák
Research assistants:	David Chvátil, Pavel Krist, Jiří Lacman, Tomáš Matlocha, Zdeněk Pulec, Pavel Šaroch, Václav Zach
Technical staff:	Michal Dobeš, Robert Herenčár, Jaroslava Herenčárová, Rudolf Jiran, Jaroslav Korunka, Hana Králová, Jaroslav Kroulík, Pavel Kuzmenko, Martin Malík, Jaromír Medo, Tomáš Navrátil, Aleš Novotný, Petr Otčenášek, Petr Petráček, Martin Plánička, Vladimír Šereda, Jaroslav Šlemr, Václav Špalek, Petr Šváb

Director´s office

Head of department:	Petr Lukáš (vice-director)
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Technical and Economic Administration

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Secretary:	Kateřina Nováková (phone 266 173 258)
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Technical staff:	František Hradec, Jaroslav Laufka, Jitka Pospíšilová, Květa Šmolíková

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Department of Radiopharmaceuticals	+ 420 – 220 941 002
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WWW Page

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