INPC 2013

INTERNATIONAL NUCLEAR PHYSICS CONFERENCE

FIRENZE, ITALY 2-7 JUNE 2013

Book of Abstracts

10 - Nuclear Physics Based Applications

Foreword

In the present booklet we have collected the one-page abstracts of all contributions (invited, oral and poster) accepted at the INPC2013 Conference in the topic

Nuclear Physics Based Applications

The submitted abstracts have been divided into the various topics of the Conference following mostly the indication given by the authors. In few cases, where the subject was on the borderline of two scientific areas or it appeared misplaced, the abstracts have been moved to the booklet of the more appropriate topic.

The abstracts are numbered and arranged alphabetically according to the name of the first author. In the parallel and poster sessions of the Conference, each contribution will be identified by the number of the corresponding abstract.

We wish you a pleasant and stimulating Conference.

The Organizing Committee

Nuclear Physics Based Applications (AP)

AP 001.	Neutron cross sections for advanced nuclear systems at n TOF (CERN) *M. Barbagallo* Contact email: *massimo.barbagallo@ba.infn.it*
AP 002.	Estimated radiation dose in organs of female and male adult phantom by FDG-F18 in the lungs for Monte Carlo method *W. Belinato, W.S.Santos, R.M.V. Silva, D.N.Souza* Contact email: *wbfisica@gmail.com*
AP 003.	In-vivo and in-vitro fluctuations in the α-activity of microscopic samples of Thorium and in the dose that is absorbed by nearby tissues. *A. Bianconi, M. Corradini, M. Leali, E. Lodi Rizzini, L. Venturelli, and N. Zurlo* Contact email: *andrea.bianconi@ing.unibs.it*
AP 004.	Proton Computed Tomography system: recent results and upgrade status *M. Bruzzi, M. Bucciolini, M. Carpinelli, C. Civinini, G.A.P. Cirrone, G. Cuttone, D. Lo Presti, S. Pallotta, C. Pugliatti, N. Randazzo, F. Romano, M. Scaringella, V. Sipala, C. Stancampiano, C. Talamonti, E. Vanzi, M. Zani* Contact email: *mara.bruzzi@unifi.it*
AP 005.	Evaluation of Radon concentration in some Northern Romanian salt mines *M.R. Calin, I. Radulescu* Contact email: *rcalin@nipne.ro*
AP 006.	The Radiopharmaceuticals Production and Research Centre established by The Heavy Ion Laboratory of the University of Warsaw *J. Choiński, J. Jastrzębski, K. Kilian, I. Mazur, P. J. Napiórkowski, A. Pękal, D. Szczepaniak* Contact email: *jastj@slcj.uw.edu.pl*
AP 007.	Studies on Ancient Gold Metallurgy Using Micro-PIXE, Proton Activation Analysis (PAA) and Micro-SR-XRF *B. Constantinescu, A. Vasilescu, D. Stan, V. Cojocaru, D. Ceccato, R. Simon* Contact email: *bconst@nipne.ro*
AP 008.	A small-area scintillator hodoscope used for components test of MPD detector in NICA experiment *Madalina Cruceru, I.Cruceru, A.G.Litvinenko, E.I.Litvinenko, V.F.Peresedov* Contact email: *madalina.cruceru@nipne.ro*

AP 009.	INCL4.6-Abla07 – New results and capabilities in applications of spallation reactions *J.-C. David, A. Boudard, J. Cugnon, A. Leprince, S. Leray, D. Mancusi* Contact email: *jean-christophe.david@cea.fr*
AP 010.	Fragmentation cross sections at intermediate energies for Hadrontherapy and Space radiation protection *M. De Napoli, F. Romano, C. Agodi, A.A. Blancato, G. Candiano, G.A.P. Cirrone, G.Cuttone, D. D'Urso, F. Giacoppo, T. Licciardello, A. Musumarra, D. Nicolosi, L. Pandola, G. Raciti, E. Rapisarda, D. Sardina, V. Scuderi, C. Sfienti, S. Tropea, M. Bondì, F.Cappuzzello, D. Carbone, M. Cavallaro* Contact email: *marzio.denapoli@ct.infn.it*
AP 011.	The MODES_SNM project *M. Doherty* Contact email: *modochar@revenue.ie*
AP 012.	Cross-section measurements of deuteron induced nuclear reactions at ARRONAX facility *C. Duchemin, A. Guertin, F. Haddad, V. Métivier, N. Michel* Contact email: *Charlotte.Duchemin@subatech.in2p3.fr*
AP 013.	Neutron Activation Analysis for Characterization of Metallurgical and Environmental Materials *Antoaneta Ene, Marina V. Frontasyeva* Contact email: *aene@ugal.ro*
AP 014.	Calculations for evaluating the activation in biological protection to a high intensity ultra-short pulses laser, using Fluka capabilities *Maria Gabriela Florescu, Doina Eugenia Pantazi* Contact email: *florescug@router.citon.ro*
AP 015.	Development of a standard phantom of the human eye to internal dose assessments *O.V. Fotina, D.O. Eremenko, T.V. Gulyaeva, S.Yu. Platonov, O.A. Yuminov, A.V. Tultaev* Contact email: *Fotina@srd.sinp.msu.ru*
AP 016.	The influence of the heavy ions irradiation on the liquid matter structural properties *D.A. Gavryushenko, V.M. Sysoev, K.V. Taradiy, T.S. Vlasenko* Contact email: *sonychko@bigmir.net*

AP 017.	Comparison of different physical models inserted in MCNPX 2.6 particle transport code for spallation neutron yield calculations *Zohreh Gholamzadeh, Zahra Alipoor, Seyed Amir Hossein Feghhi, Claudio Tenreiro* Contact email: *cadmium_109@yahoo.com*
AP 018.	Experimental evaluations of Radon and Thoron exhalation from building materials, by means of alpha spectrometry measurements of the short-lived progenies. *D. Guadagnuolo, M. Guida, D. Guida, A. Cuomo, S. Mancini* Contact email: *dguadagnuolo@unisa.it*
AP 019.	Investigation of groundwater-surface waters interactions in karst environments, using Radon as an environmental tracer through alpha-spectrometry measurements of its short-lived progenies *D. Guadagnuolo, M. Guida, D. Guida, A. Cuomo, V. Siervo* Contact email: *dguadagnuolo@unisa.it*
AP 020.	Internal radiocesium contamination of residents in Fukushima after the Fukushima NPP accident as measured by extensive whole-body-counter surveys *R. Hayano* Contact email: *hayano@phys.s.u-tokyo.ac.jp*
AP 021.	Instrumental Neutron Activation Analysis (INAA) of Rock Samples from Blue Nile Gorge, East Gojjam, Ethiopia *Asres Yihunie Hibstie, A.K.Chaubey, Awoke Taddesse Hailu and Dilbetigle Assefa Mamo* Contact email:*yihuniehibs@gmail.com*
AP 022.	Qualification tests for tungsten shielded container *G. Iancso* Contact email: *georgetaiancso@yahoo.com*
AP 023.	Improved contact elements for Tritium removal technology based on hydrogen-water isotopic exchange *Gheorghe Ionita, Ionut Spiridon,Gheorghe Titescu, Constantin Ciortea and Ioan Stefanescu* Contact email: *gheorghe.ionita@icsi.ro*
AP 024.	Evaluate an Impact of Low Nuclear Radiation Doses for Thorium Oxide on Human Blood Components: *In Vitro* *A.H.Ismail, M.S. Jaafar ,S. B. Samat and Zakariya A. Hussein* Contact email: *asadhawlery@hotmail.com*

AP 025.	Nuclear fragmentation measurements for hadrontherapy: 95 and 400 MeV/nucleon ^{12}C+^{12}C reactions in E600 and FIRST experiments. *D. Juliani, J.C. Angelique, B. Braunn, J. Colin, D. Cussol, J. Dudouet, Ch. Finck, J.M.Fontbonne, P. Henriquet, M. Labalme, R. Rescigno, M. Rousseau, M.G. Saint-Laurent* Contact email: *didier.juliani@iphc.cnrs.fr*
AP 026.	A Prototype Scintillating-Fibre Tracker for the Cosmic-Ray Muon Tomography of Legacy Nuclear Waste Containers *R. Kaiser* Contact email: *r.kaiser@glasgow.ac.uk*
AP 027.	Measurement, Evaluation and Benchmarking of Selected Differential Cross-Sections Suitable for EBS (Elastic Backscattering Spectroscopy) and NRA (Nuclear Reaction Analysis) *M. Kokkoris, A. Gurbich* Contact email: *kokkoris@central.ntua.gr*
AP 028.	CHIPS_TPT models for exclusive Geant4 simulation of neutron-nuclear reactions at low energies *M.V. Kosov, I.V. Kudinov, D.I. Savin* Contact email: *mikhail.kossov@itep.ru*
AP 029.	New isotopes for medical applications *Ulli Köster* Contact email: *Ulli.Koster@cern.ch*
AP 030.	Nuclear fragmentation studies for Hadrontherapy in Caen, France *M.Labalme, B. Braunn, J. Colin, D. Cussol, J. Dudouet, Ch. Finck, J.M. Fontbonne, P.Henriquet, D. Juliani, J. Krimmer, M. Rousseau, S. Salvador, M.G. Saint-Laurent* Contact email: *labalme@lpccaen.in2p3.fr*
AP 031.	Measurement of ^{136}Ce, ^{156}Dy and ^{168}Yb Thermal Neutron Capture Cross Sections *Jeong-Yeon Lee, Yeongduk Kim, Gwang-Min Sun* Contact email: *yeon@sejong.ac.kr*
AP 032.	Studies of atmospheric tracers ^{7}Be and ^{22}Na in Finland; The Summary *A.-P. Leppänen, I.G. Usoskin, and J. Paatero* Contact email: *ari.leppanen@stuk.fi*
AP 033.	Nuclear techniques and nuclear reaction data for investigation of paintings and stained glasses *G. Maino and M. Monti* Contact email: *giuseppe.maino@unibo.it*

AP 034.	Simulations of fragmentation reactions for hadrontherapy *D. Mancusi, A. Boudard, B. Braunn, J. Cugnon, J.-C. David, S. Leray* Contact email: *davide.mancusi@cea.fr*
AP 035.	Nuclear microprobes in biomedicine and environment: technical developments and applications *<u>P. Moretto</u>, P. Barberet, A. Carmona, G. Devès, C. Habchi, S. Incerti, R. Ortega, S. Roudeau, H. Seznec* Contact email: *moretto@cenbg.in2p3.fr*
AP 036.	Applications of Atom Trap Trace Analysis in the Earth Sciences *P. Mueller, K. Bailey, W. Jiang, Z.-T. Lu, T.P. O'Connor* Contact email: *pmueller@anl.gov*
AP 037.	^{99}Mo production via ^{100}Mo(n,2n)^{99}Mo using accelerator neutrons *Y. Nagai* Contact email: *nagai@rcnp.osaka-u.ac.jp*
AP 038.	Nuclear-related techniques at LABEC for the analysis of atmospheric aerosols *S. Nava, G. Calzolai, M. Chiari, M. Giannoni, F. Lucarelli, M. Fedi, L. Giuntini, L. Carraresi, F. Taccett* Contact email: *nava@fi.infn.it*
AP 039.	The FLUKA code: recent developments and applications in hadron therapy *R. Nicolini* Contact email: *roberto.nicolini@mi.infn.it*
AP 040.	Fukushima Nuclear Power Plant Accident And Nuclear Physicists *Takaharu Otsuka* Contact email: *otsuka@phys.s.u-tokyo.ac.jp*
AP 041.	Determination and Evaluation of the Differential Cross-Sections of the ^{2}H(d,p) Reaction at Energies and Detection Angles Suitable for NRA (Nuclear Reaction Analysis) *V. Paneta, M. Axiotis, P. Gastis, A. Gurbich, M. Kokkoris, A. Kontos, A. Lagoyannis, M. Meyer, P. Misaelides, G. Perdikakis, R. Vlastou* Contact email: *vpaneta@inp.demokritos.gr*
AP 042.	Nuclear fragmentation measurements for hadrontherapy *V. Patera* Contact email: *Vincenzo.Patera@lnf.infn.it*

AP 043.	Study of best coincidence time resolution of LYSO crystals coupled to fast and high quantum efficiency photomultipliers *R. Perrino, R. De Leo, F. Garibaldi, L. Lagamba, F. Loddo, G. Masiello, E.Nappi and A. Ranieri* Contact email: *roberto.perrino@le.infn.it*
AP 044.	Nuclear-physics applications of MYRRHA *Lucia Popescu* Contact email*: lpopescu@sckcen.be*
AP 045.	Nuclear medicine and opportunities of modern methods of radionuclide diagnostics in Kazakhstan *B.Prmantayeva, T.Konurbayev, S.Nurkenov* Contact email*: jan_erke_2002@mail.ru*
AP 046.	Proficiency test: A quality assurance method for high-purity based gamma spectrometry system *I.Radulescu, M. R. Calin* Contact email: *rileana@ifin.nipne.ro*
AP 047.	Simulation toolkit with CMOS detector in the framework of hadrontherapy *R. Rescigno, D.Juliani, Ch. Finck, J. Baudot, D.Dauvergne, G.Dedes, J.Krimmer, C.Ray, V.Reithinger, M.Rousseau, E.Testa, M.Winter* Contact email: *regina.rescigno@iphc.cnrs.fr*
AP 048.	Nondestructive measurement of environmental radioactive strontium *S. Saiba, T. Okamiya, S. Tanaka, R. Tanuma, Y. Totsuka and J. Murata* Contact email: *saiba@rikkyo.ac.jp*
AP 049.	Measurement of neutron yield by 62 MeV proton beam on a thick Beryllium target *M. Schillaci, M. Osipenko, M. Ripani, R. Alba, G. Ricco, M. Barbagallo, A. Celentano, P.Boccaccio, N. Colonna, L. Cosentino, A. Del Zoppo, A. Di Pietro, J. Esposito, P. Figuera, P.Finocchiaro, A. Kostyukov, C. Maiolino, D.Santonocito, C.M. Viberti* Contact email: *schillacim@lns.infn.it*
AP 050.	The Current Situation of Cervical Brachytherapy in Brazil *R.M.V. Silva, L.E. Macedo, J.D. Pinezi, W. Belinato, D.N. Souza* Contact email: *divanizi@ufs.br*
AP 051.	Adaptation and Security Validation of a irradiator Suitable for Use of Cesium-137 Sources *R.M.V. Silva, W.S.Santos, D.O. Junot, W. Belinato, D.N. Souza* Contact email: *divanizi@gmail.com*

AP 052.	Nuclear techniques for studying soft matter at ISOLDE/CERN *M. Stachura, A. Gottberg, M. Kowalska, K. Johnston, L. Hemmingsen* Contact email: *monika.stachura@cern.ch*
AP 053.	Studies on Iznik ceramics and Byzantine glass pigments using milli-PIXE and Neutron Induced PGAA *D. Stan, B. Constantinescu, Z. Szoekefalvy-Nagy, I. Kovacs, Z. Kasztovszky, B. Maroti* Contact email: *daniela@nipne.ro.*
AP 054.	Systematic study of activation cross sections of deuteron induced reactions for applications and for reaction model developments *F. Tárkányi, F. Ditrói, S. Takács, A. Hermanne, B. Király, M.P. Takács, J. Csikai, M. Baba, H. Yamazaki, M. S. Uddin, A. Mohamadi, A. V. Ignatyuk, S. M. Qaim* Contact email: *tarkanyi@atomki.hu*
AP 055.	Nuclear reaction data for investigation of accelerator based production routes of radiolanthanides for therapy *F. Tárkányi, S. Takács, F. Ditrói, A. Hermanne, M.Baba, A.V. Ignatyuk* Contact email: *tarkanyi@atomki.hu*
AP 056.	Energy Dependence of Fission-Product Yields *A.P. Tonchev, C.W. Arnold, J.A. Becker, C. Bhatia, M. Bhike, E.M. Bond, T.A. Bredeweg, B. Fallin, M.M. Fowler, M.E. Gooden, C.R. Howell, J.H. Kelley, R. Macri, W.A. Moody, C. Ryan, G. Rusev, S. Sheets, M.A. Stoyer, W. Tornow, D.J. Vieira, J.B. Wilhelmy* Contact email: *tonchev2@llnl.gov*
AP 057.	Annihilation radiation gauge for relative density and multiphase fluid monitoring *A.Vidal, G. Viesti, F. Pino, H. Barros, L. Sajo-Bohus* Contact email: *sajobohus@gmail.com*
AP 058.	Event based neutron activation spectroscopy and analysis algorithm using MLE and metaheuristics *B. Wallace* Contact email: *barton.wallace.1@ulaval.ca*
AP 059.	Stars, supernovae and meteorites: laboratory studies of nucleosynthesis using accelerator mass spectrometry *A.Wallner, I. Dillmann, K. Fifield, F. Käppeler, G. Korschinek, C. Lederer, A. Mengoni, M. Paul, P. Steier and S. Tims* Contact email*: anton.wallner@anu.edu.au*

AP 060.	Bio-Medical and Plant Biology Imaging Tools Derived from Nuclear Physics Detector Development *Andrew Weisenberger* *Contact email: drew@jlab.org*
AP 061.	Measurements of fission products beta decay properties using a total absorption spectrometer *A.A.Zakari-Issoufou et al.* Contact email: *zakari@subatech.in2p3.fr*

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Neutron cross sections for advanced nuclear systems at n_TOF (CERN)

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More than ten years ago n_TOF, an innovative neutron time-of-flight facility based on a neutron spallation source, started operation at CERN with the aim of addressing the request of high accuracy nuclear data for advanced nuclear energy systems and nuclear astrophysics. In this decade two experimental campaigns, n_TOF-Phase 1 (2001-2004) and n_TOF-Phase 2 (2009-2012) took place, resulting in an extensive program of neutron induced fission and capture cross section measurements.

The well suited features of the facility, namely the high instantaneous neutron flux, high resolution and wide energy range, together with state-of-the-art detectors and data acquisition system allowed to collect high accuracy and high resolution neutron cross-section data on a variety of isotopes, many of which radioactive. In particular, important results have been obtained on U, Pu and minor actinides, necessary for improving safety and efficiency of current nuclear reactors, as well as for new generation systems for energy production and nuclear waste transmutation.

Recently a second experimental area, at a shorter flight path distance than the first one, has been proposed and it is actually under construction. The shorter flight-path will ensure a 25 times higher fluence per pulse relative to the first beam line, resulting in a very strong reduction of background. This will allow to measure isotopes with short half life, as well as reactions characterized by low cross section.

After a brief description of the facility, the most significant results relevant for advanced nuclear energy systems will be presented. Finally, the applicative program foreseen in the second experimental area will be discussed.

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Estimated radiation dose in organs of female and male adult phantom by FDG-F18 in the lungs for Monte Carlo method

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The lung is an organ that has high rates of cancer and fluordeoxiglucose (FDG-F18) is commonly used for imaging by positron emission tomography combined with computed tomography - PET/CT for region diagnostic neoplasic. This inevitably contributes dose to the patient in internal organ. The study of this doses deposition coefficient for radionuclide FDG-F18 absorbed in lungs for the other organs of the patient was computed using Monte Carlo method.

In this study was considered that the radionuclide is present in the entire volume of the lungs, producing the doses of interest, well as spectrum of fluorine was the inserted in the input data file. The interactions occurred in two phantoms, female and male adult human phantoms based on polygon mesh surfaces (FASH and MASH)[1,2] in postures and anatomy based ICRP 89 [3]

With the aid of Monte Carlo n-particle MCNPX (version 2.7.0) [4,5], the results for the twelve internal organs, recomendation sufgested of International Commission Radiological Protection (ICRP) nº 110[6], for two simulators Fash and Mash were compared, which showed small distortion due to anatomical structural difference of the patients studied.

[1] Cassola V F, de Melo Lima V J, Kramer R and Khoury H J, FASH and MASH: Female and Male Adult human phantoms based on polygon meSH surfaces. Part I: Development of the anatomy, Phys Med Biol 55(2010) 133-162

[2] Cassola V F, Kramer R and Khoury H J, Posture-specific phantoms representing female and male adults in Monte Carlo-based simulations for radiological protection, Phys Med Biol (2010) 55 4399-4430.

[3] ICRP 89, Basic anatomical and physiological data for use in radiological protection: reference values.International Commission on Radiological Protection, Pergamon Press, Oxford, 2003.

[4] D. B. Pelowitz, ed., *MCNPX User's Manual, Version 2.7.0*, Los Alamos National Laboratory report LA-CP-11-00438 (April 2011).

[5]J. S. Hendricks, *et al.*, *MCNPX 2.7.0 Extensions*, Los Alamos National Laboratory report LA-UR-11-02295 (April 2011).

[6] ICRP 110, Adult Reference Computational Phantoms, International Commission on Radiological Protection, Pergamon Press, Oxford, 2009.

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

In-vivo and in-vitro fluctuations in the $\alpha-$activity of microscopic samples of Thorium and in the dose that is absorbed by nearby tissues.

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The Thorium-232 decay series produces six α particles from the decays of nuclear species whose half-lives differ by many orders of magnitude. In particular, at some stage in the chain of decays one has three consecutive emissions within hours, four within days. When one considers a small deposit of Thorium that is formed inside the human body ($1-10$ micron size), this leads to a non-standard pattern of fluctuations, both in the emission rate and in the dose that is absorbed by the surrounding tissues. Because of nuclear recoil, a part of the thorium-232 daughters produced in the chain of decays are expelled from the original sample and, in the case of an in-vivo sample, transported to distant places. Exploiting available information on this process from the literature, we produce a Monte Carlo simulation of some aspects of this process, and in particular calculate relevant fluctuations, for in-vivo and in-vitro Thorium samples. An example is reported in fig.1, taken from ref. [1].

This study has to do with the still unexplained effects in the long period (decades) of small Thorium internal contaminations. In the long period, rare (non-poissonian) fluctuations may cause high localized concentrations of activity rate.

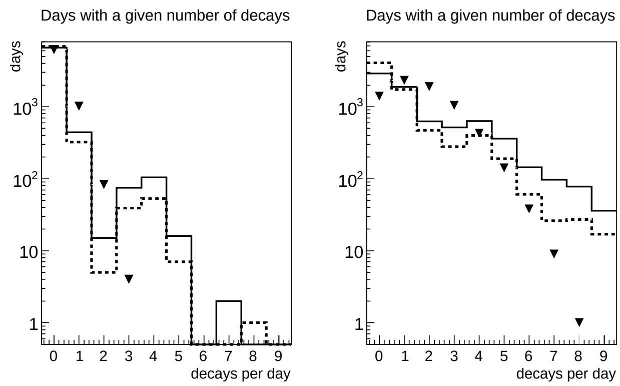

Figure 1: *Distribution of the number of days in which a given number of $\alpha-$particles has been recorded. Left panel: Thorium sample (A) (volume 2 μm^3). Right panel: Thorium sample (B) (20 μm^3). Dotted histograms: period (1), i.e. from 0 to 20 years. Continuous histograms: period (2), i.e. from 21 to 40 years. Triangles: Poisson distributions for period (2). At $t = 0$ the sample is composed by 232 and 228 isotopes of Thorium only, with equal initial activity. This is the typical outcome of a chemical refinement process on natural Thorium.*

[1] A.Bianconi et al, “Thorotrast: analysis of the time evolution of its α activity concentration, in the 70 years following the chemical purification of Thorium”, Physica Medica, in press.

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Proton Computed Tomography system: recent results and upgrade status

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Proton Computed Tomography (pCT) is a medical imaging technique based on the use of proton beams with energies above 200MeV to directly measure stopping power distributions inside the tissue volume. Prima (PRoton IMAging) is an italian collaboration working on the development of a pCT scanner based on a tracker and a calorimeter to measure single protons trajectory and residual energy. The tracker is composed by four planes of silicon microstrip detectors to measure entry and exit positions and angles.
Residual energy is measured by a calorimeter composed by YAG:Ce scinitillating crystals. A first prototype of pCT scanner, with an active area of about 5x5 cm^2, has been constructed and characterized with 60 MeV protons at the INFN Laboratori Nazionali del Sud Catania (Italy) and with 180 MeV protons at Svedberg Laboratory Uppsala (Sweden). A new pre-clinical prototype with an extended active area up to 5x20 cm^2, real time data acquisition and a data rate up to 1 MHz is under development. A description of the two prototypes will be presented together with first results concerning tomographic image reconstruction.

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Evaluation of Radon concentration in some Northern Romanian salt mines

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The knowledge of radon concentration levels in underground environments is essential for therapeutic purposes of different respiratory and rheumatic diseases. In order to develop speleotherapy in Romania, this paper presents the results of an indoor radon concentration levels survey in some salt mines in Romania.

The survey was carried out using radon monitor Pylon AB-5 system methodology. In order to investigate whether differences in depth and microclimate parameters translate into significant differences in salt mine indoor radon concentrations, have been chosen three salts mine test sites placed in the Northern part of Romania (Cacica [1] , Ocna Dej [2] and Ocna Turda [3]) in stable areas of the mining field at 32–120 m depth.

Environmental microclimate conditions (mean values of air temperature 10–14.5 ^{0} C, air humidity 65–80 %, air velocity 0.2 m/s saline aerosols and low microbial factors) have anti-bacterial, anti-microbial, and anti-inflammatory properties and recognized therapeutically effects on human body's health.

The radon concentration was calculated using relation:

$$C_{Rn} = \frac{CPM/INT - BG}{S}$$

where: C_{Rn} - the radon gas concentration (Bq/m^3); CPM - the count for the interval (in cpm); INT – time interval (min), BG - the background (in cpm); S - sensivity (new calibration factor = 1.558 ±0.021±1.32% cpm/(pCi/L) ±4% = 0.0421 cpm/(Bq/m^3) ± 4%).

The measuring of the natural background ionizing radiation in salt mines was made using the Berthold Umo LB 123 portable integrated impulse debit meter (used in rate mode) equipped with a gamma probe - Counter-timer and at an integration times of 3600 s/measure. The measurement and calibration procedures were conducted in conformity with the procedures of the accredited (SR EN ISO/CEI 17025: 2005) SALMROM laboratory. Dose rate in various locations in salt mines were between 2 nSv/h ± 4.9% and 4 nSv/h ± 9.6%.

The analyzed environmental conditions and recorded low levels of indoor mean radon concentration 6.9± 039 Bq/m^3 demonstrated the best suitability of the investigated three salt mines in Romania for speleotherapeutic applications.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

The Radiopharmaceuticals Production and Research Centre established by The Heavy Ion Laboratory of the University of Warsaw

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At the beginning of this century, after more than six years of the successful operation of the heavy ion cyclotron a new direction in the development of the Warsaw Heavy Ion Laboratory (HIL) was necessary in order to maintain its vitality and place in the forefront of the Polish research infrastructures. From a number of discussed options the installation of a new, commercial p/d cyclotron for the Positron Emission Tomography (PET) radioisotopes was selected. Supported by subsidies from the Polish Ministry of Sciences, International Atomic Energy Agency, Ministry of Health, European Structural Funds and University of Warsaw the Radiopharmaceuticals Production and Research Centre (RPRC) was established on the premises of HIL. The Centre equipped with the 16.5 MeV proton and 8.4 MeV deuteron GE PETtrace cyclotron, a number of hot cells, automatic synthesis and dispensing units and quality control equipment is intended to produce commercial radiopharmaceuticals based on ^{18}F (Fluorodeoxyglucose, FDG) and research radiopharmaceuticals based on ^{18}F but also on ^{11}C and ^{15}O. For this aims the radiopharmaceutical production area is separated on the routine FDG production laboratory and the research laboratory. The close vicinity (about 500 m) of the Nuclear Medicine Department of the Warsaw Medical University, equipped with the modern PET-CT scanner will facilitate the development of the diagnostics and research program even including the shortest lived radioisotope ^{15}O after the installation of the underground capillary line (in preparation). The ^{15}O isotope is also demanded by an animal micro-PET, located closely in chemistry-biology new research unit of the University of Warsaw. Similarly, the production of longer lived metallic radioisotopes will be possible after the external beam line installation on the cyclotron.

Besides the regular everyday production of the commercialized FDG radiopharmaceutical, synthesis of other known species are planned for preclinical research in collaboration with Warsaw Consortium for PET Collaboration or members of the Scientific Campus Ochota network. Another research area will be the innovative radiopharmaceuticals for PET-CT or PET-NMR.

An important example of cyclotron beam use for non-PET radiopharmaceuticals will be research into an alternative (via accelerators) way of producing the most popular isotope in nuclear medicine, ^{99m}Tc, presently obtained from the nuclear reactor produced ^{99m}Mo generator. This activity will be performed within the research contract with the International Atomic Energy Agency and will be also supported by Polish NCBiR research funding agency subsidy.

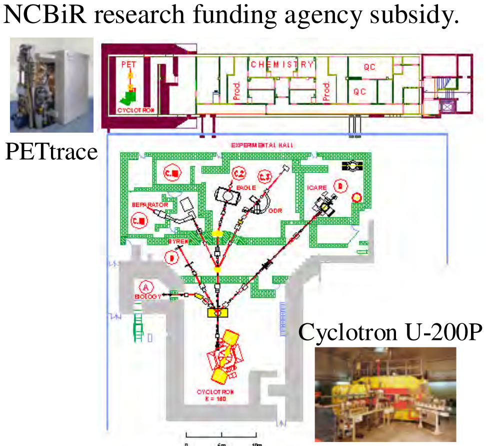

Figure 1: *The layout of the University of Warsaw Heavy Ion Laboratory with the Radiopharmaceuticals Production and Research Centre addition at the top.*

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Studies on Ancient Gold Metallurgy Using Micro-PIXE, Proton Activation Analysis (PAA) and Micro-SR-XRF

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Placer deposits were the most important ancient gold source. Panned occurring gold contains several impurities as quartz, cassiterite, chalcopyrite, pyrite. For the authentication of ancient gold artefacts (jewellery and coins) found on Romanian territory, the most likely use of Transylvanian unrefined alluvial gold from placers must be considered. To demonstrate it, we present the analyses of 50 micro-samples (1-2 mg) from most famous Dacian gold items - “Koson”-type staters and spiraled bracelets recuperated between 2006 and 2012 by Romanian authorities from the international market of antiquities - by micro-SR-XRF at ANKA Synchrotron, Karlsruhe. Four “Koson” whole coins were also analyzed by PAA (gamma-ray spectra) at the Bucharest 9 MV HV Tandem accelerator. 10 small samples of alluvial gold of different origin were analyzed by 2 MeV protons micro-PIXE at AN2000 accelerator of Laboratori Nazionali di Legnaro, Italy, to be compared with the archaeological gold analyses. 10 Transylvanian native gold samples were also analyzed by PAA at Bucharest Tandem. The elemental compositions of Dacian items featuring relatively large amounts of silver (10% on average) and small amounts of copper (1% on average), fit the pattern for native gold, which contains up to 40% silver and up to 1% copper, indicating there was no intention to refine the employed gold. Moreover, each analyzed item showed a rather inhomogeneous composition due to the fact that the manufacturers were not used an advanced technology: most likely, a mixture of gold nuggets and gold dust was melted down without being perfectly homogenized. Both cold working and sintering of gold concentrates are expected to conserve in the final product many mechanical impurities, like isolated minerals and inclusions. Traces of tin – most probably from cassiterite - were observed in practically all the items. Copper concentration in artefacts is higher than in Transylvanian native gold, related to the presence of accompanying gold minerals in gold dust and nuggets - e.g. chalcopyrite ($CuFeS_2$) “fool’s gold” - due to probably confusion made by Dacian “miners” and to the primitive processing of the raw material.

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

A small-area scintillator hodoscope used for components test of MPD detector in NICA experiment

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This hodoscope is a position sensitive detector used for the determination of position resolution of particles generated in nuclear interactions at high energy ($\sqrt{S_{NN}}$=3-11GeV). This is a new type of detector because it uses the plastic scintillators with spectral emission having the maximum at 580 nm coupled at PIN Hamamatsu photodiodes. Usually in this kind of experiments are used position-sensitive devices with scintillators and photomultipliers tubes where the position resolution is high and operates at high voltage. The proposed hodoscope operates at low voltage and the position resolution is better (smaller than 5mm). The detector structure (Fig.1.) is made from two perpendicular planes of plastic scintillator rods, each having eight elements. Every rod is coupled to very small charge sensitive preamplifiers.

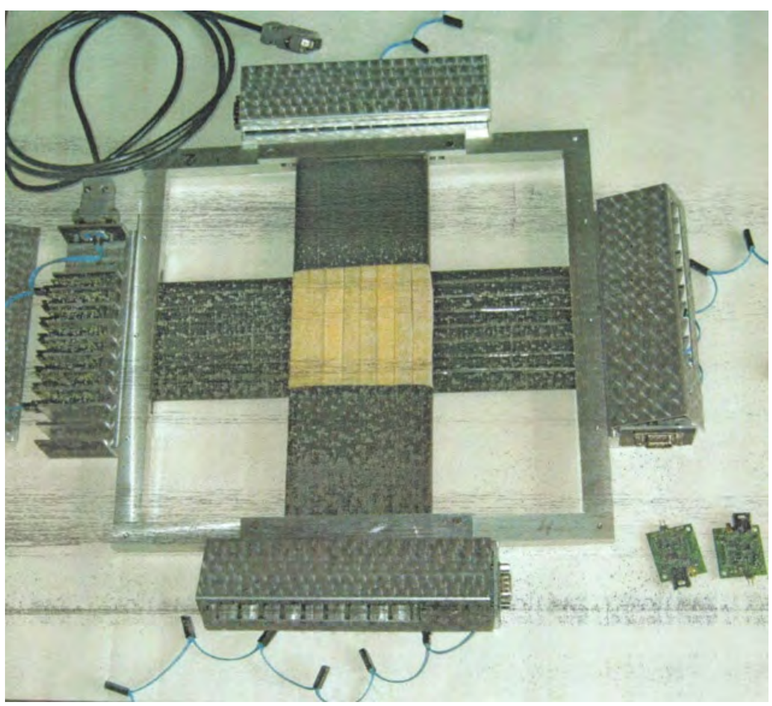

Figure 1: *Hodoscope with plastic scintillators and charge sensitive preamplifiers*

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

INCL4.6-Abla07 – New results and capabilities in applications of spallation reactions

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The main features of spallation reactions are known for a long time, but in the last ten years their modeling has been improved significantly, thanks to confrontation with new good quality experimental data. One of the best models on the market, according to an IAEA benchmark [1], is the combination INCL4.6-Abla07. INCL4.6 [2] handles the first stage of the reaction (intranuclear cascade) and Abla07 [3] takes care of the second one (deexcitation). Moreover these models have been implemented in a beta version of MCNPX2.7, similarly as the preceding versions in MCNPX2.5.0, to perform calculations for macroscopic targets.

We present here some of the latest developments and the improvements that they bring through several applications. (1) The production of cosmogenic nuclides in meteorites submitted to bombardments by proton, neutron and alpha projectiles. (2) Study of the effect of the transport of particles in an experiment measuring the production rates of light charged particles by the interaction of a neutron beam with a few cm thick target. (3) Tritium production study in the Megapie target. (4) Production of isotopes with a charge two unit higher than the target (Fig. 1). It will be shown that the right prediction of the production rates requires the combination of detailed calculation of light charged particle emission and of low energy reactions induced by these particles [4]. (5) Predictions for the ESS target activity together with an estimate of the uncertainty of the evaluation.

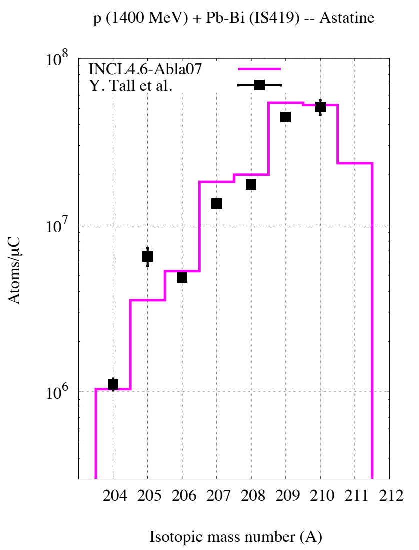

Figure 1: Astatine release rates measured by the ISOLDE collaboration at 1.4 GeV compared to MCNPX simulation, using INCL4.6-Abla07.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Fragmentation cross sections at intermediate energies for Hadrontherapy and Space radiation protection

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Nuclear fragmentation measurements are of great interest in many fields of interest, form the hadrontherapy, the new frontier for cancer therapy, to the space exploration. In hadrontherapy, the capability to predict how the beam fragmentation modifies the delivered dose and the biologicall effectiveness is crucial for a correct tumor treatment [1]. Similarly, an effective shielding and a correct evaluation of the radiological risks for the astronauts require the knowledge of the radiation field inside the space vehicles and the human body generated by the galactic cosmic rays fragmentation [2]. In order to obtain realistic fragmentation predictions, the only way to overcome the shortcomings of analytical calculations is the use of reliable Monte Carlo simulations. However, the physical models used in such codes need to be tuned and validated by experimental fragmentation data. Since a limited set of experimental fragmentation cross sections is available and in particular, to our knowledge, no double differential fragmentation cross sections at intermediate energies are present in literature, we have started a campaign of fragmentation measurements at the INFN - Laboratori Nazionali del Sud (LNS) in Catania. The double differential cross sections and the angular distributions of the secondary fragments produced by the interaction of a 62AMeV ^{12}C beam on thin ^{12}C [3] and ^{197}Au targets have been measured over a wide angular range. Moreover, we have measured secondary fragments produced in conditions closer to the clinical case, i.e. using thick tissue-like target materials. In this contribution, together with the experimental results, we will also discuss the comparison between the measured fragmentation cross sections and the Geant4 Monte Carlo predictions. In particular, two Geant4 nuclear reaction models, the Binary Light Ions Cascade and the Quantum Molecular Dynamic, have been compared and validated.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

The MODES_SNM project

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MODES_SNM (Project MODES SNM, http://www.modes-snm.eu/) is funded under the FP7 Security Programme, aimed at developing a prototype for a mobile, modular detection system for radioactive and Special Nuclear Materials (SNM). In order to maximize the detection capability for SNM, the prototype will combine detectors for fast and thermal neutrons, as well as for gamma rays.

The key technologies in MODES_SNM are represented by high-pressure scintillation cells filled with noble gases (He and Xe), as recently developed by ARKTIS Radiation Detector Ltd. (http://www.arktis-detectors.com/) [1, 2] and novel fast digitizers designed by CAEN for fast processing of the radiation events.

The MODES_SNM system is designed to offer a close fit to the requirements of a Portable Radiation Scanner (PRS) [3], which is a device conceived mainly for covert detection of unauthorized or undeclared activities. The specific feature of PRS is rapid radionuclide identification, providing advantages for monitoring at locations where the number of false alarms due to NORM materials is high (e.g., border crossings, airports, major public events).

The project started officially at the beginning of 2012 with an expected duration of 30 months. In the first part of the project an intense R&D effort has been realized to provide state-of-the-art system components optimized for a mobile instrument to be used by non-expert operators. In the second part of the project the system will be integrated, laboratory qualified and then used in field tests. The demonstration phase of the project will be performed directly by end users in different European locations.

The aim of the talk is to provide a general overview on the importance of detection of radioactive and SNM materials and to discuss the developments achieved by the MODES_SNM collaboration.

This work is supported by the European Union through the MODES SNM project (Call FP7-SEC-2011-1, ERC grant agreement n◦ 284842). Participants to MODES_SNM are the Universities (Padova and Insubria, Italy, Liverpool, U.K., ETH Zurich, Switzerland), SME (ARKTIS Radiation Detector, Switzerland, CAEN, Italy), National Nuclear Research Center (NCNR, Poland) and end-user (The Revenue Commisioners, Ireland). The University of Padova is the Project Coordinator.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Cross-section measurements of deuteron induced nuclear reactions at ARRONAX facility

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TThe ARRONAX cyclotron [1], acronym for "Accelerator for Research in Radiochemistry and Oncology at Nantes Atlantique" is a new facility installed in Nantes, France. It is a high intensity - up to twice 375 ?A for protons - and high energy - up to 68.7 MeV - multiple projectiles - protons, deuterons, alpha particles - cyclotron. Two beams can be extracted at the same time for protons and deuterons in dual beam mode. ARRONAX has 6 experimental vaults among which four are connected to hot cells through a rabbit system and are devoted to radionuclide production. Its main objective is the production of radionuclides for medical use. Other developed activities are radiolysis and radiobiology using a pulsed alpha beam and physics. ARRONAX is also intended to form young scientists. A dedicated program has been launched on production of innovative radionuclides for beta- and alpha targeted radiotherapy using proton or alpha particles. Since the accelerator is also able to deliver deuteron beams, we have reconsidered the possibility to use them to produce medical isotopes. Indeed, in some cases, the use of deuterons allows higher production yield than protons. In this study, we have focused on cross section measurements of isotopes dedicated to therapy. Data have been measured for Rhenium-186 and Thorium-226 deuteron induced production. The first radionuclide is a beta- emitter which has been used in clinical trials for palliation of painful bone metastases resulting from prostate and breast cancer [2] while the second one is an alpha emitter of great interest since it has been found to be a more potent alpha particle emitter for leukemia therapies than Bi-213 [3]. On ARRONAX deuteron induced production cross-sections are measured from 15 MeV to 35 MeV using the stacked-foils' technique [4]. A novelty in our work is the use of monitor foils behind each target foil in order to record efficiently the incident particle flux and its energy all over the stack, by a relative calculation using referenced cross section. Typical irradiation uses a beam intensity of 100 nA during 30 min. Activity measurements are made using gamma spectrometry. Isotopes of interest as well as contaminants created during irradiation are measured since a good optimization process is supposed to find the best compromise between production yield and purity of the final product. Our new sets of data will be compared with the existing data [5,6] and with results given by TALYS code calculations [7].

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Neutron Activation Analysis for Characterization of Metallurgical and Environmental Materials

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Experience in applying non-destructive nuclear analytical technique – instrumental neutron activation analysis (INAA) – in metallurgical industry and environmental studies is reviewed.

INAA was applied at Horia Hulubei Institute of Physics and Nuclear Engineering IFIN-HH, Bucharest-Magurele, Romania and Frank Laboratory of Neutron Physics (FLNP) of Joint Institute of Nuclear Research (JINR) at Dubna, Russia, to investigate the elemental content of final products (steels, slags) involved in metallurgical industry at Iron and Steel Works at Galati (Romania) and of soil samples collected at different sites in the vicinity of the industrial enterprise – steel mill, blast furnace or slag dump.

The INAA results for minor and trace elements in steels obtained at IFIN-HH are compared with those obtained by Ion Beam Analysis techniques Particle-induced X-ray (PIXE) and Gamma-ray (PIGE) Emission in terms of number of determined elements, sensitivity and matrix effects.

INAA at FLNP-JINR carried out in two irradiation steps allowed determination of 40 elements (Na, Mg, Al, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Co, Zn, As, Br, Rb, Sr, Zr, Mo, Sb, I, Cs, Ba, La, Ce, Nd, Sm, Eu, Tb, Dy, Tm, Yb, Hf, Ta, W, Au, Hg, Th, and U) in slags and soils. The complementarity of INAA with Energy-dispersive X-ray fluorescence (EDXRF) is discussed based on the performed analyses at "Dunarea de Jos" University of Galati (UDJG), Romania, on metallurgical slags and soils. The results for the investigated soils are compared with the permitted concentration values for heavy metals (HMs) and other trace elements, and with values found in the literature for the European and world median elemental concentrations in the earth crust. Inter-element correlations are calculated for different depths and the relation between metal amounts and the distance from the influence zones of industrial objective with ferrous processing activities is discussed.

The perspectives of applying INAA to characterization of high purity materials such as LiN and BN in combination with their structure characterization using imaging techniques are described.

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Calculations for evaluating the activation in biological protection to a high intensity ultra-short pulses laser, using Fluka capabilities

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New technologies, such as matter irradiation with radiation produced by hyperintense beam laser, can generate different types of particles accelerated to high energies up to GeV range. Due to the size of modern facilities, and economic considerations that normally prevail in the shielding design, it is required the use of convenient radiation protection that will ensure doses less than the limits allowed for staff and public. There are currently some common materials that can attenuate, to acceptable levels, effective radiation intensity and meet performance requirements.

Special nature of these types of radiological installations makes of interest the behavior of shielding materials, due to activation induced by interaction of radiation with surroundig structures matter. Evaluation of activation products is important because of the increasing number of these facilities, hence the study of the potential radiological risk in long-term operating conditions, including problems that may occur during decommissioning is necessary.

The paper will present the results obtained for several shielding material considerred to the operation of a high intensity laser, more than 10^{21} W/cm^2, peak power up to 1PW, and with a duration of 35 fs per pulse; this is in progress objective of The National Institute for Laser, Plasma & Radiation Physics (INFLPR) in Bucharest - CETAL. Study considered shielding materials exposed to electron beams of energies up to 1 GeV, and protons up to 100 MeV.

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Development of a standard phantom of the human eye to internal dose assessments

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The work is done in a series of studies on the development of α-emitter pharmaceutical "Astatine-211" [1]. One of the key objectives of the study is the assessment of radiation exposure to the eye and lens of the eye in relation to the known cases of eye disease in clinical use of the isotope ^{131}I (which is analog to the developed pharmaceutical "Astatine-211") for the thyroid gland treatment. To solve this problem in the environment of GEANT-4 was simulated human anatomy and were evaluated absorbed fractions in the target "eye" from all the organs sources, and the reverse ("eye" as the source organ) for γ-radiation of standard range energies [2] and α-spectrum of ^{211}At with a known activity distribution of the pharmaceutical. Modeling the anatomy is based on the application of standard MIRD phantom model [3]. To go to more accurate estimates of the absorbed dose within the created software ORNL phantom is introduced, which is specific for age and gender. Primary testing of ORNL model for γ-radiation was carried out. The created software allows visualization of particle tracks and anatomy design to prevent inadvertent errors in the initial conditions of the activity distribution of radiopharmaceuticals. As a result of a study two new organs the eye and eye-lens are added in the standard adult-human phantom. Software calculations show that the use of α-emitter radiopharmaceutical "Astatine-211" reduces the radiation exposure on the eyes and eye-lens by few orders of magnitude in comparison with the use of I-131 with the same therapeutic doses in the irradiated organ - the thyroid gland.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

The influence of the heavy ions irradiation on the liquid matter structural properties

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From the nonequilibrium thermodynamics point of view description of the relaxation phenomena in the liquid matter after the irradiation is closely related to the description of chemical reactions and the molecule excitation reactions after the irradiation. The main idea of the present work is to check the possibility to implement the equilibrium thermodynamics to describe the stationary nonequilibrium states of the systems. Theoretical study of the system is based on the fundamental equations of Bogoliubov chain for the case of the stationary equilibrium state, and the state of the liquid under the irradiation which is a nonequilibrium one is treated as perturbation. Let one have a homogeneous system characterized by a system of n external parameters and m internal parameters. Recent describe the internal structure of the system otherwise one can treat them as a kind of some "internal temperature" that characterizes the energy distribution between the internal states of the system. Even in such homogeneous multicomponent system in which only one chemical reaction occurs entropy production exists. Under the influence of external factors such as irradiation, the system moves up to a stationary nonequilibrium state characterized by the minimum of the entropy production. Such a nonequilibrium state is characterized by the perturbated momentum distribution. The system of integro-differential equations to determine the pair distribution function, that is the main characteristic function of the liquid systems, is introduced. Our theoretical studies have shown that the it is possible to use the formalism of equilibrium thermodynamics to describe the nonequilibrium systems through the introduction of an effective temperature.

Comparison of different physical models inserted in MCNPX 2.6 particle transport code for spallation neutron yield calculations

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The Spallation Neutron Source is an accelerator-based neutron source facility that provides the most intense pulsed neutron beams in the world for scientific research and industrial developments such as neutron scattering research which has applications in structural biology and biotechnology, magnetism and superconductivity, chemical and engineering materials, nanotechnology, complex fluids, and so on. The spallation source can be used as neutron pulse source for neutron radiography imaging, subcritical reactors, reactor waste burning and others [1]. MCNPX 2.6 is a general purpose Monte Carlo radiation transport code designed to track 34 particle types over broad ranges of energies. It is the next generation in the series of Monte Carlo transport codes that began at Los Alamos National Laboratory nearly sixty years ago. The code uses models of BERTINI, ISABEL, INCL4 and CEM for intera nuclear cascade calculations along with DENSER (associated with RAL or ORNL fission models) and ABLA for de-excitation [2]. Heavy targets such as Pb are useful to yield high spallation neutron yields [3]. The transport code has been used to evaluate ability of its different physical models to estimate spallation neutron yield. A proton beam of 0.8, 1.0, 1.2 and 1.8 GeV energy respectively has been used to induce spallation neutrons in a Pb target of 15 cm radius and different 20-60 cm thicknesses. A Gaussian proton beam of FWHM of 0.2 cm has been used and the spallation neutron yield has been calculated using different physical models. The models have been compared for different target radiuses and proton energies. A comparison between experimental and simulations has been done.

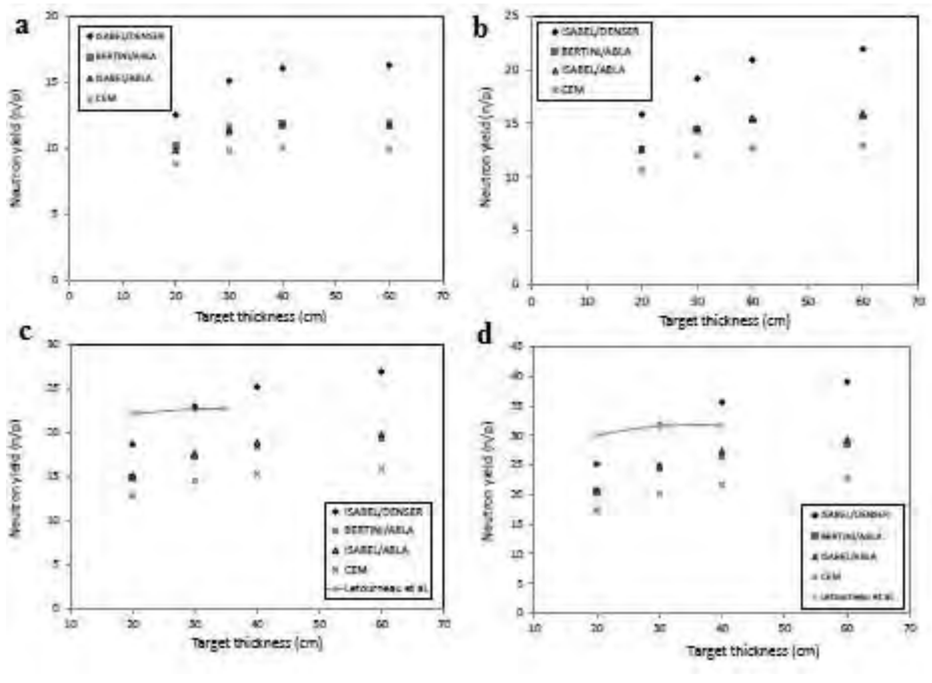

Fig. Evaluation of different physical models for neutron spallation yield, a) 0.8 GeV, b) 1.0 GeV, c) 1.2 GeV, d) 1.8 GeV

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Experimental evaluations of Radon and Thoron exhalation from building materials, by means of alpha spectrometry measurements of the short-lived progenies.

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Radon and thoron are relevant physical contaminant agents for indoor air as they are a significant source of ionizing radiation exposure for the population, providing more than half of the annual effective equivalent dose. Their activity concentrations may result from contributions of several sources and from a complex combination of factors and processes. One of the most relevant contributions to the entry and accumulation of indoor radon and thoron is given by the building materials. The aim of this study is to set up a scientific protocol to evaluate and estimate how building materials affect the activity concentrations of radon and thoron inside indoor environments. In order to evaluate the maximum values of concentrations to which workplaces or residential places occupants would be exposed and, then, to identify a correct technique of mitigation, ensuring the respect of default limits imposed by law, a simplified procedure has been developed to predict indoor activity concentrations. Our approach is based on two successive phases. The first one is an experimental phase based on on-site alpha-spectrometry measurements of radon's and thoron's alpha-emitting short-lived progenies, by means of the radon detector RAD7, capable to measure activity concentrations in soil-gas, in water, in the air and from exhalating building materials. The second phase is based on a steady-state modelling procedure for the entry and the accumulation of radon and thoron, developed with the STELLA II SOFTWARE environment. In comparison with global analytical models published in literature, our approach greatly simplifies the complexity of the model, and enables the operator to distinguish clearly and evaluate the different contribution by each source to the radon and thoron entry and accumulation inside a confined space. Finally, original results about the application of the above approach to different kinds of building materials (concrete, brick and tuff), together with the application to a single detached test-house, are reported.

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Investigation of groundwater-surface waters interactions in karst environments, using Radon as an environmental tracer through alpha-spectrometry measurements of its short-lived progenies

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Surface waters and groundwater resources assessment represents one of the main issues in planning and management of the territory and requires more and more interdisciplinary-based scientific researches, particularly in physics, geology and hydrology. Karst aquifers provide the 25% of the global drinking water resources to the world's population and sustain aquatic life in most fluvial systems, providing several ecological services to humans. Being characterized by complex links between surface waters and groundwater, they turn out to be very vulnerable to contamination and pollution. Complex interactions and exchanges between surface water and groundwater exist, due to gaining river segments from karst groundwater and losing river segments towards the aquifer, influencing also on-shore and off-shore submarine springs. Radon is a ubiquitously occurring natural component of groundwater, occurring as a dissolved gas. The chemical and physical properties of radon and its behavior in the groundwater allow for its use as naturally occurring aqueous tracer. The alpha-spectrometry measurements of radon's short-lived progenies turns out to be an useful tool of investigation in different topics, like evaluation and quantitative assessment of industrial contamination in different typologies of water bodies, support for hydrological modelling tasks, assessment of natural radioactivity in networks of distribution of drinking water. The aim of this study is to show the feasibility of this methodology to evaluate and characterize groundwater contributions in some relevant karst environments in Campania region (southern Italy). To this purpose, various measurement campaigns have been made for the acquisition of data about radon activity concentration in the river and spring waters, using a radon monitor, RAD7, capable to measure activity concentrations in soil-gas, in water, in the air and from exhalating building materials.

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Internal radiocesium contamination of residents in Fukushima after the Fukushima NPP accident as measured by extensive whole-body-counter surveys

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The severe accident involving the Fukushima Dai-ichi nuclear power plant (NPP), triggered by the Great East Japan Earthquake and resulting Tsunami on March 11, 2011, dispersed large amounts of radionuclides, which were deposited on soil and water in Fukushima Prefecture and surrounding regions of Japan. If we apply the transfer factor from deposition density to committed effective dose (CED) obtained from post-Chernobyl accident studies, internal exposures in excess of a few mSv/y would be expected to be frequent.

After the accident, many nuclear physicists in Japan voluntarily worked on radiation monitoring, screening of residents for contamination, and measurement of deposition densities of radionuclei on soil.

Another important contribution was to access the internal exposure risks of residents using whole body counters (WBCs), as there were not enough number of experts in Fukushima, and there were many confusions in operating the WBCs and in interpreting the results.

I have been helping medical institutions in Fukushima since the fall of 2011, and have so far evaluated the internal exposure of nearly 40,000 residents [1]. Our results show that the internal exposure levels of residents are much lower than estimated from the Chernobyl transfer factor; between 12 to 20 months after the start of the Fukushima Dai-ichi NPP accident, the ^{137}Cs detection frequency was 1.0 % (0.09 % among children).

In particular, in the town of Miharu (the ^{137}Cs deposition density being about 100 kBq/m^2), where we measured 95% of the children (ages 6–15) enrolled in town-operated schools, the ^{137}Cs body burdens of all children were below the detection limit of 300 Bq/body in the fall of 2012. This is the first sampling-bias-free assessment of the internal exposure of children in Fukushima.

These results are not conclusive for the prefecture as a whole, but are consistent with results obtained from other municipalities in the prefecture, and with prefectural data. This does not mean, however, that Fukushima residents are free of internal exposure risks, as evidenced by a small number of senior citizens whose body burden exceeded 100 Bq/kg.

The reasons for the great difference in the estimated CEDs based on deposition density and the actual internal contamination found in our studies remain incompletely understood. It may be completely due to the effectiveness of the protection measures instituted for food, or possibly an indication of other fundamental differences between the avenues of exposure after Chernobyl and those in Fukushima.

Conscientious and well-supervised food testing/screening and whole-body counting must be carried out continuously in Fukushima in order to maintain the low-level of internal exposure.

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Instrumental Neutron Activation Analysis (INAA) of Rock Samples from Blue Nile Gorge, East Gojjam, Ethiopia

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Neutron activation analysis (NAA) is an analytical technique based on the measurement of radio-nuclides formed directly or indirectly by neutron irradiation of the material of interest. The main objective of this study is to assess elemental availability and concentration in rock samples of the Blue Nile Gorge area between Gohatsion and Dejen towns. The hydrocarbon potential of the Paleozoic sediments is much debated in this Grand Canyon.The authors maintain that the hydrocarbons were frequently remobilized and redistributed into younger sediments. Paleozoic rocks could have produced significant amount of hydrocarbons in areas characterized by strong Mesozoic sedimentary subsidence. The recent developments in activation analysis techniques now offer the prospect of rapid, reliable analyses for many elements in concentrations as small as parts per million or parts per billion. The neutrons obtained from isotopic neutron source of (α, n) type were used in this paper.

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Qualification tests for tungsten shielded container

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The paper presents the results of qualification tests available at "Horia Hulubei" National Institute for Physics and Nuclear Engineering (I.F.I.H. – HH), Romania, for a tungsten shielded type A container, and for its package. This container is for transport and storage of two ionizing radiation sources (^{60} Co and ^{75} Se) and must safely ensure the colimate iradiation being the main component of The Equipment for Vehicles Non-intrusive Examination. This kind of equipment is designed and manufactured for the first time in Romania and it was be tested for qualification in order to obtain the producing and operating authorization from the national body controlling the nuclear activities. With this authorization, the manufacturer may answer to many demands for this equipment, especially for drugs and explosives screening detection.

The tungsten shielded type A container is a national new because it is intended for **two** ionizing radiations **sources** with **very great activity**: 74 GBq (^{60} Co) and 2,41 TBq (^{75} Se).

The tungsten shielded container and its package passed the following qualification tests:

1. Radiological tests and measurements: dose equivalent rate at the surface and at1 m (for container and for package); reproductibility of sources position (for container); external unfixed contamination of the container surface; capability to resist at repetitive decontaminations (for container) and transport index (for package).
2. Mechanical and climatic tests: thermal conditions for storage and transportation (for container and package); rain conditions and lifetime test (for container) and free drop, stowage, penetration (for package).

One of the most important radioprotection conditions is dose equivalent rate. For this it was evaluated the measuring expanded uncertainty. Its value not exceeded 6% (for a value of dosimeter uncertainty of 5%). This value gives confidence in accuracy of measuring methods and the way these were used.

As a result of the values of the qualification tests which were within the reglementated radioprotection fields, tungsten shielded type A container was approved (qualificated) and it was obtained the Radiological Security Authorization (ASR) for operating.

IMPROVED CONTACT ELEMENTS FOR TRITIUM REMOVAL TECHNOLOGY BASED ON HIDROGEN - WATER ISOTOPIC EXCHANGE

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The combined cryogenic distillation and catalysed isotopic exchange(CD-CE) between hydrogen (deuterium) and liquid tritiated water it's one of the most suitable technology for removal and recovery of tritium from tritiated water produced in fissions and fusion reactors. In order to promote liquid water- hydrogen isotopic exchange(LPCE process) the use of hydrophobic catalyst with high separation efficiency and long stability lifetime it's needed. For LPCE process, the key issue and driver force on the same time consists of in preparation characterization and application of a high efficient catalyst with high hydrophobic properties which to allow to be used in direct contact with liquid and vapor water without of loss of its catalytic activity

The tritium from tritiated water is transferred to the hydrogen gas through the following consecutive reactions:

$$HTO_{(L)} + H_2O_{(V)} \longleftrightarrow HTO_{(V)} + H_2O_{(L)} \qquad (1)$$

$$\underline{HTO_{(V)} + H_{2(G)} \longleftrightarrow HT_{(G)} + H_2O_{(V)} \qquad (2)}$$

$$HTO_{(L)} + H_{2(G)} \longleftrightarrow HT_{(G)} + H_2O_{(L)} \qquad (3)$$

It has been reported by many researchers that reaction (1) becomes effective only in presence of **hydrophobic catalyst** which repels the liquid water but allows to water vapor and hydrogen gas to reach the active catalytic center and accelerate the isotopic transfer process. On the other hand the process (2) it a conventional water distillation process and need an efficient contact element (hydrophilic packing) in order to increase the contact area between water vapor and liquid water. The isotopic exchange of tritium between the hydrogen gas, water vapor and liquid water can take place simultaneously or successively depending of inner structure and geometry of exchange column and of contact elements. The elements contact (catalyst and hydrophilic packing) can be arranged in ordered or unordered structure.

After long research years, several countries, have developed many types of hydrophobic catalysts and hydrophilic packing, different as composition, shape, physic-textural parameters, operating conditions, etc.

Based on the authors' experiments and results and, the present paper it is focused on the new improved contact element for tritium isotopic exchange, developed by ICIT Rm-Valcea. These new improved contact element are devoted to equipped the LPCE column within Experimental Pilot Plant for Tritium Removal Facility

current status concerning the application of hydrophobic catalysts in LPCE process. Two type of hydrophobic catalysts proved good performances in LPCE process and are applied in environmental applications , too:

The paper presents an assessment of main characteristics and performances for the both types of contact elements(catalyst and hydrophilic packing) both in nuclear but non nuclear applications. The comparison of the performances, of the time life and operation conditions it's very useful in the process of selection of catalytic mixed packing for Water Detritiation System(WDS) and Isotopic Separation System(ISS) from the ITER.

Evaluate an Impact of Low Nuclear Radiation Doses for Thorium Oxide on Human Blood Components: *In Vitro*

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Complete blood counts were evaluated in 30 human blood samples (22 male and 18 female). Whole blood samples irradiated by the doses ranged 5)12 µSv/hr from Thorium oxide, and for different time of exposure.

CR-39 NTDs were used to estimate an incident alpha particle density from Thorium oxide on the blood samples. On the other hand, digital radiation dosimeter (RAM DA3-2000) was used to estimate an incident radiation dose. The results show that the main effect was in platelet count and the weight blood count; this was depended on the average dose and the time of exposure. On the other hand, effective time of exposure has been estimate by using 10gm of Thorium Oxide and average dose= 9.77µSv per hour. It was found that the effective to do changes for the human blood components around 2 minutes. .

The research demonstrated that a very small radiation dose from source of Thorium oxide can suppress platelet cell induction by alpha radiation. Weight blood count spectrum was changed in most of the samples, depending on the time of exposure. This is demonstrated the low radiation dose can result in cancer cell, and this is agreement with the essentially of the cell cancer.

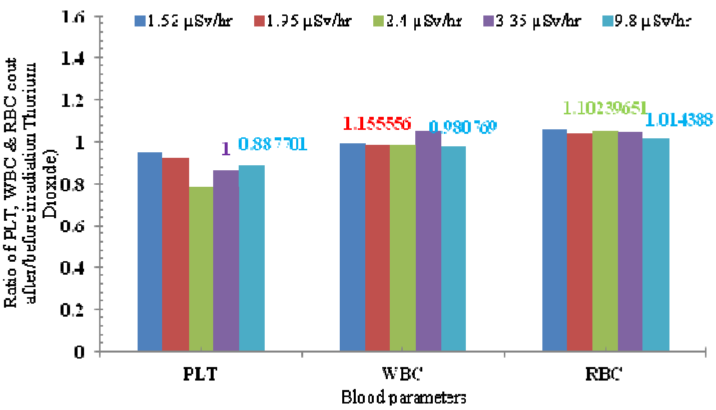

Fig.4 Ratio of PLT, WBC, and RBC with the variation of exposure dose of Thorium Dioxide

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Nuclear fragmentation measurements for hadrontherapy: 95 and 400 MeV/nucleon $^{12}C+^{12}C$ reactions in E600 and FIRST experiments.

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Radiation therapy is one major cancer treatment mean. In order to spare the healthy tissues, many advances have been introduced in the last decades to improve the dose conformation to the tumor. Ion beam therapy (or hadrontherapy) is an emerging modality, which is rapidly spreading worldwide (about 60,000 patients treated so far with protons), due to the depth-dose profiles of protons or light ions, presenting a maximum at the end of their trajectory (the so-called Bragg peak). However, the secondary fragments produced by the nuclear interactions of the beam with the tissue lead to deposit some energy beyond the Bragg peak. This extra dose has to be carefully evaluated to estimate long-term biological side effect in the healthy tissues.

Treatment plans for hadrontherapy (i.e. carbon) are based on Monte-Carlo simulation [1, 2] where the predictions of various theoretical models present uncertainties due to a lack of precise measurements of fragmentation processes in the energy range of interest for charged particle therapy (and space radiation application), especially for double differential cross-sections [3]. Measurements were already made in the past to constraint the simulation models for different impinging energies and to further improve them, the results of two experiments on $^{12}C+^{12}C$ reaction at different energies, designed to enhance the existing measurements, will be presented.

The FIRST (Fragmentation of Ions Relevant for Space and Therapy) experiment aims to measure fragmentation differential cross-section for energies ranging from 100 to 1000 MeV/nucleon at GSI [4]. A campaign was done with that setup in summer 2011 at GSI facility with a 400 MeV/nucleon impinging beam of carbon on a thin carbon target (8 mm). Measurements, at lower energies, were already performed at 95 MeV/nucleon at GANIL [5] on thick targets. An experiment with the same setup (E600) was performed with a carbon beam on thin targets (~200 µm), including one of carbon, in spring 2011.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

A Prototype Scintillating-Fibre Tracker for the Cosmic-Ray Muon Tomography of Legacy Nuclear Waste Containers

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Cosmic-ray muons are naturally-occurring charged particles which are observed at sea level at a rate of 1 per square centimetre per minute. Their high energies (around 3 GeV) allow them to easily penetrate materials. At these energies, they interact with matter primarily through Coulomb scattering from atomic electrons and nuclei. These properties are exploited in muon tomography to image objects inside industrial nuclear waste containers which block or restrictively attenuate more common forms of radiation, such as X-rays or gamma-rays.

To this end, a prototype scintillating-fibre detector system has been developed by the Nuclear Physics group at the University of Glasgow in collaboration with the UK National Nuclear Laboratory (NNL). This system consists of four tracking modules, two above and below the container to be interrogated. Each module consists of two orthogonal planes of scintillating fibres yielding one space point per module. Per plane, 128 _fibres of 2mm pitch, are read out by one Hamamatsu H8500 64-channel MAPMT with two fibres multiplexed onto one pixel. A dedicated mapping scheme has been developed to avoid space point ambiguities while retaining the high spatial resolution provided by the fibres. The configuration allows the reconstruction of the incoming and scattered muon trajectories, thus enabling the container content, with respect to material density (or atomic number Z), to be determined.

The advantage of the chosen design is its ruggedness as the tracking modules do not require a complicated gas system or contain fragile components, thus making it ideal for deployment in an industrial environment. The design and construction of the detector system are presented alongside performance analysis with respect to muon tracking.

A likelihood-based image reconstruction algorithm was developed and tested using a dedicated GEANT4 simulation of the prototype detector system and detailed Monte Carlo modelling of the muonic properties. Images reconstructed from this simulation are presented in comparison with preliminary results from data taken on a test setup. The experimental results verify the simulation, and in both, clear discrimination is observed between the low, medium and high-Z materials imaged.

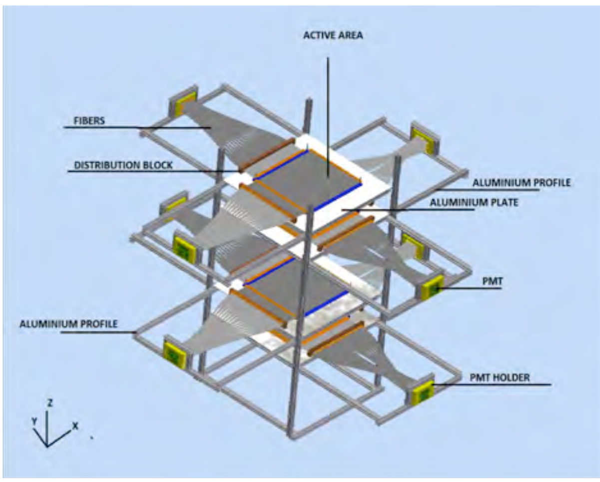

Figure 1: *Schematic View of the Prototype Detector.*

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Measurement, Evaluation and Benchmarking of Selected Differential Cross-Sections Suitable for EBS (Elastic Backscattering Spectroscopy) and NRA (Nuclear Reaction Analysis)

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The recent creation of IBANDL (http://www-nds.iaea.org/ibandl/), an especially designed library supported by IAEA, which mainly contains experimental differential cross-sections suitable for IBA (Ion Beam Analysis) has been a milestone for the evolution of EBS (Elastic Backscattering Spectroscopy) and NRA (Nuclear Reaction Analysis). However, the most reliable differential cross-sections, suitable for widely used analytical programs, yielding high-accuracy light-element depth profile distributions, are the theoretically evaluated ones. The -so far- evaluated datasets are made available to the scientific community through the on-line calculator SigmaCalc (http://www-nds.iaea.org/sigmacalc/) and through IBANDL as well. Nonetheless, while there has been an enormous progress concerning EBS measurements and evaluations [1], in the case of NRA, the situation is far less satisfactory. This can be partly explained from the fact that existing NRA differential cross-section datasets in literature are still not abundant, or are often discrepant, while, at the same time, the theoretical evaluation strongly depends on the quality and availability of experimental differential cross-section data over a wide range of energies and detector angles. It should also be noted, that in many cases (e.g. d–NRA), the evaluation presents additional strong and interesting theoretical challenges, such as the problem of taking into account the co-existence of two reaction mechanisms (direct and compound) with energy-dependent contributions, which seems to be critical for the correct interpretation of the results. Moreover, it is practically imperative to test the reliability of the obtained evaluated results, *a posteriori*, through a rigorous benchmarking process. The results of the benchmarking experiments can in turn provide the necessary feedback for the fine tuning of the optimal potential and resonance parameters and this clearly demonstrates that the theoretical evaluation is indeed a dynamical process.

In the current work the whole evaluation procedure is presented, including differential cross-section data measurements and assessments, theoretical calculations and tuning of the appropriate benchmarking results. The adopted nuclear theory models include different R-matrix approaches [2, 3] (for the analysis of resonances), along with DWBA (Distorted Wave Born Approximation) calculations (when there is a significant direct mechanism contribution). Specific examples of such evaluations are presented for the particular cases of the p+^{12}C, d+^{12}C, and d+d systems, which demonstrate the complexity of the process, as well as, the variety of problems which need to be addressed in order to achieve accuracies in the order of 4-7% (concerning the reproduction of experimental charged-particle spectra at steep backward detection angles). Future perspectives, including the evaluation of differential cross-sections suitable for PIGE (Particle-Induced Gamma-ray Emission) are also discussed and analyzed.

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CHIPS_TPT models for exclusive Geant4 simulation of neutron-nuclear reactions at low energies

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The CHIPS (Chiral Invariant Phase Space) physics package [1], included in Geant4 [2,3], simulates all nuclear reactions for all projectiles and for all energies by one universal quark-level model [4-7]. At low energies the quark-level algorithm becomes ineffective due to tight kinematic limits, so that in final state of nuclear reactions the Non-relativistic Phase Space algorithm [4] is used. In all Geant4 versions the low-energy neutron-nuclear reactions are simulated by the inclusive HP physics package. The corresponding Geant4 physics list is CHIPS_HP. Recently within TPT (Toolkit for Particle Transport) program new low energy exclusive models have been developed. The TPT libraries can be used in Geant4 via CHIPS_TPT physics list.

The exclusive TPT algorithms of low energy reactions are different from the inclusive algorithms of HP (Geant4) or MCNP [8]. Ideally in TPT the R-matrix approach could be used: a projectile neutron creates a compound nucleus, which step by step decays in nuclear fragments and photons. Practically the narrow R-matrix spikes are not resolved by existing data bases, so the compound excitation spectrum is pseudo-continuous. For the first decay one can't use the corresponding branching of the particular nuclear level, so in practice different (n,hγ) reactions are parametrized (where h stands for n, p, d, t, ^{3}He, α or even nn, np, nα...) via excitation cross-sections for different long living levels of the final gamma-active isotopes, which are de-excited by a gamma cascade. The principal feature of the TPT algorithm is the subsequent decay of a gamma-active isotope with energy and momentum conservation at each reaction step and, as a result, in each neutron-nuclear interaction. That is why the TPT algorithms are called exclusive, whilst the HP and MCNP algorithms are conserving energy only as a mean value and hence can be called inclusive algorithms.

The exclusive TPT algorithms demand special treatment of the existing inclusive data bases in ENDF-6 format [9], so a dedicated compact TPT data base was constructed and released together with the TPT libraries. As a result, TPT can simulate such effects as kinematical width of gamma-lines and kinematical correlations of secondary particles. Strict energy and momentum conservation implemented in TPT, as well as in any CHIPS algorithm, is essential for KERMA standardization of sources. In addition to the development of the low energy algorithms TPT program is the only place where the CHIPS algorithms are supported and developed, while in the upcoming versions of Geant4 the CHIPS physics package is going to be deprecated. The goal of the presentation is to demonstrate, that the exclusive TPT algorithms fit the inclusive data on the level of the inclusive HP and MCNP algorithms and in addition provide new features for simulation of neutron-nuclear reactions.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

New isotopes for medical applications

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Radioisotopes play an important role for diagnostics and therapy in nuclear medicine.
The leading isotopes for SPECT (^{99m}Tc) and PET (^{18}F) are characterized by nuclear properties (half-life, energy and branching ratio of gamma rays or positrons respectively) that are very well matched to many diagnostic applications.

On the other hand, for therapy the traditional isotopes are not necessarily optimized for all applications. ^{131}I is perfect for treating thyroid cancer and some other thyroid dysfunctions, but its high energy gamma rays cause a considerable dose to adjacent persons and require a prolonged isolation of the patient. Therefore, applications that do not make use of the chemical properties of iodine but that are using antibodies, peptides or other targeted bioconjugates for receptor targeted radionuclide therapy should be better combined with other therapeutic radionuclides.

Some of these “new” isotopes are not yet available commercially and require unconventional production methods. A recent example is the production of a quadruplet of four different terbium isotopes produced by thermal neutron capture in the high flux reactor of Institut Laue Langevin (^{161}Tb) and by GeV proton induced spallation of tantalum targets and on-line mass separation at ISOLDE-CERN (^{149}Tb, ^{152}Tb, ^{155}Tb) respectively. These four isotopes cover all nuclear medicine modalities (low energy gamma ray emission for SPECT, positron emission for PET as well as beta-minus, alpha and Auger electron emission respectively for therapy), but have identical (bio-)chemical behavior. That makes them particularly interesting for “Theranostics” where the administrated activity of the therapeutic isotope is individually optimized based on the measured patient-specific uptake of the corresponding diagnostic isotope.

While present RIB facilities play an important role in facilitating preclinical research towards new promising applications in nuclear medicine, future RIB facilities could even provide certain isotopes with unique properties in sufficient quantities for clinical applications.

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Nuclear fragmentation studies for Hadrontherapy in Caen, France

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Hadrontherapy treatments consists in irradiating a tumor with light ions. This requires a very high precision on the dose location in order to keep the benefits of the precise ions ballistic. A part of the uncertainty on physical dose deposition is due to ion fragmentation along its path in the patient. Up to now, the simulation codes are not able to reproduce the fragmentation process with the required accuracy. The constraints on nuclear models and the measured fragmentation cross sections are not sufficient for light projectiles on light targets in the energy range from 30 to 400 MeV/u.

In this context a program of fragmentation measurements has started in Caen in 2007. A first experiment on thick water equivalent targets has been performed on May 2008 at GANIL. Energy and angular distributions of the fragments coming from the nuclear reaction between ^{12}C at 95 MeV/u and thick PMMA targets have been measured [1]. Data comparisons with GEANT4 simulations using BIC, QMD, INCL physics list have shown discrepancies up to one order of magnitude for production rates. The shapes of the angular and energy distributions are also not well reproduced.

As it is difficult to constrain the nuclear reaction models by a direct comparison to thick targets experiments, a second experiment has been performed with a 95 MeV/u ^{12}C beam on thin targets (C, CH_2, Al, Al_2O_3, Ti) in May 2011 at GANIL. To detect the charged fragments, the experimental set-up included five three stages $\Delta E - E$ telescopes with two Si detectors (thickness: 150 μm and $1mm$) and one CsI scintillator (thickness: 10 cm). These telescopes were mounted on rotating stages to cover angles from 4 to 45° with 2° steps. The double differential cross sections ($\frac{\partial^2\sigma}{\partial E \partial \Omega}$) of fragments produced at 95MeV/u in C-H, C-C, C-O, C-Al and C-^{nat}Ti reactions have been obtained for angles from 4 to $45°$. First comparisons with GEANT4 simulation (BIC, QMD) show huge discrepancies.

The results of these experiments performed at GANIL will be presented with a focus on thin targets. The results of GEANT4 simulations will also be shown for comparison with experimental data.

To complete the results of the 2011's experiment at forward angles, a new experiment with a 95 MeV/u ^{12}C beam on thin target is expected at GANIL in 2013. The goal is to measure the differential cross sections of fragmentation at 0 and 2° in order to complete the distributions obtained for C-H, C-C, C-O, C-Al and C-^{nat}Ti reactions. The WP2 of the national network "France HADRON" includes the measurement of nuclear data of relevant interest for hadrontherapy. Thus, new experiments are expected at GANIL with 50 MeV/u and 95 MeV/u ^{12}C, ^{7}Li... beams in the following years.

Finally, a new advance resource center for hadrontherapy, the ARCHADE center [2], is expected in Caen. The ion beams delivery, from alpha to carbon, is planned for 2018. A full program of fragmentation studies from 100 to 400MeV/u is planned within the WP4 of the scientific programm of ARCHADE.

The ARCHADE center and the complete program of measurements in Caen will be presented.

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Measurement of ^{136}Ce, ^{156}Dy and ^{168}Yb Thermal Neutron Capture Cross Sections

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For several low abundance stable nuclei, the thermal neutron capture cross sections are not well measured, while the cross sections for isotopes with high abundances are already well measured. Especially, the cross sections of the thermal neutron capture reactions on ^{136}Ce, ^{156}Dy, and ^{168}Yb are poorly measured, though the capture cross section data play essential roles in determining neutron capture cross sections over wide energy regions in nuclear data evaluations.

Our experiments, different from the commonly used method of using gold foil as reference, are performed using natural foils for which we know the relative abundances of all isotopes and thermal neutron capture cross sections. Therefore, we can obtain the cross sections of low abundance isotopes, which are not known well, by comparing the yields of gammas from the neutron captures by various isotopes in the foils. The advantage of this method is the cancellation of potential systematic errors from thermal neutron flux, flux profile, foil thickness, foil size, and irradiation time.

To measure thermal neutron capture cross sections, we used the high thermal neutron flux from the research reactor HANARO at Korea Atomic Energy Research Institute. We irradiated the natural Ce, Dy, and Yb foils (99.9 % pure) in the neutron irradiation facility for 6.0 h, 8.5 h, and 3.0 h, respectively, considering the neutron capture cross sections of the natural isotopes in the natural foils, material sizes, and gamma intensities and activations after neutron captures. And we measured the gammas from the irradiated Ce, Yb, and Dy foils with a Be-windowed HPGe detector located at KAERI.

We could measure the thermal neutron capture cross sections of ^{136}Ce, ^{156}Dy, and ^{168}Yb by comparison with the activity measurements of their reference isotopes ^{140}Ce, ^{164}Dy, and ^{174}Yb and obtained new cross section values of 7.64±0.63 barn for ^{136}Ce, 14.38±1.94 barn for ^{156}Dy, and 1346.1±32.0 barn for ^{168}Yb.

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Studies of atmospheric tracers ^{7}Be and ^{22}Na in Finland; The Summary

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Radiation and Nuclear Safety Authority - STUK monitors airborne radioactivity in Finland. Monitoring stations are located in different parts of the country, three stations above Arctic Circle. The airborne radioactivity is monitored by pumping air through a filter where the filter is changed after predetermined time period. The filter is then measured with a HPGe detector in a low background environment. The main aim of monitoring is to monitor anthropogenic radionuclides but the data also contains concentrations of natural radionuclides. It has been suggested by several authors that cosmogenic radionuclides such as ^{7}Be can be used as a natural tracer for atmospheric dynamics eg. [1]. However, the use of cosmogenic isotopes has been difficult due to the lack of effective analysis methods and computing power.

Time series of ^{7}Be concentrations in surface air starting from 1987 has been collected and analyzed using novel time series analysis tools. Analyses showed that there are several periodicities in surface air ^{7}Be concentrations ranging from 2-14 years. In coherence analyses these periodicities were found to follow different teleconnection indices e.g. North Atlantic Oscillation index. Since the observation data is weekly data, intraseasonal oscillations were also studied, in earlier studies by other authors periodicities from 20-30 days were found and they were linked to solar rotational period [2]. In our studies, we didn't found 20-30 day periodicities but we discovered a period of 45-90 days which was speculated to be caused by meridional wind oscillations or Arctic Oscillation.

The ^{10}Be/^{7}Be ratio has been proposed to be used as radiochronometer for atmospheric dynamics [2]. The main problem using ^{10}Be/^{7}Be ratio as a radiochronometer lies in the difficulty of the measurement where atomic mass spectrometer (AMS) must be used. In airborne radioactivity measurements two cosmogenic isotopes are observed simultaneously ^{7}Be and ^{22}Na. In ^{7}Be/^{22}Na ratio there is a distinct annual cycle where low ratios are observed during summer and high ratios during winter where the ^{7}Be/^{22}Na ratio is dependent on the origin of the air mass. The ^{7}Be/^{22}Na ratio changes as a function of altitude where low ratios are produced in the upper atmosphere, mainly in stratosphere. We showed that ^{7}Be/^{22}Na ratio can be used as a complementary method to ^{10}Be/^{7}Be ratio allowing more simple measurements and thus wider range of available data.

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Nuclear techniques and nuclear reaction data for investigation of paintings and stained glasses

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The work of art is a physical multilayer complex system, interacting with its surrounding, inseparable from the materials which compose it and from their evolution over time. An ideal methodology for investigating a painting or any other historical or artistic artifacts should be non-destructive (namely, respecting the physical integrity of the object), allowing a single object to be investigated at various positions and points in a reasonable amount of time. Moreover, measurements must be sensitive enough to detect not only major constituents but also trace elements, and multi-elemental so providing information on many elements in a single measurement.

Nuclear physics offers a broad spectrum of tools and methods, fulfilling at last some of the previously mentioned points for determining the elemental analysis of the painting matter such as: Neutron activation (Autoradiography), Particle-induced X-ray emission (PIXE), Particle-induced gamma ray emission (PIGE), Rutherford backscattering (RBS), Accelerator mass spectrometry (AMS), etc., along with many other methods employed in material sciences like Raman spectroscopy, the various x-rays fluorescence induced by x-rays and photons (XRF, μ-XRF, etc.).

Among these methods, many are based on the use of ionizing radiation and a short review is presented of non-destructive nuclear techniques applied to the investigation of cultural heritage artifacts and relevant results concerning paintings and stained glasses. Main aspects are discussed concerning nuclear reaction cross-sections for PIXE and PIGE analyses, especially referring to cultural heritage diagnostics, within the framework of ion beam analysis (IBA) methods.

Nuclear data relevant to light-element analysis in archaeometry are specifically considered and their impact on the knowledge and conservation of the cultural heritage is pointed out, especially discussing most significant examples concerning the beneficial use from the evaluated nuclear data on the results obtained by the application of this nuclear analytical technique. Consistently, relevant topics are discussed concerning the evaluation of the requested nuclear reaction data, on the basis of the existing experimental values and nuclear model calculations, according to the appropriate parameterization and the effects on the calculation results. Recent results are presented for $(p,x\gamma)$ reaction data, by comparing critically selected experimental data and the relevant model calculations, with regard to significant isotopes of low- and medium-mass elements of actual interest when considering alloys and other fabrication techniques for archaeological objects.

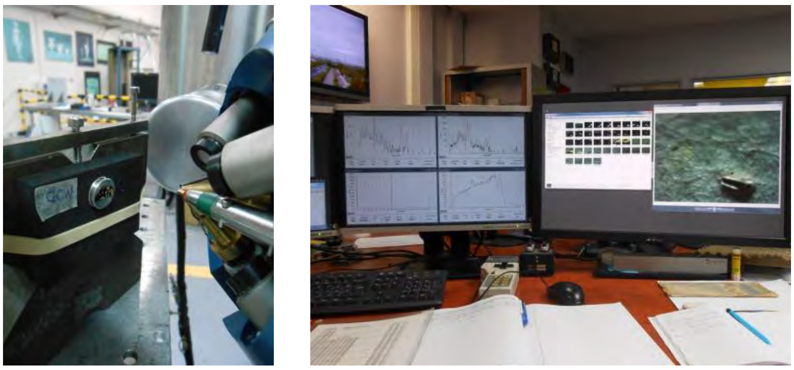

Figure 1: *Measurements performed at AGLAE facility, Paris, France*

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Simulations of fragmentation reactions for hadrontherapy

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Hadrontherapy is a successful method of treating certain types of cancer by irradiating them with accelerated beams of hadrons. Compared to traditional radiotherapy techniques such as photon or electron beams, hadrontherapy in general allows better confinement of the dose deposition to the tumour volume. At the same time, however, hadrons can undergo nuclear reactions with the nuclei in the human body, triggering the production of secondary particles that can deliver unwanted dose to sensitive organs. This is especially a concern in the case of hadrontherapy with light ions (notably ^{12}C). The cross sections for such fragmentation reactions must be known to a good degree of accuracy when planning treatment.

Reliable nuclear-reaction models are necessary to estimate the effect of nuclear fragmentation whenever experimental data are not available. For nucleon-induced or light-nucleus induced reactions, intranuclear-cascade models can be considered to be among the most appropriate tools. In particular, we shall focus on the Liège Intranuclear Cascade model (INCL), which was conceived as a tool for the study of nucleon-induced reactions at high energy and has since been extended to lower energies and, recently, to light-ion induced reactions. The INCL model is presently available in several popular radiation-transport codes, such as PHITS and Geant4, and is expected to be distributed with the new MCNP6 code.

This paper will illustrate the application of the C++ version INCL++ to several systems of interest for hadrontherapy, with special focus on ^{12}C therapy. We shall validate the model by comparing its predictions with existing thin-target experimental data (double-differential particle-production cross sections, fragmentation cross sections). Furthermore, we shall demonstrate the usefulness of the INCL++ model for hadrontherapy-related studies by comparing the results of thick-target simulations with measurements of double-differential and/or inclusive particle yields. The INCL++ results will also be compared with the predictions of other models available in transport codes. As an example, Figure 1 compares model predictions for proton yields from a 200-AMeV ^{12}C projectile on a thick water target.

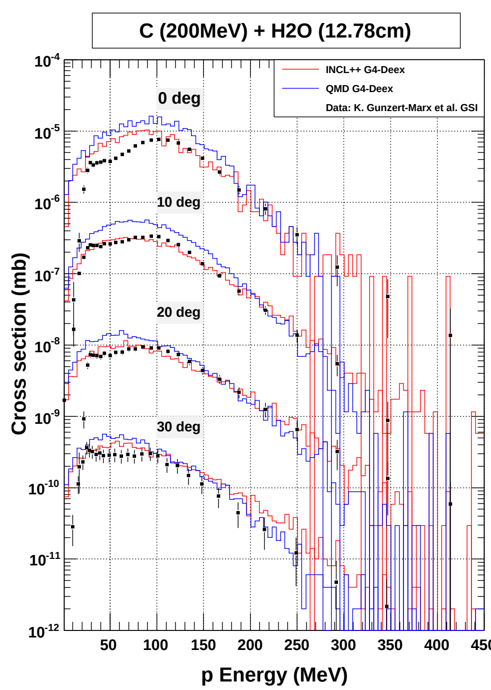

Figure 1: Double-differential proton yields from a 200-AMeV ^{12}C projectile on a thick water target, as calculated by INCL++ and G4QMD. Data from Gunzert-Marx et al., New J. Phys. 10 (2008) 075003.

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Nuclear microprobes in biomedicine and environment: technical developments and applications

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Despite the fact that a lot of efficient analytical and chemical imaging techniques have been extensively developed in bio labs and at worldwide facilities for applications in biomedicine nowadays, microanalysis based on elemental mapping at ppm level of sensitivity and on a micron or submicron scale remains a challenge. Among those techniques, a few of them have proved their capability to measure trace elements and to deliver tissue images with sub-micrometer resolution, both rapidly and non destructively, authorizing the localization of cellular structure. Even though routine sound applications are steadily developed at our facilities, one can reasonably question the future of this technique when compared to SIMS, Synchrotron Radiation nanofocussed X-ray beams or even Immnuno-labelling combined with fluorescent probes in the optical visible wavelength. Hopefully, the versatility of nuclear microprobes, the possible quantification in absolute mode and the easy access to the instrument, even with the support of transnational European Actions [1], are still strong arguments for the use of nuclear microprobes. The combination of high resolution proton microbeams with PIXE, RBS, STIM in 2D or 3D mode offers a large panel of analytical possibilities.

New fields have been opened during the last decade. In plant biology, remediation of polluted soils in the environment, including radioactive species gave rise to new applications. After the pioneering work of the FP5 consortium NANODERM [2], Nanotoxicology is now an active domain of research where studies in cultured cells or multicellular organisms exposed to artificial nanoparticles are becoming widespread. On a technical point of view, sample cryo-preparation techniques have been implemented and first cold stages, aiming at limiting sample damages, have been installed in end-stations of microbeam lines. Real applications of PIXE-Tomography in biological samples have been obtained. The aim of this talk is to present a review covering new technical progress and achievements in Biology and Environment.

[1] SPIRIT (www.spirit-ion.eu)
[2] NANODERM (www.uni-leipzig.de/~nanoderm/)

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Applications of Atom Trap Trace Analysis in the Earth Sciences

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With the successful development of the Atom Trap Trace Analysis (ATTA) method, radiokrypton dating has become available for the first time to the Earth science community at large. This novel tool, based on laser cooling and trapping and single atom counting of rare noble gas isotopes such as ^{81}Kr (230,000 yrs half-life) and ^{39}Ar (270 yrs), is enabling new research opportunities and improved understanding in the Earth sciences, with implications in studying climate change and in water resource management. Examples of applications of ATTA in the Earth sciences are: (1) ATTA measurements of ^{81}Kr in old underground water reservoirs such as the Nubian Aquifer of Africa, the Great Artesian Basin of Australia, and the Guarani Aquifer of South America to understand the long-term behavior of these large aquifer systems. ^{81}Kr dating with more extensive sampling will be carried out on major aquifer systems around the world. (2) The feasibility and accuracy of ^{81}Kr dating of old ice has been tested with the well-dated stratigraphy of Taylor Glacier in Antarctica. (3) A systematic survey of ^{39}Ar throughout the oceans, particularly when combined with ^{14}C data, will fill major gaps in our knowledge of deep ocean circulation and mixing, and will allow more accurate predictions of oceanic sequestration of atmospheric CO_2.

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^{99}Mo production via ^{100}Mo(n,2n)^{99}Mo using accelerator neutrons

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^{99m}Tc, the daughter nuclide of ^{99}Mo with $T_{1/2}$=66 h, is the most common radioisotope used in diagnosis. In fact, more than 25 million medical diagnostic procedures have been performed worldwide every year using ^{99m}Tc-based radiopharmaceuticals. Therefore, a reliable and constant supply of ^{99}Mo is the key issue to ensure the routine application of ^{99m}Tc. About 95% of ^{99}Mo has been produced by the fission reaction of highly enriched ^{235}U in research reactors in the world. However, a number of incidents of the reactors caused the shortage of ^{99}Mo, which has triggered widespread discussions on the medium- and long-term supplies of ^{99}Mo.[1)] In fact, many efforts are being made for the domestic production of ^{99}Mo or ^{99m}Tc worldwide.[1,2)]

We proposed a new route to produce ^{99}Mo via ^{100}Mo(n,2n)^{99}Mo using fast neutrons from an accelerator.[3)] The reaction cross section is large, 1.5 b at a neutron energy E_n≈14MeV, which is ten times larger than that of ^{98}Mo(n,γ)^{99}Mo at the thermal energy. We have performed all important steps necessary to obtain high-quality ^{99m}Tc using ^{99}Mo, which was produced using fast neutrons from ^{3}H(d,n)^{4}He.[4)] The intensity of 14MeV neutrons at a ^{100}Mo sample position is the key issue for sufficiently producing ^{99}Mo. Recently, significant progress has been achieved in accelerator technology, which enables us to obtain high-flux fast neutrons with a most probable energy of 14MeV by C(d,n) using 40 MeV deuterons.[5)]

We showed that other medical isotopes, such as ^{90}Y, ^{64}Cu, and ^{67}Cu, are significantly produced using accelerator neutrons.[6,7)]

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Nuclear-related techniques at LABEC for the analysis of atmospheric aerosols

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At the 3 MV Tandetron accelerator of the LABEC laboratory of INFN (Florence, Italy) an external beam facility is fully dedicated to PIXE-PIGE measurements of elemental composition of atmospheric aerosols (PM, particulate matter). All the elements with $Z > 10$ are simultaneously detected by PIXE in few minutes, with minimum detection limits ranging between below 1 and 10 ng/m^3. This setup allows us an easy automatic positioning, changing and scanning of samples collected by different kinds of devices (PM low-volume samplers, multistage cascade impactors, continuous streaker samplers): long series of daily PM samples can be analysed in short times, as well as size-segregated and high time-resolution aerosol samples [1]. Owing to X-ray self-absorption inside each individual aerosol particle, the concentrations of the lightest detectable elements (Na, Mg, Al) can be underestimated by PIXE. For this reason PIGE is routinely performed simultaneously with PIXE to improve the quantitative analysis of these elements.

In order to obtain a complete reconstruction of the aerosol mass, we implemented the detection of H, C, N and O, which are main constituents of particulate matter, by means of in-vacuum Elastic Backscattering Spectrometry (EBS) and Particle Elastic Scattering Analysis (PESA) on samples collected on PTFE filters [2].

Furthermore, an experimental procedure for radiocarbon measurements on aerosol samples by Accelerator Mass Spectrometry (AMS) has been recently developed. These analyses give fundamental information for the assessment of the contribution of natural and anthropogenic sources (fossil fuel combustion, biomass burning, biogenic aerosols) to the carbonaceous aerosol load in atmosphere [3].

The experimental set-ups will be described and discussed in this presentation, highlighting advantages and limitations of the different techniques, and a number of results obtained in recent monitoring campaigns, performed in urban and remote areas, both on a daily basis and with high time resolution (hourly samples), will be presented.

Thanks to the capability of detecting all the crustal elements, IBA analysis are unrivalled in the analysis of mineral dust: as a consequence they are very effective in the study of natural aerosols, like, for example, Saharan dust intrusions [4]. Among IBA-detectable elements there are also important markers of anthropogenic sources, which allow effective source apportionment studies in polluted urban environments.

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The FLUKA code: recent developments and applications in hadron therapy

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FLUKA [1,2] is a Monte-Carlo code able to simulate interaction and transport of hadrons, heavy ions and electromagnetic particles from few keV (or thermal energies in the case of neutrons) to cosmic ray energies in whichever material. The highest priority in the design and development of the code has always been the implementation and improvement of sound and modern physical models. Close attention is also paid to the validation of such models through the comparison with benchmark experiments.

FLUKA is successfully used in several fields, including particle physics, cosmic ray physics, dosimetry, radioprotection, hadron therapy, space radiation, accelerator design and neutronics. The code is the standard tool used at CERN for dosimetry, radioprotection and beam-machine interaction studies.

An overview of the status of the code and its principal applications of interest for hadron therapy will be given, in particular concerning the verification of the dose delivery predicted by treatment planning systems; the prediction of β^+ emitter distribution for treatment verification with PET techniques (both after the treatment and in-beam); the prediction of prompt γ-ray and particle emission for online range verification.

A summary of recent developments in the FLUKA physical models will also be discussed, with particular interest in those concerning hadron therapy applications: among the others, the improvement of nucleus-nucleus reaction cross-sections; the refinement of the prompt photon emission model; the development of a physics-driven model for acollinearity in positron annihilation at rest; the implementation of built-in scoring for quantities of radiobiological interest.

[1] "The FLUKA code: Description and benchmarking" G. Battistoni, S. Muraro, P.R. Sala, F. Cerutti, A. Ferrari, S. Roesler, A. Fassò, J. Ranft, Proceedings of the Hadronic Shower Simulation Workshop 2006, Fermilab 6–8 September 2006, M.Albrow, R. Raja eds., AIP Conference Proceeding 896, 31-49, (2007)
[2] "FLUKA: a multi-particle transport code" A. Fassò, A. Ferrari, J. Ranft, and P.R. Sala, CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Fukushima Nuclear Power Plant Accident And Nuclear Physicists

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The Fukushima Dai-Ichi Nuclear Power Plant caused a major accident in March, 2011 after the plant suffered huge Tsunami waves. While no major destruction of the reactors has been reported, a large amount of radioactive materials leaked out. The earthquake destroyed external power lines to the plant, and Tsunami damaged all emergency power generators. Due to the lack of electricity, the cooling of the reactors was lost. The resultant high temperature produced hydrogen gas by the reaction of water and fuel rod (Zr metal), and this hydrogen gas exploded, emitting fission products into the air. Details of the accident have not been clarified yet.

Emitted radioactive materials important to human being and environments are ^{131}I, ^{134,137}Cs, *etc*. These were spread over a wide area soon by air streams and have fallen onto the earth by rain. It was very urgent to examine how much inhabitants and the environment were contaminated. This survey had to be done very quickly, accurately and widely. The knowledge, skill and experience of nuclear physicists match very well to this need, and there were two big operations starting right after the accident. One is the survey on human beings aiming at ^{131}I, particularly for young generations. The other is the survey of radioactivity from the soil. For both, many nuclear physicists over the nation have participated and contributed. The latter, for instance, yielded a “map” of ^{134,137}Cs and ^{131}I in Fukushima region based on the γ-ray data from 11000 soil samples taken at 2200 locations. A summary of such activities will be presented including some others, as well as possible contributions to future energy issues.

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Determination and Evaluation of the Differential Cross-Sections of the ^{2}H(d,p) Reaction at Energies and Detection Angles Suitable for NRA (Nuclear Reaction Analysis)

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Deuteron implantation has been extensively used in the past as a means for the modification of the physical properties of metals, compounds and semiconductors. The accurate determination of the resulting deuteron depth profiles presents a strong analytical challenge for all the principal IBA (Ion Beam Analysis) techniques. Among these, ERDA (Elastic Recoil Detection Analysis) has been successfully employed in the past for the study of ultra-thin deuteron layers, being close to the target's surface, whereas NRA (Nuclear Reaction Analysis), using the ^{2}H(d,p) reaction, has been proposed for in-beam monitoring purposes [1], and indeed seems to be the most promising candidate, especially in the case of complex matrices or for the study of deep-implanted layers.

NRA, a well-established IBA technique nowadays, presents important advantages, such as high isotopic selectivity, enhanced sensitivity for many nuclides, capability of least-destructive depth profiling, and possibility of simultaneous analysis of more than one light element in near–surface layers of materials. Moreover, in the particular case when deuterium is used as probing beam, critical advantages for d-NRA studies emerge, due to: a) the simultaneous excitation of most light elements (e.g. B, O, N, C, F, Al, Mg and S) usually co–existing in complex matrices, either as main constituents or as impurities, and b) the enhanced sensitivity and accuracy, mainly due to the generally large cross-sections of the deuteron–induced nuclear reactions.

The creation of IBANDL (http://www-nds.iaea.org/ibandl/), an especially designed library supported by IAEA, which contains differential cross-sections suitable for IBA that can be directly incorporated in widely used analytical programs, has significantly enhanced the analytical power of NRA, and d-NRA in particular. However, the most reliable differential cross-sections are the theoretically evaluated ones, and for d-NRA a lot of key reactions, such as the ^{2}H(d,p) one, still need to be addressed.

In the present work differential cross-section values for the ^{2}H(d,p) reaction have been determined at 140°, 150°, 160° and 170°, for $E_{d,lab}$=900-1600 keV, with an energy step of 50 keV, using a well-characterized, thin, and polished C:D target deposited on a Si wafer. Also, selected data points were measured at four more backward detection angles, up to 110°, in order to facilitate the subsequent theoretical evaluation. In the case of d–NRA such an analysis presents strong and interesting theoretical challenges; particularly the problem of taking into account the co-existence of two reaction mechanisms (direct and compound) with energy-dependent contributions seems to be of vital importance. In order to address this problem, different R-matrix codes have been employed, along with DWBA calculations. The results, in graphical and tabular form, will soon be available to the scientific community through the on-line calculator SigmaCalc (http://www-nds.iaea.org/sigmacalc/) and IBANDL.

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Nuclear fragmentation measurements for hadrontherapy

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Nuclear fragmentation processes are relevant in different fields of basic research and applied physics and are of particular interest for light ion tumour therapy by means of light ions beam, and for space radiation protection applications.
The informations about the yelds and the spectra of secondaries produced by a therapeutical ion beam in the path to the tumour inside the patient are crucial to estimate the dose imparted to the health tissues around the tumor. Furthermore the fraction of secondaries escaping from the patient can provide informations about the pattern and the amount of the dose released, being of interest for monitoring purpose.
Experiments focused on fragmentation studies applied to hadrontherapy at GSI and LNS will be presented and the first analysis results will be reported.

Study of best coincidence time resolution of LYSO crystals coupled to fast and high quantum efficiency photomultipliers

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We have investigated the coincidence time resolution (CTR) achievable between two short and small (3x3x3 mm^3) LYSO crystals with high light yield produced by Proteus manufacturer, each coupled to a fast rise time (T_r) and high quantum-efficiency (QE) photomultiplier (PMT), and exposed to a ^{22}Na source in a back-to-back geometry. Two PMT types produced by Hamamatsu Photonics have been tested: the R9880U-110 type equipped with a super bialkali QE cathode and T_r of 0.57 ns, and the R7600U-200 one, a ultra bialkali QE cathode with T_r of 1.4 ns. The lowest CTR measured value, 140 ps FWHM at 511 keV, obtained for the R7600U-200 PMT, is considered the best timing achievable with the tested scintillators. A slightly worse CTR, 160 ps, has been obtained for the R9880U-100 PMTs. The influence of QE and T_r on the deduced values will be discussed. The measured deterioration of the CRT values with the crystal length will be shown. The results may have relevance in the positron emission tomography implemented with the time-of-flight technique (TOF-PET).

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Nuclear-physics applications of MYRRHA

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MYRRHA, (Multi-purpose hYbrid Research Reactor for High-tech Applications), is a hybrid system, that combines a 600-MeV x 4-mA proton linear accelerator and a lead-bismuth eutectic (LBE) cooled fast spectrum research facility. MYRRHA can be operated in both sub-critical (accelerator-driven system (ADS)) and critical modes, allowing fuel developments for innovative reactor systems, material developments for GEN IV systems, material developments for fusion reactors, medical radioisotopes production and industrial applications (e.g. Si-doping). The system will also demonstrate the ADS full concept by coupling the three components (accelerator, spallation target and subcritical reactor) at a reasonable power level to allow operation feedback, scalable to an industrial demonstrator and allow the study of efficient transmutation of high-level nuclear waste.

Moreover, by branching off a small fraction of the proton beam, the ISOL@MYRRHA facility will be operated in parallel to the MYRRHA-ADS. This facility should use up to 200-μA x 600-MeV proton beam for the production of Radioactive Ion Beams (RIBs) via the Isotope Separator On Line (ISOL) method. By combining the high primary-beam intensity with selective ionization and a beam-purification system with high mass-resolving power, it will be possible to produce intense RIBs with high purity. ISOL@MYRRHA aims to be complementary to existing facilities, by focusing on experimental programs requiring long uninterrupted beam times. These are experiments which

- hunt for very rear phenomena,
- need high statistics,
- need many time-consuming systematic measurements,
- have inherent limited detection efficiency.

Measurements with high-intensity beams and extended/regular beam times are an important source of information for quasi all fields in science making use of RIBs, ranging from fundamental-interaction measurements with extremely high precision over systematic measurements for condensed-matter physics and production of medical radio-isotopes. In nuclear physics, e.g. determining precise values of extremely small decay branches (in the order of 10^{-6}) or crystal γ-ray spectrometry with very high resolution can provide crucial experimental input for understanding aspects of nuclear structure. Long beam times could be also of interest for astro-physics, when nuclear reactions with small cross sections are involved, but the absence of a post-accelerator in the present design of ISOL@MYRRHA will prevent such kind of studies. Although higher-energy secondary beams are not discarded for a later phase, only research with low-energy beams (up to 60 keV) is addressed for the moment.

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Nuclear medicine and opportunities of modern methods of radionuclide diagnostics in Kazakhstan

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Nuclear medicine is a branch of radiation medicine, which is based on the use of open (non-encapsulated) radioactive substances for the purpose of diagnosis, treatment and in scientific research. Nuclear medicine techniques are not traumatic and provide unique information on the nature of the ongoing process, the extent of its prevalence, the presence of focal formations. In many cases, the use of open radioactive sources has no alternative, and especially in the diagnosis, because the information obtained is based on the functional aspect of nuclear biomedical technologies.

The emergence of a new generation of diagnostic equipment in Kazakhstan allows early assessment of functional and morphological state of organs at the molecular level and the introduction of innovative instrumental and methodological approaches for the local non-traumatic exposure tumors in the early stages of the disease.

Modern equipment of Nuclear medicine center at JSC "National Diagnostic Center" enables high-quality short-term studies, thus reducing the time and pain assessment of each patient, and increasing the capacity of separation. More than 20 studies in various fields of medicine are held daily, such as: oncology - application of nuclear medicine technology and PET/CT to determine the exact stage of the disease, monitor patient's response to treatment and to predict the result of the early detection of relapse in cancer patients. Using radioactive substances, in particular, F-18 (FDG), etc., can identify the different types of tumors and change the type of treatment depending on the results of the study. Accordingly, the surgical approach or chemotherapy may be selected in accordance with the research results of the individual patient.

1228 PET/CT studies were held in 2011. More detailed results of research using F-18 (FDG) are described in the paper [1].

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Proficiency test: A quality assurance method for high-purity based gamma spectrometry system

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The activity of SALMROM laboratory, part of Life and Environmental Physics Department from IFIN-HH, consists in regular monitoring the environmental radioactivity, on daily/monthly bases, in the area of the institute and nearby. Routinely measured isotopes in environmental samples are ^{40}K, ^{60}Co, ^{137}Cs, ^{241}Am and progenies of ^{238}U and ^{232}Th series. Some other activities, devoted to research programs, are related to evaluation of radon concentration in salt mines, caves, construction sites or former industrial area, to radionuclide inventory in water, soil or vegetation in the environment.

The quality assurance of the laboratory for gamma spectrometry measurements has been assessed by the annually organized proficiency test (PT) by IAEA. These PTs evaluate the validity and reliability of the analytical results. Reference materials were distributed to the participating laboratories and, using a rating system, their analytical results were compared to the reference values assigned. It is of major importance to obtain accurate analytical results of radionuclides, our laboratory producing acceptable results for most of the radionuclides reported: ^{60}Co, ^{133}Ba, ^{137}Cs, ^{152}Eu and natural radionuclides, excepting ^{226}Ra; and only for few radionuclides, ^{241}Am and ^{226}Ra, it was indicated the need for corrective actions in the analysis process. More results (Table 1) and corrective actions, for water and soil samples, are discussed in the paper. The detector used is a coaxial p-type HPGe detector (ORTEC, model GEM30P4) having a relative efficiency of 35% and energy resolution of 1.85 keV at 1332.5 keV, ^{60}Co [1]. The minimum detectable activities (MDA) for 200 g soil sample and 350000 s counting time, for important radionuclides such as ^{226}Ra, ^{40}K, ^{137}Cs, ^{60}Co and ^{241}Am are 4.1, 18.9, 0.5, 0.8 and 1.4 Bq kg-1, respectively.

Table 1: *Results of the PT for one spiked water and a soil sample.*

Analyte	IAEA Value [Bq/kg]	IAEA Unc [Bq/kg]	Lab Value [Bq/kg]	Lab Unc [Bq/kg]	Lab Unc %	z-Score	u-Test	Ratio Lab/ IAEA	Trueness	Precision	Final Score
Am-241	4.7	0.1	3.85	0.36	9.35	-0.90	-2.27	0.82	A	A	A
Ba-233	5.0	0.1	5.60	0.37	6.61	0.60	1.57	1.12	A	A	A
Co-60	15.3	0.2	14.57	0.60	4.12	-0.24	-1.15	0.95	A	A	A
Cs-134	7.7	0.1	7.90	0.60	7.59	0.13	0.33	1.03	A	A	A
Cs-137	6.2	0.1	6.55	0.31	4.73	0.28	1.07	1.06	A	A	A
Eu-152	15.4	0.2	14.19	0.86	6.06	-0.39	-1.37	0.92	A	A	A
H-3	50.2	0.9	52.9	4.5	8.51	0.27	0.59	1.05	A	A	A
SOIL											
Ac-228	41.0	2.0	38.3	2.9	7.57	-0.33	-0.77	0.93	A	A	A
Am-241	0.21	0.08									
Bi-214	50.0	2.8	42.5	2.9	6.82	-0.75	-1.86	0.85	A	A	A
Cs-137	14.4	0.6	14.6	0.6	4.11	0.07	0.24	1.01	A	A	A
K-40	485	11	465.9	17.0	3.65	-0.20	-0.94	0.96	A	A	A
Pb-212	36.5	1.6	37.6	1.6	4.26	0.15	0.49	1.03	A	A	A
Pb-214	50.0	3.8	43.6	2.0	4.59	-0.64	-1.49	0.87	A	A	A
Ra-226	50.2	2.0	39.6	1.7	4.29	-1.06	-4.04	0.79	N	A	N
Tl-208	13.0	0.7	13.5	1.0	7.41	0.19	0.41	1.04	A	A	A

Through the provision of reference materials, validated procedures, control and performance assessment by the organization of proficiency tests and inter-comparison exercises, IAEA has been assisting laboratories in testing, improving and maintaining the reliability and quality of analyses of radioactive material [2]. In the frame of accreditation systems, the use of reference materials, both for quality control and proficiency testing, has therefore increased in recent years [3]. Proficiency testing that includes distribution of homogenous portions of the test material for analysis as an unknown is a method for assessing and documenting the reliability and accuracy of the analytical data produced.

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[2] A. Shakhashiro et al., Appl. Rad. Isot. 67, 139-146 (2009);
[3] ISO/IEC 17025:2005 General requirements for the competence of testing and calibration laboratories, 2005.

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Simulation toolkit with CMOS detector in the framework of hadrontherapy

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"Hadrontherapy" is a collective word to describe the many different techniques of oncological radiotherapy which make use of fast non-elementary particles (mainly protons and carbon ions) to locally treat many types of tumors. Compared to conventional radiotherapy, this technique presents two main advantages: a precise ballistic, with a finite range and a maximum dose deposition at the end of the path of the ions (called Bragg peak) and an enhanced biological efficiency in the Bragg peak region. This allows one to better target the tumor while preserving the surrounding healthy tissues. However, nuclear fragmentation may occur, which causes a dispersion of the dose due to secondary particles. For carbon therapy, high energy charged particles like protons and alpha may escape the patient volume [1]. The tracking of such particles in the forward direction has been shown to provide an effective imaging technique of the Bragg peak position [2], [3].

The QAPIVI (Quality Assurance by Proton Interaction Vertex Imaging) project aims to perform a feasibility study on the real time monitoring of the dose deposition in the patient during a cancer treatment. The detection technique uses, as three-dimensional tracking system, a set of CMOS sensors planes [4]. The characteristics of this device are a high granularity (about 20 microns pitch) to reconstruct the tracks with a high spatial resolution (few microns) and a small thickness (about 50 microns) to minimize the Multiple Scattering effect. The trajectories of protons emerging from patients are reconstructed and the intersection between them and the direction of the beam allows one to measure the position of vertex fragmentation.

A new simulation package based on GEANT4 [5] and ROOT [6] has been developed. This package allows us to realize a simulation of several experimental setups considering geometrical solution in the hadrontherapy framework. Different reconstruction algorithms (clustering, tracking and vertexing) will be presented. Preliminary sensitivity of the proposed technique will be discussed in light of the information collection from outgoing particles, according to our simulation. In particular the distribution of kinematical quantities (particle charge, energy....) will be shown as well as the precision achieved on the estimation of Bragg peak position in the case of homogeneous target.

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[4] C. Hu-Guo et al., Nucl. Intr. Meth. A 623 480(2010);
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Nondestructive measurement of environmental radioactive strontium

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This project is motivated to contribute on a social restoration from the Fukushima nuclear power plant accident triggered by the big earthquake in 2011, by establishing a new quick way to measure environmental radioactivity utilizing nuclear physics instruments. The main radioactivity concerned after the accident are from I-131 (8.0 days), Cs-134 (2.1 years) and 137 (30 years), Sr-89 (51 days) and 90 (29 years). We are aiming to establish a new detection technique which enables us to realize quantitative evaluation of the strontium radioactivity by means of nondestructive measurement without chemical separation processing, which is concerned to be included inside food, environmental water and soil around us, in order to prevent us from undesired internal exposure to the radiation.

Most of the radioactivity such as cesium isotopes, released from the nuclear power plant is gamma-emitting nuclei, which are relatively easy to be determined their radioactivity by performing a gamma-spectroscopy using germanium detectors or conventional scintillation counters/survey meters. On the other hand, Sr-90 is very hard to be measured by the gamma-spectroscopy because of its small gamma-decay branching ratio of about 0.01%. Therefore, only small numbers of food or soil samples were measured during surveying projects by applying the standard chemical separation procedure which requires about two weeks to wait Sr-Y radio equilibrium. The half-life of Cs-137 is as long as the half-lives of Sr-90, however, biological half-lives of them are very different (Cs-137: 3 months, Sr-90: 50 years) because of their chemical property differences. Indeed, strontium isotopes are easy to be replaced with calcium and absorbed in bones, where they are very hard to be released out. Therefore, quantitative determination of environmental strontium radioactivity is important concerning the effect on our life.

According to the governmental large-scale surveying project leaded by MEXT around the power plant, relative abundance of Cs-134 to Cs-137 is confirmed to be almost constant, however, that of Sr-90 to Cs-137 is widely spread from about 0.01% to 10% [1]. Therefore, we cannot make a reliable estimation of strontium radioactivity by using a constant abundance ratio using measured value of cesium radioactivity. That is why direct measurements of them are required. Present project is going to measure Sr-90 radioactivity by performing a physical beta-spectroscopy utilizing the relatively large Q_beta of Y-90 (64 hours, 2.3MeV), which is the daughter nucleus of Sr-90. We have tried several ideas to suppress contributions on the continuum beta spectrum obtained by a plastic scintillation counter, for example, applying a gamma anti-coincidence to veto beta-gamma emitting nuclei such as Cs-134. We are trying to separate the Sr-90 contribution as a high energy tail from other sources using a high resolution detector. Project background around the power plant accident, status, technical aspects of our device and their results will be presented at the conference.

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http://radioactivity.mext.go.jp/ja/contents/7000/6213/24/338_0912_18_rev0914.pdf (2012)

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Measurement of neutron yield by 62 MeV proton beam on a thick Beryllium target

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Within European Partitioning & Trasmutation research programs, infrastructures specifically dedicated to the study of fundamental reactor physics and engineering parameters of future fast-neutro-based reactors are very important. In this respect, Accelerator-Driven Systems (ADS), based on a fast subcritical reactor core where fission reactions are maintained in a steady-state by supplying neutrons from an external source, offer a promising opportunity. Based on these considerations, an ADS low-power prototype was recently proposed and designed within the INFN-E project [1]. It is based on a 70 MeV proton beam impinging on a thick Beryllium converter and a fast subcritical core, as schematically shown in Fig.1. The high power cyclotron already foreseen for the INFN SPES project on radioactive ion beams at Laboratori Nazionali di Legnaro, offers the possibility to build such a prototype in order to study fundamental physics of future fast reactors.

The design of the proposed neutron amplifier requires a detailed knowledge of the neutron yield produced from a Beryllium target in the energy region of interest. Due to the scarce amount of data for that reaction, a dedicated measurement was performed at INFN Laboratori Nazionali del Sud, covering a wide angular range from 0 to 150 degrees and an almost complete neutron energy interval, thanks to the use of the proton beam delivered by the LNS superconducting cyclotron.

In this talk the preliminary data are discussed together with the proposed ADS facility.

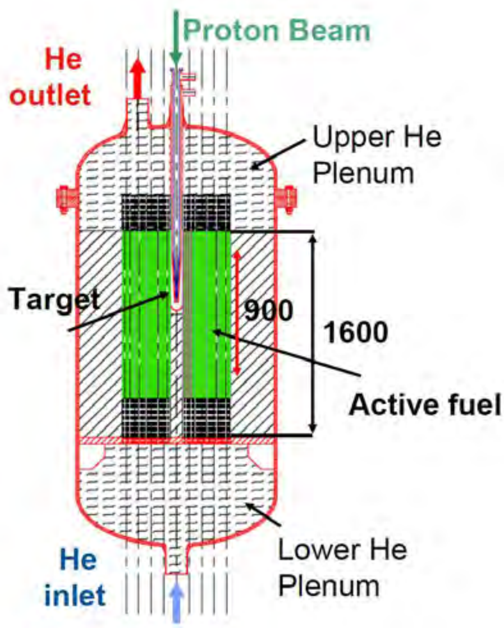

Figure 1: *Overview of the proposed ADS facility*.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

The Current Situation of Cervical Brachytherapy in Brazil

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In order to check the current status of intracavitary brachytherapy in the treatment of cervical cancer conducted in Brazil, with respect to equipment, planning methods, prescriptions, evaluations and dose fractionings in organs at risk, a questionnaire containing relevant questions to these themes was referred to radiotherapy services throughout Brazil in 2012. The list of the instituitions participants was obtained in the electronic site of the Brazilian Society of Radiotherapy. Previously, the questionnaire was validated by a group of physicists and radiotherapists experts. The questionnaire consisted of 09 multiple choice questions. From the data analyzed, queried the 166 centers, 91 are operational and 73 reply the questionnaire. Approximately 60% of centers reported using only radiographs for performing brachytherapy planning and only 31% said they have equipment capable of supporting planning in three dimensions. The vast majority said that the sessions are held after brachytherapy. There was not much difference between the institutions on the prescribed dose and type of fractionation. All doctors consulted said they use the points described in ICRU 38 to prescribe and evaluate the dose and only 3% reported using some alternative method. Much of the centers of Brazil brachytherapy is provided with sophisticated processing equipment, allowing better tumor localization and most effective treatment. However, what we see is that there is little difficulty in access to routine imaging equipment such as CT scanners and MRIs.

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Adaptation and Security Validation of a irradiator Suitable for Use of Cesium-137 Sources

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The ionizing radiation is employed for various purposes like the equipment sterilization and treatments of malignancies diseases. However, the risk related to the use of this type of radiation is always present. Thus, the need for research on new detectors remains nowadays. For example, thermoluminescent dosimeters (TLD) and optically stimulated (OSL), which are widely used in personal dosimetry are subject of many studies. Aiming to give a new application for 137Cs sources that were previously used in brachytherapy, we developed an irradiator for TL and OSL pellets irradiations, it was named SOPHIA. The irradiator was assembled from a cubic iron casing filled with lead, with external dimensions of 25 x 25 x 25 cm³. SOPHIA has three different drawers, each one being provided with two door sample holder suitable for pellets with dimensions of up to 2 cm. The irradiation may be made with one source, three or eight sources. To check the distribution of doses in the sample holder it was used EBT-3 radiocromicfilms and CaSO4:DyTLD. Regarding security conditions of irradiating the whole routine procedure for placement and removal of samples we performed simulations using the transport code MCNPX. 2.7.0 [1,2], a generator spectrum DEXRAX32 and to represent the user it was used the ICRP-110 [3] male voxel phantom. The obtained results were compared with the responses of nanoDot OSLdosimeters. The SOPHIA presented proper security conditions and the doses received by users during a placement procedure and extraction values comply with the standards of radiation protection regulations.

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[2] J. S. Hendricks, *et al*., *MCNPX 2.7.0 Extensions*, Los Alamos National Laboratory report LA-UR-11-02295 (April 2011).
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Nuclear techniques for studying soft matter at ISOLDE/CERN

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Due to the complexity of "living systems" nuclear techniques are not commonly used in biology and biochemistry even though they offer powerful insights to local properties. The ISOLDE facility is, however, a perfect place to carry out experiments with Perturbed Angular Correlation of γ-rays (PAC) spectroscopy. This technique is suitable for addressing different biological problems, such as: heavy metal ion - protein interaction, dynamics of protein folding or protein – protein interaction, providing information on the molecular and electronic structure at the metal site [1]. A short overview of recent ISOLDE studies on *de novo* designed peptides, natural proteins, plants and bacteria will be presented.

Furthermore, recently a new avenue of research in the fields of wet chemistry and biochemistry has been opened at ISOLDE: β-NMR spectroscopy has been successfully applied in the first ever experiment on liquid samples. The method is over a billion times more sensitive than conventional NMR on liquids and thus may be applied to elements which are otherwise difficult to explore spectroscopically, such as Mg^{2+}, Zn^{2+} or Cu^{+}. The setup and the first β-NMR results of ^{31}Mg implanted into an ionic liquid will be shown [2].

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Studies on Iznik ceramics and Byzantine glass pigments using milli-PIXE and Neutron Induced PGAA

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The paper discuss the composition – major, minor, traces elements - of mineral pigments from some Iznik ceramics objects and from some Byzantine glass bracelets using external milli-beam PIXE – at the EG-2R electrostatic accelerator and Neutron Induced Prompt Gamma Ray Activation Analysis – PGAA - at the Budapest Research Reactor, Budapest. 15 small sherds of famous Turkish coloured (mainly blue) ceramics imitating Chinese porcelain produced in Iznik (Asian part of Turkey, approx. 100 km East of Istanbul) were analysed by external milli-PIXE using 3 MeV protons and 10 small pieces of Byzantine (IX-X Centuries) coloured glass bracelets analysed by both external milli-PIXE and PGAA . The Iznik ceramics fragments were found in two important Mediaeval commercial towns from Romania - Piua Petrii near Danube, at the border with Ottoman Empire and Suceava, former capital of Moldavia. The X-XI Centuries Byzantine bracelets were discovered during the archaeological excavations from Isaccea - Noviodunum, a commercial settlement now disappeared, on Danube, approx 100 km from the Black Sea. During the milli-PIXE experiment we concentrated on blue-coloured Iznik sherds to detect the presence of Cobalt - supposed to be the main pigment used by Iznik workshops, and on the trace elements accompanying Cobalt - especially Arsenic and Nickel, which can distinguish between Cobalt minerals from Saxony (Erzgebirge) - As plus Ni - and Cobalt minerals from Iran (Kashan mountains) - only Arsenic. The analysis demonstrated the use of Cobalt minerals from Saxony for Piua Petrii sherds and the use of Kashan minerals for Suceava sherds. The explanation could be the fact that Suceava Iznik samples are older (XVI Century) than Piua Petrii objects (XVII Century), Ottoman Empire having no commercial relations with Saxony during the wars of famous Sultan Suleyman the Magnificent. As concerning the other colours, we detected Antimony (and some Tin) for yellow, Manganese from dark brown, Copper from green and, of course, Lead from the glaze of sherds. Iron is a special case since it is present both in the clay and in the pigments, so the separation is rather difficult. For the painted (coloured stripes) Byzantine bracelets the main pigments contain: Iron and Manganese for black stripes, Chromium for yellow, Lead also for yellow in other samples, Iron and Copper for red, Iron for blue, Titanium for "silver" (mica?). The variety of pigments and the artistic quality are arguments for the provenance of the bracelets from a specialized workshop somewhere in an important Byzantine city, possibly even Constantinople.

Bulk elemental composition of 13 not-painted Byzantine glass samples were determined by non-destructive PGAA using cold neutron beam of the Budapest Research Reactor. PGAA was able to quantify all the major components, as H_2O, Na_2O, K_2O, MgO, CaO, SiO_2, TiO_2, MnO, Fe_2O_3, minor elements of S, Cl, colorants of Co and Cu, traces of B, Nd, Sm and Gd.. All the investigated glass proved to be sodium-glass, except one, which turned to be potassium glass - an item supposed 4-500 years “younger” than the others, also having a significantly high amount of As and trace level of Ag. Higher concentrations of H in four samples are attributed to the elevated corrosion states of the objects.

Finally, some conclusions on the milli-PIXE and Neutron Induced PGAA advantages in ceramics and glass analysis are presented.

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Systematic study of activation cross sections of deuteron induced reactions for applications and for reaction model developments

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Activation cross sections of deuteron induced reactions are fundamental data for applications around modern accelerators for medical radioisotope production, for radiation dose estimations in accelerator and target technology, for radioanalytical studies in biomedical research and wear control by thin layer activation technique (TLA), etc. The status of experimental data of cross sections for deuteron induced reactions was very poor earlier, no systematic study has been performed before and among the published data (except for a few well measured monitor and medically important reactions) large discrepancies existed. For most of the applications, however, complete experimental data set is required to determine thick target yields and optimize the processes involved.

It is well known, that due to modeling problems of deuteron stripping, breakup and other related processes the predictivity of the presently used theoretical codes to calculate the cross sections of deuteron induced reactions is rather moderate. In connection with different running research projects using activation cross sections of deuteron induced reactions we hence performed a systematical experimental study to determine deuteron induced activation cross sections for different target materials during the last decades.

The targets were irradiated with external beams of the cyclotrons of Debrecen (MGC 20E), Jülich (CV28, JULIC), Brussels (CGR 560), Louven La Neuve (CGR 930 Cyclone) and Sendai (AVF 110) up to 50 MeV. The standard stacked foil irradiation technique was used to measure the cross sections. The main specificity of our experimental methodology is the approach of the use of monitor reactions: the excitation function of the chosen monitor reactions are always re-measured simultaneously over the whole energy range using the same experimental arrangements as for the investigated target.

More than thousands of reactions have been induced in the study on the following 57 target elements: B, C, N, Ne, Mg, Al, Si, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Kr, Y, Zr, Nb, Mo, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, Xe, Cs, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Re, Os, Ir, Pt, Au, Tl and Pb. The newly measured excitation functions are compared with the literature data and with the results of nuclear reaction model codes: ALICE-IPPE, EMPIRE-II, GNASH and TALYS.. Conclusion of systematic comparison of the data and the results of theoretical models contributed to improvement of elements of the models including the used potentials, the reaction parameters, reaction mechanism and phenomenological corrections. The new experimental data give basic information for every day applications and for dedicated activation data files prepared for different projects at research and nuclear data centers (FENDL, TLA, Medical Isotopes, CP Beam Monitors).

The main conclusions of the study: the quality of the experimental data is still not good enough, even for the important reactions and the capability of the theoretical codes with standard parameters in many cases is still very far from satisfactory.

Due to certain experimental circumstances and limited time the cross section data for some important targets in case of products with short and very long half life are still missing. The experimental studies will be continued.

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Nuclear reaction data for investigation of accelerator based production routes of radiolanthanides for therapy

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Lanthanides have similar biological properties to calcium, which is the basis of the increasing role their radioisotopes play in internal radiotherapy. All lanthanides have similar chemical properties regarding labeling processes. The wide range of physical characteristics of their radionuclides (decay mode, half-life and radiation) makes choices possible to match specific requirements.

Although most of the radio-lanthanides are produced in nuclear reactors, directly or from radionuclide generator systems, accelerator based production routes are also possible. Depending on the nuclear reaction used for production, either no-carrier added (nca) or carrier-added (ca) radionuclides can be obtained.

Nuclear reaction data are of basic importance for optimizing the production yield, the radionuclidic impurity levels and to estimate the amount of carrier, since for efficient internal radiotherapy high labeling yields are needed, which requires high radionuclide purity and no carrier added production routes. The accelerator based production routes of radio-lanthanides are not investigated as thoroughly as the reactions leading to production of diagnostic radioisotopes.

The targetry is simple in case of odd Z- material, where only one or two stable isotopes exist and cheap targets with natural composition can be prepared. In the case of even Z-materials, however, large numbers of stable isotopes are present giving rise of numerous radionuclidic impurities. Purity can be increased by using highly enriched target materials resulting in an additional problem of recovery of the expensive target material after irradiation.

The reliable cross-section or yield data required to optimize production routes can be obtained from direct experimental studies or from theoretical calculations verified by experiments.

As a first step we started the investigation of production routes of radio-lanthanides applied commonly or candidate for therapeutic use by irradiating targets with natural composition of all lanthanides (La to Lu) with protons and deuterons.

Cross-section data were determined for production of ^{139,141}Ce, ^{142,143,145}Pr, ^{149}Pm, ^{153}Sm, ^{149}Eu, ^{159}Gd, ^{161}Tb, ^{165}Dy, ^{161,166}Ho, ^{165}Er, ^{167,170}Tm, ^{169,175}Yb, ^{177}Lu (all are recognized or potential therapeutic radionuclides). The productivity of different routes and the capability of the theoretical codes to predict excitation curves are discussed. The properties of the investigated charged particle induced reactions are compared with neutron induced reactions, when both production routes are possible.

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Energy Dependence of Fission-Product Yields

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The dependence of fission-product yields (FPY) on incident energy is central to calculations of the performance of nuclear reactors, accelerator-driven systems, potentially critical masses, and basic physics. We have measured FPY from fission of ^{235}U, ^{238}U, and ^{239}Pu for incident neutron energies of 1 to 15 MeV using quasi-monoenergetic neutrons produced at the 10 MV Tandem Accelerator at TUNL. Dual-fission chambers containing deposits of thin (10 μg/cm^2) and thick (200 mg/cm^2) ^{235}U, ^{238}U, and ^{239}Pu foils detected the total fission events from the thin foil. Post-irradiated fission product activities from the thick foil were measured by high-resolution γ-ray spectroscopy over the period up to three months. This presentation describes the data analysis of the energy dependence of certain fission product yields and the method to obtain highly-accurate fission-product yield ratios. Results from this analysis will be compared with state-of-the-art modeling of FPY.

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Annihilation radiation gauge for relative density and multiphase fluid monitoring

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Abstract

Two-phase flow occurs in reactor cooling equipment, and liquid holdup could greatly affects heat transfer. The knowledge of the multi-phase flow parameters is important for the petroleum industry, specifically during the transport in pipelines and network related to exploitation wells. Development of an on-line fluid multiphase monitor employing annihilation radiation gauge is proposed. The difference pressure measured by a Veturi-meter is coupled with a radiation monitor based on positron-electron interaction [1]. Gas-liquid flow in horizontal pipes is studied to determine transient liquid phase in a laboratory system. Relative density and fluid phase time variation is monitored employing a fast nuclear data acquisition set-up that include two large volume BaF2 scintillator detectors coupled to an electronic chain and data display. Fluid parameters are determined by the difference in count rate of coincidence pulses [2]. The heart of the nuclear monitor is a radioisotope source of ^{22}Na that emits positrons generating gamma radiation emitted in opposite direction allowing a reference energy and mass flow monitoring. The system is a new approach for multiphase on line monitoring of the fluid mass and the relative density during transport based in gamma ray coincidence. The operational characteristics of multyphase fluid were determined on a laboratory purpose made system, on that set-up the fluid composition, temperature and pressure could be changed. Monte Carlo simulations for a pipe of OD=5cm were compared with experimental results, and details of the developed equipment performance are given. We observed for instance that a 4% variation in the fluid level could be obtained within 2σ certainty and the system stability is around 2%. The system performance shows essential characteristics to design field processing equipment in the future, such as e.g. gas-liquid separators.

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Event based neutron activation spectroscopy and analysis algorithm using MLE and metaheuristics

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Techniques used in neutron activation analysis are often dependent on the experimental setup. In the context of developing a portable and high efficiency detection array, good energy resolution and half-life discrimination are difficult to obtain with traditional methods [1] given the logistic and financial constraints. An approach different from that of spectrum addition and standard spectroscopy analysis [2] was needed. The use of multiple detectors prompts the need for a flexible storage of acquisition data to enable sophisticated post processing of information. Analogously to what is done in heavy ion physics, gamma detection counts are stored as two-dimensional events. This enables post-selection of energies and time frames without the need to modify the experimental setup. This method of storage also permits the use of more complex analysis tools. Given the nature of the problem at hand, a light and efficient analysis code had to be devised. A thorough understanding of the physical and statistical processes involved was used to create a statistical model. Maximum likelihood estimation was combined with metaheuristics to produce a sophisticated curve-fitting algorithm. Simulated and experimental data were fed into the analysis code prompting positive results in terms of half-life discrimination, peak identification and noise reduction. The code was also adapted to other fields of research such as heavy ion identification of the quasi-target (QT) and quasi-particle (QP). The approach used seems to be able to translate well into other fields of research.

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Stars, supernovae and meteorites: laboratory studies of nucleosynthesis using accelerator mass spectrometry

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Accelerator mass spectrometry (AMS) represents a sensitive technique for studying stellar nucleosynthesis processes in the laboratory through ultra-low isotope ratio measurements. In particular, for studying long-lived radionuclides such a technique yields much higher sensitivities when counting atoms directly rather than measuring decay products.

An overview on recent AMS measurements at the University of Vienna and at the Australian National University with respect to nuclear astrophysics will be given. Two different applications utilizing AMS have been conducted:
(i) the search for live supernova(SN)-produced radionuclides in terrestrial archives. Such studies probe directly specific nucleosynthesis sites and will help understanding heavy element nucleosynthesis in massive stars. We will report on new data suggesting an unexpected low abundance of interstellar ^{244}Pu, a perfect nuclide to study r process nucleosynthesis that serves also as a probe for r process sites. We will report on newest measurements of SN-produced live ^{60}Fe in deep-sea sediments and we will also detail a new measurement of its strongly disputed half-life value.
(ii) the simulation of stellar nucleosynthesis processes in the laboratory via the study of dedicated nuclear reactions. Key ingredients to our understanding of nucleosynthesis and the isotopic pattern of our environment are accurate cross-section data. Our data for a series of neutron-capture reactions allow a systematic comparison with existing data from complementary techniques. We will also demonstrate the high precision of this method as well as the limits of this approach.

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Bio-Medical and Plant Biology Imaging Tools Derived from Nuclear Physics Detector Development

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Basic nuclear physics research requires continuing advances in detector technology. Often, new detection technology can have applications outside basic nuclear physics research. For over 80 years various sciences have been using radioactive isotopes as tracers for increasing our understanding of biological processes in living systems. New nuclear physics detection technologies using scintillators and photo multipliers have been used to develop imaging tools for radioisotope detection and imaging in bio-medical and plant biology applications. Nuclear imaging techniques such as positron emission tomography (PET) and single photon emission computed tomography (SPECT) benefit greatly from advances in nuclear physics detector technology. Bio-medical research utilizing animals as in pre-clinical research and in clinical applications such as cancer detection and treatment have benefited much from nuclear physics detector advances. New imaging tools are being developed for plant biology research to enhance our understanding of metabolic processes necessary for efficient biofuel production in a changing environment and of best bioassays for environmental remediation. The Radiation Detector and Imaging Group at Thomas Jefferson National Accelerator Facility has been applying detector technology to these applications. The examples of detector systems for medical and plant biology applications as well as scientific motivations driving use of radioisotope tracers in these applications will be presented.

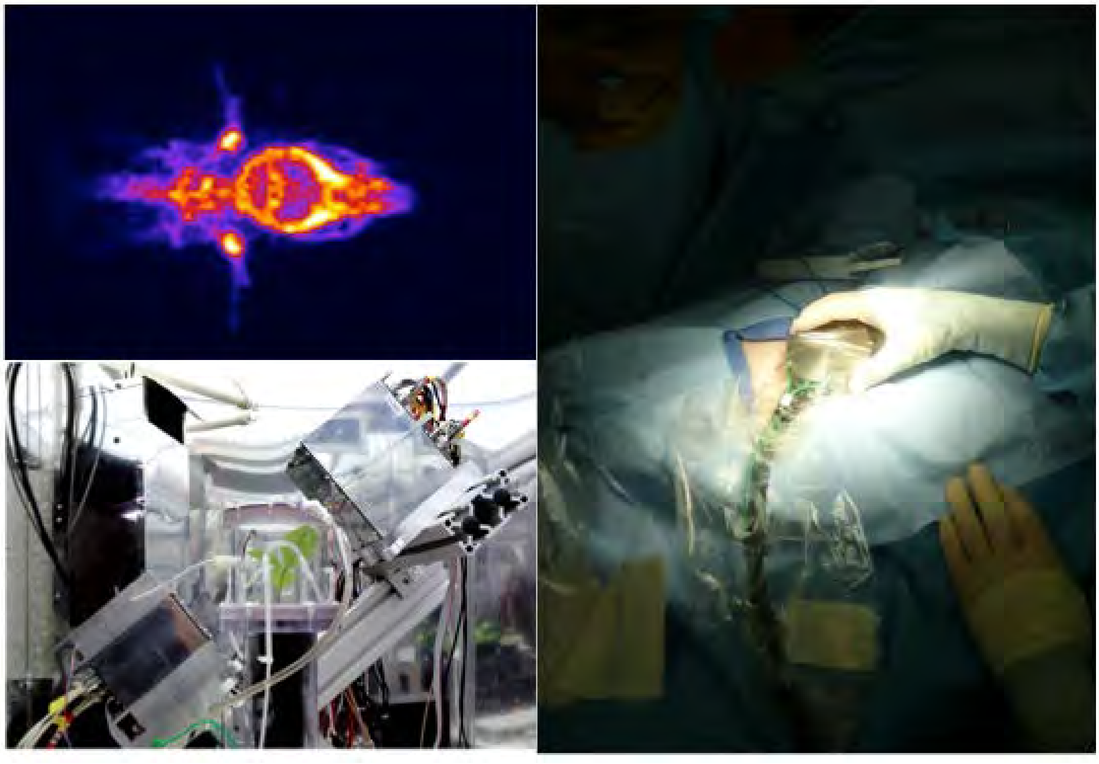

Figure 1: *(Right) Surgeon using a silicon photomultiplier based handheld gamma camera in the operating room. (Left-top) Image of a mouse injected with Tc-99m-methylene diphosphonate obtained with a crystal scintillator based gamma-camera. (Left-bottom) Plant biology PET study using C-11 tagged CO_2 gas.*

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Measurement of fission products beta decay properties using a total absorption spectrometer

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In nuclear rectors, fission products are mainly neutron-rich nuclei that essentially beta decay, some of them, emitting delayed neutrons. The beta decay properties of these nuclei are at the origin of reactor antineutrino emission as well as decay heat production. The calculation of antineutrino spectrum [1] is important for fundamental and applied neutrino physics, such as neutrino oscillation measurements and non-proliferation studies. The decay decay heat is around 8% of a reactor nominal power and its calculation [2] represents a key parameter for safety issues.

In some cases, the beta decay properties of these neutron-rich nuclei are not well known and they can suffer from the Pandemonium effect [3]. This effect comes from the difficulty of reconstructing nuclear level patterns via beta decay measurements with Germanium (Ge) single peak detectors, especially when transitions are of high-energy or in regions of high-density levels. This systematically distorts the calculations of the energy levels feedings of the nucleus and also the associated spectrum.

New β decay measurements of fission products important for their contribution in antineutrino spectrum reconstruction and reactor decay heat evaluation have been performed at the JYFL accelerator from the University of Jyvaskyla (Finland) in November 2009 using a Total Absorption Spectrometer (TAS), sensitive to the β population rather than to the individual γ rays. This device is made by an array of scintillator crystals covering 4π in solid angle around the source in order to absorb all emitted γ rays and a Si-detector is placed in front of the source to tag β emission. The use of this detection technique combined with the high mass identification power of the Penning trap system of JYFL allows us to measure the beta intensity distribution in the full energy range correcting the Pandemonium effect.

We will present an overview of the TAS techniques, the interest of these measurements in neutrino spectra and decay heat calculation and the results from this experiment. We will show the new beta feeding and beta strength distributions provided by our analysis and will compare them with previous data.

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10 - Nuclear Physics Based Applications