Nuclear Physics

Nuclear Spectroscopy

The activities of the group include two sets of different problems. Both subjects utilize in general similar nuclear spectroscopy techniques and the same heavy ion beams produced by the TANDAR accelerator.
The first set of problems corresponds to applied research (from the point of view of nuclear physics but not necessarily of the other disciplines) and tries to contribute in other areas generating interdisciplinary and partly technological activities. Applications to biomedical and environmental problems are being pursued. On this sector, we can distinguish three lines:

a) Trace element analysis; b) Development of a heavy ion microbeam; c) Feasibility studies on novel accelerator-based cancer therapy modalities.

The second set of problems is in the field of basic research on nuclear structure.

Trace Element Analysis

The most frequently employed techniques are PIXE and PIGE (Particle Induced X-ray (Gamma) Emission). The first one is a high-sensitivity multielement analysis technique based on the heavy ion excitation and detection of characteristic X-rays of the elements present in samples of diverse origin. In biomedicine, problems studied have been, among others, metabolic alterations in living species related to presence of Zn and multielement determination with emphasis on aluminium concentration in sinovial fluid samples. As far as environmental problems are concerned the PIXE technique has been applied to the determination of lead concentration and other polluting agents in atmospheric aerosols of Buenos Aires city and surroundings. Since our last survey, Pb concentration in Buenos Aires diminished by a factor of about 20 after the introduction of unleaded gasoline in Argentina, a behavior similar to that observed in other large cities around the world. The PIGE tecnique, which utilizes gamma-rays of nuclear origin induced by heavy ions, is an interesting alternative in the case of very light elements. We have applied it for the detection of boron traces in connection with BNCT (Boron Neutron Capture Theory).

Heavy ion microbeam

We aim at implementing at one of the beam lines of the TANDAR accelerator a facility which could be characterized as a nuclear microscope, i.e., a heavy ion microprobe. This microbeam in conjunction with nuclear and atomic techniques of excitation and detection like PIXE, PIGE, HIRBS (Heavy Ion Rutherford Backscattering), STIM (Scanning Transmission Ion Microscopy), etc., will allow the quantitative determination of the multielement composition, the modification of properties and structural characterization of different systems with a spatial resolution of the order of a micron. This microprobe and its associated beam line has been mechanically mounted on an antivibration base and will become operative in 2001.

Feasibility Studies related to Cancertherapy

- **Protontherapy**
  The charged particle beams have definite advantages compared to other types of radiation (like gamma rays) for tumor treatment. In some cases, like eye melanoma, spectacular success has been achieved. This technique is known as protontherapy. There is interest to stimulate activity which may eventually lead to the introduction of this modality in our country. In this context external proton and Li beams have been produced at the TANDAR laboratory and a program to irradiate small animals and cell cultures was started in collaboration with radiobiology personnel. Relative Biological Effectiveness (RBE) associated with p and Li beams of different energies was determined for different tumor cell lines. In particular the Li beams aim at simulating the effects of the Li fragment being emitted in the BNCT reaction (see below).
- **Boron Neutron Capture Therapy (BNCT)**
  With the proton or deuteron beams available at the TANDAR accelerator it is possible to generate a neutron flux that can be used to carry out feasibility studies related to a possible therapy by boron neutron capture, BNCT, based on the very high cross section of the capture reaction $^{10}B(n,\alpha)^{7}Li$. The

idea is to load selectively a tumor with boron and irradiate it with neutrons. The "microexplosion" associated to each reaction has a high lethality for cancer cells affecting only the immediately surrounding tissue. In the past BNCT has been based exclusively on nuclear reactors for research and treatment. There is however currently a strong tendency and important progress towards the development of accelerator-based neutron sources. There is a generalized perception that if BNCT is to become an option for cancer treatment it would be necessary to have accelerator-based neutron sources, not only due to their much lower cost and complexity but also because the implantation of a nuclear reactor in a hospital would not be acceptable given the public perception in relation with this type of facility. We have started to explore the neutron production via protons of relatively low energy (some MeV) on a lithium target. A LiF neutron production target has been built and neutron flux determinations have been performed both trough the activation method and through the detection of the 478 keV gama ray following the BNCT reaction. The latter method will serve to monitor on-line the dose delivered to a tumor. We have studied the 13C(d,n) reaction as a candidate for accelerator-based BNCT trough a collaborative project with scientists from the Laboratory for Accelerator Beam Applications at MIT. We have also started to explore the possibility of developing a low-energy (2 MeV), high-current (20 microA) proton accelerator for BNCT.

Basic research on nuclear structure

This program includes several high-spin nuclear structure topics of current interest. One is the study of coupling schemes of valence nucleons in deformed nuclei, in particular in doubly odd species, in which we have recently found connections to the identical band problem. Here our attention is focused on structures which included aligned pseudospins as means to produce twin bands (i.e. bands with very similar transition energies) in neighboring nuclei. During the course of these investigations a very interesting result was obtained, namely twin –bands but with very different moments of inertia ("non-identical" twin bands). Also the problem of signature inversion has been the subject of several investigations. Finally, we mention the study of the octupole instability in the actinide region. The aim has been here to map out the reflection asimmetry degree of freedom to reach the predicted maximum in this deformation and to establish the limits for performance of in-beam spectroscopic studies in the presence of a very severe fission competition.

"Alternating parity bands in $^{218}Fr_{87}$"

M.E. Debray, M.A. Cardona, D. Hojman, A.J. Kreiner, M. Davidson, J. Davidson, H. Somacal, G. Levinton, D.R. Napoli, S. Lenzi, G. De Angelis, M. De Poli, A. Gadea, D. Bazzacco, C. Rossi-Alvarez and N. Medina

Phys. Rev. ***C62*** *(2000) 024304*

States in doubly odd $_{218}$Fr have been studied using in-beam spectroscopy α-γ-γ coincidence techniques mainly through the ^{209}Bi(^{18o}, $2\alpha n$) reaction at 94 MeV bombarding energy, using the 8π GASP-ISIS spectrometer at Legnaro. ^{218}Fr 4 shows a band structure, with interleaved states of alternating parities connected by enhanced *E*1 transitions. Tentative spin assignment and the relation between the structure of ^{218}Fr and its isotone ^{220}Ac is discussed.

"Coupling modes in doubly odd nuclei: The case of ^{172}Ta"

D. Hojman, M.A. Cardona, M. Davidson, M.E. Debray, A.J. Kreiner, F. Le Blanc, A. Burlón, J. Davidson, G. Levinton, H. Somacal, J.M. Kesque, F. Naab, M.J. Ozafrán, P. Stoliar, M. Vázquez, D.R. Napoli, D. Bazzacco, N. Blasi, S.M. Lenzi, G. Lo Bianco and C. Rossi-Alvarez

Phys. Rev. ***C61*** *(2000) 064322*

High-spin states in doubly odd ^{172}Ta were investigated in two different experiments by means of in-beam γ-ray and internal-conversion electron spectroscopy techniques. Excited states of ^{172}Ta were populated using the ^{159}Tb(^{18}O, 5*n*) and ^{165}Ho(^{12}C, 5*n*) reactions at beam energies of 93 and 79 MeV, respectively. Eleven rotational bands, including twin bands in the normal deformation regime, have been observed and their configurations discussed. Three isomeric states have been found and their half-lives measured. Alignments, band crossing frequencies, and electromagnetic properties have been analyzed in the framework of the cranking model.

"Transition strengths in odd-odd ^{80}Rb"

M.A. Cardona, G. García Bermúdez, R.A. Kaye, G.Z. Solomon and S.L. Tabor

Phys. Rev. ***C61*** *(2000) 044316*

Lifetimes of levels in ^{80}Rb have been measured using the Doppler shift attenuation method. The high-spin states have been populated through the ^{55}Mn(^{28}Si, 2*pn*) reaction at 90 MeV. Collective enhancement was observed in the *B(E*2) values of the two most strongly populated bands, while the *B*(*M*1) values of the yrast band exhibit a large alternating pattern. Transition quadrupole moments were deduced from *E*2 transition strengths and compared with those predicted by Woods-Saxon cranking calculations.

"Signature Inversion in Odd-Odd Nuclei Around A=80"

G. García Bermúdez, M.A. Cardona

Act. Phys. Hung., Heavy Ion Physics ***11*** *(2000) 345*

Signature inversion in odd-odd nuclei have been found systematically in regions of mass number A 80, 130 and 160, and although several explanations have been proposed to interpret this phenomenon, it is still not well understood. The data of electromagnetic properties obtained through lifetime measurements, will be very useful to elucidate this phenomenon. In the present work, we review several lifetime studies that measured the B(M1) strengths in the mass A 80 region. The results show that the alternating pattern in the B(M1) strengths is preserved across the signature inversion region. Also is reviewed the critical angular momentum, frequency and moment of inertia at the signature inversion point for several mass regions. The correlations among these and other nuclear parameters are discussed.

"Acumulación de Zn en Ovarios de Sapo Bufo Arenarum. Efecto sobre el Metabolismo de Carbohidratos"

T.M. Fonovich de Schroeder, A.F.Preller, F.U.Naab, M.E.Caraballo, A.Burlón, M.A.Cardona, M. Debray, D.Hojman, M.J.Ozafrán, M.E.Vázquez and A.M.Pechén de D'Angelo

Brasilian Journal of Toxicology ***13,*** *N° 1 (2000) 55*

Females of the toad Bufo arenarum accumulate Zn when they are maintained in a cage besides the Reconquista river (province of Buenos Aires). Ovulation occurs normally when these animals are injected with homologous hipophysis, as compared to control ones. Oocytes from these females can not only be fertilized but also develop until they reach the gastrula stage. Significant inhibition (27 %) of embryonic development can be observed from the muscular response stage on. In vivo simultaneous microinjection with Zn and [U-14C]Glucose rendered a decrease in the incorporation of the label in glycogen as well as in CO2. Glucose-6-P dehydrogenase activity was inhibited in vitro by Zn at 1,53 mM, a concentration similar to the ones accumulated in the ovary and microinjected into the oocytes en the previous experiments. Our results are in agreement with an inhibitory effect of Zn on early developmental stages of th embryos, probably due to deficient production or NADPH, ribose-5-phosphate and ATP in the oocytes.

"In-phantom dosimetry using the ^{13}c(*d,n*)^{14}n reaction for BNCT."

A. Burlon, A. J. Kreiner , S. White, J. C. Yanch, B. Blackburn and D. Gierga .

Proceedings of the XIX International Symposium on Neutron Capture Therapy for Cancer, Osaka, Japan, (2000) 53

The use of the ^{13}C*(d,n)*^{14}N reaction at E_d =1.5 MeV for accelerator-based boron neutron capture therapy is investigated. Among the deuteron-induced reactions at low incident energy, the ^{13}C*(d,n)*^{14}N reaction is one of the best because of the advantages of carbon as a target material and its large cross section. The deuteron beam was produced by a tandem accelerator at MIT's Laboratory for Accelerator Beam Applications. The resulting neutron spectra were evaluated in terms of RBE-dose rates at different depths inside a water-filled brain phantom using a heavy water moderator and lead reflector assembly. Dosimetry results were obtained using the dual ionization chamber

technique for fast neutrons and photons and bare and cadmium-covered gold foils for the thermal neutron flux. The RBE-doses in tumor and healthy tissue were calculated from experimental data assuming a tumor ^{10}B concentration of 40 ppm and a healthy tissue ^{10}B concentration of 11 ppm. All results were simulated using the code MCNP, a Monte Carlo neutron and photon transport code. A treatment time of 90 minutes was obtained for a tumor located at 5.7 cm depth within the brain, assuming a 20 RBE-Gy dose in a single beam session and a 4 mA deuteron current.

Heavy-Ion Physics And Accelerator Mass Spectrometry

This group focused its activities on the study of basic aspects of nuclear reaction mechanisms and on applied research in connection with the analytical technique known as accelerator mass spectrometry (AMS). Even though the subjects covered by these two lines are very different, they share similar instrumental and methodological requirements as far as the performance of the actual experiments is concerned.

The nuclear-reaction line consisted mainly of two main sub-projects:

- Search for chaotic behaviour in nuclear reactions: Theoretical studies predict that, under certain conditions, nuclear scattering might exhibit peculiar behavior associated with the quantum manifestation of chaotic phenomena. In order to clarify this point we have studied the $^{16}O + ^{28}Si$ system for which exhaustive calculations have been recently performed. The obtained experimental results have been compared with the theoretical two-dimensional patterns obtained for the elastic and inelastic cross sections as a function of the energy and the scattering angle for that system.
- Subcoulomb fusion barrier distributions: Fusion cross sections at energies close to or below the Coulomb barrier present behaviours which are related to various structural aspects of the nuclei involved in the collision. These features become particularly noticeable when the results are analysed in terms of the so called “barrier distributions”. We are investigating several reaction systems with the aim of identifying the effect of the inelastic and transfer channels in the barrier distributions obtained from the measurement of quasi-elastic excitation functions at backward angles.

The other research line has a more applied character and it is related to the use of the Tandar particle accelerator as an extremely sensitive mass spectrometer for the determination of very low concentrations of long-lived radioisotopes. In this we intensively studied the production of radioisotopes in meteorites. We have also started preliminary work on the research of long-range environmental effects of human activity in the nuclear field. For that goal we propose to measure the concentration of the isotopes ^{129}I, ^{36}Cl, and ^{99}Tc in samples collected in the vicinity of nuclear power plants, covering the entire process starting with the ion production from the samples of interest up to the separation from different backgrounds and its final identification.

“A coupled-channel analysis of scattering, two-neutron transfer and fusion in medium heavy-ion collisions”

J.E. Testoni, O. Dragun, H Massmann and M.R. Spinella

Nuc. Phys. ***A669*** *(2000) 173*

Scattering, two--neutron transfer and fusion processes are analyzed in the scope of a coupled--channel formalism using collective excitations in the real and a gauge space. A small set of collective states simplifies the calculation of formfactors allowing an easy evaluation of interesting physical quantities such as cross--sections, probability densities, currents, fusion rates, spin distributions and probability sources and sinks in the different channels. The availability of these quantities makes possible an insight that clarifies the underlying reaction mechanisms. In particular, a barrier, modified by the coupling between channels, is introduced, permitting an interpretation of relevant characteristics of the interaction processes. The system $^{18}O + ^{60}Ni$ is specifically studied at energies of E=63 and 65~MeV for the scattering and two--neutron transfer, respectively, and at energies around the Coulomb barrier for fusion. In this case, it can be observed that the presence of the transfer channel plays a catalytic role in the enhancement of the fusion cross--section by incrementing the contribution of the dispersion channels.

“Barrier distribution for the $^{32}S + ^{110}Pd$ system derived from the quasielastic scattering excitation function”

O.A. Capurro, J.E. Testoni, D. Abriola, D.E. Di Gregorio, G.V. Martí, A.J. Pacheco and M.R. Spinella

Phys. Rev. ***C61*** *(2000) 037603*

We measured the quasi-elastic scattering excitation function for the $^{32}S + ^{110}Pd$ system at a backward angle and at energies around the Coulomb barrier. A fine enough energy step was adopted in order to obtain a representation of the

barrier distribution through the first differentiation of the data. Our results were compared with the barrier distribution that was deduced from fusion data for the same system.

"Transfer Reactions with Vibrational Nuclei"

H.D. Marta, R. Donangelo, J.O. Fernández Niello and A.J. Pacheco

Phys. Rev. ***C61*** *(2000) 064610*

A previously developed semiclassical model of transfer reactions is extended to the case in which one of the collision partners is a vibrational nucleus. In these systems a rapid transition from normal to anomalous slope at the Coulomb barrier is experimentally observed in the two proton stripping reactions. We demostrate that this behaviour can be reproduced by the model.

"Quasi-elastic scattering measurements in the systems ^{12,13}C + ^{105,106}Pd"

O.A.Capurro, J.E.Testoni, D.Abriola, E.Achterberg, D.E.DiGregorio, G.V.Martí, A.J.Pacheco, and M.R.Spinella

Acta Physica Hungarica, Heavy Ion Physics ***11*** *(2000) 355*

Quasi-elastic scattering excitation functions at backward angles and near barrier energies for the systems ^{12,13}C+^{105,106}Pd have been measured. The first derivative of the cross sections respect to the energy was determined. The purpose of this work is to evaluate if such derivative is a good representation of the barrier distribution involved in the fusion process. The results are analyzed considering that the characteristics of the barrier distribution depends on the effective Q-values.

"The AMS Technique and Environmental Applications at the Tandar Laboratory"

G.V. Martí, J.O. Fernández Niello, R. Liberman, D. Alvarez, A. Arazi, D. Abriola, E. Achterberg, O. Capurro, M. di Tada, A.M.J. Ferrero, A.J. Pacheco, M. Ramírez and J.O. Testoni

Acta Physica Hungarica, Heavy Ion Physics ***11*** *(2000) 473*

The accelerator-mass-spectrometry (AMS) technique developed at the TANDAR laboratory in Buenos Aires is being mainly dedicated to environmental and astrophysical problems. For this purpose, from the earliest stages the activities have been aimed to address the upgrading and optimization of different components of the accelerator . Taking into account that only an excellent performance of the ion source and of the accelerator itself will provide reliable conditions to apply this technique, we have emphasized our work on the following areas: a) ion source and sample preparations, b) general stability and beam transmission through the accelerator, and c) detection systems. In this work we report a summary of these activities and we describe the progress achieved along all these lines. Finally, we present and discuss the initial results of the application of AMS to the measurement of the latitudinal distribution of the long--lived radioisotope ^{36}Cl in rainwater samples, and to the study of ^{59}Ni in meteorite material.

"Search for chaotic behavior in nuclear scattering"

G.V. Martí, A.J. Pacheco, J.E. Testoni, D. Abriola, O.A. Capurro, D.E. DiGregorio, J.O. Fernández Niello, E. Achterberg, D.E. Álvarez and M.R. Spinella

Acta Physica Hungarica, Heavy Ion Physics ***11*** *(2000) 269*

Angular distributions for the elastic and inelastic scattering in the ^{16}O + ^{28}Si system have been measured in two energy regions, one close to the Coulomb barrier and the other well above. Fine steps in both bombarding energy (0.5-1.0 MeV) and scattering angle (0.8() make it possible to compare the data with the theoretical calculations that predict, for each of these regions, distinctive cross-section patterns in correspondence with the classical occurrence of either regular or chaotic regimes. The experimental results show specific differences between the two explored energy ranges in qualitative agreement with the theoretical predictions.

"Barrier Distributions Derived from Quasielastic Excitation Functions for the ^{12,13}C + ^{105,106}Pd Systems"

O.A. Capurro, J.E. Testoni, D.Abriola, D.E. Di Gregorio, G.V. Martí, A.J. Pacheco, M.R. Spinella and E. Achterberg

Phys. Rev. ***C62*** *(2000) 014613*

Quasielastic excitation functions for the ^{12,13}C + ^{105,106}Pd systems were measured at near barrier energies. The representations of the fusion barrier

distributions derived from the measured cross sections were analyzed by comparison with simplified coupled-channel calculations. The influence of transfer reaction channels can be distinguished from that due to the inelastic excitation. The influence of two-phonon state on the barrier distributions was evaluated.

"Piguem Nonraltá o Campo del Cielo. Meteoritos en el Monte Chaqueño"

J.O. Fernández Niello and R.G. Liberman

Ciencia Hoy ***10****, N° 59 (2000) 18*

Incansables viajeros del sistema solar encuentran, a veces, reposo en nuestra Tierra. Estos cuerpos, que llamamos meteoritos, adquieren un interés científico cada vez mayor a medida que se perfeccionan las técnicas de investigación destinadas a develar la preciosa información en ellos contenida. Más allá de este interés, tan propio de nuestro tiempo, se llega a sentir, ante ellos, un asombro reverente, tal vez no demasiado distante de aquel que pudo llevar a su sacralización en épocas remotas.

"The AMS system and research program at the TANDAR Laboratory"

J.O. Fernández Niello, R.G. Liberman, O.A. Capurro, A.M.J. Ferrero, G.V. Martí, A.J. Pacheco, D. Abriola, M. Ramírez, J.E. Testoni, E. Achterberg, D.E. Alvarez and M. di Tada

Nuclear Instruments and Methods in Physical Research ***B172*** *(2000) 91*

Several aspects of the AMS program at the TANDAR laboratory are discussed. The current activities are focused on environmental and cosmological applications. One of the projects has been the study of the global fallout of the radioisotope ^{36}Cl and its latitudinal distribution in the southern hemisphere. We have also undertaken some of the preparatory work to measure the concentration of several radioisotopes in extraterrestrial samples obtained from a meteorite fall in northern Argentina. An important fraction of our effort in pursuing these studies has been the optimization of the technique in our 20UD tandem. We discuss the results of recent tests carried out to evaluate the current capabilities of the accelerator regarding general stability, predictability, and transmission efficiency, following the upgrading and adaptation activities.

"Evaluación de Secciones Eficaces de Fusión a Energías Próximas a la Barrera Coulombiana utilizando un Formalismo de Canales Acoplados"

J.E. Testoni, O. Dragun, M.R. Spinella and H. Massmman

Anales AFA ***10*** *(2000) 47*

A coupled-channel formalism is presented which allows to calculate, simultaneously, cross sections corresponding to elastic, inelastic, transfer of two neutrons and fusion. The nuclear excitations are considered as rotations in the real space and the two-neutron transfer as a rotation in a gauge space. The target as well as the proyectile are considered to have zero spin. For different reaction channels the formalism permits to obtain wave functions, angular distributions of differential cross sections, total cross sections, excitation functions and spin distributions.

"Angular momentum in the ^{6}He+^{209}Bi reaction deduced from isomer ratio measurements"

P.A. DeYoung, B. Atallah, B. Hughey, P.L. Jolivette, M. Kern, G.F. Peaslee,V. Guimaraes, J.J. Kolata, D. Peterson, P. Santi, R. White-Stevens, E.F.Aguilera, E. Martinez-Quiroz, F.D. Bechetti, M.Y. Lee, J.A. Zimmerman, J.D.Hinnefeld and O.A. Capurro

Phys. Rev. ***C62*** *(2000) 047601*

The angular momentum distribution of the compound nucleus is a fundamental characteristic of the reaction dynamics and can provide insight into reactions involving neutron- or proton-rich projectiles. Specifically, following the fusion of ^{6}He with ^{209}Bi (at center-of-mass energies of 18 to 27 MeV), 212At is formed by the evaporation of three neutrons from the compound nucleus. The decay process leaves the residual 212At in either the ground state (Jpi = 1-, T1/2=314 ms) or a metastable state (Jpi = 9-, T1/2 = 119 ms). The ratio of the number of residual 212mAt to the total number of 212At residual nuclei is sensitive to the original momentum distribution of the compound nucleus. The measured isomer ratio is consistent with that predicted by standard models. This agreement is observed even at the lower energies where the measured three neutron evaporation cross section is greatly enhanced compared to model calculations. While the inclusion of coupling to the neutron-transfer channels improves the agreement with the observed cross-section data somewhat, the predicted isomer ratio then diverges from the measured ratio