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Cover illustration: Artist's conception of the DRAGON Facility [see article on page 10].

Editorial

Nuclear physics is something of a Cinderella story in modern science. For many years it has experienced society's distaste because of its role in creating nuclear weapons as well as the perceived problems of nuclear power, most notably the waste disposal problem. Yet the molecular biologists may well lift the mantle of sin onto their own shoulders and some parts of the green movement are beginning to see the benefits of nuclear power for our planet's fragile atmosphere. There are genuine prospects for reprocessing long-lived radioactive waste, thus solving the long-term storage problems. Millions of people benefit each year from procedures in nuclear medicine and our field has a wonderful array of discoveries and challenges before it which are capable of inspiring the best and brightest students. Perhaps it is time for Cinderella to go to the ball.

In terms of fundamental science, the strong interaction sector of the Standard Model is ours and its solution presents some wonderful challenges. How does confinement work; can we understand properties such as nuclear saturation in a natural way from QCD; what are the properties of hadronic matter under extremes of temperature and density; what is the nature of a "neutron" star and how were the elements formed? In collaboration with colleagues in astrophysics and atomic physics, we are beginning to explore whether the fundamental "constants of nature" are indeed constant—hence providing a glimpse of possible extra dimensions. Then there are the neutrinos, where nuclear physics techniques are revealing new and totally unexpected properties . . . and the list goes on.

How this wonderful science can be most effectively pursued is a question of great significance, and international cooperation will be more important than ever. With this in mind, the Nuclear Physics Commission of IUPAP (C12), under the Chairmanship of Shoji Nagamiya, has established a new Committee for International Cooperation in Nuclear Physics. Earlier work in this direction under first Herman Feshbach and then Bernard Frois led to a significant report prepared through a Megascience Forum, but there is a feeling in our community that more effort is urgently needed.

Of course, the success of the major facilities, which are the flagships of our field—GSI, Jefferson Lab, JHF, RIA and RHIC—must be a prime focus for this work. It is essential that the ambitious plans for these laboratories are realized in a timely fashion. However, we have had clear demonstrations that our field is rich in diversity and major discoveries can come from the smaller labs. As just a single example, the now famous θ^+, a completely new exotic hadron, was uncovered first on a beam-line at the Spring-8 light source in Japan. This has led to an enormous amount of work seeking confirmation and further details at many other facilities around the world. It may well be that the best method for determining its parity will involve experiments at the COSY facility at Jülich. Both the large and the small, working effectively together, are essential for the health of our field.

The first meeting of the new committee will be held in Göteborg, on the occasion of INPC2004. As Chair of this new committee, I would like to invite all the members of our community to reflect on the things you would most like to see come out of its work and to let any of the members know your views, either before or during the conference. I believe very strongly that effective international cooperation is essential to the exploration of the stimulating scientific questions outlined earlier.

Anthony W. Thomas
Jefferson Lab

The views expressed here do not represent the views and policies of NuPECC except where explicitly identified.

Static Moments of Exotic Nuclear Structures

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Introduction

One of the major topics of interest in nuclear structure physics is the investigation and understanding of the properties of exotic nuclei. These are nuclei with a neutron to proton ratio that differs significantly from that of stable nuclei [1]. Only if the properties of nuclei under these extreme conditions of isospin are understood and explained by nuclear models, can we be one step closer to a better understanding of the nuclear forces holding nucleons together in an atomic nucleus.

The atomic nucleus is a special quantum-mechanical system. It is made of a finite number of strongly interacting fermions, and its properties are governed by the interplay between the electromagnetic, weak, and strong interactions. Therefore, the nucleus exhibits several specific features that are induced by few- and many-body phenomena, such as pairing correlations, collective rotations, and the interplay between single particle and collective degrees of freedom. Our knowledge of the atomic nucleus is mainly based on the properties of nuclei close to the line of β-stability (stable nuclei and radioactive nuclei with a "normal" proton to neutron ratio). Although the properties of these nuclei are reasonably well described by various models, some basic ingredients are not understood. Furthermore, recent theoretical and experimental developments have shown that extrapolations towards the neutron and proton drip lines often fail. This failure is of a fundamental nature and not simply due to the use of a "wrong" set of parameters or an oversimplified approximation.

The experimental determination of the properties of the atomic nucleus and the ability to describe these nuclear properties in nuclear models, has implications for the understanding of other quantum systems, such as Bose-Einstein condensates or metallic clusters and high-T_c superconductors, and for few-body models widely used in atomic and molecular physics, as well as for various astrophysical issues.

The static nuclear moments (electric quadrupole and magnetic dipole) are basic properties of nuclei that provide detailed information about the nuclear structure. While the magnetic dipole moment is extremely sensitive to the single particle structure of the nucleons inside the nucleus, the electric quadrupole moment is a direct measure of the nuclear deformation and of the influence of collective nuclear excitations in the nuclear wave function. Both these properties can nowadays be measured for the ground states of very exotic nuclei, as well as for their excited isomeric states. These properties can be directly compared to the predictions of nuclear models, allowing the testing of the validity of these models under extreme conditions (isospin, spin, and excitation energy), as well as allowing the refinement of the parameterisation of the models.

During the last decade, significant progress has been made in the study of static moments of exotic nuclei. The increased intensities of radioactive beams, which became available at Isotope Separation On-Line (ISOL) [2] and in-flight fragmentation [3] facilities, now make it possible to study the moments of very exotic nuclei. To study the moments of these exotic radioactive beams, the old experimental techniques have been adapted to new production and selection schemes for exotic radioactive beams. Other new methods are being investigated as well.

A few of these developments, which have been going on during the last five to ten years, will be highlighted.

Moments of exotic ground states

A major breakthrough in the study of exotic ground state moments is due to the discovery of a preferred spin-orientation in the in-flight selected secondary fragment beam produced by intermediate- or high-energy nuclear reactions [4]. The presence of spin-orientation in the ensemble of exotic nuclei is the primary requirement for nuclear moment measurements. Almost all experimental techniques are based on detecting the anisotropy in the decay of the spin-oriented radioactive nuclei [5]. This spin-orientation is often induced by the nuclear reaction itself, and has been used in fusion-evaporation reactions [6]. Such reactions are used extensively for in-beam studies of moments of short-lived isomeric states, mainly in neutron deficient nuclei. For an overview see [7].

The observation of spin-orientation in projectile

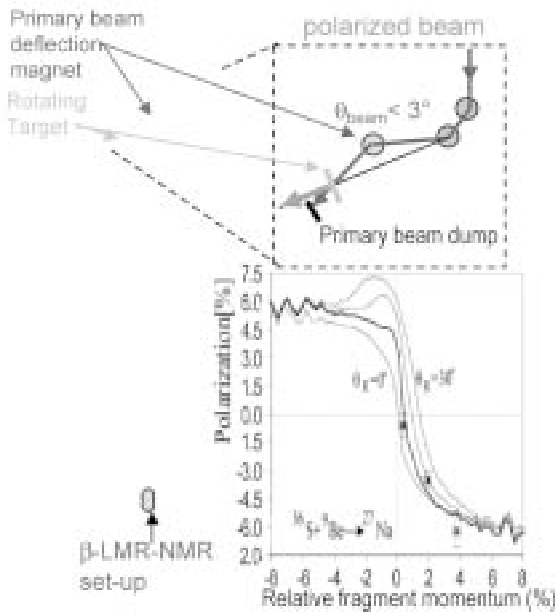

Figure 1. *A schematic view of the LISE-III spectrometer at GANIL. A spin-aligned beam is obtained by selecting the secondary beam along the primary beam direction (= normal operation mode). The upper graph illustrates how spin-polarized beams are obtained, using an additional magnet to deflect the primary beam by an angle of up to 3.5º. The lower graph shows the amount of spin-polarization for different energy selections of the fragment beam, illustrating that the polarization in the selected beam depends strongly on the selected longitudinal momentum window [10].*

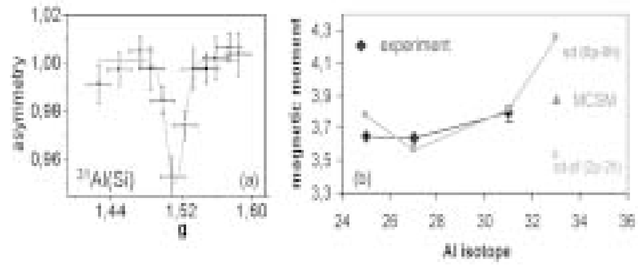

Figure 2. *(a) A measured β-NMR spectrum for a ^{31}Al polarized fragment beam (2.10^4/s) implanted in a Si single crystal. (b) Comparison of experimental magnetic moments with calculations within the sd-shell model and with more extended shell model calculations for the case of ^{33}Al (see text).*

fragmentation, even after the in-flight mass separation, opened a new area for nuclear moment studies. In combination with the very sensitive β-Nuclear Magnetic Resonance methods [8] or the newly developed β-Level Mixing Resonance method [9], the investigation of the structure of exotic ground states started a few years ago at most fragmentation facilities. With our Leuven group at GANIL (Caen, France), we are concentrating on a systematic study of the ground state moments of nuclei in and near the "Island of inversion" around ^{32}Mg. By directing the high-intensity ^{36}S primary beam onto a rotating target at the entrance of the LISE fragment separator, exotic isotopes of Al (up to ^{34}Al) or Mg (up to ^{31}Mg) are produced in sufficient amounts to allow nuclear moment studies (the minimum rate is about 10^3/s). To polarize the fragment beams at GANIL, a primary beam deflection magnet is used in front of the LISE target chamber (Figure 1).

Polarized beams are needed to measure the ground state g-factor using the β-NMR method. A typical β-NMR spectrum, measured recently for ^{31}Al [11], is shown in Figure 2(a). The experimentally known moments for the odd Al-isotopes are compared to *sd*-shell model calculations using the USD interaction in Figure 2(b). A good agreement is found in most cases. For the N=20 nucleus, ^{33}Al, a calculation is performed with the interaction from [13], allowing a *2p-2h* excitation of neutrons into the *pf*-shell. A similar calculation was performed using the Monte Carlo Shell Model [14], which predicts a 50% admixture of the intruder components in the ^{33}Al wave function, and a g-factor in between the values predicted for a pure *0p-0h* and a pure *2p-2h* state. This illustrates the sensitivity of nuclear g-factors to details of the nuclear wave function. A measurement of the ^{32,33}Al g-factors was performed recently at GANIL and the results will be published soon [15].

Spin-aligned beams, which are about five times more intense than spin-polarized beams, are obtained if no beam deflection is used. Spin-aligned beams can be used in combination with the β-LMR method to investigate the ground state nuclear quadrupole moment and to measure the nuclear spin, as done for a ^{31}Mg beam [12].

Other very powerful methods for producing pure beams of exotic nuclei are the ISOL method in combination with the laser ion source [16] and the Ion Guide ISOL (IGISOL) technique [17]. The exotic nuclei produced from an ISOL or IGISOL facility are not spin-oriented, so an external method is needed to orient the nuclear spins. This can be done by three methods: by the tilted foils interaction method [18], by implantation in an on-line low temperature nuclear orientation unit [19], or by the resonant interaction between a continuous wave (CW) laser beam and the radioactive ion (or neutralized atom) beam. At ISOLDE, a unique collinear CW-laser facility has been operational for several decades [20]. In the early years, the laser was used mainly to measure the hyperfine spectra of resonantly excited radioactive beams. A similar set-up has recently become operational at the Jyvaskylä IGISOL facility, where an ion-beam cooler has been installed to improve the quality of the IGISOL beam before it interacts with the collinear laser beam [21]. With an additional polarizer in the laser beam-line, circularly polarized laser light can be produced. This allows the resonant excitation and polarization of the ion (or atom) beam by means of the optical pumping mechanism. The atomic polarization is subsequently transferred to the nuclei via the hyperfine interaction between the nuclear and the electron

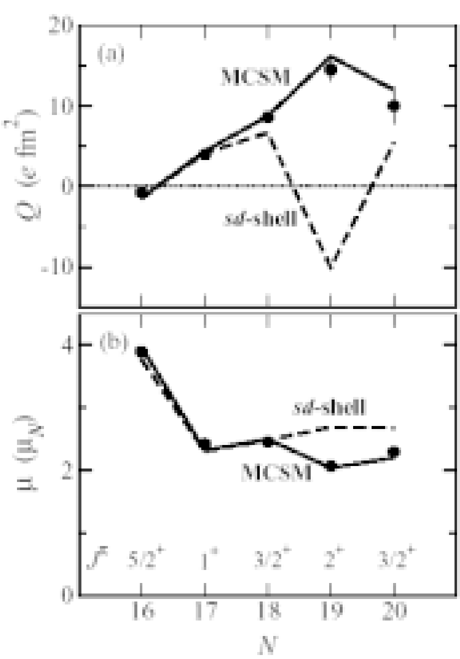

Figure 3. *Comparison of the experimental values for quadrupole and magnetic moments of the $^{27\text{-}31}$Na isotopes with various shell model calculations, taken from [24]. The good agreement between experiment and the Monte Carlo Shell Model calculations led to the conclusion that the ground states of ^{30,31}Na are governed by the 2p-2h intruder configurations, while in ^{29}Na the intruder configuration represents about 40% of the wave function. The data are taken from Keim et al. [23].*

spin. After implantation of the optically-polarized nuclei into a suitable crystal, precision measurements of the nuclear magnetic and quadrupole moment can be performed using again the β-NMR methods. This has allowed the study of the moments and spins of the halo nuclei ^{11}Li and ^{11}Be [22]. A systematic study of the quadrupole and magnetic moments of the Na isotopes up to ^{31}Na [23] revealed the need to include *2p-2h* excited states in the ground state wave function of the neutron-rich Na isotopes (Figure 3). Comparison of the experimental values with shell model calculations allowed confirmation of the observation that from N=18 on, the ground state of the Na isotopes is strongly influenced by the intruder configurations, which dominate the ground state from ^{30}Na on [24].

Moments of isomeric states

Isomeric states in nuclei provide information on the nuclear structure at high excitation energy and spin. Static moments of isomeric states have been investigated for more than 40 years, mainly with the Time Differential Perturbed Angular Distribution (TDPAD) method. Isomeric states in neutron-deficient nuclei, produced and spin-aligned via the fusion-evaporation reaction, and with lifetimes between 50 ns up to 50 μs have been investigated (see Table of Nuclear Moments in [5] and [25]). In the last few years, important developments in isomeric state research have opened up new areas of investigation, including studies on long-lived isomeric states using the Level Mixing Spectroscopy (LEMS) method, studies on long-lived isomeric states produced via the IGISOL method using collinear laser spectroscopy techniques, and the investigation of moments of very short-lived isomeric states using large Ge-detector arrays. An overview of these recent technical advances is given in [5], where the results of systematic moment measurements in the Pb region are summarized and discussed.

Static quadrupole moments of isomeric states are experimental observables that allow the phenomenon of shape coexistence in atomic nuclei to be demonstrated experimentally. We have recently been able to measure the quadrupole moments of some intruder isomers in neutron-deficient Pb isotopes using the newly developed LEMS method [26]. Comparison of these quadrupole moments to those of some "normal" isomeric states shows a larger order of magnitude than for quadrupole moments for the proton intruder configurations. These data have been compared to Hartree-Fock-Bogoliubov calculations [27] (Figure 4). The theory reproduces the experimentally observed values very well by assuming that the normal neutron isomeric states

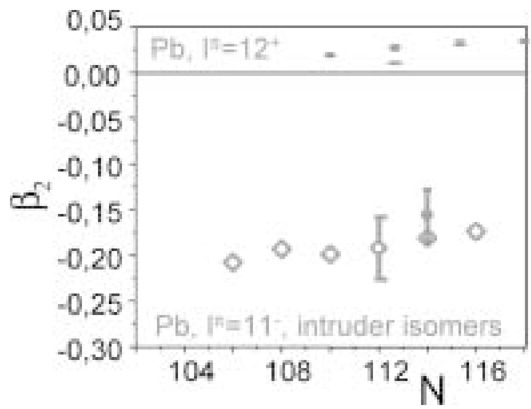

Figure 4. *Experimentally determined deformation (full dots) of the 11⁻ intruder isomeric states and the 12⁺ isomeric states in neutron-deficient Pb-isotopes (from [5] and [26]) compared to calculated deformations (open diamonds) obtained with a HBF method using a skyrme interaction [27]. This demonstrates the coexistence of near-spherical and oblate deformed states in the Pb nuclei.*

are built on the spherical minimum of the potential well, whereas the intruder proton isomers are built on the oblate minimum. In addition to the occurrence of several 0^+ states at low excitation energy in these neutron-deficient nuclei [28], this is further experimental evidence for shape coexistence in nuclei with a magic proton number and a near-to-mid-shell neutron number. Similar phenomena of shape coexistence have been predicted in lighter nuclei (e.g. in the region around ^{32}Mg [29]).

The production of isomeric states on the neutron-deficient side of the nuclear chart is still most successful using stable beams around 5 MeV/u. Combining high-intensity stable beams with a good mass and charge selection procedure could allow the investigation of isomers approaching the proton drip lines. At present, however, most moment measurements on fusion-evaporation isomeric states are still performed in-beam, which limits us to the study of yrast-isomers that are produced in reasonably "clean" reactions.

Isomers in neutron-rich nuclei have recently become accessible to nuclear moment studies, since it was found that the fragments produced in intermediate- and high-energy nuclear reactions not only occur in their ground state, but also as isomeric states (with lifetimes longer than about 100 ns, being the flight time through the fragment separator). A pioneering experiment performed on a known isomer [30] produced in a GeV/u fragmentation reaction revealed a significant amount of spin-alignment. First studies of g-factors of newly discovered isomeric states in the neutron-rich Ni region have been performed at GANIL, using the TDPAD method [31,32]. The application of hyperfine methods to study the moments of isomeric states produced via projectile fragmentation is a very promising method of obtaining nuclear structure information on excited states in neutron-rich nuclei. Comparison of the ground state and isomeric state quadrupole moments is an excellent tool for probing new nuclear structure phenomena (e.g. the presence of shape coexistence in neutron-rich nuclei).

Conclusions and perspectives

The increased production rates of radioactive beams (in their ground or isomeric states) have stimulated renewed interest in the study of nuclear moments. The g-factor and quadrupole moment of a nuclear state are two observables that can directly be compared to nuclear model predictions. Thus, not only do they reveal direct nuclear structure information, but these observables are also excellent probes with which to test the newly developed nuclear models. In the last decade, several improvements have been made in modelling the atomic nucleus in order to take into account the new nuclear structure phenomena that are being discovered in exotic nuclei. By measuring nuclear moments in a systematic way for a particular region of exotic nuclei, one can contribute to a better understanding of the nuclear structure, as demonstrated in a few examples in this article.

It is important to use complementary methods to produce the exotic nuclei of interest. Radioactive nuclear beams that are produced at high intensity at a fragmentation facility are not necessarily produced at a high intensity at an ISOL facility, and vice versa. Moreover, a second very important parameter, namely the amount of spin-orientation that can be obtained in the radioactive beam, needs to be considered in nuclear moment studies. For isomeric states in neutron-deficient nuclei, the production and spin-orientation is still optimal in stable-beam fusion-evaporation reactions, while the high-energy in-flight-produced isomeric beams are more promising for neutron rich isomeric beams.

A variety of hyperfine interaction methods is needed to allow systematic studies on a variety of nuclear states in a particular mass region. Each of these experimental techniques requires a very specific expertise, as well as a dedicated experimental set-up. It is a challenge for future generations to build collaborations in which access to all these techniques is available.

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Studies of Elemental Synthesis in Exploding Stars Using DRAGON and TUDA with Radioactive Beams at ISAC

Introduction

One of the most surprising scientific revelations of the 20th century was the discovery that we are all products of matter processed in stars, or as Willi Fowler used to say, "We are all nuclear debris." All heavy elements such as carbon and oxygen originated in nuclear cooking processes in the interior of stars. Some of this material is ejected into space in the death throes of stars contracting to white dwarfs after the nuclear fires have died—the fate of many stars, including the sun. However, this source cannot account for the abundance of light elements and it completely fails for the many elements heavier than iron, such as gold and uranium. The difference is made up of stellar cataclysms such as supernovae and novae. An excellent general description of such events can be found in the article by M. Aliotta [1]. Elements are made in stellar burning by the fusion of nuclei of the lightest elements, hydrogen and helium, into the nuclei of all heavier elements. Fusion reactions in normal burning proceeds at a slow pace. The ability to recreate these reactions in the laboratory have been extensively studied using beams of hydrogen and helium striking targets of different stable nuclei. In exploding stars the stellar burning process is much more rapid (seconds as compared to years) and short-lived radioactive nuclei are involved. Until recently the technology has not been available to obtain required information on the rates of reactions involving such short-lived species, with the exception of the first measurement performed at the Louvain-la-Neuve facility some years ago [2]. With the advent of an increasing number of high intensity radioactive beams facilities, combined with the required experimental facilities, such measurements can now be performed more readily.

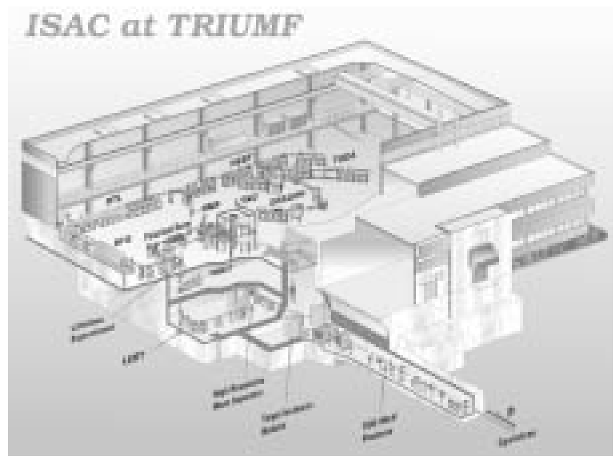

Figure 1. *The ISAC Radioactive Beams Facility at TRIUMF.*

The DRAGON Facility

The new DRAGON (Detector of Recoils And Gammas Of Nuclear reactions) facility is located at the ISAC Radioactive Beams facility [3] in Vancouver, Canada (Figure 1).

The goal of the DRAGON experimental program is to study the probability of reactions involving the capture of hydrogen or helium by a short lived exotic isotope, which results in the emission of electromagnetic radiation only. In the laboratory these reactions can only be studied by using a beam of the radioactive isotope striking a gaseous target of hydrogen or helium. To measure the rate of the reaction, the product must be efficiently and cleanly separated from the much more intense incident beam and related background sources. This is done using the DRAGON recoil separator. The rate is obtained from a determination of the absolute yield of the product as a function of beam flux.

Figure 2 is an artist's conception of the 21 meter long DRAGON facility located in the ISAC experimental hall (Figure 3). At the front end there is a recirculating, windowless gas target in which hydrogen or helium gas flows. Many high-speed vacuum pumps are needed to maintain the required low pressure on either side of the high pressure region (~4 Torr) containing target gas. At the centre of the gas target the pressure is almost 10^7 times more than a few meters on either side of it despite the fact that the gas is unconfined. The radioactive beam from

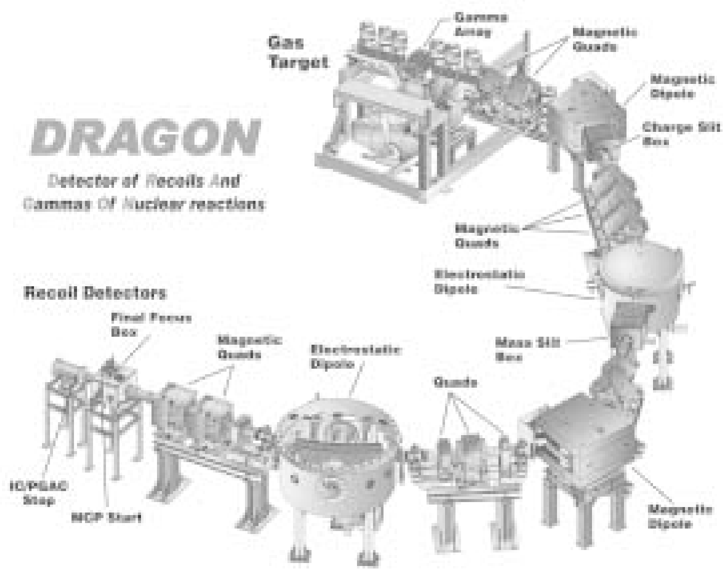

Figure 2. *Artist's conception of the DRAGON Facility*

ISAC passes through the gas target, striking and occasionally fusing with atoms of the gas. 30 bismuth germinate (BGO) γ-ray detectors surrounding the gas target are used to detect the prompt γ-radiation from the nuclear fusions. Nuclei, formed by the radiative capture reaction, continue a forward direction along with the incident beam. Both have about the same momentum and because of atomic collisions with the gas target are now in several different charge states. These two facts make separation of the reaction product from the incident beam very difficult, as the transmitted incident beam is about $10^{12} - 10^{15}$ times more numerous than the reaction product nuclei. Taking advantage of the small energy difference between product and beam, a complicated system of bending magnets, focusing magnets, and electrostatic dipoles is used to carry out this separation. A series of nuclear detection systems at the final focus is used to identify and count the reaction product.

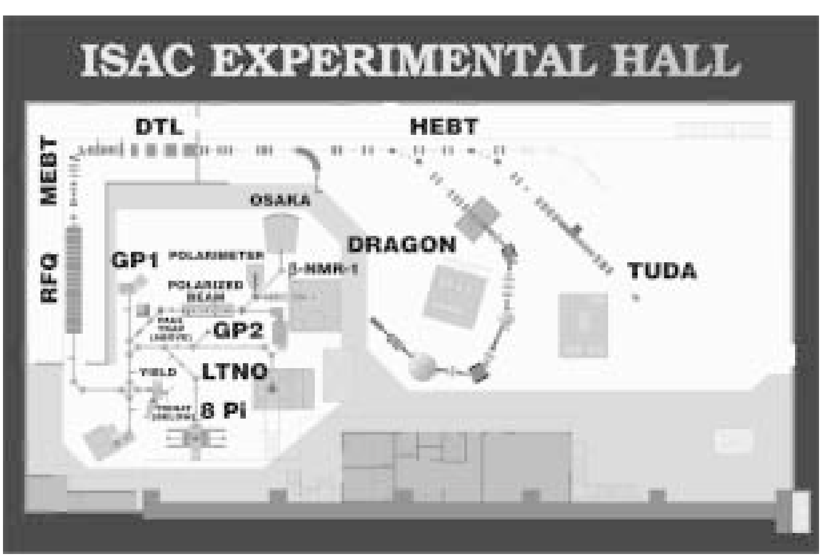

Figure 3. *The ISAC Hall showing the various facilities.*

THE FIRST STUDY: $^{1}H(^{21}Na,^{22}Mg)\gamma$

The radioisotope, ^{22}Na exhibits a lifetime of 3.8 years and emits a γ-ray of 1.27 MeV. Figure 4 displays the NeNa reaction network cycle that occurs in a nova explosion and where ^{22}Na is a possible product. It has been predicted, based upon the present understanding of a nova explosion, that the presence of ^{22}Na through its gamma emission should be observed using γ-ray satellite observatories such as COMPTEL, but it has not yet been seen.

One of the important reactions in the production of ^{22}Na during a nova explosion is the fusion of protons with the unstable isotope ^{21}Na producing

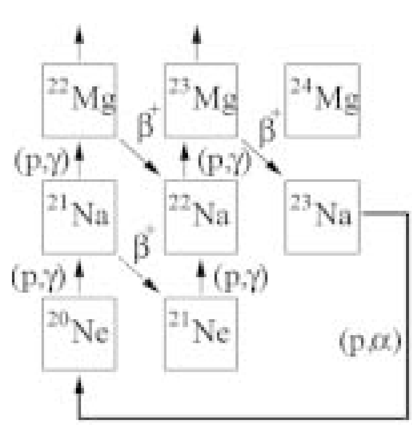

Figure 4. *The combined hot and cold NeNa reaction network cycles.*

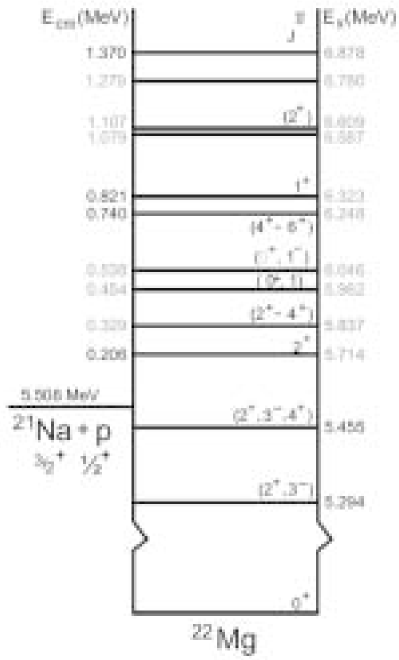

Figure 5. *Levels of ^{22}Mg close to and above the proton threshold.*

^{22}Mg and a γ-ray.

This reaction clearly plays an important role but its rate as a function of temperature has not been measured. This became the first experiment performed using DRAGON. A beam of ^{21}Na ions (lifetime of 32.4 s) was generated using the ISOL technique by bombarding a thick target of silicon carbide with 500 MeV protons from the TRIUMF cyclotron. The resulting ^{21}Na are ionized using a hot surface ion source, then extracted, mass analyzed, and accelerated (0.15 – 1.5 MeV/u) in the ISAC1 linear accelerator (Figure 3). This beam then entered DRAGON, striking and reacting with the hydrogen gas target.

Figure 5 displays the levels of ^{22}Mg above the proton threshold (4). A novae explosion is believed to exhibit a temperature of the order of 0.4 GK which corresponds to an energy of about 150 – 200 keV above the proton threshold. The state at an excitation energy of 5.714 MeV (resonance energy of 0.206 MeV) is believed to play the dominant role in a radiative proton capture on ^{21}Na in a nova explosion. To measure the resonance strength of this level, ^{21}Na beam energies of the order of 220 keV/u were employed.

Currents of ^{21}Na at the DRAGON target in this experiment were as high as 1 x 10^9 s^{-1}. At the center of the windowless, recirculating gas target system is a gas cell of 9 cm in length with a 6 mm entrance and an 8 mm exit collimator (both collimators tilted at 30°) that allows passage of the recoil nuclei within an opening angle of 20 mrad. The target pressure is typically between 4.5 T and 7.7 T monitored by a capacitance manometer. A silicon detector is positioned 30° off the beam axis to record elastically scattered protons for the normalization of beam currents. The beam flux is also monitored using an external beta detection system after the first electrostatic dipole (separates beam from recoils) to measure the radioactivity from the stopped, separated beam.

The array of 30 BGO detectors (5 cm x 15 cm, hexagonally shaped) surrounds the target cell covering a solid angle of almost 4π for γ-rays produced at the center of the target. The segmentation of the BGO detector array allows an approximate reconstruction of the original position of γ-rays

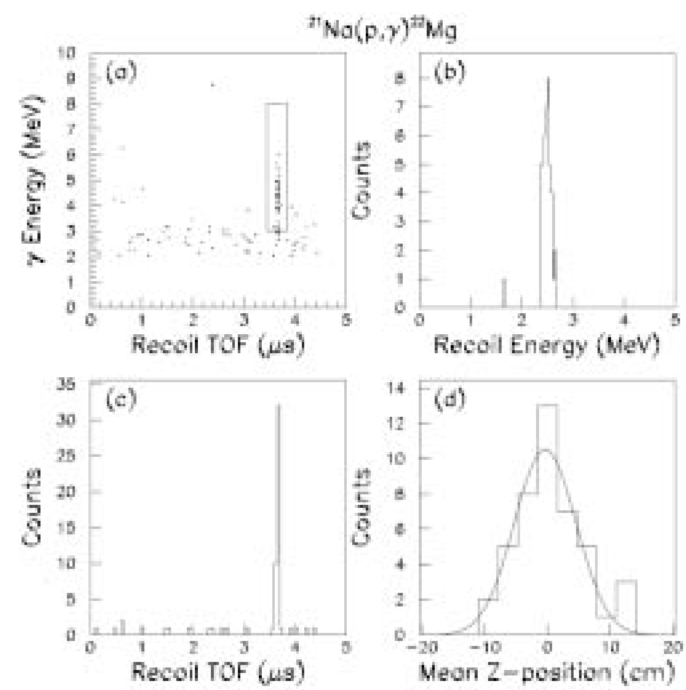

Figure 6. *Spectra when using a ^{21}Na beam energy of 220keV/u showing evidence of a resonance. (a) gamma energy vs. time-of-flight distribution through the separator; (b) gated recoil events in the DSSSD; (c) TOF projection of panel (a); (d) Hits of (-rays onto the BGO array as a function of the (z) position in the gas target with the center at z = 0.*

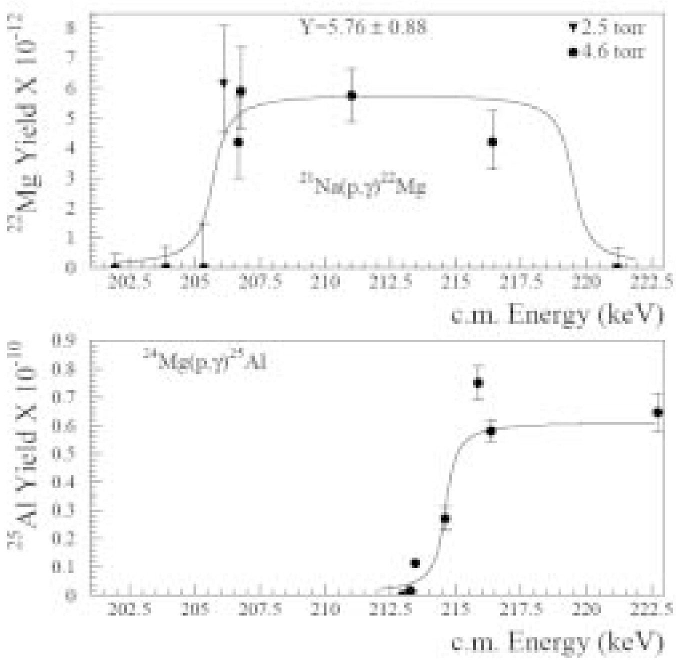

Figure 7. *(a) Excitation function of the p(^{21}Na,γ)^{22}Mg in the vicinity of the E_{cm} = 206 keV resonance. (b) In comparison, the excitation function for a stable beam ^{24}Mg(p,γ)^{25}A1 reaction with a similar resonance.*

produced at different locations in the gas target. In the course of the experiment, a high γ-flux of 511 keV γ-rays from the decay of deposited^{21} Na was observed. Therefore, a first-hit threshold has been set for a 2 MeV γ-energy and a subsequent (multiple) hit threshold of 1 MeV. γ-events above these thresholds that are scattered into multiple detectors can be reconstructed from this information.

Experimental Results

The expected and observed counting rate was of the order of a few counts per hour for the resonance of interest (206 keV). Data are displayed in Figure 6 obtained over a period of weeks at the ISAC facility. These represent a time coincidence signal between the γ-ray detector array and a double-sided Si strip detector (DSSSD) located at the focal plane of DRAGON, detecting the separated recoiling reaction heavy ion. Clearly there is a strong correlation displayed in Figure 2a with a time of flight of about 3.5 μs—the transit time passing through DRAGON. Figure 2d displays the transverse coincident γ-ray activity in the BGO array, indicating the resonance occurring in the center of the gas target.

The scanned excitation function of the radiative proton capture reaction for the resonance of interest is displayed in Figure 7. The energy of the beam (on the x-axis) was measured using the first dipole magnet of DRAGON. The magnetic field was measured using an NMR-based probe and calibrated using known resonances from stable beam reactions. The observed resonance energy (Figure 7a) gave an energy different than that in the literature. The excitation function of Figure 7b shows a measurement for a resonance of similar and well-known energy and for which we determined the correct value with our approach. It now appears that the mass of ^{22}Mg presented in the literature was inaccurate by about 6 keV.

Using the thick target yield point at the center of the excitation function (Figure 7), the rate of the reaction was deduced. This value was slightly stronger than previous theoretical estimates. Incorporating this into an elaborate code of a true stellar nova explosion indicted that the amount of ^{22}Na left at the completion of a nova is much less, as there is more ^{22}Na produced during the explosion, which then reacts away during the explosion itself. More complete information is found elsewhere (4). Reaction rates involving additional levels of ^{22}Mg were also been measured but these are of greater interest for X-Ray bursts.

TUDA

A second facilty operating at ISAC for studies of nuclear astrophysics is the TUDA (TRIUMF University of Edinburgh Detector Array) facility. While DRAGON is designed for radiative capture studies, TUDA is used for reactions involving particle emissions. The ISAC TUDA facility is a very flexible apparatus that can be modified to meet the needs of a variety of nuclear science experiments. These are scattering experiments where ion beams from ISAC are focused on targets inside the chamber and products from nuclear reactions between the ion beam and the target material are detected downstream or upstream in an array of silicon strip detectors (LEDA). The beam entrance section houses a

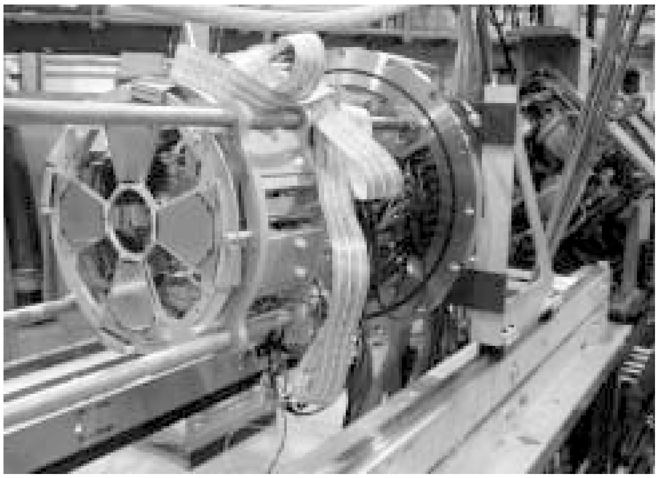

Figure 8. *General view of the TUDA detector system.*

collimator wheel, the middle section holds the target, and the end section houses the downstream flange to which the detectors are mounted. In Figure 8, the downstream flange has been pulled back from the chamber to expose four segments of a LEDA and its mounting. As shown, the LEDA detector (the flat plate with the cross) is mounted on long forks attached to the downstream flange. The structure behind the LEDA detector houses the electronics. The detector is composed of pie-shaped segments that are divided into 16 individual concentric silicon strip detectors, 0.3 mm thick. Each detector has up to 128 individual independent channels. The hole in the centre of the array allows the unscattered beam to pass through. It is possible to stack several detector pancakes together and assemble TUDA experiments in a variety of configurations depending on the reaction being studied.

At TUDA an elastic scattering experiment of radioactive ^{21}Na ions on a hydrogen [$(\text{-CH}_2)_n$] target has been performed for energies of 0.45–1.4 MeV, a study complementary to the radiative capture reaction ^{21}Na(p,γ)^{22}Mg. As for DRAGON, the ^{21}Na was produced from SiC at the ISAC production target. The total ^{21}Na current was limited to 5x10^{7} ^{21}Na s^{-1} to avoid high dead times in the data acquisition system as well as to prevent rapid degradation of the $(\text{CH2})_n$ targets. With thick targets a complete coverage of the excitation function was obtained by appropriately stepping the beam energy, while thin targets were used to investigate selected energy regions in more detail.

The TUDA facility was configured in the laboratory using two LEDA arrays with 192 channels in total, and covering angles from 4.5º to 12º and 14º to 33º, respectively. One detector was positioned 20 cm downstream of the target, while the other detector was positioned 62.8 cm downstream. From the timing clock of the linear accelerator system a signal of 86 ns interval is received and used in the timing of TDC channels. This interval corresponds to the ^{21}Na beam bunch separation received from the DTL. Typical bunch widths were less than 1 ns (FWHM). For all data resulting from beams scattered at the target, a clear correlation between timing and energy is observed, while signals from the b-decay of deposited beam particles are uncorrelated.

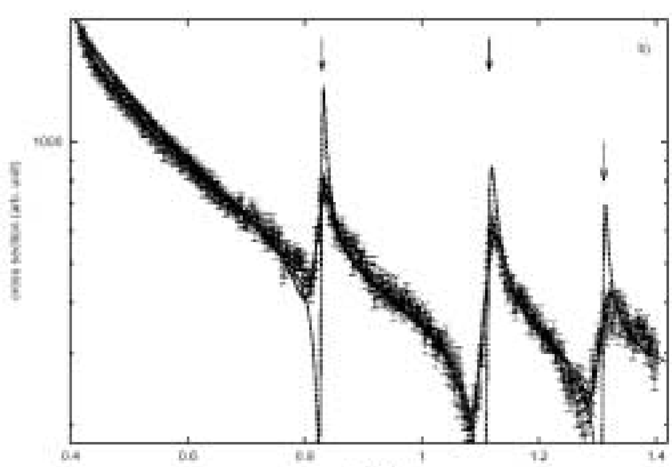

Figure 9. *Excitation function from thick target data derived by summing and combining the recoil proton spectra from all detector elements at 4.7° (lab). The cross-section (y-axis) is in arbitrary units. The figure shows the data, as well as the convoluted and calculated (dashed) fits. Positions of states from the fit are marked by arrows.*

Recoil protons emanating from the $(CH2)_n$ target were observed as the primary signal. Their energy distribution in the recoil peak directly reflects the excitation function corresponding to the beam energy loss in the target. Runs at different energies that overlap in the excitation function range were combined to yield the composite excitation function. Figure 9 shows the composite excitation function derived from several thick target measurements using eight detector elements at 4.7º (lab).

Three prominent states of ^{22}Mg have been identified in the elastic scattering of radioactive ^{21}Na ions on hydrogen and five additional states have been identified in the inelastic proton scattering to the first excited state of ^{21}Na. These are likely to be of an s-wave nature corresponding to known analog states in ^{22}Ne and ^{22}Na. These states will dominate high temperature burning as well as influence the low temperature stellar rate of this reaction.

Summary

DRAGON and TUDA are now operational facilities at the high intensity, ISOL-type ISAC radioactive beam facility. They are complementary facilities providing new information on radiative capture and particle reactions at low energies, relevant to reactions occurring in explosive nucleosynthesis events in novae, X-ray bursts, and possibly supernovae. One of the studies involving the mechanism leading to the production of the observable isotope, ^{22}Na, was described but many other studies are in the planning stages.

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Beta-beams

Introduction

Neutrino physics is going through an exciting era. The recent discovery that neutrinos can modify their own flavor (i.e., ν_e can covert to ν_m and ν_t or vice-versa) shows that, contrary to what was previously believed, neutrinos are massive particles and exhibit mixing in a similar way to quarks. These important results have been obtained using neutrinos originating from the sun, the atmosphere, reactors, and accelerators. The observation of non-zero neutrino masses and of mixing, points to physics beyond the Standard Model of fundamental interactions. This has considerable impact on different domains of physics, astrophysics—such as for the comprehension of various phenomena such as nucleosynthesis—or cosmology. Much progress in our knowledge of these elusive particles has been achieved. Still, challenging questions remain, including those concerning their Majorana or Dirac nature, absolute mass scale, mass hierarchy, mixing angle θ_{13}, and the possibility of CP violation in the lepton sector. Note that CP violation is a crucial ingredient of leptogenesis, which could help explain the matter-antimatter asymmetry in the universe.

At present, three options are under intense investigation for the study of CP violation: super-beams, neutrino factories, and beta-beams. Super-beams, where neutrinos are produced through the decay of pions and muons, are conventional beams pushed to their ultimate intensities. Neutrino factories and beta-beams are novel concepts. Neutrino factories are based on the production, collection, acceleration and storage of muons to produce muon and electron neutrinos of several tens of GeV that are sent to detectors located thousands of kilometers away. A beta-beam involves the acceleration, and storage of radioactive ions, which, through beta-decay, produce a very pure and collimated electron neutrino or anti-neutrino beam with a well-determined flux [1]. The first feasibility study has shown that this exciting new concept for the production of neutrino beams could be the basis of a future facility at CERN [1,2]. The neutrino beams would be aimed at a water Cherenkov detector similar to Ultra Underground Nucleon Decay and Neutrino Observatory, 440 kton fiducial volume (UNO) [3]. This would be located at an (upgraded) Fréjus Underground Laboratory, 130 km from CERN. An ambitious and multidisciplinary physics program could be performed with this gigantic detector.

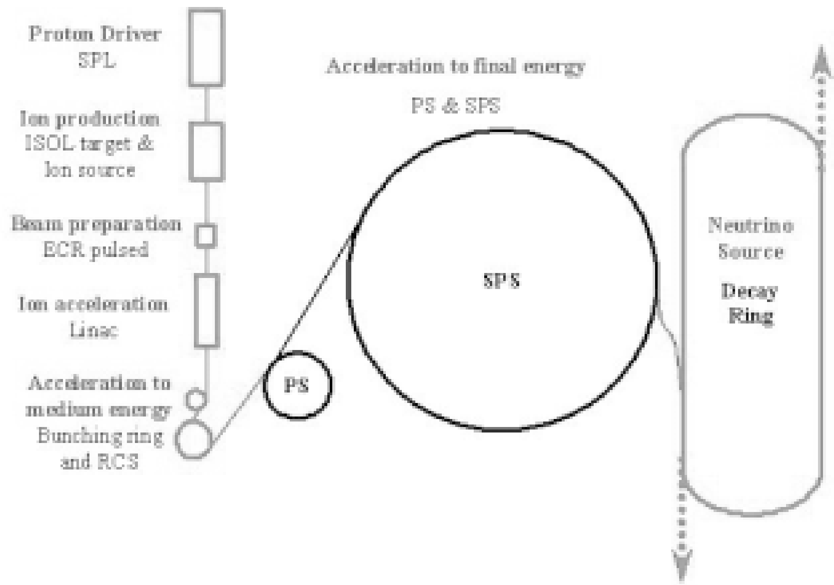

Figure 1. *The CERN conceptual design [1,2].*

The beta-beam facility

The CERN conceptual design for a beta-beam facility includes three main steps (see Figure 1), each involving specific feasibility issues [1,2]. In the first stage, protons (100 μA) delivered by the Superconducting Proton Linac (SPL) impinge on a target to produce the radioactive species of interest. After ionisation and bunching, the ions are accelerated to low energy: a linac is used to reach approximately 100 MeV/u then a fast cycling synchrotron takes them to 300 MeV/u. In the second stage, energies of about 150 GeV/u (for ^{6}He) and 60 GeV/u (for ^{18}Ne) are attained using the existing CERN accelerator infrastructure, namely the Proton Synchrotron (PS) and Super Proton Synchrotron (SPS). Finally, the ions are longitudinally stacked in a new decay ring. Several bottlenecks exist in this scenario, not least is the bunching at low energy, space charge limitations in the

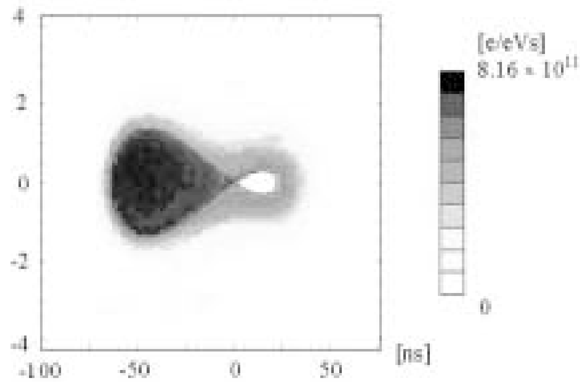

Figure 2. *Tomographic measurement of asymmetric bunch pair merging in the CERN Proton Synchrotron. A proton bunch is combined with a much smaller region of (in this case, empty) phase space.*

PS and the SPS, decay losses in the acceleration chain and, at high energy, the longitudinal stacking process in the decay ring. The proposed beta-beam facility presents strong links with the EURISOL conceptual design. This has resulted in a common bid for a design study within the 6th European Union Framework program.

The choice of isotopes is based on several criteria. The half-life should minimize the decay losses in the accelerator chain. Another constraint comes from the required collimation and energy of the neutrinos at the detector, which depend on the energy of the decaying ions. These (and other) considerations point toward two isotopes of particular interest (i.e., ^{6}He and ^{18}Ne as anti-ν and ν emitters, respectively) [1,2]. Both can be produced in large quantities by the so-called ISOL method. This yields a quasi-continuous beam, so the ions have to be bunched prior to further acceleration. Efficient bunching (< 20 μs) and full stripping of a high-intensity beam can be achieved using a high-frequency (60 GHz) ECR source [4]. While such a system does not exist today, theoretical calculations show that one can be constructed.

Injection of the ions into the decay ring requires a new scheme. Stacking means a regular top-up of the stored beam before the existing particles cease to be useful. Many stacking methods involve some form of beam cooling to increase phase space density and to make room for more particles within a given transverse and longitudinal acceptance. For light ions at high energy, the classical methods of electron and stochastic cooling are excluded. Instead, a new scheme has been proposed combining bunch rotation and asymmetric bunch pair merging. The new bunches are off momentum and are injected in a high dispersion region on a matched dispersion trajectory. Subsequently, each injected bunch rotates a quarter turn in longitudinal phase space until the initial conditions for bunch pair merging are met. In the final step, the rf bucket is manipulated by a second-harmonic rf system such that each small fresh bunch is moved into the core of a large stored one. Phase space mixing then occurs. The fact that only the central part of an existing bunch is combined with an incoming dense one results in a net increase in the core intensity of the resultant stored beam. The surrounding older ions are pushed out towards the bucket separatrix, where eventually the oldest will be lost. Asymmetric bunch pair merging has recently been demonstrated at the CERN PS (see Figure 2) [5].

A principal difference between the acceleration to high energies of stable and radioactive ions is the additional losses due to the radioactive decay of the latter. The isotopes proposed for the beta-beam conceptual design have been chosen so that no long-lived activity is left to contaminate the low-energy machines. At high energies, the ions are likely to break up. It has been shown that the induced activity is well approximated due to the simultaneous loss of the same number of protons as the total number of nucleons in the ion [6]. A first simulation of losses in the decay ring yields a dose rate in the arcs of 2.5 mSv/h after 30 days of operation and 1 day of cooldown [7]. Furthermore, the induced radioactivity in the ground water will have no impact on public safety. It has also been confirmed that the total loss in the accelerator chain will be below the nominal 1 W/m that permits hands-on maintenance. However, as far as the PS is concerned, the expected losses are on the limit of what can be accepted [8].

The predicted intensities for ^{6}He and ^{18}Ne are shown in Table 1. The conventional losses through the accelerator chain are expected to be less than 50% based on operational experience at CERN.

The beta-beam facility is imagined to come into operation while LHC operation, CNGS operation, and new fixed target physics are still part of the CERN physics programme. This has

Table 1. Intensities and average loss power for the ^{6}He and ^{18}Ne (within parentheses) beam of the beta-beam conceptual design of Figure 1. A 16 Hz fast-cycling synchrotron and 8 s SPS cycle time are assumed. Only beta-decay losses are taken into account. The number of ions stored in the decay ring (Ntot) should be roughly halved to include the other losses in the accelerator chain.

Machine	Ions extracted [10^{12} ions/s]	Batches [s]	Loss power [W]	Losses/length [W/m]
Source + Cyclotron	20 (0.8)	0.052	N/A	N/A
Storage Ring	1.02 (0.04)	1	2.95 (0.18)	0.019 (0.0011)
Fast Cycling Synchrotron	1.0 (0.04)	16	7.42 (0.46)	0.047 (0.0029)
PS	10.1 (0.52)	1	765 (56.4)	1.2 (0.090)
SPS	9.5 (0.49)	•	3630 (277)	0.41 (0.032)
Decay Ring (Ntot)	202 (9.1)	N/A	157000 (10600)	28 (1.9)

been included in the conceptual design by assuming a longer SPS cycling time than strictly necessary.

Physics Reach

A UNO-like detector would permit a rich physics program [3]. CP violation studies can be performed by comparing oscillations of ν_e to ν_m with those of anti-ν_e to anti-ν_m . The sensitivity to CP violation has been estimated assuming that the Lorentz γ of the parent ion is 60 for ^{6}He (100 for ^{18}Ne) with a flux of 2.910^{18} (1.1910^{18}) decays/year [9]. The final ion energies are chosen to match several criteria: maximizing the number of quasi-elastic events in the far detector (this scales approximately as γ^3), minimizing the number of background events, and matching the CP-odd term in the oscillation signal. Events produced by atmospheric neutrinos are the main source of background. This can be reduced to 1 event/440 kton/yr by shortening the bunch length to 10 ns in the decay ring and by exploiting the directionality of the incident beam. Systematic errors coming from, for example, cross-section estimates can be reduced by installing a close detector. Figure 3 shows the estimated CP sensitivity obtained with different combinations of beta-beams and super-beams compared with what could be achieved with a neutrino factory [9,10].

If super-beams producing ν_m and anti-ν_m are also available at CERN, this offers the unique opportunity to study T and CPT violation through comparative oscillation searches for ν_m to ν_e with respect to anti-ν_m to anti-ν_e and ν_e to ν_m versus anti-ν_m to anti-ν_e, respectively. Sending neutrinos from beta-beams and super-beams to the

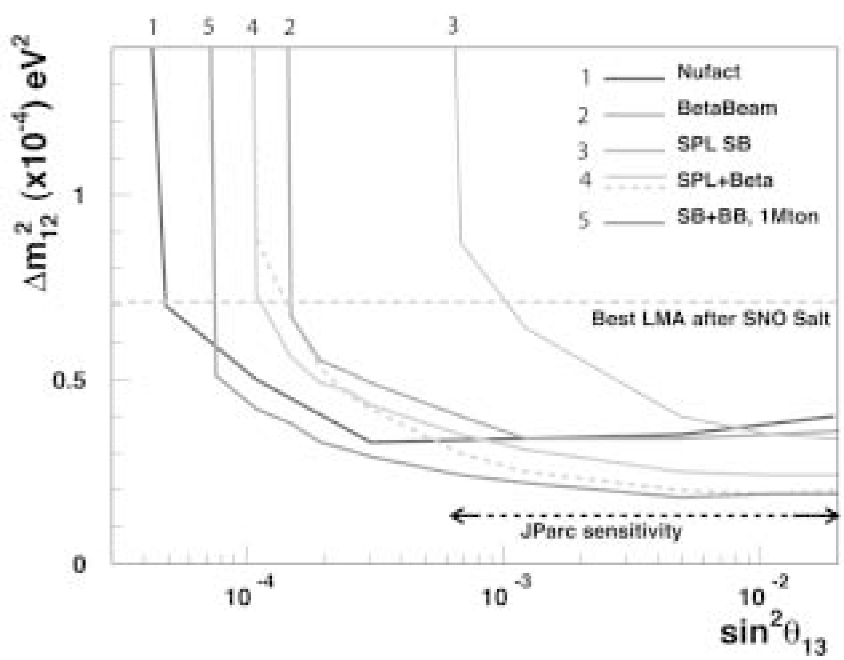

Figure 3. *CP sensitivity—defined as the ability to discriminate between $\delta = 90^0$ and 0^0 at 99 % CL—of the beta-beam (2), of the super-beam (3), and of their combination after ten years run with 440 kton (4) and a 1Mton (5) detector. Note that in the last case one can measure q_{13} as low as 1^0. (The results shown are obtained with increased ^{6}He and ^{18}Ne fluxes by 30% and a factor of 3 respectively.) For comparison, the sensitivity achievable with a 50 GeV neutrino factory (5) producing 2 10^{20} muon decays/straight section/year, and two 40 kton detectors at 3000 and 7000 km is also shown [10].*

same detector would help reduce systematic errors and offer the redundancy needed to firmly establish CP-violating effects, within the reach of the experiment [9].

Other fundamental issues could be addressed with the same detector [3]. Proton decay is one of the predictions of Grand Unified Theories that can be tested in low-energy experiments. Improved sensitivities for various proton decay modes could be achieved. The detector would permit precision solar and atmospheric neutrino studies. It would also be a powerful supernova neutrino observatory. In fact, most of the energy released in the spectacular explosion of a core-collapse supernova is emitted in a few seconds as neutrinos of all flavours. These neutrinos closely follow the different phases of the explosion until the cooling of the proto-neutron star or the formation of a black-hole. The measurement of their time and energy spectra would be of crucial importance for supernova modelling since the explosion mechanism is not yet fully understood. The number of events (10^5) collected from a galactic supernova explosion would exceed that of all other existing detectors. Such a detector would also be the only one sensitive to supernovae in other galaxies; the same number of neutrinos detected from the SN1987A would be seen from a supernova explosion as far away as the Andromeda galaxy (80 kpc).

Low-energy Beta-Beams

It has recently been proposed to use the beta-beam concept to have a facility producing low-energy neutrinos [11]. Two configurations are possible: the ions are simply collected and used as an intense neutrino source (γ=1) or the ions are accelerated and stored in a decay ring (γ=1-40) to have neutrinos of tens to about 100 MeV. In the former case, the ions would be brought inside a 4π detector; in the latter a detector would be placed close to the decay ring. This idea opens a new axis of research [11]. Low-energy neutrino beams would offer the unique opportunity to perform systematic studies on neutrino-nucleus interactions crucial for nuclear physics, high-energy physics, and astrophysics. A precise knowledge of these reactions is needed, for example, to interpret some neutrino oscillation experiments where nuclei are used to detect neutrinos, or evaluate the feasibility of new projects to measure supernova neutrinos. The role of such reactions in nucleosynthesis is also under investigation. So far, few data are available. One needs both to interpolate the neutrino-nucleus cross-sections from neutrino energies of MeV to GeV, and to extrapolate to the case of neutron-rich nuclei. As for the γ=1 configuration, measurements on neutrino properties such as the neutrino magnetic moment could be performed [12]. Since many laboratories will provide intense radioactive ion beams in the future, there are various possible sites for a low-energy beta-beam facility. Sites like GANIL, LEGNARO, or EURISOL (in the present configuration) might offer neutrino fluxes at γ=1, while neutrino fluxes at higher g could be available at laboratories such as GSI or CERN. The feasibility study of a low-energy beta-beam facility will also be studied within the framework of the EURISOL design study.

Outlook

The conceptual design presented here has been conceived with the requirement to fully exploit the existing CERN accelerators. Several improvements concerning, for example, the key issue of the neutrino intensities have been proposed and need to be carefully investigated [4,13]. Future upgrades of CERN accelerators could also be exploited to reach neutrino energies even higher than those described here, which can significantly increase the physics reach [14]. The overall physics potential of beta-beams and of the gigantic detector looks extremely promising.

Aknowledgment

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Quest for a Nuclear Georeactor

Introduction

In a time when astronauts orbit the Earth and visit the Moon, and mankind has brought vehicles to Mars and telescopes into orbit, we seldom realise that we have penetrated the Earth by only 12 km, a distance smaller than we commute daily to our work or equivalent to the cruising altitude of airplanes. Consequently, we know little about the interior of our planet, except from seismic information and study of the composition of meteorites. Recently our knowledge about antineutrinos has reached the stage that they can be used as a tool, allowing us to look at radiogenic heat sources in the interior part of the planet and associated processes.

The current understanding of the interior of our planet starts from seismological investigations by Oldham (1906) and Gutenberg (1914) that leads to the hypothesis that up to half the radius of the Earth is occupied by a fluid core. From the interpretations of earthquakes, Lehmann (1936) recognised a small, solid inner core. The fact that meteorites consist of nickelferrous iron, lead to the assumption that the fluid core of the Earth consists of molten nickel-iron. Density information stems from the work of Birch (1952). He hypothesised from seismological models and knowledge on high-pressure equations of state that the outer core was composed of a liquid iron alloy and an inner solid core of crystalline iron. The melting temperature of the alloy at the respective pressure defines the boundary. Estimates for this temperature at a pressure of 330 GPa range between 5000 and 6000 K. Figure 1 presents the principal divisions and physical states of the Earth's interior. The absence of shear velocity V_s of earthquake waves is the basis for a fluid core. The density curve shows, in addition to the major changes at the principal sections, steps in the upper mantle at about 420 km and 660 km depth.

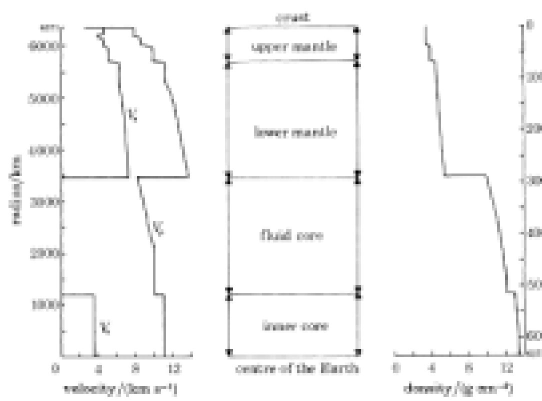

Figure 1. *Schematic representation of the principal partitions and physical states of the Earth's interior. The compressional and shear velocities of earthquake waves, presented in the right panel, are indicated by V_p and V_s, respectively. In the right panel the density as function of depth is presented. (Figure taken from Herndon, 1980).*

Heat loss from the core depends on the radial temperature gradient at the boundary of core and overlying mantle and is strongly related to mantle dynamics. There exists a large uncertainty in ΔT, due to the temperature at the inner-core boundary: ΔT= 1000 to 1800 K (Anderson 2002) over a layer of a few hundred kilometres (Lay et al. 1998). Including the thermal conductivity of the mantle silicates yields a heat flux of 0.04–0.08 W/m^2, leading to a total heat flow from the core of 6–12TW (Buffett, 2003); a considerable part of the estimated total heat flow from the Earth of 40–50TW. The total heat flow at the core-mantle boundary raises vital questions on the thermal evolution of the core and its heat sources in relation to power required to maintain the magnetic field. Radiogenic elements like ^{40}K are thought to play an essential role (Rama Murthy et al. 2003).

Buffett (2003) concludes that "the thermal state of the core remains unclear and that better knowledge of the partitioning of all radiogenic elements between various reservoirs in the planet will help to reduce some ambiguity."

Another ambiguity exists in the chemical composition of the various compartments or reservoirs and especially in the core. In general, one assumes that there is a liquid Fe-Ni alloy core surrounded by a lower and upper mantle and covered by a crust. The bulk composition of the Earth is usually assumed to be the same as that of chondritic meteorites. Within this assumption subsequent hypotheses are made to account for observations at the

Earth's surface.

An intriguing issue is the presence of helium in our atmosphere and in particular its isotope ^3He. Whereas ^4He is continuously produced by alpha decay, the only way to obtain ^3He is either as a primordial relict (e.g. Seta et al. 2001) or by decay of tritium. For the primordial relict the assumption has to be made that the mantle contains a degassed and a, deeper lying, less-degassed reservoir. The former one shows up at the mid-ocean ridge basalts, the latter one in mantle-plumes basalts. Mantle plumes with extreme high $^3He/^4He$ ratios are found at some oceanic islands such as Iceland, Hawaii, Samoa and Galapagos (Kurtz and Geist 1999). One assumption commonly made in interpreting noble gas data from mantle plumes is that the source of mantle plumes is relatively non-degassed lower mantle material. Under this assumption, high $^3He/^4He$ ratios indicate plume-like upwelling, since the deep Earth is believed to be a source of primordial ^3He with a relatively low time-integrated (U+Th)/He ratio (Georgen et al. 2003). At oceanic islands not only high $^3He/^4He$ ratios are found but also normal mid-oceanic island values. This is explained by assuming mixed reservoirs (Stuart et al. 2003).

Recently, Bercovici and Karato (2003) proposed a filtering of the mantle at the 410 km discontinuity of the density (see Figure 1). They propose that the ascending mantle rises out of a transition zone, between the 410 and 600 km discontinuities, into the upper mantle above 410 km. The material undergoes dehydration-induced partial melting that filters out incompatible elements, including He and other noble gases. They propose that this filter model can explain geochemical observations without the need for isolated mantle reservoirs. This model could bridge the gap between geochemists supporting a two-layer model at a boundary of 660 km and seismologists, supporting a whole-mantle model of circulation (Hofmann 2003).

Recently, a possible explanation for some of these questions was proposed by hypothesising a 8 km diameter, nuclear georeactor at the centre of the Earth. The hypothesis for such a reactor originates from the work of Herndon (1992) in applying Fermi's nuclear reactor theory to demonstrate the feasibility of planetary scale nuclear fission reactors. Calculations at Oak Ridge National Laboratory (Hollenbach and Herndon 2001) show that a planetary-scale nuclear reactor can operate over the lifetime of the Earth as a breeder reactor and can produce by ternary fission substantial tritium (decaying to ^3He) to explain the high $^3He/^4He$ ratios observed in oceanic basalts and fumes of volcanoes at Iceland and Hawaii. Seifritz (2003) shows that the operation of such a breeder reactor is consistent with our knowledge on breeder reactors and corresponds to a stable state.

The possibility of a nuclear georeactor is linked to the state of oxidation in the deep interior of the Earth. Herndon has convincing arguments for a state of oxidation like an enstatite chondrite, different from the more oxidised, ordinary chondrites considered by Birch. As a consequence of the highly reduced state some so-called lithophile elements including Si, Mg, Ca, U, and possibly Th occur in part of the core. These elements, tending to be incompatible in an iron alloy, are expected to precipitate at relative high temperatures. Due to their density, MgS and CaS will float to the core-mantle boundary, whereas uranium sulphide (US) and nickel silicide will sink to the Earth's centre.

At pressures that prevail in the core, U and Th, being high-temperature precipitates and the densest substances, would tend to concentrate in the Earth core by the action of gravity. In that process it will ultimately form a fissionable, critical mass. Fission produces less (half) dense fission products that tend to separate from the more dense actinides. In this way a critical reactor condition can maintain.

According to Herdon (1993) and Hollenbach and Herndon (2001), the frequent but irregular variability in intensity and direction of the Earth's magnetic field may be understandable from such a fission reactor. The production of fission products counteracts the operation of the reactor and if the rate of production exceeds the rate of removal by gravitational diffusion, the output of the reactor will decrease and may even shut down, leading to a diminished and ultimate disappearence of the Earth's magnetic field. As fission products diffuse out of the reactor region and actinides diffuse inwards, the reactor restarts and the geomagnetic field re-establishes itself, either in the same or in the reverse direction. The coupling between the georeactor and the geomagnetic field cannot be direct (Hoyng 2003) and has to proceed through changing heat-flow patterns in the core and ultimately in the mantle.

Although the georeactor hypothesis seems to be able to explain, in principle, phenomena such as elevated $^3He/^4He$ ratios and reversal of the geomagnetic field, some questions also remain about the specific mechanisms involved. It is assumed that in the working of the georeactor the fission products are separated from the fuel by diffusion or by buoyancy effects. For both processes it still has to be shown if they are effective enough. First estimates for diffusion, based on an extrapolation (using Arrhenius law) to core temperatures of diffusion coefficients and activation energies for helium in apatite (Dunai, 2000), indicate that transport over a distance of 1 km in a solid metal inner core will take 1 Ma. This is probably an order of magnitude too slow to explain geomagnetic reversals on average every 200,000 years by fission products drifting outwards and so cleaning up the core for a reactor restart. To estimate transport velocities due to buoyancy, detailed calculations are needed, but these velocities are expected to be insignificant because of the micro-gravity conditions in the inner part of the core (Seifritz 2003).

It is also difficult to imagine a sufficiently large outward flux of ^3He (needed to explain elevated $^3He/^4He$ ratios) produced inside the georeactor because an intact solid inner core will form an almost impenetrable barrier for transport. Moreover, the heat produced by the georeactor has to be removed through the solid inner core and normal heat conductivities for solids are not large enough to prevent the reactor from heating up to very high temperatures.

These estimates are based on extrapolating transport coefficients at ambient conditions to the high temperatures and pressures inside the core and assume a uniform metallic core being one solid piece. A more granular structure of the inner core with a structure of pores or fissures will allow a larger and faster transport of gaseous substances and heat. In such a case it is hard to imagine that the core will be uniform and preferential pathways may exist, which act as chimneys and may cause a non-uniform heating of the inner-outer core boundary.

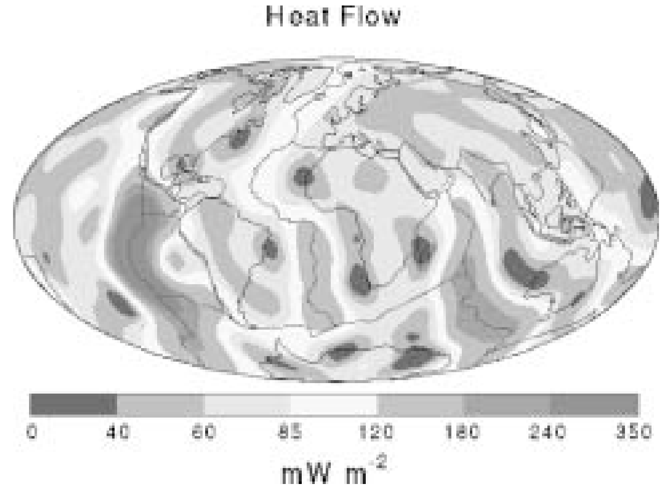

Figure 2. *Map of the heat flow at the Earth's surface. Based on the data of Pollack et al. 1993, and taken from http://www.geo.lsa.umich.edu/IHFC/heatflow.html.*

Antineutrinos as a Tool to Probe the Earth's Interior

The distribution of U and Th in the core and the mantle is not the only question to be answered. Because of the work of Herndon, it is still necessary to find out whether their concentrations decline along their decay series or by fission. One of the few methods to investigate the distribution of natural radionuclides in various reservoirs of the Earth and/or the existence of a nuclear georeactor are antineutrinos produced in β-decay and/or fission, respectively. Fortunately the decay and fission can be distinguished by the energy of the antineutrinos; 2–3 MeV for decay and up to 10 MeV for fission.

As also pointed out by Mantovani et al. (2003), the distribution of Th and U in both the oceanic and continental crust is relatively well known, some information is available on the concentrations of these radionuclides in the upper mantle, but their distribution in the deeper parts of the Earth are unknown. In general for the lower mantel it is assumed that the distribution is homogeneous and spherical symmetric. The fact that surface layers of the Earth have moved significantly throughout geological time is believed to be a surface expression of deeper motions within the Earth. If the heat sources would be homogeneously distributed there would be hardly a reason for these motions. As shown in Figure 2 the heat flow at the Earth surface ranges over an order of magnitude.

Already in 1983 Sheridan made a comparison between a number of features at the Earth surface such as spreading rate of the continents, sea-level stand and calcium-carbonate deposit rates (CCD) and the stability of the magnetic field (see Figure 3). He finds higher spreading rates, higher sea level stands and larger CCD rates at times that the magnetic field is quiet, and relates these phenomena to changes in the circulation patterns in the core and the mantle and the occurrences of mantle plumes at the Earth's surface. Changes in the circulation pattern in the mantle may influence the heat flow at

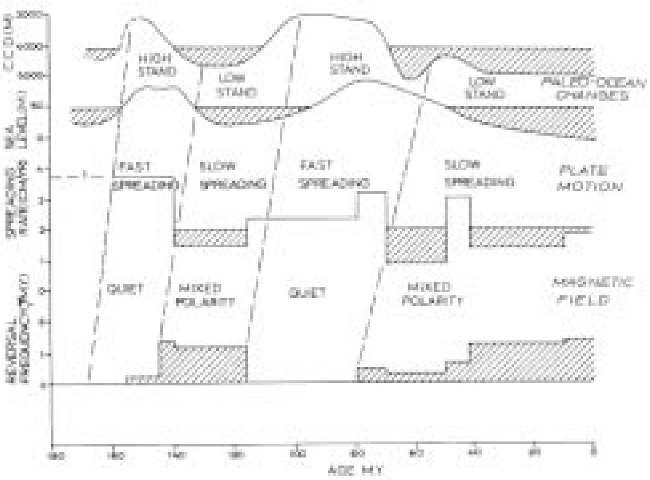

Figure 3. *Correlation over time between magnetic activity, ocean spreading rates, sea-level stands an calcium-carbonate depositon (CCD). This figure is taken from Sheridan, 1983.*

the ocean floors and thereby have an influence on global climate.

All these pieces of information require a better insight of the radiogenic heat sources in the deeper parts of the mantle and especially their inhomogeneities and their deviation from a spherical distribution. The strength of the antineutrino-flux signal at various sites on Earth will therefore be an indication of the distribution of these radionuclides in the compartments of the Earth. According to calculations by Raghavan *et al.* (1998) 40% of the signal will come from sources in the crust within about 450 km, 70% from within 1200 km and 90% from about 6000 km. The sensitivity of the measurements for antineutrino from parts of the mantle and a possible georeactor will therefore be influenced by the location of the detector relative to other (known) sources of antineutrinos such as those coming from the radionuclides in the crust or power reactors. Consequently the project requires directional sensitivity in antineutrino detection and a location that favours the detection of antineutrino sources in the mantle and in the core.

The science and technology of detecting antineutrinos, $\bar{\nu}_e$, are well established. Recently the KamLAND collaboration has confirmed the oscillation phenomena in antineutrinos (Eguchi, 2003) as observed in solar neutrinos. Also the oscillation parameters based on solar neutrinos and fission reactor antineutrinos seem to be established (see Mantovani et al. 2003). In many experiments, we propose to use the detection reaction based on inverse β-decay: $\bar{\nu}_e + p \rightarrow e^+ + n$. The visible energy of the positron signal directly provides the $\bar{\nu}_e$ energy, (E(MeV) = E($\bar{\nu}_e$) – 1.8 + 1.022 = E($\bar{\nu}_e$)–0.78. The signal can be tagged by the signal produced after several microseconds by the thermalised neutron captured by hydrogen in the aromatic organic liquid scintillator. The delayed coincidences suppress the background and the chance coincidence rate in a kiloton scintillator mass detector (such as installed at Kamioka, Japan) can be limited to several events/year (Rhagavan 2002). This corresponds to a sensitivity limit of an antineutrino flux $\Phi(\bar{\nu}_e)_{min}$~10^4 cm^{-2} s^{-1}.

In β-decay, members of the decay series of U and Th antineutrinos, $\bar{\nu}_e$, are produced. The antineutrinos from the geo-reactor will be identical in energy spectrum as those produced in power reactors. In the U series the β-decay of ^{234m}Pa, ^{214}Bi with Q-values of 2.29 and 3.26MeV, respectively, and ^{228}Ac, ^{212}Bi, and ^{208}Tl with Q = 2.11, 2.25 and 1.8 MeV, respectively, can contribute. Geo U/Th signals cut off at E_{e+} of about 2.5MeV.

For reactors—either power reactors or a geo-reactor—the antineutrino spectrum follows from their mean fuel composition, the numbers of antineutrinos per fission event, and their spectrum (see Achkar et al. 1996 and references therein). For these neutrinos, the flux depends on the distance between power reactor and detector. The existing underground laboratories at Gran Sasso, Italy, and Kamioka, Japan, are both situated on the crust and in Kamioka, near power stations.

A 3 to 10TW georeactor would yield at any point near the surface a flux $\Phi(\bar{\nu}_e)_{geo}$~1-3·10^5 cm^{-2} s^{-1} and is an order of magnitude larger than the estimated detector background of ~10^4 cm^{-2} s^{-1}. The detection of antineutrinos from the core is a valid proposition provided the background is sufficiently low. A georeactor is spectrally indistinguishable from power reactors, but the georeactor provides a strongly directional signal. Model calculations indicate that such measurements are feasible in an underground laboratory, provided the background due to the geological formation and antineutrinos produced in nuclear power reactors is sufficiently low. This condition hampers observation in the existing underground

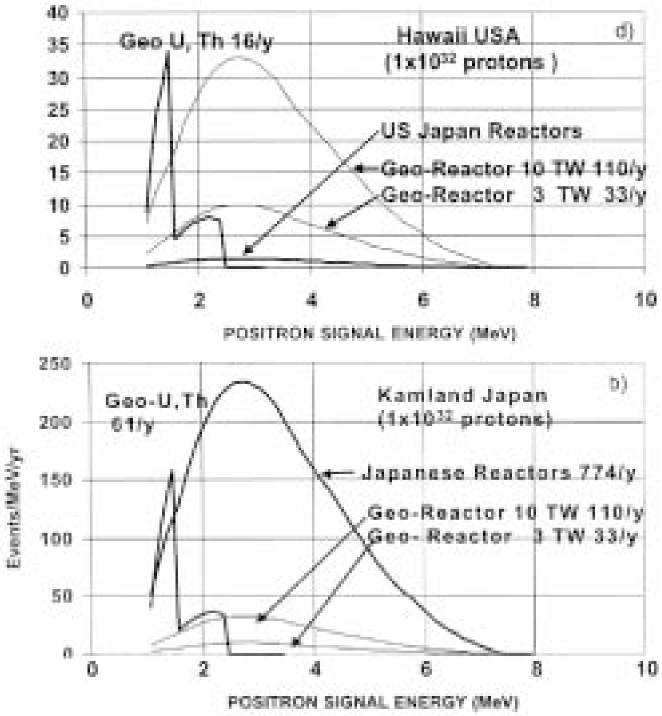

Figure 4. *Calculated positron energy spectrum for two locations: Hawaii and Kamioka. The two locations differ quite strongly in the flux from U/Th antineutrinos and from the antineutrinos produced in nuclear power stations. The situation of Hawaii will be quite similar to the one expected at Curaçao. (Figure taken from Raghavan, 2002.)*

laboratories such as Borexino at Gran Sasso, Italy, and Kamland at Kamioka, Japan, and favours locations such as Hawaii, the Aleuts, and the Antilles. Figure 4 shows the positron energy spectrum for Hawaii and Kamioka (taken from Raghavan 2002). It shows that the background at Kamioka is too large for proper detection. This is recently confirmed by measurements with the Kamland detector yielding 9 ± 6 geo-antineutrinos from an exposure of $1.4 \cdot 10^{31}$ protons year (Fiorentini et al. 2003).

Directional information could be extracted from the recoiling neutron in the reaction $\bar{\nu}_e + p \rightarrow e^+ + n$, for which the recoil angle is on average, $\langle \Phi_{recoil} \rangle = \arccos(2/(3A))$ with A the mass number of the scattering material. For the antineutrinos of geophysical interest, the neutron travels of a few cm between the locations of positron creation and neutron absorption.

Therefore development of large fiducial volume, antineutrino detector set up with sub-MeV threshold and directional sensitivity will allow us to map the radiogenic heat sources in the mantle and to settle the question if the Earth has a planetary-scale nuclear reactor at its centre.

Proposed Underground Antenna at Curaçao

We would like to propose an underground antenna to investigate the internal state of the Earth. The initial antenna should be built on Curaçao. The geology of Curaçao, as studied by Klaver (1987), indicates that Curaçao is a mantle plume originating from the boundary of the core and the mantle, some 80 Ma ago. Sample analysis by Klaver (1987) indicates that the Curaçao basalt is more than an order of magnitude lower in K, Th, and U compared to sands in, e.g., The Netherlands.

Curaçao is more than 1000 km away from the Florida power reactors and from the mountain ranges of the Andes. It provides a very low background of natural radionuclides, and because it is surrounded by a considerable mass of oceanwater, the antineutrino flux from crustal sources and power reactors will be strongly reduced. That means that the antenna set up will be especially sensitive to antineutrino sources from the mantle and a possible geo-reactor. We expect that the calculations for Hawaii will be more or less indicative for Curaçao.

The creation of such an underground laboratory will be quite unique and will also include some technological challenges. One of them is drilling into basalt; the other is the development of low-energy dissipating electronics. Despite Curaçao being a plume sticking out of the ocean floor and cooled by ocean water at a depth of about 1 km, high temperatures are expected. In the underground laboratory we expect a high density of electronic devices in the detector setup. Since additional cooling is complicated, low-energy dissipating electronics will be required. Low-energy dissipating electronics is directly linked to the telecommunication technology and its industry.

It should be noted that the geological formation of the island of Curaçao would allow calibration of an antineutrino detector with the aid of nuclear power driven vessels, which could be

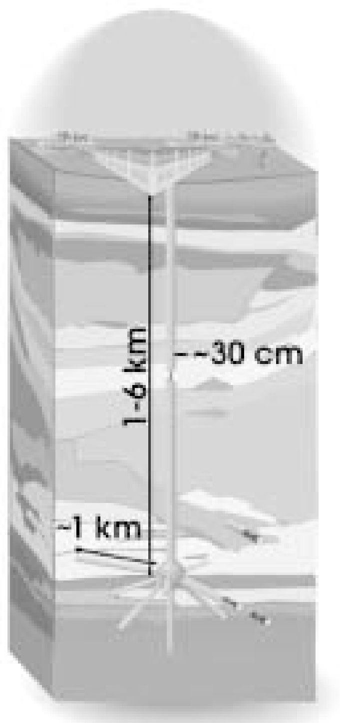

Figure 5. *Schematic presentation for an underground antenna for antineutrinos. The ultimate depth of the main shaft and the length of the secondary shaft will be determined on the basis of tests of the directionality and the efficiency of the prototype detectors.*

positioned at various locations and at variable distances from the detector.

The proposal foresees, as schematically depicted in Figure 5, in a vertically drilled main shaft of about 30 to 40 cm diameter until a depth where the detectors are not too sensitive to the muonic background. From a central point a set of 20 to 30 secondary shafts, 10 to 20 cm diameter and 0.5 to 1 km long, will be drilled by state of the art oil- and gas drilling techniques. Each secondary shaft will be loaded by a chain of antineutrino detectors and their associated data analysis and data transfer electronics.

The proposal will be carried out in a step-by-step approach with clear go-nogo decisions and associated funding. We have started in collaboration with iThemba LABS and University of Cape Town to test in the laboratory the properties of a candidate scintillator using standard electronics including coincidence and pulse-shape analyses. In next steps the directional sensitivity of the detectors will be examined at a nuclear power station and the standard electronics have to be converted to microprocessors. Before drilling the set-up will be tested in underground mine shafts.

In the end, we anticipate a world wide net of about ten antennas to tomographically image our planet. Such a global set-up will also serve as a very large base antenna system for antineutrinos produced in supernovae and gamma-ray bursts. In addition to their directional sensitivity, detection of antineutrinos will not be hampered by the overwhelming flux of solar neutrinos.

We invite interested people with expertise in one of these fields, who would like to participate in this proposed project to contact us.

This project is referred to as CURACAO (Curaçao Underground Research Arena for Core Antineutrino Observations). The authors would like to acknowledge the stimulating discussions with F. Brooks, H. R. Butcher, A. E. L. Dieperink, J. M. Herndon, P. Hoyng, G. Th. Klaver and F. R. Smit.

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Report on the Euro Summer School on Exotic Beams (Valencia 2003)

The Euro Summer School on Exotic Beams was held last September in the historical heart of the beautiful medieval city of Valencia and was organised by Dr. Berta Rubio (IFIC, Valencia), ably abetted by the other members of the Valencia nuclear physics group. For a week, more than 70 participants gathered together from all over Europe to learn about and discuss nuclear physics focused on the applications of radioactive beams. This innovative and wide field covers many aspects of nuclear science from nuclear structure to nuclear astrophysics passing through and touching on many other interesting topics.

This was the 10th of a very successful series of schools which were originally organised in Leuven, where the first seven schools were held. The last three have taken place in other European countries organised by different research centres. Since the usual conferences and workshops tend to exceed the new scientist's knowledge level, the original aim of the school was to bring this particular field of research to young scientists as well as to motivate them to continue its development. This idea, conceived originally by Prof. Mark Huyse, was so successful as far as the students (mainly PhD students and young postdocs) were concerned that it has been imitated worldwide in other areas of science. Because of the extensive discussions and close interactions between students and lecturers, an excellent atmosphere for learning is created.

In Valencia the school was held in the Collegio Major Rector Peset, whose location in the "Barrio del Carmen," an area of pubs and bars, provided the students with the perfect atmosphere to go out and enjoy the nights in Spain. The program of lectures kicked off with the special topic of transmutation by Dr. José Luis Taín (from IFIC), who talked about "The Neutron Capture Process." This is a hot topic that has strong implications for the field of energy production and nuclear waste transmutation. It triggered the interest of the media, with articles appearing a few days later in the national press. This topic was rounded off some days later by José Benlliure who focused on "The Spallation Process."

In the main series of lectures, Prof. Hans Geissel (from GSI) began with the subject "Physics with Exotic Nuclei and Exotic Atoms at Relativistic Energies." Symmetries in $N \approx Z$ nuclei were then explained by Dr. Piet Van Isacker. Dr. Gerda Neyens showed us the wide variety of techniques used to measure static electric and magnetic moments of nuclear states. Studies of the decay of nuclei around the proton drip line were covered by Prof. Ernst Roeckl. Dr. Andrés Gadea (from LNL) centered his lectures on "In-Beam Gamma Spectroscopy Techniques" and gave an overview of the current status and perspectives in this area. The main lectures were finished off by Dr. Gabriel Martinez Pinedo with the topic "Shell-Model Applications in Nuclear Physics and Astrophysics."

During their first weekend in Valencia, most of the participants and lecturers went to "L'Oceanogràfic" which claims to be the biggest aquarium in Europe. They also visited the Science Museum and the old town, making good use of the fine weather to go to the beach in the evening.

The students had the opportunity to present their own work at the school with an oral or poster presentation. This school was characterized in particular by a high level of participation and very successful poster presentations. The posters were in place from the beginning of the school, and in addition there was also a dedicated afternoon session with coffee and cookies.

A total of 24 talks of around 10 minutes each were given by PhD students. Each short presentation was followed by a few minutes of discussion in order to discuss and clarify any questions. Topics such as beta decay, targets and ion sources, nuclear reactions, theoretical calculations, and mass measurements were covered in the six sessions dedicated to the students' presentations.

One of the days of the school was devoted to social activity in order to expand people's horizons and allow them to enjoy the nice weather. It consisted of a visit to a natural park close to Valencia, called "La Albufera," which was an excellent place to observe several autochthon ecosystems. A sweet lake and movable dunes exist a few metres from the Mediterranean seashore. After swimming and playing games at the beach, all the participants ended the day with a boat excursion on the lake and returned to the city fully refreshed and ready for more nuclear physics.

The school was closed by Dr. José Luis Taín, with an amusing presentation of the "Original Paella Recipe."

On the whole, the conference

delegates were extremely satisfied by the organisation. If you would like further information about this 10th Euroschool please visit http://ific.uv.es/~euschool/index.htm, which contains all the slides of the presentations, photographs, and, perhaps most importantly, the paella recipe.

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E. Nácher, Ana B. Pérez
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Second European Summer School on Experimental Nuclear Astrophysics

The description of the universe and its structures needs input data from fields such as nuclear physics, elementary particle physics, plasma physics, and atomic physics. This multidisciplinary effort attracts a growing number of young researchers. Although many conferences take place regularly covering various aspects of the fields, the relatively short talks lead often to a situation where "experts talk only to experts," while the young researchers are given no chance to understand the basics and the current exciting problems of the various subtopics. In order to overcome this situation, a second summer school dedicated to the education of young researchers took place from September 28th to October 5th, 2003, at Santa Tecla, Sicily. The school primarily discussed (four days) various aspects of the main subtopic "Experimental Nuclear Astrophysics," while two days were devoted to the interconnected subtopics "Conundrums of the Early Universe," "Solar Neutrinos" and "Cosmochronometers." The main subtopic covered aspects of nuclear reaction rates for charged particles and neutrons, s-process experiments, r-process experiments, p-process experiments, underground accelerator laboratories, radioactive ion beams, big-bang nucleosynthesis, recoil separators, and indirect methods such as Coulomb breakup and Trojan horse. The lectures took place in the morning, while the afternoon was scheduled by the young researchers themselves. There were about 120 young participants from 14 countries all over the world. The school took place at the Santa Tecla Palace Hotel, 15 km north of Catania, located directly at the Mediterranean Sea in a comfortable and spectacular environment.

The school was welcomed by the rector of the Catania University and other authorities from Sicily. There were seven reports of the school on the Sicilian television. The social program of the school included a visit to the antique city of Syracus, a visit to Etna, and a folklore presentation of Sicily. The school concluded with a summary talk during the final dinner, where various sponsors, academic and political authorities, and the press were present.

The school was sponsored by Germany (DTL-Bochum, GSI) and Italy (INFN, INFN-LNS, Universita di Catania, Osservatorio Astrofisico di Catania, Provincia Regionale di Catania, Comune di Catania, Azienda Provinciale Turismo Catania, Azienda Provinciale Turismo Siracusa). There were also Sicilian sponsors providing wine and other products from Sicily.

A discussion with the young participants clearly demonstrated the need for a continuation of such a school, with the inclusion of some suggested improvements. It was thus decided to have a third school in October 2005 at Santa Tecla.

Claus Rolfs
Bochum

C. Spitaleri
Catania

The Labyrinth in Nuclear Structure

The International Conference on "The Labyrinth in Nuclear Structure" was held at Aghia Pelaghia in Crete, Greece, from July 13–19, 2003. It belongs to the EPS Nuclear Divisional series and was jointly organized by the I.N.P. of the National Center for Scientific Research DEMOKRITOS, NTU of Athens, the Italian Institute of Nuclear Physics (INFN), and the University of Milano (Italy). The wonderful scenery of the location and the structure of the conference encouraged informal physics discussions during noon and evening breaks, and were key factors in making the meeting very lively and stimulating. In addition, a number of evening events (welcome party and dinner, Greek night and gala dinner) available to the participants, made the social aspect of the conference very pleasant.

The Cretan Conference has established a tradition for its special character as a forum for an informal exchange of ideas, with ample time for discussion. To gain some perspective, this conference is part of a series that began in 1979 (and in its present form in 1983) and as in the past it has attracted not only experienced researchers in the field but also a large number of very active young people. It is clear that since then, an enormous amount of progress has been made. Today, nuclear structure physics is in an exciting and fascinating phase with a growing wealth of new results from a variety of experiments at the large detector arrays. These experimental results were obtained in parallel with theoretical accomplishments related to the developments in describing the many-facets of the complicated nuclear many-body problem in the extremes of isospin, temperature, and angular momentum. Several burning questions in this field, together with the developments under discussion for future activities, were addressed in the invited talks and oral contributions. The topics included, though were not limited to, physics with radioactive beams, nuclei far from stability and very heavy nuclei, drip-line physics, high-spin phenomena and exotic shapes, giant resonances, warm nuclei and chaos, and experimental perspectives.

Although it is not possible to include all the new research presented by the speakers in this report, a brief summary of some of the exciting physics illustrated and discussed at the meeting is provided. A full synopsis of the conference will be found in the conference proceedings, published in volume No. 701 of the AIP Conference Proceedings.

The recent achievements in high-spin physics presented at the conference concern the problem of the decay-out of superdeformed structures, the search for hyperdeformed shapes and the study of triaxial nuclear deformation. These problems have attracted particular interest during recent years. Gamma transitions from the decay-out of superdeformed bands provide a test to the microscopic models, and were recently identified with experiments at Gammasphere (Carpenter) and at Euroball (Duchene), just as in those nuclei in which superdeformation was first discovered. Data on charged particle decay of superdeformed light nuclei (Rudolph) and the interpretation based on the chaos assisted tunneling (Aberg) were presented. For the search of hyperdeformation, particular emphasis was put on the study of the interplay between reaction dynamics and fission barrier to optimize the population of such structures (Herskind, Fallon). It was clear from these presentations that current detector arrays, although powerful, are at the limit of sensitivity for investigating the hyperdeformation problem. For the research addressing the nuclear structure of the very heavy and very light nuclei, new insights were obtained by combining these gamma-detector arrays with other instruments. In fact, the coupling of a gamma detector array with the efficient magnetic spectrometer of JYFL (Finland) has allowed the detection of rotational bands in several heavy nuclei with Z > 100. These bands were populated with extremely small cross sections but it was very interesting to learn how shell effects can give stability at the presence of the very strong Coulomb repulsion (Julin). For the very light nuclei, new insight into the problem of clustering and exotic shapes was obtained using the combined particle-gamma detectors (Kokalowa).

The consequences of symmetries in nuclear structure were also discussed at the conference. Concerning nuclei with triaxial shapes at high spins, a series of experiments was concentrated on the problem of the chiral symmetry breaking, which was identified in odd-odd nuclei as related to the mutual orientation of the spin of the valence nucleons and of the core (Petrache). The concept of symmetry has given deep insight into nuclear physics and the application of supersymmetry theory has described multiplets of nuclear states at low spins, as discussed in the overview of this topic (Algora).

The progress in the field of nuclear structure at finite temperature was presented in connection with the rotational damping in normally deformed and superdeformed nuclei (Matsuo, Dossing) and with the gamma-decay of the giant dipole resonance in excited nuclei (Camera, Maj). Recent data on the giant dipole resonance at spins close to the fission limit (obtained with Euroball and detectors for high energy gamma-rays) indicate more clearly than in the past the occurrence of the Jacobi shape transition (oblate-prolate)—a transition which is also typical of gravitational objects rotating syncronously.

The exploration of the limits of validity of the isospin quantum number is one of the challenges of modern nuclear physics. The interesting question of isospin mixing, as addressed by the observation of E1 transitions in N = Z nuclei was discussed at the meeting based on results from Gasp and Euroball (Farnea). The extensive work on proton radioactivity, made with fusion evaporation reactions of stable beams, showed the strong influence of nuclear structure at the proton drip line in lifetime measurements (Wood).

The continuous development of acceleration beams and instrumentation in nuclear-structure studies has been crucial for the new achievements in the field. In particular, radioactive beams have opened the possibility of forming proton- or neutron-rich nuclei approaching and mapping the drip line regions. The nuclear structure studies made at GANIL, GSI, MSU and RIKEN for light nuclei around the lowest shell closures (Sorlin, Aumann, Glashmacher, Ueno) were very extensive and constitute a very important test for the theory (Gargano, Gori, Otsuka). Relativistic radioactive beams of heavier masses are being employed for gamma spectroscopy studies of medium mass nuclei with the set up RISING at GSI (Gorska) to study collective excitations and the higher shell closures.

A very interesting and extensive experimental program was recently initiated around the gamma detector array EXOGAM and the spectrometer VAMOS. It uses the low energy ISOL beams of GANIL that allow fusion evaporation reactions (G. De France), thus addressing high spin questions very far from stability. A recent experimental effort with the ISOL beams of Oak Ridge (Galindo-Uribarri) focused on Coulomb excitation measurements of "pure" beams of fission fragments such as the semimagic ^{82}Ge and doubly magic ^{132}Sn.

An important result, as a part of the experimental program carried out at TRIUMF with the ISAC facility (D'Auria), is the direct measurement for the first time of the ^{21}Na(p,g)^{22}Mg reaction, a reaction believed to play a key role in the production of ^{22}Na during novae explosions. Further measurements related to low energy reactions such as ^{8}Li(α,n)^{11}B, which is interesting for the primordial nucleosyntesis model, are planned for the very near future with the EXCYT facility at Catania (Cuttone).

The goal of the future or second generation of radioactive beam facilities is that of producing beams of better quality and higher intensity in order to approach the drip lines in medium heavy nuclei. In addition, the use of intense beams of the double magic ^{132}Sn nuclei will allow a new and extensive experimental program that is relevant also to nuclear astrophysics (nucleosyntesis). The radioactive beam facilities discussed at the meeting, presently designed and under R&D, are SPES of LNL (Pisent) and SPIRAL2 of GANIL (Savajols). They constitute an essential step towards the more ambitious ISOL facility EURISOL (Vervier). The developments for the next generation of instrumentation, based on the possibility of performing the tracking of the gamma-ray interactions, are presently under way within the AGATA project (Bazzacco). The latter heavily involves the European nuclear structure community.

It is clear that the meeting reflected the vitality of the nuclear structure field and its exciting future perspectives, which are particularly attractive to the new generation of scientists.

Angela Bracco
Universita' di Milano and INFN

Constantine A. Kalfas
INP DEMOCRITOS, Athens

The First WCI2004 Workshop on Dynamics and Thermodynamics with Nucleonic Degrees of Freedom: A Successful Experiment

Motivation and Format

After more than 20 years, an international project, called World Consensus Initiative (WCI2004), has been recently launched with the ambitious task of promoting synthesis of the main results and open problems of physics of the heavy ion collisions at the Fermi and Intermediate energies. Details can be found at the website: http://cyclotron.tamu.edu/sjygroup/wci2004/.The initiative is open to all possible contributions from interested researchers.

The workshop held at Laboratori Nazionali del Sud, Catania, Italy, on January19–24, 2004, represents the first finalized meeting of the project. Following the above motivations the meeting has been organized in a very innovative way, in an attempt to promote as a first priority an open and constructive discussion. Each session was devoted to a specific topic but based on precisely asked questions instead of invited talks. Details can be found at the above website.

Results

The workshop was very successful due to the deep involvement of all the participants, more than 80 people from the major heavy ion collision research centres of the world, in the ideal environment provided by LNS.

It is too early to present a full list of the main achievements on the way to a "world consensus," but important steps have been taken toward physics arguments and personal relationships and mutual understanding.

Equation of State

Experiment

Flows: "Reference" data for elliptic flows were selected with an amazing agreement of information obtained from very different experimental setups (INDRA, FOPI, PlasticBall) in the wide energy range 50AMeV–1AGev (Au+Au).

Stopping: This is very important because it directly extracts information on the nuclear EOS at high baryon density. The variances of the longitudinal and transverse particle emissions appear to be very sensitive observables.

Isovector EOS: The recently observed isospin transparency (neutron/proton imbalance ratios at target/projectile rapidities) is a very good observable. Neutron vs proton flows are also sensitive to the symmetry term. In absence of good neutron measurements, light isobar flows (*e.g.* ^{3}H vs. ^{3}He) can be used.

The isospin content of fragments also appears as a good indicator of the isovector channel contributions. The "isospin fractionation (distillation)" detected at Fermi energies provides a measure of the symmetry term at low densities. At higher energies, fragments are likely produced with a different mechanism from an early dense state of the matter, and a test of the symmetry term above normal density is expected.

Theory

A very important program of comparison among different transport models, used to simulate the reaction dynamics starting from fundamental in medium effective interactions, has started. Test calculations have been performed as "homework" by different transport codes.

The results for event averaged quantities (flows, stopping) appear in relatively good agreement. The differences can be easily related to the use of different effective forces (in particular for the momentum dependence) and of different parametrizations for the in medium nucleon-nucleon cross sections.

The next fundamental advancement will be the comparison of the treatment of fluctuations in these dynamical codes, related to the nature of the considered correlations. This is of great importance for the dynamics of cluster formation and in general of the decay mechanism of excited primary sources.

The Nuclear Liquid-Gas Phase Transition

Experiment

The coexistence of a mixed phase of fragments, nucleons, and light ions has been detected when nuclear systems were formed at excitation energies above 4AMeV in various experimental scenarios, central and peripheral heavy ion collisions at the Fermi energies, as well as light ion induced reactions at relativistic energies.

Various signals have been proposed in order to definitively claim that a liquid-gas phase transition of expanding nuclear matter has been observed. An important achievement on this direction was presented from a careful analysis of data for central collisions, with a contemporary presence of various expected features: bimodal distributions, negative heat capacity, spinodal decomposition remnants, as well as change in the delta scaling of the largest fragment.

A beautiful study of the time structure and mechanism of fragment production for semicentral collisions has been shown, based on the velocity correlations between fragments and projectile/target-like spectators. The amazing observation is that even fragments produced at mid-rapidity with several clear dynamical features (anisotropy, etc..) show typical equilibrium signals, like the isoscaling. In the same context the photon detection is also of large interest. The anticorrelation between thermal bremmstrahlung emission and fragment production seems to indicate the onset of a mixed phase. New radiation data are confirming the disappearing of the Giant Dipole emission at temperatures consistent with the initial point of the saturating caloric curve.

Theory

The presence of several partial equilibrium features has emerged to be the most challenging theoretical problem. People working on reaction dynamics models should be able to study the evolution of the phase space occupation, trying to isolate the degrees of freedom that are not equilibrating during the interaction time. People working in a statistical framework should develop a new "oriented thermodynamics" focusing on the analysis of ensemble partitions under some dynamical constraints.

The importance of the dynamical formation of the various equilibrated emitting sources has been treated on the basis of hybrid models, highly unsatisfactory for the large uncertainty in the matching of the two descriptions. Similar problems are clearly present in the discussion of the phase transition to deconfined matter in high energy heavy ion collisions.

Outlook

It can be stated with some confidence that this first meeting has been a good achievement. “Reference” results in theory and experiments have been selected and open problems more clearly formulated. International working groups on the above described items have been formed, which are open to all interested people. The above website will act as a main container of all contributions, including the arguments raised during the workshop, a kind of international web-agora. The goal of this work is manyfold: i) clear statement of the physics interest of the field; ii) proposal of new key experiments; iii) optimum use of the present facilities (detectors and accelerators); iv) requested utilization and/or extension of new facilities, in particular for radioactive beams; v) planning of a new generation of detectors, especially for fragments and neutrons; and vi) planning of a new generation of simulation codes with implementation of new theoretical tools.

The second WCI workshop will be held next year at the Cyclotron Institute of Texas A&M University in College Station, USA.

Maria Colonna, Massimo Di Toro,
and Piera Sapienza
LNS, INFN and
Dipartimento di Fisica ed Astronomia,
Catania, Italy

Nuclear Reactions on Unstable Nuclei and the Surrogate Reaction Technique

Determining reaction cross sections on short-lived nuclear species is a major challenge for nuclear physics and nuclear astrophysics. Many of these nuclei are too difficult to produce with currently available experimental techniques or too short-lived to serve as targets in present-day setups. Some nuclear reactions will remain immeasurable even at upcoming and planned radioactive beam facilities. It is therefore important to explore alternative methods for determining reaction cross sections on unstable nuclei.

Indirect approaches for studying nuclear reactions were the focus of the recent workshop “Nuclear Reactions on Unstable Nuclei and the Surrogate Reaction Technique,” held at the Asilomar Conference Grounds in Pacific Grove, California, January 12–15, 2004. The meeting attracted about 60 participants from the international nuclear structure and reaction communities. It was organized by physicists from Lawrence Livermore National Laboratory, with the assistance of an international advisory committee that included scientists from universities (MIT, Michigan State University, and Ohio University) and research laboratories (Argonne, Livermore, Los Alamos, Oak Ridge, TRIUMF in Canada, and the Commissariat à l’Energie Atomique [CEA] in France). Funding for the workshop was provided by N Division, Lawrence Livermore National Laboratory.

The three-and-a-half day meeting consisted of plenary talks, parallel sessions, and working group

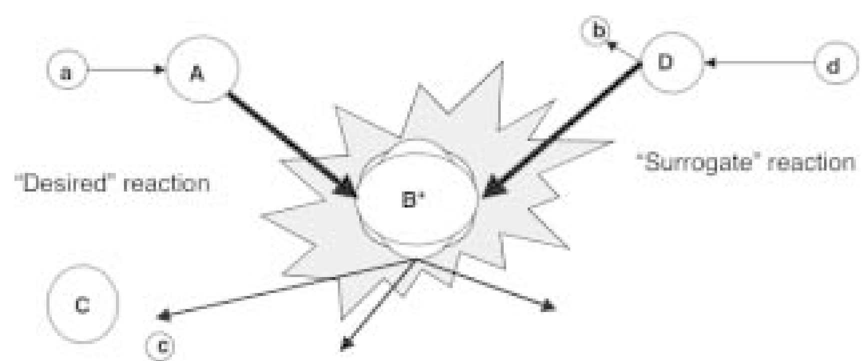


Figure 1. *Schematic representation of the Surrogate-reaction technique. The Surrogate approach allows one to indirectly determine the cross section for a two-step reaction* $\boldsymbol{a + A \rightarrow B^*}$ ’$\boldsymbol{c + C}$ *proceeding through an intermediate nuclear state* $\boldsymbol{B^*}$*, provided that* $\boldsymbol{B^*}$ *is an equilibrated “compound” state. In the Surrogate method, the compound nucleus* $\boldsymbol{B^*}$ *is produced by means of an alternative (“Surrogate”) reaction, here* $\boldsymbol{d + D \rightarrow b + B^*}$*, and the reaction cross section is obtained by combining the calculated cross section for the formation of* $\boldsymbol{B^*}$ *with the measured decay probabilities for this state. The Surrogate technique is particularly valuable when the target of interest,* $\boldsymbol{A}$*, is short lived and a suitable Surrogate reaction involving a stable target* $\boldsymbol{D}$ *can be identified.*

discussions. Nuclear astrophysics, stockpile stewardship science, transmutation of nuclear waste technology, and nuclear structure physics were identified as the primary areas that will benefit from new nuclear-reaction information. Workshop participants reviewed the status of current experimental, theoretical, and computational tools available for the study of nuclear reactions. The state-of-the-art in transfer-reaction theory, level-density calculations, and pre-equilibrium reaction studies, etc., was discussed and opportunities at radioactive beam facilities were outlined. The ANC (Asymptotic Normalization Coefficient) method, which has been applied to peripheral capture reactions in recent years, was presented as an example of an indirect technique for determining reaction cross sections. The workshop participants also learned about a new program of indirect nuclear spectroscopy studies at Oak Ridge, which employs radioactive ion beams to carry out (d,p) reactions in inverse kinematics.

At the center of the discussions was an indirect method for obtaining cross sections for a certain class of nuclear reactions (see Figure 1). The method, in a simplified form, was used in the 1970s to extract (n,f) cross sections on actinide nuclei [J.D. Cramer and H.C. Britt, Nucl. Sci. Eng. 41,177 (1970); H.C. Britt and J.B. Wilhelmy, *ibid.* 72, 222 (1979)] and to study (n,p) reactions in the mass-90 region. More recently, the data for the actinides were carefully reanalyzed [W. Younes and H.C. Britt, Phys. Rev. C 67, 024610 (2003), *ibid.* 68, 034610 (2003)] and some test experiments were carried out to explore the method in the rare earth region. These studies were critically examined at the workshop. Working groups were formed to discuss possible applications and practical limitations of the Surrogate technique, to explore various technical issues associated with implementing the method, and to develop strategies for making progress.

The consensus at the meeting was that reactions on unstable nuclei are very important and that indirect methods will play an essential role in their study. The Surrogate approach was recognized as a potentially very useful, and in some circumstances—the only feasible method for obtaining unknown cross sections. The need for careful studies of the method was emphasized and the importance of establishing benchmarks was stressed. The workshop participants also contemplated the future of nuclear reaction physics. In this context, attracting young researchers to the field and strengthening collaborations between universities and research laboratories were identified as important goals. Overall, the presentations and discussions at the workshop nicely illustrated that the study of reactions on unstable nuclei is a challenging field with complex and rich physics as well as important and fascinating applications.

The viewgraphs of the individual presentations, as well as further information about the meeting, can be found on the workshop web site, http://www-pat.llnl.gov/Conferences/Surrogates04/. A more detailed document, which provides an introduction into the Surrogate method and summarizes the results of the workshop, is in preparation.

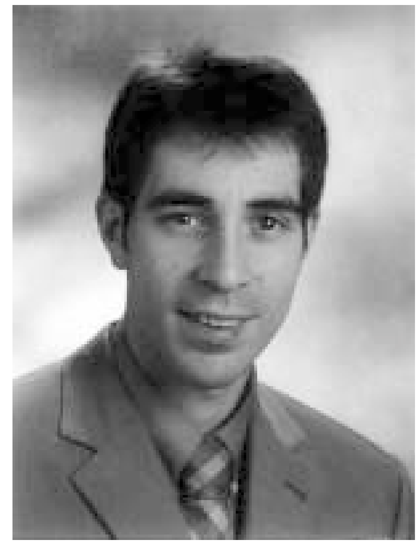
This work was performed in part under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory, under contract No. W-7405-Eng-48.

Jutta Escher
Lawrence Livermore National Laboratory

Gustav–Hertz Prize 2004

The German Physical Society (DPG) awarded the Gustav-Hertz Prize 2004 to Dr. Klaus Blaum at the Spring Meeting in Munich. This prize, each year given to one "outstanding young physicist," honours his exceptional contributions to high-accuracy mass spectrometry of short-lived radionuclides. On leave of absence from GSI, Darmstadt, and presently holding a CERN fellowship, he introduced absolute mass spectrometry to the study of short-lived nuclei at radioactive beam facilities with carbon clusters as mass reference. Using carbon, which defines the mass unit in the microscopic world, he showed that the ISOLTRAP Penning trap, installed at the on-line isotope separator ISOLDE in Geneva, is presently the most accurate mass spectrometer for short-lived isotopes with a resolving power of up to 10 million and a mass accuracy of better than 10^{-8}. Until now, the masses of around 300 nuclei could be determined with high accuracy. Recently, such measurements allowed Klaus Blaum and his colleagues of the international ISOLTRAP Collaboration to contribute significantly to fundamental tests such as the search for a scalar contribution to weak interaction, the check of the unitarity of the CKM quark mixing matrix, or the most precise test of the isobaric multiplet mass equation.

With an age of 32 years, Klaus Blaum is one of the youngest laureates to ever be awarded this prestigious prize. During his diploma and PhD work at the University of Mainz he pushed a technique to its limits. Using Resonance Ionization Mass Spectrometry he worked on extreme trace analysis by combining laser ionization with mass spectrometry. When he had finished his PhD in 2000, he joined as postdoc the Atomic Physics Division at GSI. From here he was sent to ISOLDE to take care of the ISOLTRAP mass spectrometer at CERN, which he did with great success. Soon he will go back to the University of Mainz to obtain another award, this time form the Helmholtz Association. He will establish a "Helmholtz Research Group for Young Investigators" on "Experiments with Trapped and Cooled Ions" to strengthen the already close collaboration between the University of Mainz and GSI. The University of Mainz has a long-standing expertise in physics with ion traps and GSI is building up the ion trap facilities SHIPTRAP and HITRAP for challenging experiments in nuclear and atomic physics.



Klaus Blaum

H.–Jürgen Kluge
GSi, Darmstadt and
University of Heidelberg

Tom W. Bonner Prize 2004

George F. Bertsch

George F. Bertsch is a Senior Fellow of the Institute for Nuclear Theory at the University of Washington, and a theorist who has had a lasting and influential interest in experiments across a wide range of physical science. His initial interest in the nuclear force led to the recognition of the importance of core polarization and to the development of the quadrupole-quadrupole interaction used so successfully to describe complex nuclei. The need for realistic nucleon-nucleon interactions for reaction theory led the Michigan State group, of which Bertsch was then a member, to develop an interaction ("M3Y") subsequently used in hundreds of reaction studies. For similar motivations, the practical description of reactions, Bertsch devised a computationally tractable implementation of the Boltzmann-Uehling-Uhelenbeck equation that could be applied to intermediate-energy nuclear collisions. He defined the proper observables for pion interferometry, explored the distributions of various quantum numbers in complex nuclear spectra, laid the foundations for relating the giant resonances to nuclear forces, and even predicted quantitatively the existence of such resonances in fullerene molecules. He was the first to describe, more than 20 years ago, the phenomenon of color transparency. For his many contributions and clarifying insights into the behavior of complex nuclear and molecular systems, George Bertsch has been awarded the APS 2004 Tom W. Bonner Prize.

Hamish Robertson
University of Washington

Hans A. Bethe Prize 2004

Wick Haxton, the Director of the US Department of Energy's Institute for Nuclear Theory at the University of Washington since 1991, has carried out research on a wide variety of topics in theory. He has long had an interest in neutrino physics, and developed analytic methods for describing the matter-enhancement effect that influences the oscillation of solar neutrinos. He is co-author of what has become a classic treatise on double beta decay. The interaction of neutrinos in the intermediate energy range from 20 to 1000 MeV with nuclei is complex but important in the interpretation of experiments on atmospheric neutrino oscillations. Wick Haxton's calculations have contributed to that field. He has been a leader in the renewed efforts to build a national underground laboratory in the US to explore neutrino physics, dark matter, and geological and biological sciences at great depths. Among his other interests are the shell-model effective-theory treatment of the nuclear many-body problem, and the fractional quantum Hall effect. Wick Haxton's innovative research and leadership were recently recognized by the awarding of the American Physical Society's 2004 Hans A. Bethe Prize.

Hamish Robertson
University of Washington

Wick Haxton

The Magnetic Spectrometer PRISMA

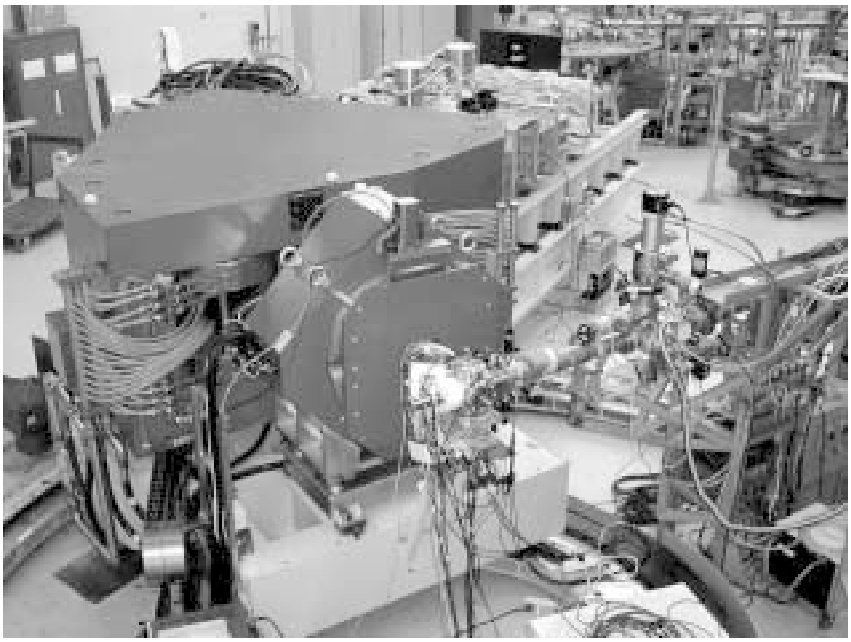


Figure 1. *The magnetic spectrometer PRISMA at LNL.*

PRISMA is the magnetic spectrometer[1] recently installed at LNL (Figure 1), designed for the A=100-200, E = 5–10 MeV A heavy-ion beams of the XTU Tandem-ALPI-PIAVE accelerator complex and for possibile use with the proposed radioactive beam facility SPES. Its main features are large solid angle 80 msr (±6° for θ and ±11° for ϕ), wide momentum acceptance ± 10%, mass resolution 1/300 via time-of-flight, energy resolution up to 1/1000, and rotation in a large angular range from –20° to +130°.

The first experiments on grazing collisions between heavy ions were performed recently. The goals of the experiments were: 1) to investigate the population of neutron-rich nuclei in the A=50–60 mass region by means of multinucleon transfer reactions, and 2) to study the dynamics of such transfer processes. ^{54}Cr, ^{56}Fe and ^{64}Ni projectiles on a heavier and more neutron-rich target like ^{124}Sn were used, at incident energies corresponding to E/V_b=1.07-1.10 depending on the system.

Two examples of mass spectra showing particular nuclei populated in the region of interest are reported in Figure 2. Very good mass and Z resolutions were reached ($\Delta A/A$=1/280 routinely). The left spectrum is obtained by selecting Z=24 events in the ionization chamber by ΔE–E identification, and various chromium isotopes are clearly identified. The second example (right) is the A/q distribution of the pure neutron pick-up channels (+xn) leading to various neutron-rich iron isotopes. Six-proton stripping and six neutron pick-up channels were observed in this reaction.

In a separate run, good energy resolution was measured for PRISMA in the case of 235 MeV ^{40}Ca on ^{208}Pb, where true elastic scattering was clearly separated from inelastic excitations of low-lying states of both Ca and Pb.

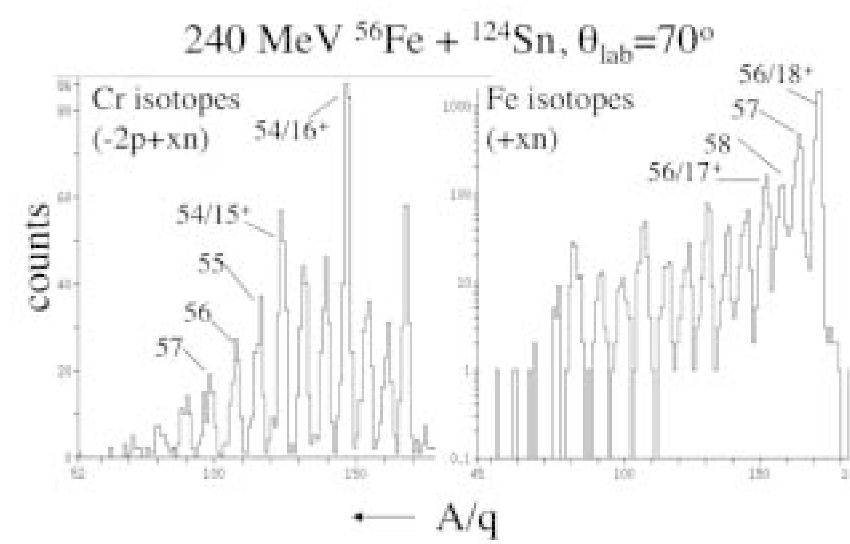


Figure 2. *A/q spectra measured with PRISMA during one of the recent runs.*

The construction of CLARA, the array of Clover detectors [2] from the Euroball collaboration, was completed recently. In a coupled operation with PRISMA, CLARA will allow the study of nuclear structure of moderately neutron-rich nuclei, populated at relatively high angular momentum by means of binary reactions such as multinucleon transfer and deep inelastic.

The project will largely benefit from the stable beams at medium and high intensity, which will be available from PIAVE+ALPI.

References

1. A. M. Stefanini et al., LNL Annual Report 2002, INFN-LNL (Rep)198/ 2003, p. 147.
2. A. Gadea et al., ibidem, p.150; A. Gadea et al., *Eur. J. Phys.* A, 20, 193 (2004).

Alberto M. Stefanini and the PRISMA collaboration
INFN—Laboratori Naz. di Legnaro, Padova, Italy
Univ. di Padova and INFN— Sez. di Padova
Univ. di Napoli and INFN— Sez. di Napoli
Univ. di Torino and INFN— Sez. di Torino

Joint Institute for Nuclear Astrophysics (JINA)

The Joint Institute for Nuclear Astrophysics (JINA) is a collaboration between the University of Notre Dame, Michigan State University, and the University of Chicago to address a broad range of experimental, theoretical, and observational questions in nuclear astrophysics. In the fall of 2003, JINA received a five year grant by the National Science Foundation Physics Frontier Center (PFC) program. This funding offers the opportunity for JINA to develop as an intellectual center with the goal enabling swift communication and stimulating collaborations across field boundaries and at the same time providing a focus point in the rapidly growing and diversifying field of nuclear astrophysics.

Hendrik Schatz (left) and Michael Wiescher (right).

Nuclear astrophysics focuses on questions at the interface of nuclear physics and astrophysics. It addresses the role of nuclear structure and nuclear reaction processes as engines of stellar evolution and stellar explosions and seeks to find answers to the fundamental questions about the origin of the elements found today throughout the universe. Because of the extreme nature of the stellar conditions, the understanding of these nuclear processes poses an enormous challenge to astrophysicists, nuclear theorists, and experimentalists. Advances in experimental nuclear astrophysics now allow physicists to investigate many stellar processes in the laboratory. These advances span a wide range of techniques and facilities. They include innovative methods to measure the extremely slow reactions in the interiors of stars, as well as new facilities to produce the very same exotic, short-lived nuclei that come to existence in the extreme environments of stellar explosions.

While these experiments are pursued at the accelerator facilities at Notre Dame, Michigan State University, and Argonne National Laboratory, complementary theoretical questions about the macrophysics aspects and conditions of stellar evolution and stellar explosion are addressed by JINA at the University of Chicago, at Notre Dame, and with associated groups at the University of California at Santa Cruz and Santa Barbara, the University of Arizona, Argonne National Laboratory and Los Alamos National Laboratory. This component branches towards fundamental understanding of the processes governing life and death of stars as well as to the identification of unique signatures for present and future observation. Close collaboration and exchange of scientists between these institutions is necessary to address the broad and complex range of scientific goals.

JINA will foster an interdisciplinary approach to the open questions in nuclear astrophysics. It will drive further advances in nuclear physics and astrophysics that are specifically needed to answer open questions in nuclear astrophysics, and it will ensure that advances in individual fields will ultimately lead to progress in our understanding of nuclear astrophysics. Find out more about JINA by visiting our website at www.JINAweb.org.

letter to the editor

Sir,

The feature article by D.-O. Riska, "Nuclear Exchange Currents" in vol. 13/no. 3, p. 11–14, attributes the idea of axial quenching via virtual Δ(1232) resonant states to M. Rho (1974) (ref. 26) and to K. Ohta and M. Wakamatsu (1974) (ref. 27), with the quenching factor of g_A given in eq. (6) (the Lorentz-Lorenz factor).

These results were first given in M. Ericson, A. Figureau, and C. Thévenet, Phys. Lett. 45B, 19(1973). This priority is clearly acknowledged in the quoted papers.

In ref. 27: "The purpose of this paper is to reinvestigate the model propsed by Ericson et al."

In ref. 26: "The reduction of g_A in nuclear matter by the Lorentz-Lorenz effect [was] first established by Ericson, Figureau and Thévenet."

In addition, the presently favored value from data for the parameter $g' \approx 0.3$ agrees with that of our original formulation.

Magda Ericson
IPNL, Lyon, and CERN, Geneva

Public Awareness of Nuclear Science: Why and How

Motivation

In the last few decades, public awareness of science has become of utmost importance for the prevalence and sometimes even the survival of scientific disciplines. This is especially the case in our democratic societies where there is a special need for justification on how the taxpayer's money is spent. The general public has become more and more critical about the necessity of research, either because of the scepticism that research brings no benefit for society, or even worse that scientific discoveries can bring harm to it. There exists a schism in this respect between the ivory towers of the academic world and the general public. This is especially true for the field of nuclear science and its applications as will be exemplified below. Research institutions and universities have become aware of that fact and have started and increased their efforts to intensify public outreach.

There exist at least three profound reasons to promote physics:

1. *Cultural reasons:* Physics is an important part of our cultural heritage: it contributes to answer fundamental questions such as the structure of matter, the birth and fate of our universe, and the origin of life in the cosmos. Furthermore, physics is relevant for the understanding of the environment and the place mankind occupies in nature. Scientific knowledge and rational thinking as exemplified in physics is also an antidote to irrational fears and their wide-spread pseudo-solutions like esotericism, astrology, etc. After all scientific methods and reasoning are the natural and strongest opponents of pseudo-scientific disciplines.

2. *Economic reasons:* Technology and innovation created through physics plays an important role in creating wealth, thus acting as a driving force in our societies. Achievements of physics have not only initiated new technologies but have also been applied in and contributed to advances in life sciences, medicine, chemistry, and geo-sciences. In the new century physics will be involved in important research issues like climate change, energy sources and storage, new innovative materials, information technology, transport, health, and environment. It is therefore essential that the industrial and technological infrastructure and progress be supported and backed up by a sound scientific and fundamental basis of scientific knowledge and research in physics.

Scientific outreach is required to raise interest and vocations for technical professions required by tomorrow's society. Research based upon physics is not only a necessity for large industrial companies, but is also emerging in small- and medium-sized companies in innovative high-tech areas. In fact, physicists should also be made aware of and participate more in the possibilities of entrepeneurship and of founding their own firms.

3. *Socio-political reasons:* Science literacy of the public is required to use intelligently our high-tech technology. In our democratic societies the citizen's attitude is of profound importance and the key to adopting or rejecting new technologies. Furthermore, an important issue that has been overlooked before and has now become a pressing problem is the public understanding and communicating risk of modern technologies, including the risks associated with possible accidents. This difficult problem is also inherently linked to communicating physical methods to the public in an appropriate manner.

The Challenges

Traditionally, researchers at universities retired into an ivory tower and often have an outdated perception of public outreach. Furthermore, physicists sometimes unfortunately possess an arrogant and spoiled attitude and a refusal to consider the opinion of the public and communicate with them actively. In this respect there exist statements like: "The public won't understand anyway!" Other bad examples underlining the arrogance of some physicists are: "Physics is, and must remain, the leading science!" This is not true anymore, because other leading sciences (e.g., the life sciences and informatics) have emerged. With such an elitist statement one does not create friends in other scientific communities and are not very helpful in popularisation efforts of physics.

Unfortunately, only a minority of physics departments and associations are willing to enter a dialogue with society on a broader basis and communicate its messages to the public in an effective, modern, and professional way. However, more and more of them have become aware of the relevance of public outreach and started programs and efforts in this direction. That public outreach of physics can effectively be seen by the success of the "Year of Physics 2001" with many public events about physics in the German Federal Republic. This contributed to an increase of the enrolment of physics students at German universities by 28.2% in the subsequent academic year [1].

Communication and public outreach has also radically changed with the emergence of the new media and especially the internet. The new media have their potential for providing significant steps in promoting progress in the education and popularisation of science and technology. Sometimes academics contrary to the younger generation are not willing to study and engage themselves in these new developments. Physicists are often experts in computer techniques (the www was invented at CERN), but are ignorant in the didactical, social and economic aspects of internet communication and outreach. For example, websites of scientific institutions are often ignoring target group definition and marketing research, are not implementing dissemination strategies, and suffer from inadequate maintenance.

The Special Problem of Nuclear Science

Nuclear Science has many fascinating aspects and can make a great number of claims:

- Research on nuclei is studying the matter around us, since 99.5% of the matter we see around us is made up of nuclei.
- All the elements around us, including the ones that are vital for life, where formed through nuclear processes in the big bang and in stars.
- The energy emitted by the Sun and the geological changes in the Earth are due to nuclear processes in their interiors. Both of these are essential for the existence of life on our planet.
- Nuclear science is the window for studying and connecting phenomena of the infinitesimally small objects like fundamental particles and the gigantic large objects like stars.
- Nuclear science has denoted through its applications many benefits for mankind, i.e., through nuclear medicine.

So, what is the problem with the public opinion about nuclear science? Contrary to the above facts, the image of nuclear science in the real world outside its scientific community has a negative image as exemplified in the following examples and conceptions:

- Nuclear science is associated by the public, including the young generation, mainly with atomic bombs (Hiroshima and Nagasaki) and reactor accidents (Tschernobyl)
- Radioactivity cannot be seen, smelt, or touched, is man-made and very dangerous
- The term Nuclear Magnetic Resonance (NMR) has been changed to Magnetic Resonance Imaging (RMI)
- Depleted uranium in projectiles causes leukaemia (Kosovo, Iraq)
- A survey among school children (16–18 yr) shows the following top 5 ranks for the most interesting subjects in nuclear science, its applications and consequences [2]:
    1. Nuclear weapons
    2. Environmental risks
    3. Health and social risks
    4. Universe
    5. Radiation biology.
- The basics of nuclear physics as well as benefits of applied nuclear physics reached a much lower rank in this survey.

The deeper reasons for the decline of the public image are complex and will not be discussed here. An excellent overview of the roots of the negative public attitude is discussed in the book *Nuclear Fear* by the American science historian S. Weart [3].

Because of the negative image presented above the present perspectives of nuclear physics are not very bright at present. The consequences of this general scepticism of physics in general and nuclear science specifically are manifold: shortage of qualified physics teachers in school and of students in physics and specifically of graduate students in nuclear physics; and closing down of nuclear research institutions and university institutes, transfer of academic positions to other fields like computer science, life sciences, and lack of young physicists and especially nuclear physicists in research institutions and modern industry

A Countermeasure: PANS

A few years ago a working group, PANS (Public Awareness of Nuclear Science), was formed as a common initiative of NuPECC (Nuclear Physics European Co-ordination Committee) and the Nuclear Physics Board of the European Physical Society. It consists of about 25 scientists working in Europe, who have an interest in and experience with communicating science to non-scientists.

The goal is to enhance the knowledge of nuclear science to a broad public by producing material describing basic features of the atomic nucleus and peaceful applications of nuclear physics. Making people aware that we all live in a natural radiation environment is another important topic.

The hope is that these activities will contribute to a more informed public concerning nuclear issues. It is a European-wide activity, which by combining the experience already gathered in different European countries, enables the realisation of projects too large for a single country.

Three main projects under the umbrella of PANS have already been finished or are underway. They are:

- The Book *NUCLEUS—A Trip into the Heart of Matter* written especially for the interested public and high school pupils [4]. This book describes topics like fundamental properties of the nucleus, the role of nuclear processes in the Universe, and various nuclear applications. The target groups of this book are the public, and specifically high-school teachers and their pupils. Presently, translations from English are agreed upon or under discussion for the following languages: Czech, Dutch, French, German, Portuguese, and Serbian.
- The EU-funded exhibition *Radioactivity—A Facet of Nature* provides hands-on interaction with the public and has its main focus in showing that radioactivity is an important part of our natural environment. It was presented in the framework of the 2000 European Science and Technology Week in Paris, Wiesbaden, and Milano. This exhibition has since then already been shown in many other European cities.
- The objective of the web-based science communication system *NUPEX (NUclear Physics EXperience)* is the communication of nuclear science and its applications to the public [5]. The primary target group are schools (i.e., teachers as science communicators and their pupils). This EU-funded project started on January 1, 2003 and will create a high-quality web-based one-stop shop for contents in nuclear science and applications in at least 5 European languages. This web-based information system will be launched in October 2004.

Summary

Changing entrenched public opinion against nuclear science and its applications can be an uphill-struggle and can be a long, hard, expensive, and sometimes demoralising task. Its success is also difficult to benchmark. However, if nuclear science and its application are to have a long-time future the community has to make every effort to change public opinion in its favour.

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