The recent NuPAC meeting at CERN provided an overview of the laboratory’s present and future activities in nuclear astrophysics, nuclear-structure physics and related areas.

The energies attained at CERN and other particle physics laboratories are useful not only for probing nature’s deepest layers, they also enable the study of matter in the relatively low range up to a few million electron-volts. This range is typical of supernovae and X-ray bursters, and is also relevant for most nuclear-structure phenomena. Experimentalists at CERN have exploited these lower energies for many years, and the present status of their achievements and the prospects for further studies were the subject of the recent Nuclear Physics and Astrophysics at CERN (NuPAC) meeting held on 10–12 October 2005.

These activities are concentrated at CERN around the Isotope Separator On-Line (ISOLDE) and Neutrino Time-of-Flight (n_TOF) facilities. Both come under the ISOLDE and Neutron Time-of-Flight Experiments Committee (INTC), which has been asked by the CERN management to review the scientific case for the two facilities. NuPAC is one step in this review process.

In many ways, nuclear-structure physics is experiencing a renaissance. Some of the “basic truths” about nuclear structure, believed to be universal only 20 years ago, are now known to be approximations that hold for stable and close-to-stable nuclei, but that cannot be used further away from stability. For example, we are used to thinking in terms of nuclear shells based on unassailable “magic” numbers. However, it is possible to move far enough away from the stable nuclei for the balance between the number of neutrons and protons in a nucleus to be so disturbed that the magic numbers can and do change. Reaching the regions where this happens and performing detailed studies of how and why the changes occur are important tasks for nuclear physicists. So far “erosions” of the magic numbers \( N = 8, 20 \) and \( 28 \) are known, and it seems that they are at least partly replaced by \( N = 6 \) and 16, although our present understanding is not complete.

Another change when we move far away from stable nuclei is that continuum states need to be taken into account much more directly because binding energies become low (turning to zero at the neutron drip-line). The structure and dynamics of loosely bound nuclei show new phenomena, such as the spatially extended halo and the “pygmy” resonances at low-excitation energies. This is a challenging area for both experimentalists and theoreticians.

Two of the sessions at NuPAC were dedicated to the evolution of nuclear structure towards and at the driplines. Several theoretical talks outlined how far recent developments have taken us in descriptions of nuclear structure and reaction theory for loosely bound systems, of the evolution of shell structure and nuclear shape as the proton and neutron numbers change, and of the very complex problem the fission process presents. The experimental talks gave examples of the widely different techniques that are used today and planned for the near future.

**Measuring the nucleus**

Using the low-energy ISOLDE beams, properties such as mass, radius and magnetic moment can be measured relatively directly and in a model-independent way for “long-lived” states (that is, with half-lives longer than a few milliseconds). Decay experiments also make use of these beams and provide information about many aspects of nuclear structure. For the past four years it has also been possible to perform reaction experiments through post-acceleration in the Radioactive Beam EXperiment (REX-ISOLDE) accelerator. Most of these experiments have used the Miniball gamma-ray detector array.

Speakers at the meeting stressed the importance of the planned energy upgrade of REX-ISOLDE to at least 5.5 MeV per nucleon. This will enable reaction experiments to be performed with all of the 800 and more nuclei that ISOLDE can now produce. Participants also strongly supported the continuation of the beam development programme that is ISOLDE’s hallmark. On the “wish list” are beams of even more kinds of nuclei, as well as improved quality (intensity, isotopic purity, phase space extent) for existing beams.

A reliable knowledge of nuclear structure is one of the basic requirements for properly understanding how energy is produced in stars, and thereby how stars evolve. The session dedicated to these...
questions presented various aspects of the problems as seen by astronomers, theoreticians and nuclear experimentalists. Half of the heavy elements produced are made in what is known as the s-process, the slow neutron capture that takes place in massive stars in later stages of their evolution. Experimental data are still needed as input for a complete understanding, in particular of the weak s-process component (nuclei below mass number 90). One of the main lines of the future n_TOF physics programme is to measure these neutron-capture processes with sufficient resolution. Explosive astrophysical events – such as supernovae, novae and X-ray bursters – quickly drive nuclei far from the region of stability, and data collected at ISOLDE can benefit in several ways the theoretical modelling of these events.

**Further uses**

Experiments in nuclear physics dominated the early stages of the investigation into weak interactions. Particle physics has taken the place of nuclear physics for many decades, but nuclei still provide important information through precision experiments that restrict the low-energy limit of the phenomena seen more directly at higher energy. A short session at NuPAC gave two examples of this: on the one hand nuclear measurements are needed to improve further the unitarity test of the Cabibbo–Kobayashi–Maskawa quark-mixing matrix; and on the other hand precision measurements of beta-decays in ion and/or atom traps are sensitive to new interactions. These experiments typically run for up to a decade to obtain the required low level of systematic uncertainties.

A session was devoted to presentations of applications of nuclear physics. Basic data on neutron-capture cross-sections on many nuclei are indispensable to enable further developments of nuclear technologies – for example, the accelerator-driven systems for transmutation or the thorium cycle with its potential for a significant reduction of the amount of radiotoxic waste. As several speakers outlined, it is an important part of the present and future n_TOF programme to provide these data. The application of radioactive nuclei in solid-state physics and life science has been an important facet to provide these data. The application of radioactive nuclei are indispensable to enable further developments of nuclear technologies – for example, the accelerator-driven systems for transmutation or the thorium cycle with its potential for a significant reduction of the amount of radiotoxic waste. As several speakers outlined, it is an important part of the present and future n_TOF programme to provide these data. The application of radioactive nuclei in solid-state physics and life science has been an important facet of the ISOLDE programme for many years, and some of the high-energy. A possible future use of radioactive ions as probes of nanostructures was outlined; this again requires isotopically pure beams of high beam-optical quality. Also discussed was the use of radioisotopes in nuclear medicine, where progress in biomedicine combined with the introduction of new high-purity radioisotopes opens new possibilities for diagnosis and therapy.

The last session was devoted to the proposed upgrades of the ISOLDE and n_TOF facilities, and of the proton injectors on which they depend. The ISOLDE community is proposing an upgrade project, HIE (High Intensity and Energy)-ISOLDE, that includes increasing the REX energy to 5.5 MeV/u in 2009, with the goal of reaching 10 MeV/u in 2011. Furthermore, the beam quality will be improved with the help of, for example, new ion sources, an upgraded laser ion source with a trap close to the target, low-energy beam coolers and charge breeders. The target and ion source development programme would be boosted to keep the leading edge in this key field.

The n_TOF community is proposing to restart the facility (after refurbishing the target) and to use a different moderator to increase the proton flux at low energy. It is envisaged that at a later date the n_TOF facility will have a new, shorter TOF tube with a target area that is fully equipped to handle radioactive sources. In principle, such an arrangement could enable sources collected at ISOLDE to be used at n_TOF.

The faster cycling of the Proton Synchrotron (PS) Booster could in the short term provide ISOLDE with more protons. CERN’s Accelerator Beams Department is developing a scheme that will permit the Booster to cycle at 900 ms without any additional risk for the aging PS magnets. Further in the future, Linac 4 will make even more protons available for both ISOLDE and n_TOF, and will serve as the first step towards a megawatt proton source at CERN, the Superconducting Proton Linac (SPL) (CERN Courier September 2004 p31). The long-term goal of the ISOLDE community is to realise the European Isotope Separation On-Line Radioactive Ion Beam Facility (EURISOL) – a high-intensity radioactive beam facility that will enable nuclear physicists to probe even further into the unknown. The SPL would be a suitable driver for EURISOL.

The opportunities at the present nuclear-physics and astrophysics facilities at CERN are clearly not yet exhausted. The proposed upgrades will further boost the scientific reach of the facilities and serve a community of more than 500 users. It will be interesting to follow the development of this programme over the coming years.

**Résumé**

*La frontière des basses énergies pour le CERN*

La récente réunion NuPAC, tenue au CERN, a fait le point des activités du laboratoire en astrophysique nucléaire, en physique de la structure nucléaire et dans des domaines connexes. Ces activités sont essentiellement menées aux installations ISOLDE et n_TOF. ISOLDE étudie des propriétés du noyau (notamment sa masse et son rayon) utiles pour comprendre la structure nucléaire, qui joue un rôle dans l’évolution stellaire. L’importance du relèvement de l’énergie de REX-ISOLDE a été soulignée. Des applications de physique nucléaire, telles que les systèmes pilotés par accélérateurs pour la transmutation nucléaire, s’appuient en particulier sur n_TOF.

*Mats Lindroos and Karsten Riisager, CERN.*
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